ENERGY EFFICIENCY IN FERTILIZER PRODUCTION AND USE

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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.

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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.