ENERGY EFFICIENCY IN FERTILIZER PRODUCTION AND USE

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Contents

Summary

Fertilizers are an important factor in modern-day agriculture. They are responsible for substantial increases in crop yields, and allow crops to be planted in soil that would otherwise be nutrient deficient. The relative significance of fertilizers is increasing as the population grows and as more developing countries increase their fertilization rates. Yield increases from fertilized crops come at a cost; fertilizers are large energy consumers, accounting for about a third of energy consumption in US crop production. This article describes why and how fertilizers are used, worldwide fertilization trends, the energy lifecycle of fertilizers, and measures to improve the energy efficiency of fertilizer production and use.

1. Introduction

Fertilizers are characterized as an indirect energy consumer on the farm. Other indirect energy consumers include chemical pesticides, hybrid seeds, and special feed supplements for livestock. Indirect energy consumers differ from direct energy consumers, such as tractors, irrigation pumps, and other types of agricultural equipment, in that the majority of the energy consumption associated with fertilizers is accomplished away from the farm. Fertilizers are widely used in agriculture to maintain soil fertility and to increase crop yields. Their application has grown immensely since the early 1900s, and continues to grow at a steady rate in developing countries. Fertilizers enable high yields on less crop area than would be required without the use of fertilizers; therefore, they are an important element in worldwide food production. As the population continues to grow, more and more agricultural output will be required, and fertilizers will play a vital role. In spite of their benefits, fertilizers are associated with high energy consumption. In particular, they are very dependent on natural gas for production. Energy constraints and high fuel costs necessitate the implementation of energy efficiency measures in the production and use of fertilizers. Section 2 describes the use of fertilizers to improve crop productivity. Section 3 summarizes trends in fertilizer use by geographical region, nutrient, and crop type. Section 4 discusses the energy lifecycle of various fertilizers. Finally, Section 5 presents the predominant energy efficiency opportunities for fertilizer production and use.

2. Fertilization for Crop Productivity

Plants require at least 16 essential elements for healthy growth. Air and water provide three of these elements (carbon, hydrogen, and oxygen), while the others are extracted from the soil. Table 1 lists essential plant nutrients obtained from the soil. These nutrients are separated into two main categories: macronutrients and micronutrients. Macronutrients are further categorized as primary or secondary. The table also lists nutrients that are required to a lesser degree by some plants. The predominant nutrients required by plants are nitrogen (N), phosphorus (P), and potassium (K). These are also the main nutrients in chemical fertilizers.

Macronutrients	**Micronutrients**	**Additional nutrients important for some plants**
Primary macronutrients:	Boron	Sodium
Nitrogen	Chlorine	Silicon
Phosphorus	Copper	Cobalt
Potassium	Iron	Aluminum
	Manganese	
Secondary macronutrients	Molybdenum	
Calcium	Zinc	
Magnesium		
Sulfur		

Table 1. List of essential plant nutrients obtained from soil

As plants are grown and harvested, they deplete the soil of its nutrients. The degree of depletion is a function of crop variety. For example, legumes are capable of nitrogen fixation, and therefore require less nitrogen than crops without the ability to fix nitrogen, such as corn. Whatever nutrients are depleted from the soil must then be replaced to maintain soil fertility. Soil fertility is increased in two main ways: organically and inorganically. Research has revealed that a combination of inorganic and organic fertilization strategies results in higher crop yields than with either approach applied on its own.

Organic fertilization is accomplished through the addition of organic waste to the soil. Organic waste can include livestock manures, crop residues, compost, and sewage sludge. The benefits of organic materials to the soil are twofold. First, the materials replenish the soil with nutrients. As organic material decomposes, the minerals within it become available to plants growing within the soil. The decomposition is accomplished by microorganisms in the soil. For uncomposted organic material, the nitrogen content of the soil may decrease temporarily as the microorganisms use it for cell production during the decomposition process. The second way in which organic materials improve the condition of the soil is by increasing water infiltration and water-holding capabilities, enhancing aeration, and improving soil aggregation. Organic fertilizers are generally considered more environmentally friendly; however, some organic fertilizers derived from industrial waste may contain toxic substances, such as heavy metals, which are hazardous to humans.

Inorganic fertilization consists of adding chemical fertilizers to the soil. The inorganic fertilizers are commercially manufactured, and are formulated to contain a vast array of nutrient compositions and concentrations. Some fertilizers contain one main nutrient source, while others contain multiple sources. The main nutrients in mixed inorganic fertilizers are nitrogen, phosphorus, and potassium; however, they often contain micronutrients as well. Different nutrient compositions suit different crops and soil types. The level of nitrogen in a fertilizer is expressed as a percentage of total elemental nitrogen, and is often obtained by combining more than one source of nitrogen to achieve a total nitrogen percentage. Some important nitrogen sources are ammonium nitrate, urea, and ammonium phosphate, among others. The level of phosphorus is expressed as the quantity of available phosphate (P_2O_5), where 44% of P_2O_5 is phosphorus. The level of potassium is expressed as the quantity of soluble potash (K_20), where 83% of K_2O is potassium. Fertilizers are commonly differentiated by their nitrogen–phosphate–potash levels. For example, a 5–10–5 fertilizer contains 5% total nitrogen, 10% available phosphoric acid, and 5% soluble potash; the remaining 80% could be any combination of secondary macronutrients, micronutrients (usually a small percentage), and inactive ingredients. The same ratio of primary ingredients is found in a 15–30–15 fertilizer, but the concentrations are three times as high. Therefore, the 15–30–15 fertilizer is more nutritious per unit weight than the 5–10–5 fertilizer.

Without some sort of fertilization, much more land would be required to achieve the same yields as found with fertilized crops. Fertilization greatly increases crop productivity. In fact, nitrogen fertilizers are commonly credited with one-third of US crop productivity. Moreover, according to documents released by the Department of Agriculture, one unit of energy in the form of nitrogen can yield six units of energy output; the additional nitrogen enables plants to utilize more solar energy. However, the benefits of fertilization diminish with increased application after a certain optimum level. In addition, overfertilization can result in environmental problems, such as nitrate pollution in surface and ground water.

The degree of nutrient mobility and the availability of nutrients to a crop planted within the soil are dependent on a variety of factors. These factors also influence the productivity of applied fertilizer:

- soil moisture content
- soil pH

- soil oxidation potential
- soil electrical conductivity
- chemical activity of soil components
- biological activity of microorganisms
- quantity of organic material
- nutrient balance of applied fertilizer
- responsiveness of particular crop to fertilizer
- type of irrigation
- manner in which plants are protected
- plant population
- degree of weeds.

When planted in nutrient-deficient soil, plants will not thrive, and yields will be less than optimal. Signs of nutrient deficiencies vary by nutrient type. For example, a nitrogen deficiency can result in plants with weak stalks and small, light-green leaves. A deficiency in phosphorus can yield dark green foliage, with purple-tinted leaves or petioles. A potassium deficiency might cause yellowing or dead areas near the leaf tips and margins. With an iron deficiency, upper leaves can turn yellow in between the large veins.

3. Trends in Fertilizer Use

Until about 1950, farmers throughout the world relied on animal wastes and/or crop rotation with nitrogen-fixing crops to keep the soil fertile. Though these practices are still common in some locations, much of the world’s agriculture now uses inorganic (chemical) fertilizers to supplement and restore soil nutrients. Figure 1 shows the trends in world fertilizer consumption since 1920. Between 1920 and 1960, phosphate fertilizer consumption was greater than that of either nitrogen or potash fertilizer. After 1960, nitrogen fertilizer consumption quickly surpassed that of phosphate and potash fertilizer. Today, nitrogen fertilizer consumption is about 2.5 times higher than that of phosphate fertilizer, and almost four times higher than that of potash fertilizer. Total fertilizer consumption is about 80 times its 1920 rate.

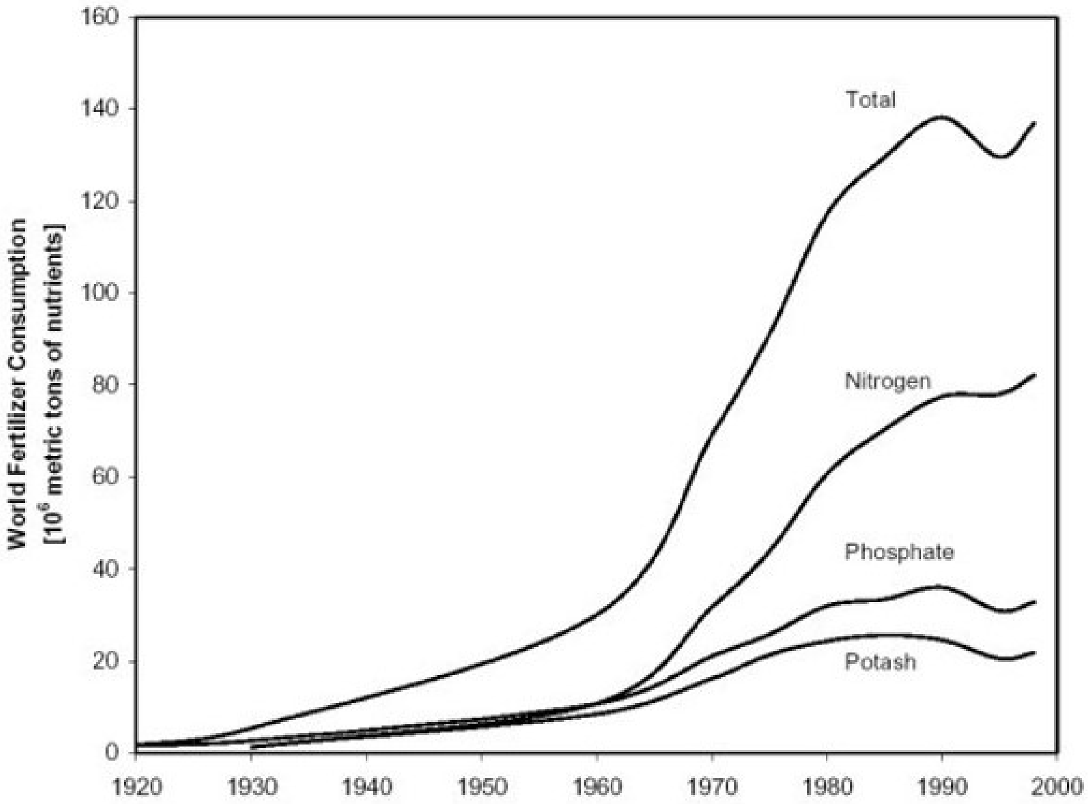

Figure 1. World fertilizer consumption by nutrient, 1920–2000. Source: data compiled from International Fertilizer Industry Association, <www.fertilizer.org/ifa/statistics/STATSIND/pkann.asp>.

Figure 1 shows a dip in fertilizer consumption in the mid-1990s. This dip corresponds to economic problems and changes in Central Europe and the Former Soviet Union. The dramatic declines in fertilizer consumption for Central Europe and the Former Soviet Union are illustrated clearly in Figure 2, which also shows fertilizer trends for other regions of the world. Fertilizer consumption reached its maximum in the early 1980s for developed areas, such as Western Europe and North America, and has since leveled off somewhat. Socialist Asia has seen a significant rise in fertilizer consumption, increasing from about 1 million to 38 million metric tons of nutrients between 1960 and 1999. The consumption rise in South Asia is also notable—increasing from less than 1 to over 22 million metric tons of nutrients. Other developing regions, including Latin America, East Asia, Near East, Africa, and Oceania, have increased fertilizer consumption steadily since the middle of the twentieth century.

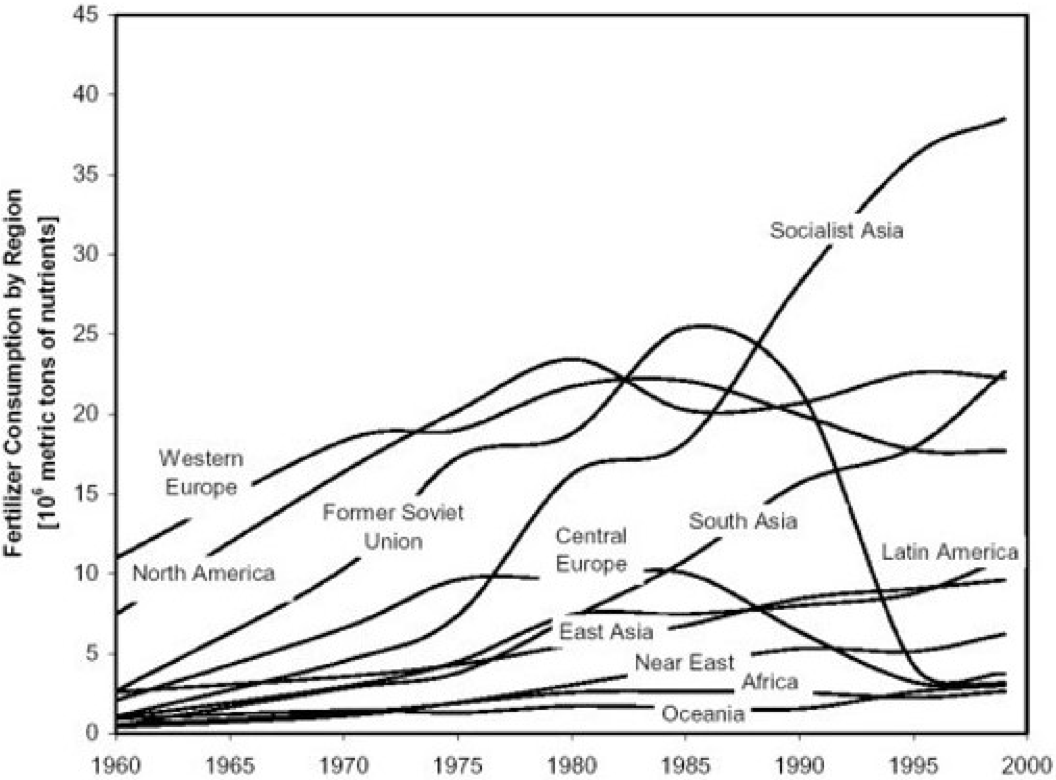

Figure 2. Trends in fertilizer consumption by region. Source: data compiled from International Fertilizer Industry Association, <www.fertilizer.org/ifa/statistics/STATSIND/pkann.asp>.

Figure 3 illustrates the relative importance of each primary nutrient by region. Developing Asia uses an enormous quantity of nitrogen fertilizer; in fact, it consumes more than three times as much nitrogen fertilizer as North America. The nitrogen–phosphate–potash ratio of fertilizer consumption for Developing Asia is roughly 6–2–1; for North America, the ratio is roughly 2½–1–1. Latin America consumes the three types of fertilizers in more equal quantities, with nitrogen use only slightly higher than phosphate use, and phosphate use only slightly higher than potash use. Worldwide, the current nitrogen–phosphate–potash ratio of fertilizer consumption is about 8–3–2.

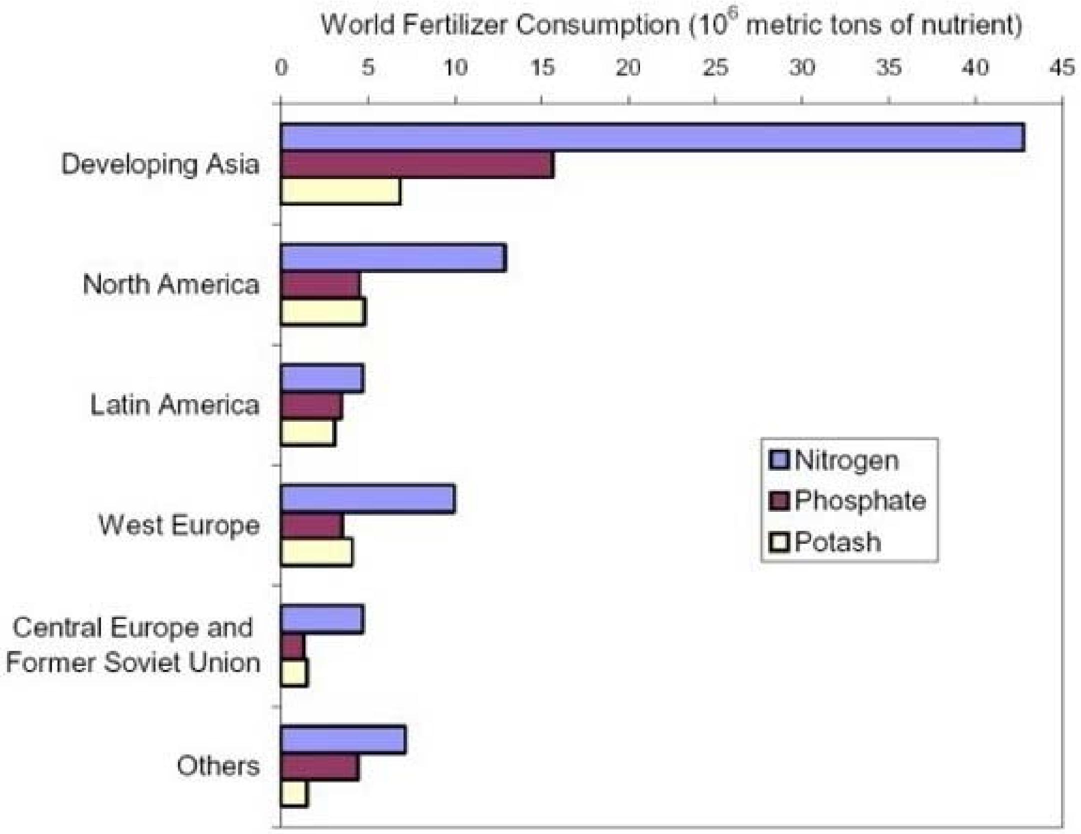

Figure 3. World fertilizer consumption by region and nutrient, 1998/1999. Source: data compiled from International Fertilizer Industry Association, <www.fertilizer.org/ifa/statistics/STATSIND/pkann.asp>.

Figure 4 shows fertilizer consumption per unit crop area for selected countries and crops. The crops plotted (maize, wheat, soybean, and potato) are four of the most significant crops in the world. Among these, potatoes require the most fertilization. Brazil and the United States use over 500 metric tons of nutrients per thousand hectares (50 metric tons per square kilometer). Fertilizer consumption for potato crops is also notable, but to a lesser extent, in Canada, China, and Mexico, where between 200 and 300 metric tons of nutrients per thousand hectares are used. In the United States, China, and Mexico, soybean crops (which are capable of nitrogen fixation) are the least fertilized of the four types of crops displayed. For the countries listed, the fertilization consumption for soybeans ranges from about 40 to 150 metric tons of nutrients per thousand hectares. Maize is another crop with high rates of fertilization. In the United States and Canada, about 260 metric tons of nutrients per thousand hectares are used for maize crops. Fertilization for wheat crops is particularly high for China and Mexico when compared with the other countries included in Figure 4; both countries use about 200 metric tons of nutrients per thousand hectares.

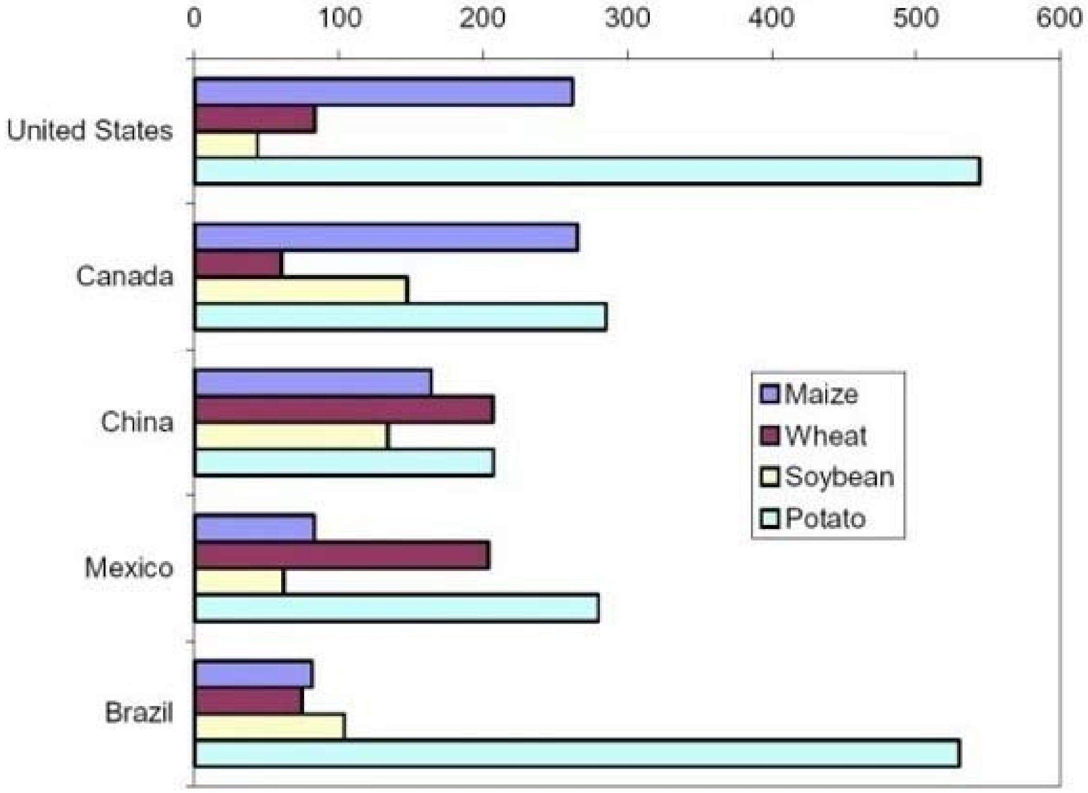

Figure 4. fertilizer consumption per unit area by region and crop. Source: data compiled from International Fertilizer Industry Association (IFA), International Fertilizer Development Center (IFDC), and Food and Agriculture Organization of the United Nations (FAO). (1999). *Fertilizer Use by Crop, 4th Edition*. Rome, Italy: IFA, IFDC, and FAO.

As the world's population continues to grow, and as more countries become further developed, there will be an ever-increasing demand for greater agricultural output. Some of this increased output could come from newly cultivated land, but some of it must also come from higher yields per unit area. Fertilization will surely play a large role. Therefore, it is more important than ever to increase the efficiency of fertilization production and use.

4. Energy Intensity of Fertilization

Inorganic fertilizers are major consumers of energy in the agricultural sector. In the United States, inorganic fertilization accounts for about a third of total energy input to crop production. In contrast to tractors, irrigation pumps, and other types of equipment, fertilizers are indirect energy consumers. That is, the bulk of energy use associated with fertilizers is not consumed directly at the agricultural site, but indirectly during its production, packaging, and transportation to the site. Additional energy is then used on-site during fertilizer application.

Most fertilizer energy use is attributable to the production of nitrogen fertilizers with natural gas. Natural gas is the principal energy resource for creating anhydrous ammonia, a key nitrogen fertilizer. The natural gas provides a source of hydrogen in the synthesis of ammonia by the Haber process. Over 90% of nitrogenous fertilizers contain ammonia and/or other fertilizer elements derived from ammonia (e.g., ammonium nitrate, sodium nitrate, calcium nitrate, ammonium sulfate, ammonium phosphates, and urea). Producing ammonia is a very energy intensive process; it requires about 1090 to 1250 m^3 of natural gas to produce 1 metric ton of anhydrous ammonia (35 000 to 40 000 ft^3 natural gas per short ton). In 1999, over 15 million metric tons (17 million short tons) of ammonia were produced in the United States, with almost 90% of that going to the fertilizer industry. This amount corresponded to about 3% of total US natural gas production. Natural gas is also used in other ways in the fertilizer industry. For example, natural gas as a fuel provides the process heat for producing other types of fertilizers. It is estimated the natural gas supplies between 70 and 80% of all energy for fertilizer production.

Each of the three primary nutrients in inorganic fertilizers has a different set of energy requirements during its lifecycle. However, these requirements can be separated into four main stages: production, packaging, transportation, and application. Table 2 summarizes the world average energy requirements by nutrient type and lifecycle stage for inorganic fertilizers. The table clearly shows the relatively high energy intensity of nitrogen production. Nitrogen production requires roughly 70 000 kJ per pound of nutrient (30 000 Btu per kg). This corresponds to almost 90% of nitrogen's total energy requirement. In contrast, the production of phosphate and potash account for only about 45% of the total energy requirement for these nutrients. Moreover, the energy requirement for nitrogen fertilizer is 4.5 times that of phosphate fertilizer, and 5.7 times that of potash fertilizer.

	Energy requirement (world average) Btu/lb (kJ/kg)		
	Nitrogen	**Phosphate**	**Potash**
Produce	29 899 (69 530)	3313 (7700)	2753 (6400)
Package	1119 (2600)	1119 (2600)	774 (1800)
Transport	1936 (4500)	2452 (5700)	1979 (4600)
Apply	688 (1600)	645 (1500)	430 (1000)
Total	33 642 (78 230)	7529 (17 500)	5936 (13 800)

Table 2. Energy requirements to produce, package, transport, and apply inorganic fertilizers. Source: data compiled from Helsel Z.R. (1992). Energy and alternatives for fertilizer and pesticide use. *Energy in Farm Production, Volume 6* (ed. R.C. Fluck), pp. 177–201. New York: Elsevier.

Organic fertilizers also have energy requirements. In fact, transportation and application energy demands are often higher for organic fertilizers since they are less nutritious per unit weight. Some of the requirements for processed organic fertilizers may include:

- collection of organic waste,
- loading and transportation of waste to a processing plant,
- unloading and putting waste into windrows,
- turning and irrigation of windrows to expedite composting,

- collection, loading, and transportation of composted waste from processing plant to field,
- unloading waste for storage, and
- loading and applying waste to field by farm equipment.

Organic material can be applied directly to a field, but it will then take longer to decompose, delaying the availability of nutrients to plants. In addition, “fresh” application will often result in a temporary nitrogen deficiency in the soil, as microorganisms use the nitrogen for cell production during the decomposition process.

Organic fertilizers that are processed obviously require more energy that those that are directly applied. Therefore, there is a point at which the energy expenditure per unit weight of nutrients in transporting and composting the organic material exceeds the energy requirement of inorganic fertilizers. For example, according to a study in the state of Florida, the use of broiler compost is viable as long as the composting plant is within 15 miles of both the broiler house and the field to be fertilized. A greater distance would require more energy in the form of transportation fuel than is cost-effective.

5. Energy-Efficient Fertilization Practices

Since natural gas is such a critical resource in fertilizer production, natural gas price fluctuations have a dramatic effect on fertilizer costs. As energy costs continue to rise, and the demand for fertilizers increases, this effect is becoming more pronounced. The implementation of energy-efficiency measures in the production and use of fertilizers will help curb the effects of rising gas costs, as well as the effects of energy costs in general.

One of the most obvious areas of energy consumption to address in the fertilizer industry is the production of anhydrous ammonia for nitrogenous fertilizers. Efficiency strides have been made since the inception of the original Haber process in the early 1900s, but more improvements are still possible. This area of energy consumption is the responsibility of fertilizer manufacturers. Some of the main opportunities for production improvements are listed in Section 5.1.

5.1. Measures to Increase the Efficiency of Ammonia Production

- Replace process equipment with high-efficiency models.
- Improve process controls to optimize chemical reactions.
- Recover process heat.
- Maximize the recovery of waste materials.

The next area of energy consumption to address is the application of fertilizers to crops. Measures to improve the use of fertilizers are the responsibility of the farmer. Therefore, the efficient use of fertilizers is more controllable by farmers (and is thus more directly applicable to farmers) than is the efficient production of fertilizers. The principal opportunities for increasing the efficiency of fertilizer use are described in the following paragraphs.

5.2. Measures to Increase the Efficiency of Fertilizer Use

Test the soil: It is critical to test the soil to determine the level of soil nutrients. Soil testing also provides information about the soil's pH and organic matter content. Knowledge of the soil characteristics will help optimize the use of fertilizers. Once the nutrient level of the soil is known, only use the amount of soil additives necessary to amend the soil to the required level. If some fields associated with a given farm have low fertility, while others have high fertility, only fertilize the fields with low fertility, rather than fertilizing all fields equally. It is typically recommended that soil testing be done in one to four-year intervals on all crops.

Maintain soil pH: The pH of a soil is a determining factor for the availability of plant nutrients. In most cases, a fairly neutral soil pH in the range of 6.0 to 7.5 is desirable for maximum nutrient availability, particularly for the primary nutrients of nitrogen, phosphorus, and potassium. However, different nutrients have greater availability at different pH levels. For example, minor nutrients such as iron, copper, and zinc are more available in acidic soils, whereas those such as calcium and magnesium are more available in moderately alkaline soils. The pH of acidic soils can be raised to the neutral level by liming with minerals such as dolomite and calcite. Basic soils can be made more acidic by adding iron and sulfur fertilizers, or acidic organic materials such as pine needles. It is generally more cost-effective to raise the pH than to reduce it.

Use high-analysis fertilizers: It is less energy-intensive to use high-analysis fertilizers. These fertilizers contain a larger fraction of nutrients per volume, resulting in lower transportation, storage, and handling requirements than for fertilizers that are not as nutrient rich. This applies both to individual chemical compounds and to formulated fertilizers. For example, some compounds are more nutrient-rich than their alternatives (e.g., ammonium nitrate contains about 60% more nitrogen than ammonium sulfate). In addition, some formulated fertilizers use less filler material to achieve a given ratio of ingredients. Therefore, per unit weight, high-analysis fertilizers contain more energy.

Use known products: New fertilizer products are constantly coming to the market. It is prudent to avoid the use of newer products until they become well established. Instead of rushing to purchase the latest innovation, conduct research to find out what products and practices are proven and recommended for the particular soil type and crop, and then implement the proven technologies.

Apply fertilizers efficiently: One of the most important methods for increasing fertilization efficiency is to apply the appropriate amount of nutrients in the required location. Efficient fertilizer application is accomplished by distributing the fertilizer uniformly in the needed area. Too much fertilizer in a given area results in waste. If feasible, consider band application of fertilizer in place of broadcasting. This will lower fertilizer requirements. In addition, if possible, combine the application of fertilizer with other tillage tasks to reduce the number of passes on the field. For example, it is more efficient to apply starter fertilizer during the planting or drilling stage than it is to apply it by broadcasting. It is also very important to make sure fertilizers are applied so that they are incorporated in the rooting zone.

Apply fertilizers at the appropriate time: Plants will utilize nutrients more efficiently if the nutrients are applied at the correct point in the plants' growing cycle. In particular, phosphorus should be applied early on as a nutrient for seedling development, and nitrogen application should be timed so that the nitrogen enters the rooting zone at the optimum time for the specific crop. Proper timing will increase yields and reduce fertilizer energy use. Another benefit of proper timing is that the plants will more likely be able to assimilate the nutrients before nutrient leaching and volatilization occur.

Investigate the application of fertilizers through the irrigation system: In some cases it may be feasible to add nutrients to irrigation water. This will hasten the transport of nutrients to the root zone, but over-irrigation could result in the loss of nutrients to leaching.

Mulch to prevent nutrient loss: If cost-effective, the use of mulch provides many benefits to crops. In addition to keeping the ground temperature cooler and reducing evaporation, it can lessen nutrient volatilization. The application of plastic, or similar, mulch will also reduce nutrient leaching in times of heavy rainfall.

Consider rotating crops with legumes: Legume crops are capable of nitrogen fixation, and therefore they can restore the nitrogen level in the soil if their waste products are tilled back into the ground. It is very effective to rotate nonlegume crops (which depend heavily on nitrogen) with legume crops to reduce the requirement for nitrogen fertilizer amendment. Table 3 shows ranges of values for nitrogen added to soils from various legume crops. (The values were obtained from two sources, and show some variation; the estimates from Source (b) are lower than from Source (a) in most cases.) Generally, annual legumes do not leave behind as much nitrogen as biennial or perennial varieties. It is also important to note that more nitrogen is added to the soil for unharvested legume crops; nevertheless a benefit is still achieved from harvested crops. For farmers who do not want to lose a cash crop, a good legume choice might be soybeans, as the soybeans can be sold, and the residual plant material can be incorporated into the soil for a lesser (but still helpful) nitrogen benefit. Another alternative is 'interplanting,' in which alternate rows of legumes and the cash crop are planted. In this scenario the benefits of a cash crop and legume crop are combined. However, interplanting is more labor intensive and complicated. Legumes are also useful as cover crops. They can be planted in summer, and then tilled in during the spring to serve as a nitrogen source for a subsequent crop. One limitation of cover crops is that the timing for the second crop may not be optimal.

Type of legume crop	Nitrogen addition per unit crop area	
	Source (a) **lb acre^{-1} (kg ha^{-1})**	**Source (b)** **lb acre^{-1} (kg ha^{-1})**
Perennial		
Alfalfa	172–196 (193–220)	
80–100% stand		120–140 (134–157)
50–80% stand		40–60 (45–67)
<50% stand		0–20 (0–22)
Red clover (pure stand)	74–133 (83–149)	40–60 (45–67)
Biennial		
Sweet clover	116 (130)	100–120 (112–134)
Annual		
Bean	40 (45)	
Pea	53–89 (60–100)	
Peanut	42 (47)	
Soybeans	58–98 (65–110)	15–60 (17–67)
Vetch	60–100 (67–112)	

Source: Data compiled from: (a) Buchholz et al. (1993); (b) Poincelot (1986).

Table 3. Addition of nitrogen to soil by legume crops. Source: data compiled from: (a) Buchholz et al. (1993) and (b) Poincelot (1986).

Utilize organic waste if cost-effective: Animal and other types of organic wastes can provide a very good source for soil nutrients. In addition to their nutritional benefits, organic waste fertilizers also improve the soil’s quality by increasing its water-holding capacity, filtration, aeration, and soil aggregation. One downside of organic fertilizers is that they contain fewer nutrients per unit weight than inorganic fertilizer, and the nutritional content is often less characterized. Depending on their source, they may also contain heavy metals, soluble salts, weed seeds, and other undesirable contents. In many cases the use of organic fertilizers, augmented with inorganic nutrients as needed, is an energy-efficient and cost-effective alternative. However, if the distances between the source of organic material, the composting plant, and the end-use location are large, the costs associated with transporting and applying the wastes may outweigh the benefits of reduced chemical fertilizer use.

Glossary

Fertilizer:	Organic or inorganic material that is added to soil to provide additional nutrients for plants. Fertilizers are used for soils that are nutrient-deficient naturally, or for soils that have been depleted of nutrients by harvesting and/or grazing.
Forage crops:	Crops used for food by livestock. Legumes and grasses are important forage crops that provide a food source for livestock animals, which in turn provide milk, meat, and labor for humans.
Haber process:	A high-pressure, high-temperature chemical process for synthesizing ammonia from hydrogen and nitrogen in the

	presence of a catalyst.
Inorganic fertilizer:	Fertilizer produced artificially by chemical means. Inorganic fertilizers are formulated with varying combinations of nutrients. The primary nutrients are nitrogen, phosphorus, and potassium.
Leaching:	Removal of a soluble material from a permeable and insoluble solid by a liquid solvent (e.g., the removal of nutrients in soil by water).
Legumes:	Any member of the Leguminosae family, which is also referred to as the bean or pea pod family. Legume is the name of the fruit produced by the Leguminosae family. Legumes include beans, peas, alfalfa, and soybeans, all of which are important sources of protein and fat. Legumes are also capable of nitrogen fixation, and if returned to the soil can increase its nitrogen content.
Nitrogen fixation:	The conversion of atmospheric nitrogen into forms that be used by plants. Humans and animals can then absorb the nitrogen through consumption of plants or animals that have consumed plants.
Organic fertilizer:	Fertilizer consisting of organic material, such as animal manure, plant (green) manure, compost, fishmeal, and bone meal. Organic fertilizers add fewer nutrients to the soil per unit weight than inorganic fertilizers, but have the advantage that they provide valuable soil conditioners that improve soil properties, whereas inorganic fertilizers do not.
Organic substance:	A substance of animal or vegetable origin.
Stand of plants:	A grouping of plants in a given area that is distinguishable from nearby vegetation.
Volatile substance:	A substance that is easily carried off by evaporation (e.g., the loss of nutrients from soil by evaporation).
Windrow:	A row of material (e.g., organic waste) on a field.

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Biographical Sketches

Clark W. Gellings' 30-year career in energy spans from hands-on wiring in factories and homes to the design of lighting and energy systems to his invention of "demand-side management" (DSM). He coined the term DSM and developed the accompanying DSM framework, guidebooks, and models now in use throughout the world. He provides leadership in The Electric Power Research Institute (EPRI), an organization that is second in the world only to the US Department of Energy (in dollars) in the development of energy efficiency technologies. Mr. Gellings has demonstrated a unique ability to understand what energy customers want and need, and then implement systems to develop and deliver a set of R&D programs to meet the challenge. Among his most significant accomplishments is his success in leading a team with an outstanding track record in forging tailored collaborations—alliances among utilities, industry associations, government agencies, and academia—to leverage R&D dollars for the maximum benefit. Mr. Gellings has published 10 books, more than 400 articles, and has presented papers at numerous conferences. Some of his many honors include seven awards in lighting design and the Bernard Price Memorial Lecture Award of the South African Institute of Electrical Engineers. He has been elected a fellow of the Institute of Electrical and Electronics Engineers and the Illuminating Engineering Society of North America. He won the 1992 DSM Achiever of the Year Award of the Association of Energy Engineers for having invented DSM. He has served as an advisor to the US Congress Office of Technical Assessment panel on energy efficiency, and currently serves as a member of the Board of Directors for the California Institute for Energy Efficiency.

Kelly E. Parmenter, Ph.D. is a mechanical engineer with expertise in thermodynamics, heat transfer, fluid mechanics, and advanced materials. She has 14 years of experience in the energy sector as an engineering consultant. During that time she has conducted energy audits and developed energy management programs for industrial, commercial, and educational facilities in the United States and in England. Recently, Dr. Parmenter has evaluated several new technologies for industrial applications, including methods to control microbial contamination in metalworking fluids, and air pollution control technologies. She also has 12 years of experience in the academic sector conducting experimental research projects in a variety of areas, such as mechanical and thermal properties of novel insulation and ablative materials, thermal contact resistance of pressed metal contacts, and drag reducing effects of dilute polymer solutions in pipeflow. Dr. Parmenter's areas of expertise include: energy efficiency, project management, research and analysis, heat transfer, and mechanical and thermal properties of materials.

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