

ENERGY EFFICIENCY IN AGRICULTURAL EQUIPMENT

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Summary

Thoughtful implementation of energy-efficiency improvements in agricultural equipment will help reduce the cost of food production. This article describes energy-efficiency alternatives as they relate to crop and livestock equipment. The specific types of equipment targeted are tractors, implements, crop drying systems, livestock cooling and heating systems, lighting, and farm motors and drive systems.

1. Introduction

Food production in the form of crops and livestock consumes much less energy on average than the processing and distribution of food. For example, food production accounts for less than about one-fifth of US energy consumption in the food industry. The remaining four-fifths or so is used in the processing and distribution of the food. Nevertheless, energy-efficiency efforts in food production can have an impact.

When considering the area of food production alone, fertilizers and pesticides consume the largest share of energy, accounting for roughly two-fifths of food production energy in the United States. (See *Energy Efficiency in Fertilizer Production and Use*.) The next

largest end-use is agricultural equipment, which in the current treatment includes field machinery, crop drying equipment, and livestock equipment. This grouping of agricultural equipment accounts for more than one-quarter of all food production energy use in the United States. Transportation, irrigation, and miscellaneous end-uses account for the remaining quantity of food production energy consumption. (*Energy Efficiency in Pumping and Irrigation Systems* provides a discussion of efficiency measures in pumping and irrigation systems.)

This article pertains to energy efficiency in agricultural equipment. Section 2 describes efficiency measures for crop equipment. Its particular focus is on tractors and implements and crop drying equipment. Section 3 treats energy-efficient alternatives for livestock equipment, with discussions of evaporative cooling, milk heat recovery, groundwater-ice bank milk cooling, and efficient lighting. Finally, Section 4 presents efficiency measures for motors and drives, namely energy-efficient motors, variable frequency drives for agriculture ventilation fans, and variable speed drives for dairy vacuum pumps.

2. Crop Equipment

The food products from crops are used not only to feed humans, but also for feeding livestock. In fact, the majority of energy consumed in livestock agriculture is in the form of feed from crops. Therefore, crop energy efficiency impacts all aspects of food production: grains, produce, meat, dairy, and so on.

The energy intensity of crops is widely variable among the different types of crops. For all crops, a large amount of energy is input at no cost from the sun. Therefore, an energy accounting of crops shows that the energy content of the sum of inputs other than the sun (for example, fuel, electricity, chemicals, and machinery) is less than the energy content of the crop product. That is, an apple is likely to contain more energy than was “paid” to be put into it. Crops requiring a lot of post-processing, such as tobacco, are generally much more energy-intensive than simple crops, such as feed grains. Fruits and vegetables are moderately energy-intensive because of the relatively high quantities of fertilizers, pesticides, and irrigation required. The subsequent sections summarize measures to improve the energy efficiency of tractors, implements, and crop drying equipment.

2.1. Efficient Use of Tractors and Implements

Tractors and their various implements are used for many crop operations, such as tilling, planting, cultivating, harvesting, and spraying fields. They are critical for the agricultural sector and consume a considerable portion of total crop energy use. In fact, in the United States they are the second largest end-use of energy for crop production, next to fertilizers and pesticides. Energy use related to crop machinery can be divided into direct and indirect forms. Indirect energy use encompasses the energy consumed to produce the materials, manufacture the equipment, and transport the equipment to the end-use location. It also includes the energy associated with maintaining and/or replacing components of the equipment. The present discussion focuses on direct energy use, which is the fuel used to operate the machinery. Many measures exist to improve

the fuel efficiency of crop machinery and related operations. The predominant measures are summarized as follows.

- *Use diesel fuel and engines.* Most tractors in the United States currently use diesel engines and fuel because of the energy efficiency and operational benefits. Nevertheless, older machinery that is still operated with gasoline should be considered for replacement with a diesel alternative. Diesel engines are advantageous for agricultural applications because they are capable of accomplishing a given amount of work with approximately 10% or less fuel than gasoline engines. Diesel engines also tend to require less maintenance. Diesel fuel contains more energy per gallon, and is usually less expensive than gasoline, making it economically attractive from an operation point of view. However, diesel engines typically require a higher capital investment.
- *Match the equipment with the operation.* It is important to use the appropriate machinery for a given task. Tractors are more efficient when used near capacity. If possible, it is desirable to use a smaller tractor for operations requiring a lighter load, and larger tractors for operations requiring a heavier load. For small farms, this is not economically viable. Instead, a large tractor can be used efficiently on smaller jobs by shifting to higher gears, and throttling down the engine. The engine will consume less fuel at lower engine speeds.
- *Follow good maintenance practices.* As with all equipment, a little preventative maintenance goes a long way toward improving efficiency. To optimize performance, tune up engines regularly, clean or replace air filters, clean electrical equipment, and provide the proper lubrication. In addition, insure that tractor tires are inflated to the correct pressure to optimize traction. It is also important to keep implements in good repair. For example, make sure that blades are sharp in order to reduce resistance during field operations.
- *Operate equipment properly.* Careful operation of the tractor and implements will optimize fuel efficiency. Make sure that the machinery and controls are adjusted correctly for the particular operation. Also, reduce unnecessary idling. It is more efficient to turn the equipment off during extended breaks than to run it. The tractor will also work most efficiently if the correct tire tread is chosen for the soil conditions.
- *Use ballast of the tractor correctly.* Another item related to both equipment selection and operation is proper ballasting of the tractor for given conditions. If a tractor is heavier than necessary for an operation, the additional weight can result in soil compaction as well as decreased fuel economy. Alternatively, if there is not enough ballast on the tractor, the wheels are more apt to slip, and wear on the tires is increased. For a tractor with insufficient ballast for a particular operation, adding wheel weights can increase the ballast.
- *Optimize traffic patterns on the field.* It is best to reduce the frequency of turns during field operations. One way to accomplish this is by traveling lengthwise along a rectangular field (that is, in the direction parallel to the longest side). This will reduce the number of turns when compared with traveling parallel to the width, or shortest side. It is also important to eliminate unnecessary overlap while traversing the field. Reducing turns and minimizing overlap save both fuel and time. Getting the job done in a timely fashion has the added benefit of

increasing yields. This is particularly true for critical operations that result in greater yields if performed at the optimum time, such as planting and harvesting.

- *Balance yield with energy use.* In some cases, the yield is increased by using equipment capable of operating at higher speeds and with wider implements. However, heavy-duty equipment is more expensive and uses more fuel than slower, lighter equipment. The benefits of increased yield need to be balanced with the higher capital and energy costs associated with heavier tractors and wider implements.
- *Combine operations to reduce trips over the field.* Another way to reduce fuel use is to combine multiple implements and operations in one pass. For example, in some cases it may be feasible to form a seedbed, fertilize, and sow the seeds in a single pass, rather than in three passes.
- *Select efficient equipment.* The energy efficiency of the equipment being used is an obvious determinant of fuel consumption per unit of output. It is best to purchase efficient equipment at the outset, even though it might require a higher initial investment than standard equipment. Usually the annual energy savings will quickly payback the initial cost differential. However, it is important to conduct an economic analysis to insure that the calculated payback periods are acceptable. Tractors are often operable for several decades, so inefficient equipment can result in high operating costs that continue for many years. It is less cost-effective to replace existing equipment with high-efficiency equipment before the original equipment has reached the end of its useful life, although in some cases this is justified. Again, an economic analysis will help determine when and if equipment replacement is viable. The Department of Agricultural Engineering at the University of Nebraska has a program in which different makes and models of tractors are compared. This is a good resource to use when choosing a tractor. The fuel economy of a tractor depends on various factors, including the engine efficiency, weight-to-power ratio, weight distribution, and number of drive wheels. The soil conditions and implements driven also affect the fuel use. For example, the use of primary tillage equipment (for example, moldboard and chisel plows) results in the highest energy consumption of all crop operations. In addition, high draft soils such as clay and clay loam generally require more energy to till than low draft soils such as sand or sandy loam soils.
- *Reduce tillage operations.* As mentioned previously, primary tillage operations are very energy-intensive. In general, the reduction of tillage operations is advantageous for reasons such as lower fuel consumption, less expensive equipment, reduced labor, improved water filtration, reduced soil erosion, and less topsoil lost. The energy consumption during tillage is a strong function of the amount of earth that is moved. Moldboard plows are the most energy-intensive type of tillage equipment; they dig deep into the earth, tilling a large quantity of earth, and thoroughly mixing in crop residue. Chisel plows and heavy offset disks result in moderate energy use as they move less earth and achieve shallower tillage than moldboard plows. Some farmers choose a no-tillage approach, which reduces fuel consumption, but can increase chemical use. That is, by eliminating the primary tilling stage, crop residue remains closer to the surface where it can lead to weed and insect problems; moreover,

more fertilizer is required for some crops to achieve the same yield. The benefits of reduced tillage must be balanced with the costs of increased energy consumption in the form of chemicals. Table 1 shows an example comparing the energy required to produce corn in moderate draft soil for four types of planting systems: moldboard tillage, chisel tillage, disk tillage, and no tillage. In this example, the form and rate of nitrogen are different for the no-tillage system and are associated with a higher energy input in order to achieve a comparable yield. As can be seen in the table, the two reduced tillage systems result in overall energy savings compared with the moldboard plow system. Specifically, the chisel plow and disk systems achieve savings of 670 and 2130 liters of diesel per square kilometer (0.72 and 2.28 gallons per acre), respectively. However, the no-tillage system requires 7490 liters more of diesel per square kilometer (8.01 gallons per acre) than the moldboard plow system. Hence, the energy use of the fertilizer is a determining factor when comparing the tillage versus no-tillage solutions. The energy quantities will vary depending on particular conditions, but this example shows the importance of balancing all aspects of energy consumption in order to optimize the yield of a crop. If it were possible to keep the form and rate of nitrogen used in the no-tillage alternative comparable to that used in the various tillage alternatives, the no-tillage method would use less energy than the moldboard plow, chisel, and disk systems. (Methods to improve the energy efficiency of fertilizer use are discussed more thoroughly in *Energy Efficiency in Fertilizer Production and Use*).

Type of energy input	Energy required by type of planting system (gallons per acre ^a – diesel fuel equivalent)			
	Moldboard plow	Chisel plow	Disk	No tillage
Fuel used on the farm for crop operations	6.60	5.95	4.75	1.65
Manufacture and maintenance of crop machinery	3.30	2.97	2.37	0.83
Herbicide use	1.75	2.01	2.25	2.88
Nitrogen use	27.10 ^b	27.10 ^b	27.10 ^b	41.40 ^c
Total	38.75	38.03	36.47	46.76
Savings compared with moldboard plow	NA	+0.72	+2.28	-8.01

^a 1 gallon per acre is equivalent to 935 liters per square kilometer

^b Application of 150 lb per acre as anhydrous ammonia

^c Application of 180 lb per acre (surface applied) as 28% liquid nitrogen

Table 1. Comparison of energy required for producing corn with moldboard plow, chisel plow, disk, and no-tillage planting systems—variable rate and form of nitrogen
 Source: data compiled from Siemens J.C., Griffith D.R., and Parsons S.D. (1992).
 Energy requirements for corn tillage-planting systems, Table 6, *National Corn*

Handbook,
<www.inform.umd.edu/EdRes/Topic/AgrEnv/ndd/agronomy/ENERGY_REQUIREMENTS_FOR_CORN_TILLAGE-PLANTING_SYSTEMS.html>

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Bibliography

EPRI. (1989). *Evaporative Cooling Systems for Livestock and Poultry*, 2 pp. RP 2788-4, Palo Alto, CA: EPRI. [This technical brief summarizes the characteristics of evaporative cooling systems for livestock and poultry applications.]

EPRI. (1993). *A Comparative Demonstration of Alternative Milk Cooling*, 73 pp. TR-1026861993, Palo Alto, CA: EPRI. [This report compares various alternative milk cooling technologies.]

EPRI. (1996). *Adjustable Speed Drive for Dairy Vacuum Pumps*, 2 pp. TC-106969, Palo Alto, CA: EPRI. [This commentary discusses the use of adjustable speed drives for dairy vacuum pumps.]

EPRI. (1997). *Milk Heat Recovery on Dairy Farms*, 2 pp. TB-108364, Palo Alto, CA: EPRI. [This technical brief examines the recovery of heat from warm milk on dairy farms.]

EPRI. (1998). *Energy Efficient Farm Motors*, 2 pp. TB-109951, Palo Alto, CA: EPRI. [This technical brief discusses the use of energy efficient motors in farm applications.]

EPRI. (1998). *Energy Efficient Ventilation and Lighting Systems for Livestock Production Facilities*, 78 pp. CR-110334, Palo Alto, CA: EPRI. [This report describes energy efficient ventilation and lighting systems in the specific application of livestock production facilities.]

EPRI. (1999). *Variable Frequency Drives for Controlling Agriculture Ventilation Fans*, 2 pp. TB-112663, Palo Alto, CA: EPRI. [This technical brief discusses the application of variable frequency drives on agriculture ventilation fans.]

Fluck, R.C. and Baird, C.D. (1980). *Agricultural Energetics*, 192 pp. Westport, CT: AVI Publishing Co., Inc. [This textbook describes the relationships between energy and agriculture with particular emphasis on identifying and quantifying the energy flows for different agricultural systems.]

Griffith, D.R. and Parsons, S.D. *Energy Requirements for Various Tillage-Planting Systems*, NCR-202, 13 pp. Iowa State University, Ames, IA: NCR Extension Publications. [This report compares the energy requirements for deep tillage, reduced tillage, and no-tillage planting systems.]

Poincelot, R.P. (1986). *Toward a More Sustainable Agriculture*, 241 pp. Westport, CT: AVI Publishing Co., Inc. [This book examines all factors involved in creating a more sustainable agriculture. Particular attention is paid to organic farming, energy conservation, air quality, and soil and water sustainability.]

Siemens, J.C., Griffith, D.R., and Parsons, S.D. (1992). Energy requirements for corn tillage-planting systems, *National Corn Handbook*, 8 pp.

<www.inform.umd.edu/EdRes/Topic/AgrEnv/ndd/agronomy/ENERGY_REQUIREMENTS_FOR_CORN_TILLAGE-PLANTING_SYSTEMS.html. > [This article details the factors that influence energy usage in corn tillage-planting systems.]

Smith, C.B. (ed.). (1976). *Efficient Electricity Use*, 960 pp. New York, NY: Pergamon Press. [This handbook provides a comprehensive discussion of efficient energy practices for end users in the industrial, commercial, residential, transportation, and agricultural sectors. It also discusses efficiency from the perspective of equipment and process designers as well as system planners.]

Biographical Sketch

Clark 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). Mr. Gellings coined the term DSM and developed the accompanying DSM framework, guidebooks, and models now in use throughout the world. He provides leadership in 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 Mr. Gellings' 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 in 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 U.S. 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.