Energy Requirements in Conservation Tillage

W. W. Frye

Department of Agronomy, University of Kentucky, Lexington, KY 40546

Several years have past with little being said about an energy crisis. Yet the world has less energy today than it had at the height of the energy crisis. More reserves of fossil energy have been found and some of these reserves have been developed; however, in ways we may have potential less energy now than we did then. Nuclear fission has grown in disfavor as a source of energy, construction of breeder-reactor plants has been halted, and, at times, the country has appeared to be on the brink of restricting the use of high sulfur coal. Energy consumption in the U.S. has been far below the projections of a few years ago.

ROLE OF ENERGY CONSERVATION

What accounted for the rapid transition from crisis shortage to a glutenous oversupply? There were a number of contributing factors, but first and foremost was energy conservation. Americans in general adopted an energy conservation attitude during the years of the energy crisis, and it still affects our lifestyles in many ways. It is apparent in the smaller, more fuel-efficient cars we drive, increased carpooling, and use of mass transit, thermostat settings that are lower in winter and higher in summer, greater use of solar energy and wood to conserve fossil fuels, and better home insulation.

Although it appears there is no energy shortage at this time, an energy crisis will very likely emerge again in the near future. Our society is highly dependent upon fossil fuels. The world's supply of these fuels is finite and is diminishing rapidly with use. Currently, recovery of fossil fuels meets or exceeds the demand and new discoveries will ensure a supply for several years in the future. However, most energy experts agree that the inevitable is the eventual depletion of fossil fuels to a level so low that their recovery will no longer be economically feasible (Pollard, 1976). If plentiful, safe alternative energy sources are not developed, a very serious energy crisis will occur long before that time. In addition to actual shortages, we may encounter politically motivated, government imposed, or industry inflicted artificial shortages. Continuation of conservation efforts will delay the time of run-out of fossil fuels and help prevent or ease future energy crises, but they are not likely to prevent crises.

Probably only a small portion of energy conservation can be attributed to a conscious effort to conserve fossil fuels as natural resources. More likely, the major motivation for adopting conservation measures is to save money. The same has been said about the adoption of conservation tillage by farmers. Conservation tillage reduces soil erosion, saves labor, conserves soil water, decreases tractor fuel requirement, and often increases crop yields. As a result, profits increase, thus providing the momentum for the rapid adoption of the practice. Improving energy use-efficiency will continue to play an important role in American agriculture, as well as in all other sectors of our economy, as long as energy prices remain relatively high.

ENERGY USED IN PRODUCTION AGRICULTURE

Production agriculture uses only about 3% of the U.S. energy demand, and the amount of energy used in tillage is only a portion of that. Therefore, energy conservation through tillage systems has little affect on total energy use, but it can save a substantial amount of production costs for individual farmers.

The greatest amount of energy used in nonirrigated crop production in the U.S. is for tillage and nitrogen fertilizers (Table 1). Therefore, the greatest effects can be obtained from energy conservation efforts in these areas. This paper compares the energy requirements of no-tillage and conventional tillage and points out crop production practices that will conserve energy and reduce production costs.

Table 1. Distribution of energy used in production agriculture. (American Chemical Society, 1974).

Input	Distribution of energy used in production agriculture
	%
Fuel	32
Fertilizers	23
Methods and Machinery	20
Electricity	14
Pesticides and other chemicals	6
Feeds and other uses	5

ENERGY REQUIREMENTS FOR FIELD OPERATIONS

Energy requirements for various management inputs and field operations vary greatly among references in the literature. The values shown in Table 2 are intermediate values based on several sources and are rather well supported by research measurements on energy use. Table 2 can be used to analyze the energy requirement of any cropping system. A list of production inputs and field operations is all that is needed.

Tillage

Tillage, where used, is one of the more energy-intensive inputs in crop production. When the same amount of N fertilizer is used, the energy requirement for producing a particular crop is generally proportional to the amount of tillage (Frye and Phillips, 1980). The conventional tillage system usually involves moldboard plowing followed by at least one disking as secondary tillage. No-tillage has much lower fuel requirement because it eliminates both the primary and secondary tillage operations.

Planting

Except in sandy soils, no-tillage planting would be expected to require slightly more energy than conventional tillage. Host studies have shown that the bulk density of no-tillage soi1 at planting time is usually greater than conventional tillage soil. Therefore, pulling the planter through the firmer soil at the proper depth requires more energy. No-tillage planting in sandy soils may require less energy because of excessive looseness under conventional tillage.

Weed Control

Chemical herbicides are used for weed control in all tillage systems; economics dictate it. As tillage is decreased, the need for herbicides increases. It is a fairly commonly accepted estimate that no-tillage requires about 1.5 times more herbicides than conventional tillage. This greater energy requirement offsets some, but not all of the energy saved by less tillage.

Some herbicides are formulated with petroleum or petroleum derivatives as the carrier. Thus, both the active ingredients and their carriers represent energy. The energy represented by other herbicides is due largely to manufacturing. Therefore, the amount of energy represented by herbicides varies considerably. Because herbicides make up such a small part of the total energy used in crop production, a convincing argument can be made for adopting a single energy value to represent most of the herbicides for the purpose of making energy estimates. With the exception of paraquat which is estimated to represent about 1.2 gal diesel fuel equivalent (DFE) per pound of active ingredient (a.i.), an energy value of about 0.5 gal DFE per pound a.i. is thought to be a fairly representative value for most of the commonly used herbicides (Frye, 1985).

Research in Minnesota (Nalewaja, 1974) on weed control methods for corn showed that use of herbicides compared very favorably with cultivation and

Table 2. Estimated average energy requirements of crop production inputs and operations (adapted from Frye, 1984).

Management input or operation	Unit	DFE[1] (gal/unit)
Machinery manufacture and repair	100 lb machinery	24
Primary tillage		
Moldboard plow (8 inches depth)	ac	1.82
Chisel plow (8 inches depth)	ac	1.18
Disk (once)	ac	0.64
Secondary tillage		
Disk	ac	0.64
Spike-tooth harrow	ac	0.32
Field cultivator	ac	0.64
Subsoiler (14 inches depth)	ac	2.14
Plant (36 inches)		
Conventional and reduced tillage	ac	0.43
No-till age	ac	0.53
Weed control		
Herbicides	lb a.i.	0.48
Spray herbicides	ac	0.11
Apply herbicides and disk second time	ac	0.75
Cultivate (each time)	ac	0.43
Fertilizer		
Nitrogen	lb N	0.17
Phosphorus	lb P_2O_5	0.02
Potassium	lb K_2O	0.01
Broadcast granular fertilizer	ac	0.21
Spray liquid fertilizer	ac	0.21
Apply anhydrous ammonia (no-tillage)	ac	1.18
Apply anhydrous ammonia (plowed soil)	ac	0.75
Irrigation	ac	30.91
Harvest		
Corn picker-sheller	ac	1.39
Combine	ac	1.60
Miscellaneous		
Shred cornstalks	ac	0.75
Disk cornstalks	ac	0.43
Grain drill	ac	0.53
Seed	lb	0.05

[1] Diesel fuel equivalent (155 MJ/gal).

hand labor in terms of both energy requirement and profit due to weed control. Net profits due to weed control were about $61, $78, and $-66 per acre, respectively, for cultivation, herbicides, and hand labor. Thus, economics excludes hand labor as a viable alternative weed control method.

Field Machinery

The use of large tractors and field machinery has contributed greatly in making agriculture energy-intensive and energy-dependent. At the same time, it has been mainly responsible for the rapid increase in production output per farm worker. Today, on the average, one farm worker produces enough food for 60 persons.

Since the time-consuming practice of tilling the soil is eliminated in no-tillage, the need for large, time-efficient equipment is greatly reduced, allowing selection of optimum-sized equipment to obtain greater energy efficiency. Also, less machinery is need for no-tillage than for conventional tillage. Phillips et al. (1980) estimated that no-tillage requires about 18% less energy for manufacturing and maintaining machinery than does conventional tillage.

Seeding Rates

Generally, it is recommended that seeding rates be about 20% higher for no-tillage than conventional tillage. It is estimated that this increases the energy requirement for no-tillage corn by slightly less than 0.1 gal DFE/acre, a rather insignificant amount.

FERTILIZER MANAGEMENT FOR ENERGY EFFICIENCY

Of the energy used in fertilizer manufacture, about 83 percent is for nitrogen, 11 percent for phosphorus, and 6 percent for potassium (Nelson, 1975). A pound of fertilizer nitrogen represents about 0.17 gal DFE. Therefore, any appreciable effect on energy conservation through improved efficiency in the management of fertilizers on the farm must be in nitrogen fertilizers. When irrigation or crop drying are not used, nitrogen fertilizer is usually by far the largest single fossil energy input into grain production (Phillips et al., 1980). Energy conservation through nitrogen fertilizers can be attained by improving nitrogen fertilizer efficiency in the field, using legume crops in the cropping system to provide a portion of the nitrogen needs of nonlegume crops, and using waste materials, e.g., animal manure or industrial wastes, as sources of nitrogen. This paper will emphasize nitrogen-use efficiency and legume cover crops as energy conservation measures.

Nitrogen fertilizer efficiency can be improved significantly by proper timing and placement of the application and nitrogen efficiency has been shown to be greater under no-tillage corn than conventional tillage corn.

No-Tillage vs Conventional Tillage

Several researchers have shown that nitrogen fertilizer is used more efficiently in no-tillage than conventional tillage, when based on the increase in grain yield per increment of fertilizer N (Frye et al., 1981; Moschler and Martens, 1975; Phillips et al., 1980; Wells, 1984). One can calculate an energy output:input ratio (Energy O/I) for nitrogen fertilizer using the following relationship outlined by Frye (1984):

$$\text{Energy O/I} = \frac{(Y_{m+1} - Y_m)(E^P)}{(N_{m+1} - N_m)(E^N)} \qquad [1]$$

where

Y_m (bu/acre) = yield with mth increment of applied fertilizer N, m = 0, 1, 2, 3, ...

E^P (gal DFE/bu) = estimated amount of energy per bu of crop produced

N_m (lb/acre) = amount of mth increment of fertilizer N applied

E^N (gal DFE/lb) = estimated amount of energy represented by pound of fertilizer N.

Based on results from corn tillage studies on four soils in Kentucky, Frye calculated Energy O/I values (gal DFE in grain/gal DFE in N fertilizer) as 4.7 for conventional tillage and 9.3 for no-tillage with the first increment of 75 lb/acre fertilizer N. The second 75-lb/acre increment of N resulted in energy output:input ratios of 0 for conventional tillage and 4.1 for no-tillage. The latter ratio arises from the commonly observed phenomenon in which corn grain yields peak at higher rates of N in no-tillage than in conventional tillage (Phillips et al., 1980; Wells, 1984). This has been attributed to more efficient use of fertilizer N by no-tillage corn due to more available soil water.

Although more nitrogen fertilizer, thus more energy, is usually required to obtain peak corn yields with no-tillage than with conventional tillage, the nitrogen (and energy) is used more efficiently, because it increases yield and produces more biological energy. Occasionally writers discuss the greater need for nitrogen fertilizer as a disadvantage of no-tillage, when in fact it is usually both economically sound and energy efficient.

Time of Application

A well-known principle of crop production is that nitrogen fertilizer is more efficient if most of it is applied just before the start of rapid uptake by the crop. For corn that is about 30 to 40 days. The University of Kentucky recommends that the fertilizer nitrogen application be decreased by 35 lb/acre for no-tillage corn on moderately well drained soil or for conventional tillage corn on moderately well or poorly drained soil, if as much as two-thirds of the nitrogen is applied 4 to 6 weeks after planting the corn. The lower nitrogen requirement associated with delayed application results from improved use-efficiency of the nitrogen fertilizer. Apparently the increase in efficiency is a result of less nitrogen loss by leaching and denitrification (which is potentially large under the drainage conditions described above) and less immobilization of nitrogen, especially in no-tillage. Delayed application of nitrogen fertilizer is usually more advantageous under no-tillage than conventional tillage.

The nitrogen fertilizer saved when farmers follow the above recommendation represents about 6 gal DFE/acre. It is estimated that delayed application is practiced on at least 100,000 acres annually of corn in Kentucky (K.L. Wells, personal communication). That amounts to a potential energy savings of 600,000 gal DFE/year by Kentucky farmers alone.

Significant responses to starter fertilizers have been shown by research in certain areas. Touchton and Rickerl (1985) reported a 32-bu/acre yield increase attributable to 22 lb/acre of each N and P_2O_5 starter fertilizer. In terms of energy output:input, an additional 4 gal DFE/acre resulted in output of 83 gal DFE/acre of biological energy. The response to in-row subsoiling averaged 77 bu/acre in their study, amounting to a return of about 200 gal DFE/acre biological energy for an investment of only about 2.14 gal DFE/acre fossil fuel. This illustrates how fossil energy can be used efficiently to produce additional biological energy.

Fertilizer Placement

Subsurface banding of nitrogen fertilizer increases its efficiency compared to surface broadcast application, in both conventional tillage and no-tillage (Wells, 1984). This is especially true with urea-ammonium nitrate solutions or dry urea, since a substantlal amount of nitrogen may be lost-by ammonia volatilization from surface-applied urea (Fox and Hoffman, 1981; Murdock and Frye, 1985). In addition to potential volatilization losses, efficiency of nitrogen fertilizer is lost through immobilization in no-tillage (Smith and Rice, 1984). Recent work in several states indicates a significant advantage of subsurface application of nitrogen fertilizer for no-tillage corn, which presumably avoids the immobilization problem. In a 3-year no-tillage corn study in Kentucky (1982-84), Earles (1985) obtained yield advantages averaging 12 and 8 bu/acre for subsurface banding compared to surface broadcast application of ammonium sulfate at rates of 75 and 150 lb/acre N, respectively.

Subsurface placement of fertilizers requires substantially more fuel energy than surface broadcast application, especially for no-tillage. As pointed out previously, additional energy input that produces a substantial yield increase is likely to be an energy-efficient practice because of a favorable Energy O/I relationship. If conducted as a separate operation, a reasonable estimate of the fuel energy required to apply dry or liquid fertilizers in a subsurface band might be the same as for anhydrous ammonia injection. This value is estimated to be 1.18 gal DFE/acre in no-tillage soil and 0.64 gal DFE/acre into conventionally tilled soil (Frye, 1984). Since both these values represent less energy than is contained in a bushel of corn (2.6 gal DFE/bu), only a small increase in yield due to the subsurface-band placement would be necessary to make it energy efficient.

The approxiinately 10-bu/acre increase obtained by Earles (1985) represents about 26 gal/acre additional biological energy production. To determine the economic feasibility, however, one must take into account labor and time, both of which are greater for subsurface banding than for surface broadcast application.

NITROGEN FROM LEGUME COVER CROPS

Current research in several states shows that a substantial amount of nitrogen can be provided by legume cover crops in nonlegume row-crop production. The method most often used to determine the amount of nitrogen supplied to the nonlegume crop is to equate the yield response to the legume cover crop without nitrogen fertilizer to the yield response to nitrogen fertilizer without the legume cover crop. However, that method is not completely satisfactory. In many cases, the legume cover crop has an effect on yield of the nonlegume crop that appears to be in addition to the effect of nitrogen supplied. That is, the yield response of the nonlegume crop to a combination of nitrogen fertilizer and the legume cover crop tends to parallel, at a higher level, the crop's response to nitrogen fertilizer with a nonlegume cover crop or no cover crop. The results in Table 3 show this. Because of this, it would be a mistake to assume that the nitrogen fertilizer recommendation could be decreased by the amount estimated to be provided by the legume cover crop.

Table 3. Effect of hairy vetch cover crop on yield of no-tillage corn at Lexington, Kentucky, 1977-81 (adapted from Frye, 1984).

	N applied (lb/acre)		
Winter cover	0	44	88
	--Yield of grain (bu/acre)---		
Corn stalk residue	60	83	109
Rye	64	91	121
Hairy vetch	103	119	144

Since the legume cover crop tends to result in additional yield instead of simply replacing nitrogen fertilizer in the cropping system, it is difficult to evaluate the energy conservation value of the cover crop. Several methods may be used, all of which give different views that can be interpreted in different ways. One is the method discussed above in which the yield with a legume cover crop and without nitrogen fertilizer is plotted on the response curve of yield without a legume cover crop but with nitrogen fertilizer. Applying this method to the yield data in Table 3, it has been estimated that hairy vetch provided about 80 lb/acre/yr nitrogen to the corn (Frye, 1984). In terms of fossil fuel this would represent almost 14 gal DFE/acre.

Another method is to place a biological energy value on the additional yield attributed to the legume cover crop, i.e., yield with legume cover crop minus yield with nonlegume cover crop or no cover crop. Evaluating hairy vetch in comparison with rye (Table 3) in this way gives 99, 73, and 60 gal/acre DFE with 0, 44, and 88 lb/acre fertilizer nitrogen, respectively. This is energy produced essentially free of fossil energy expenditure, since it represents energy in add-on yield due to the presence of the legume.

SUMMARY

Energy conservation has played an important role in relieving the energy crisis of the 1970's. The motivation for energy conservation is mainly to save money rather than to save energy per se as a resource. This is especially true in production agriculture because only about 3% of the total U.S. energy demand is used in production agriculture. Energy conservation through improved efficiency of energy use in crop production saves money and increases the farmers' profits.

Since tractor fuel for tillage and nitrogen fertilizer represent the two largest inputs of energy into crop production, conservation efforts should be directed toward these inputs because that is where conservation will have the greatest effect. No-tillage has advantages over conventional tillage in both of these areas. Because most tillage is eliminated, less fuel is required in the no-tillage system. Some of the fuel energy saving is offset by increased herbicide requirement, but the increase due to herbicides is much less than the fuel saved. Nitrogen fertilizer use-efficiency has been shown to be greater for no-tillage than conventional tillage corn. The result is a higher energy output:input ratio with no-tillage. This is usually explained as an effect of improved soil water relations associated with the mulch.

Other practices to increase nitrogen efficiency and conserve fossil energy or produce additional biological energy include delayed application of all or most nitrogen fertilizer for 4 to 6 weeks instead of applying it all at planting, subsurface banding compared to surface broadcast of nitrogen fertilizer, use of starter fertilizers in some areas, in-row subsoiling in some soils, and using legumes to provide a portion of the nitrogen needs of nonlegume crops or to increase their yield above that with nitrogen fertilizer alone. Energy conservation occurs through management when the same yields are produced with less energy, higher yields are produced with the same amount of energy, or higher yields are produced more efficiently (higher energy Output:input ratio) with more energy.

REFERENCES

American Chemical Society. 1974. Agriculture depends heavily on energy. Chem. Eng. News. 52(10):23-24.

Earles, E.H. 1985. Effects of nitrification inhibitors and nitrogen fertilizer placement on corn yield and soil nitrogen. Unpublished M.S. thesis. Department of Agronomy, University of Kentucky, Lexington, KY.

Fox, R.H., and L.D. Hoffman. 1981. The effect of N fertilizer source on grain yield, N uptake, soil pH, and lime requirement in no-till corn. Agron. J. 73:891-895.

Frye, W.W., and S.F. Phillips. 1980. How to grow crops with less energy. pp. 16-24. In Cutting energy costs. The 1980 Yearbook of Agriculture. U.S. Dept. of Agri., Washington, D.C.

Frye, W.W., R.L. Rlevins, L.W. Murdock, and K.L. Wells. 1981. Energy conservation in no-tillage production of corn. pp. 255-26. In Crop production with conservation in the 80s. ASAE Pub. 7-81. Amer. Soc. Agric. Engr., St. Joseph, MI.

Frye, W.W. 1984. Energy requirement in no-tillage. pp. 127-151. *In* B.E. Phillips and S.F. Phillips (ed.) No-tillage agriculture principles and practices. Van Nostrand Reinhold, New York, NY.

Moschler, W.W., and D.C. Martens. 1975. Nitrogen, phosphorus, and potassium requirements in no-tillage and conventionally tilled corn. Soil Sci. Soc. Amer. Proc. 39:886-891.

Murdock, L.W., and W.Y. Frye. 1985. Comparison of urea and urea-ammonium polyphosphate with ammoniuml nitrate in production of tall fescue. Agron. J. (in press).

Nalewaja, J.D. 1974. Energy requirements for various weed control practices. Proc. North Central Weed Control Conf. 29:19-23. St. Paul, Minn.

Nelson, L.W. 1975. Fertilizers for all-out food production. In W.P. Martin (ed.) All-out food production: Strategy and resource implications. ASA Spec. Pub. No. 23. Amer. Soc. Agron., Madison, WI.

Phillips, R.E., B.L. Blevins, G.W. Thomas, W.W. Frye, and S.A. Phillips. 1980. No-tillage agriculture. Science 208:1108-1113.

Pollard, W.G. 1976. The long-range prospects for solar-derived fuels. Am. Scientist 64:509-513.

Randall, G.W. 1984. Efficiency of fertilizer nitrogen use as related to application methods. pp. 521-533. In R.D. Hauck (ed.) Nitrogen in crop production. Amer. Soc. Agron., Madison, WI.

Rice, C.W., and M.S. Smith. 1984. Short-term immobilization of fertilizer nitrogen at the surface of no-till and plowed soils. Soil Sci. Soc. Amer. J. 48:295-297.

Touchton, J.T., and D.H. Rickerl. 1985. Starter fertilizer placement with in-row subsoilers. p. 7. In Highlights of Agric. Res. Vol. 32. Ala. Agric. Exp. Sta.., Auburn, At,.

Wells, K.L. 1984. Nitrogen management in the no-till system. pp. 535-550. In R.D. Hauck (ed.) Nitrogen in crop production. Amer. Soc. Agron., Madison, WI.