Effects of conservation tillage and practices on energy consumption for corn

by

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INTRODUCTION

In recent years both agricultural products and energy supplies have risen to importance in world priorities. Energy sources required for agriculture are primarily oil and natural gas. These are the energy resources that are being depleted most rapidly. Currently the United States consumes more petroleum than it produces. Generally agreed upon is the fact that we must become more energy self-sufficient. Mideast oil prices have skyrocketed in past months and promise to increase even further. Conservation and intelligent use of energy is imperative.

As oil prices go up, much of the world remains hungry. According to Time (November 11, 1974) approximately a half billion people suffer from hunger, with ten thousand of these dying of starvation each day. In addition, population continues to climb. There are two hundred thousand more people each day; world population doubles every thirty-five years. To compound the food supply problems, much of the world is demanding a better diet, including more protein. The Soviet Union with its large grain purchases from the western world in the last three years has proven that it is now a nation of meat eaters. Meat itself is not very energy efficient with approximately five pounds of grain required to produce a pound of beef. All of this demand for food results in increased food prices vigorously protested by American consumers.

The much publicized green revolution has attempted to buy time for underdeveloped countries to get their populations under control. A close look at the green revolution, however, reveals that it is quite energy intensive. It stresses the use of fertilizer, machinery, and irrigation along with good seed to increase crop yields. Fertilizer and irrigation in particular require large amounts of energy. The use of machinery to replace human labor also increases the energy requirements, although mechanization results in more food being produced.

The problem of increasing food production while decreasing energy use is a knotty one. Some preliminary research has been done on it, mainly in the last four to five years. Gross estimates have been made of the total energy use in agriculture. Relatively little data are available on actual on farm energy use for crop production. The farm is a place where a rather peculiar mix of resources and management is blended into a product. A great range of energy efficiencies probably exists on different farms. Faced with possible energy shortages at worst and high fuel prices at best, the farmer must now consider his energy inputs. As energy prices go up so do those prices for energy intensive inputs for crop production. This study attempts to determine just what those energy inputs are for a prominent midwestern crop, corn.

OBJECTIVES

Specific objectives of this study were:

1. To determine energy requirements for corn production inputs under three different tillage systems. The inputs to be considered were:
   a. Fuel used in actual field operation of farm machinery.
   b. Energy used to manufacture farm machinery and to transport the finished machinery to the farm.
   c. Herbicides
   d. Insecticides
   e. Fertilizers
2. To determine the amount of time spent in corn production with these different tillage systems;
3. To determine field efficiencies of the field operations used in these different tillage systems.

REVIEW OF RELATED LITERATURE

Only recently has there been much concern about energy use in agriculture. A vast majority of figures now seen on the subject have been derived from government census, U. S. Department of Agriculture, or American Society of Agricultural Engineers (ASAE) data. In many cases there have been broad assumptions using average values. Little actual farm record data were found.

Energy figures as reported in this study will be in both kilocalories (1 kcal = 3.97 Btu) and equivalent gallons of no. 2 diesel fuel. Since both gasoline and diesel (no. 2) fuel are commonly used as energy sources for agricultural operations and their energy contents per gallon differ, a conversion factor (0.8907) will later be shown (in the analysis of data) to change gasoline data to no. 2 diesel fuel data. Also, gasoline engines are inherently less energy efficient than comparable diesel engines.

Since energy has come to take more importance in our national affairs, several researchers have explored its use in agriculture and food production.

Steinhart and Steinhart (1974) estimated that on-farm direct fuel use was 232×10^{12} kcal (8.75 trillion gallons of no. 2 diesel fuel) in 1970 based on information from the 1964 <u>Census of Agriculture</u>.

Hirst (1973) using Herendeen's (1973) energy per dollar coefficients estimated that agriculture used about 4.4% (554×10^{12} kcal or 20.9 trillion gallons of no. 2 diesel fuel) of the 1963 U.S. energy budget. Forty-four percent of the agriculture energy was used directly on the farm.

Pimentel et al. (1973) estimated that corn yield increase in the last fifty years is 60 to 80 percent attributable to energy resource inputs. By using mean values of U.S. Department of Agriculture figures, they computed that corn production in 1970 would use about 79.7×10^{4} kcal (30.1 gallons of no. 2 diesel fuel) burned in farm machinery per acre. Mean values were used as corn was considered to be an intermediate energy use crop. Fuel burned in farm machinery was estimated to be second only to nitrogen as the largest energy user in corn production.

Several midwestern states have published extension bulletins on fuel use per acre. Many of their values have been calculated from ASAE and Nebraska Tractor Test data.

Lane et al. (1973) estimated fuel requirements for field operations in Nebraska from data in the 1973 Agricultural Engineers' Yearbook. Power requirements were first computed for various implements and soil conditions. Then fuel requirements were determined by assuming a fuel conversion efficiency.

Firth and Promersberger (1974) published estimates of fuel consumption for farming and ranching operations in North Dakota. Values were expressed in gasoline gallons per acre and were calculated from 1972 Agricultural Engineers' Yearbook data. Also, average fuel efficiencies for different size tractors were noted from Nebraska Tractor Tests.

Hull and Hirning (1974) published estimated fuel use per acre for different field operations in an Iowa State Cooperative Extension Service Bulletin. Ayres (1974) followed this up with fuel estimates for a more extensive listing of field operations.

Other studies have made use of the ASAE data for power and draft requirements.

Marley (1960) estimated horsepower-hours per acre requirement for different field operations on a 690 acre farm in Clay County, Iowa. Estimates were based on ASAE and North Dakota Agricultural Experiment Station data for draft and horsepower requirements. This was part of a larger study on time and field efficiencies.

Clark and Johnson (1974) studied energy needed for grain sorghum production using different tillage systems. Again, ASAE data were used. An average tractor efficiency of 12 horsepower-hours per gallon (somewhere between typical gasoline and diesel fuel tractor engine efficiencies) was assumed. Energy inputs for machinery and chemical production were also computed.

Some data pertaining to actual fuel use in the field are available. Wald (1968) reported fuel use for conventional and rotary tillage systems on a per acre basis. Data were obtained by two methods: (1) use of auxiliary fuel tanks and (2) meters in the fuel lines. The amount of fuel used from the auxiliary tanks was determined by weight. Only tillage operations were involved with this study.

Hurburgh (1974) listed diesel fuel use per acre for various field operations from data taken over a several year period at a farm near Rockwell City, Iowa. LP gas used for crop drying was also available from the same source. The same field operation (e.g., planting) under different tillage systems did not necessarily use the same amount of fuel per acre.

Much of the energy data available for field operations has been derived from generalized government or ASAE machinery management data. Few actual field data have been recently published. Much earlier data tends to be of marginal use as tractor efficiencies and tillage operations have changed. Also, since energy use in field operations tends to vary with soil type and moisture, more field data are needed for comparison with data already available.

SELECTION AND DESCRIPTION OF TEST SITE

Since little actual field data were available for fuel consumption during field operations, it was desired to find a test site actually operated by local farmers. It was felt that data obtained from university or corporate owned farms, or from small plots might not accurately reflect what was happening on family farms in the midwest. The farmers would of course have to be cooperative in helping keep accurate records for the study.

The Agricultural Research Service watersheds near Treynor, Iowa, offered a suitable location for the fuel study. The staff was conducting research on minimum tillage systems, and staff members were interested in the amount of energy needed to operate these systems. Three different types of reduced tillage systems were being used on the watersheds: (1) tandem disk on contoured ground, (2) till planter on contoured ground, and (3) till planter on terraced ground. Each of these tillage systems was available in large, field sized plots that were farmed by local operators. In addition, the watersheds were all within three miles of each other offering similar soil types and meteorological conditions. Thus, the Treynor watersheds offered a site to carry on fuel research for various field operations under three different tillage systems. The land would be cultivated by local farmers having a past history of cooperation with the Agricultural Research Service.

The Treynor watersheds are located in the western half of Pottawattamie County, Iowa, approximately 15 miles southeast of Council Bluffs.

The Agricultural Research Service has four watersheds at Treynor. Figures 1 and 2 are maps of the watersheds. These four watersheds were split into three areas by tillage system for the fuel study. The south two Watersheds, One and Two, have been in continuous corn and are approximately contoured. They contain 200.8 acres of cultivated cropland. Watershed Three is also approximately contoured and contains 95.9 cultivated acres. Grass in this watershed has been replaced by continuous corn since 1972. Watershed Four is level terraced and contains 169.4 cultivated acres of continuous corn. The terraces are steep backslope with tile outlets. Terrace spacing which had been as recommended by the Soil Conservation Service was doubled in 1972.

The soil on the watersheds is a deep loess. It ranges in depth from 15 feet in the valleys to 80 feet on the ridges. Underlying the loess is a layer of glacial till. The soils are of the Marshall-Monona-Ida-Napier series. They have moderate to moderately rapid permeability. Slopes on the watersheds range from 2 to 4 percent on the ridges to 12 to 18 percent on the sides. The land is almost entirely tillable.

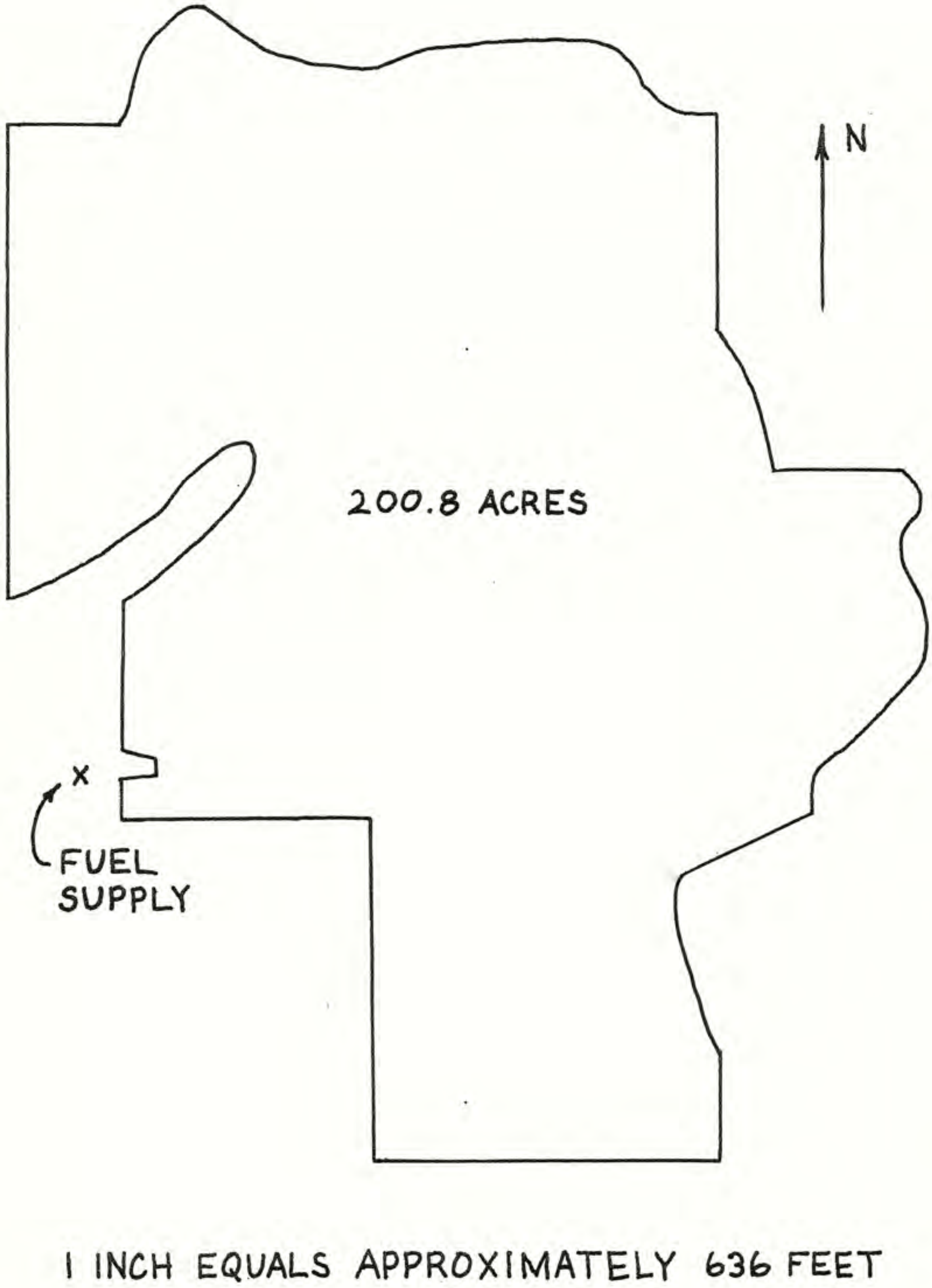

Figure 1. Map of Watersheds One and Two

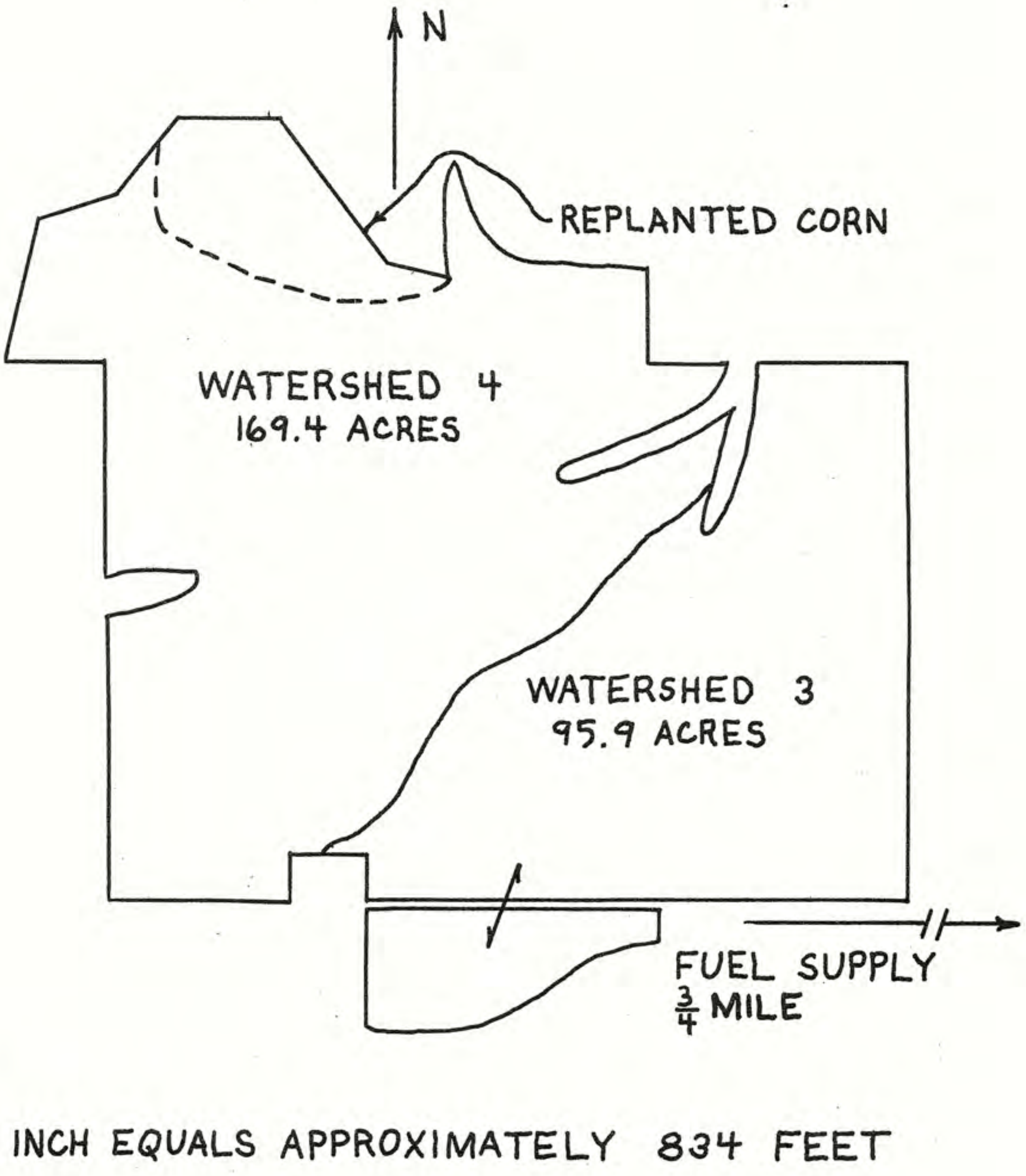

Figure 2. Map of Watersheds Three and Four

Three areas of on-going research are being conducted at the watersheds. They are hydrology, sediment movement, and nutrient movement. These three areas are continuously being studied as related to land use, fertility treatment, and management practices in general. One such study taking place on Watershed One is the application of 400 lbs. of nitrogen per acre. Primary interest in this study concerns the amount of nitrogen runoff lost. The fuel study was not affected by this as the same implement (knife number) was used in applying a more conventional rate of nitrogen to Watershed Two.

As mentioned before, a different set of field implements was used on Watersheds One and Two than that set used on Three and Four. Watersheds One and Two (contoured ground) used a tandem disk system of primary tillage. It consisted of field operations with a tandem disk (2 times), fertilizer applications, springtooth, planter, sprayer, cultivator, and combine harvest. Watersheds Three and Four (contoured and terraced ground, respectively) used a till planter tillage system. This included field operations with a stalk shredder, fertilizer applicators, till planter, cultivator (2 times), and combine harvest. The disked ground was tilled seven to eight inches deep, a somewhat more conventional tillage system than the till planter. Small ridges with the previous year's corn residue windrowed between the ridged rows characterized the till planter system.

Two different farmer operators were in charge of field operations on the watersheds. Mr. Bobby Deitchler used the tandem disk tillage system on Watersheds One and Two. Mr. Deitchler is primarily a grain farmer working some other cropland in addition to the two watersheds. His home farmstead is located on the two watersheds he operated in the study. During some off months of the year, Mr. Deitchler works in a nearby town at an equipment dealer's business. Mr. Richard Vorthmann, together with son Bill, operated the till planter system on Watersheds Three and Four. Both engage in the same farm enterprise which includes livestock (hogs and cattle) in addition to the cropland. Other land besides the two watersheds is cropped by the Vorthmanns. Forage and grain crops are raised. Richard Vorthmann's farmstead, the site of his fuel supply tanks, was approximately three-fourths of a mile from the watersheds while Bill's farmstead was one mile away from the watersheds. All three of these farm operators indicated an interest in the study and were willing to cooperate with the work.

Thus, a suitable area to obtain field records of fuel use was found. Also, two major tillage systems could be compared, the tandem disk and till planter. Opportunities for comparison of the same implement system used by the same operators on both contoured and terraced ground were also available.

MATERIALS AND METHODS

The study involved gathering data for three separate areas. First and most important was the amount of fuel used in each tillage system. Fuel use was to be calculated in gallons per acre. The second area of interest concerned time. It was desired to know how much time per acre was spent in each field operation and in the tillage systems in general. Lastly, in conjunction with the time data, some field efficiency data could be obtained for these farmer operated plots. Three separate yet interrelated areas of data were to be gathered.

The basic problem in fuel use was to determine as nearly as possible the number of gallons per acre of fuel used on the fields to be studied. Since it would not be possible to have an observer at the site for much of the time, the method used would have to be convenient for the farmer operator. If the method used was not a convenient or attractive one to the farmer, reliable data might not be obtained.

After considering convenience as well as accuracy and reliability, it was decided to measure fuel directly at the supply tank. Tractors and other self-propelled machines would be filled up at the fuel storage tank before leaving for the field. On return from the field the fuel tank would be again filled and the amount shown by the meter would be recorded as that necessary for the field operation. On Watersheds One and Two the fuel storage tanks were located adjacent to the fields. The fuel supply was approximately three-quarters of a mile away from the fields on Watersheds Three and Four. Travel time and fuel would not be deducted from the data for two major reasons. First, many midwestern farmers often must travel more than a mile to get to their field from their fuel tank. Since it was desired to obtain typical farm data, it was decided to include travel as part of the field operations. Secondly, for operations of any time duration in the field travel fuel and time would be negligible (e.g., minor maintenance operations during the course of a day would most probably take up more time and fuel).

Meters were located on the fuel tanks between the tank and the supply line (see Figure 3). On Watersheds One and Two gravity flow meters were used. They were obtained locally and were Tokheim Gravity Flow Model 727. One each was on the diesel fuel and gasoline tanks. On Watersheds Three and Four again two flow meters were used, one on diesel fuel and one on gasoline. The diesel fuel meter was an electric pump model. A gravity flow meter was used on the gasoline tank. Both were manufactured by Tokheim. The meters were all calibrated for temperature and specific gravity corrections.

Using this method of filling fuel tanks up at the supply tank before and after field operations, the quantity of fuel used for each operation was determined. By knowing the number

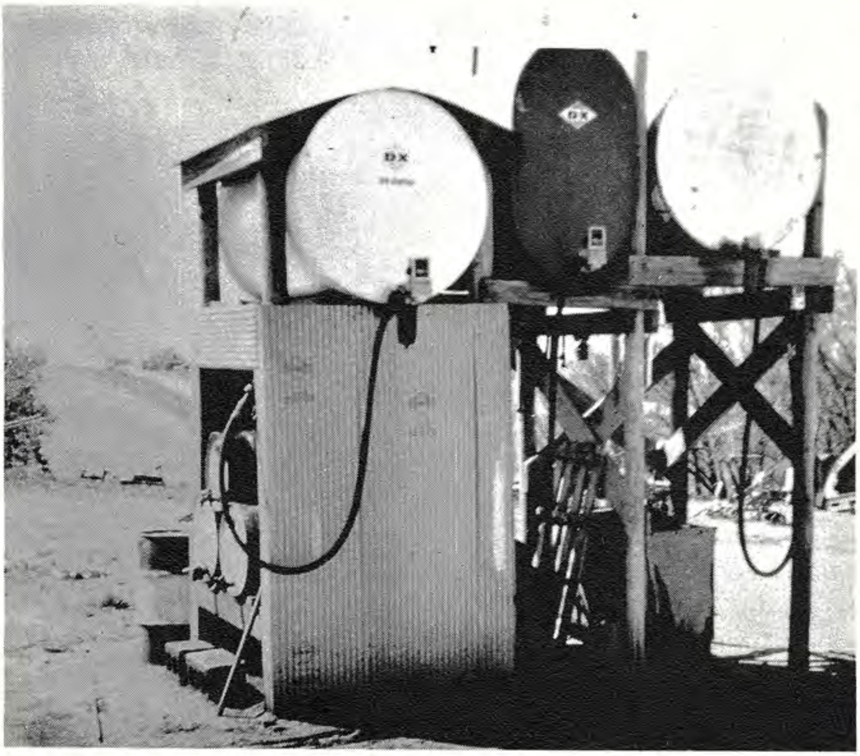

Figure 3. Fuel storage tanks with meters between the tank and line

of cultivated acres from Agricultural Research Service data, the number of gallons per acre for each field operation could be determined.

A time record was also kept. The time of field operations was easily kept in conjunction with the fuel data. A start time was noted when the tractor or other implement was first filled up. The stop time was then noted whenever the implement was returned from the field for fuel, meals, etc. Start time was again noted on return to the field. The difference in these start and stop times was then that amount of time devoted to field work. A date was kept also in order to record when each field operation was started and finished and links with any other data being recorded.

Field efficiency data from the watersheds was obtained from actual time of field operation (as determined above), acres covered, and speed and width of the field implements. The procedure used in computation was that outlined in the <u>1973 Agricultural Engineers' Yearbook</u>. Actual field capacity was determined by the actual time of field operation and acres covered. Speed and width of implement determined theoretical field capacity. Field efficiency was then the ratio of actual field capacity to theoretical field capacity.

When possible, field efficiencies were checked with actual on-site observations. These observations consisted of a time and motion study of the field operations. Through this study it was possible to actually determine the amount of time spent doing constructive work in the field and the amount of time lost in turning, maintenance, loading, unloading, etc. This method employed the use of three stopwatches. One stopwatch was ready to go, one was running, and one was stopped. Through the use of a single control the stopwatch ready to go would start, the stopwatch running would stop, and the stopwatch stopped would be reset and ready to go, all simultaneously. This allowed the timing of events continuously, one right after another. Thus, events in field operations were continuously timed and recorded as to productive or unproductive work. Field efficiencies could be determined as the ratio of productive work time to total work time. The data were recorded on a clipboard directly below the stopwatches. This time and motion study method has been used for years in industry and more recently has been applied in agriculture.

To gather all the fuel and time data for the watersheds when an observer was not present, a logbook arrangement was used. Nine columns were entered in the logbook. They were date, watershed number, start time, stop time, number of hours, approximate acres, gallons of fuel, operation, and comments. The number of hours was the difference between start and stop times and also a helpful check in making sure that data entered were correct. Both the approximate acres covered and number of hours would be helpful in filling in any gaps that might arise in the data. The comments section was mainly to include any unusual conditions affecting time losses and fuel consumption or other conditions having a bearing on the study. Speed was later added to the logbook for field efficiency determinations.

The logbook was felt to be convenient to the farmer operator as well as providing reliable and accurate data. Logbook data sheets were placed in a bound folder. The folder was to be kept near the fuel tank or with other easily accessible farm records.

Fuel use, time of work, and field efficiencies were thus recorded in the study. The data were from fields of ninety or more acres in size and locally farmed. The farmer operators were engaged in farming as their principle vocation. The data was to be representative of family farm conditions. The key to gathering data was the logbook. It provided reliable as well as inexpensive and convenient information.

In addition to the fuel, time, and field efficiency data, information was also recorded about herbicide, insecticide, and fertilizer applications, and specific farm machinery used. An attempt was made to estimate energy inputs for these necessities of corn production.

FIELD WORK ON THE WATERSHEDS

As mentioned before, the farmers all had other field work besides the watersheds to do in addition to livestock operations and machinery maintenance and repair. During most years, some field work is attempted in the fall. In the preceding fall, 1973, no field work was accomplished however. During the winter months, cattle were grazed on Watersheds Three and Four. The cattle mashed some of the stalk residue and slightly flattened some of the ridges in the row. A complete listing of all equipment used is in Table 1.

Early Spring Work

Field work began on Watersheds One and Two with a disking operation. All 201 acres were disked twice between March 30 and May 5. Much of this work was done in two and three hour time periods with the farmer being assisted by his son after school. Fertilizer was applied during this same time period. The potassium and phosphorus were applied dry by a truck with a rotary spreader. A diesel tractor and applicator tank applied the nitrogen as anhydrous ammonia. Both applications were contracted as custom work from a fertilizer supply company in nearby Treynor.

Watershed Three started out field work with a stalk shredding operation from March 27 to April 2. Custom fertilizer application followed in April. Potassium and phosphorus

Table 1. Complete listing of all equipment used

Watershed No.	Equipment Used	Date Used
1 and 2	IH 1066, diesel, tractor	
1 and 2	AC 190, gasoline, tractor	
1 and 2	Deere 730, gasoline, tractor	
1 and 2	Disk, 19 ft., Krause	3-30, 5-5
1 and 2	Springtooth, 18 ft., Kent	5-2, 5-15
1 and 2	Planter, 4-38 in., IH Cyclo	5-1, 5-16
1 and 2	Sprayer, 7-38 in., boom	5-6, 5-17
1 and 2	Cultivator, 4-38 in., Deere	6-7, 6-17
1 and 2	Combine, 4-38 in., AC Gleaner C-2	10-26, 11-5
1 and 2	Fertilizer truck, 60 ft.	N.A.
1 and 2	NH_3 Applicator, 280 in., pulled by 1070 Case	N.A.
3 and 4	IH 856, diesel, tractor	
3 and 4	Deere 4020, diesel, tractor	
3	Stalk Shredder, 4-38 in., IH	3-27, 4-2
4	Stalk Shredder, 4-38 in., IH	4-1, 4-23
3	Fertilizer truck, 60 ft.	N.A.
4	Fertilizer truck, 60 ft.	N.A.
3	NH_3 Applicator, 200 in., pulled by 4020 Deere	N.A.
4	NH_3 Applicator, 200 in., pulled by 4020 Deere	N.A.
3	Planter, 4-38 in., Buffalo (Flex) Till	4-27, 5-3
4	Planter, 4-38 in., Buffalo (Flex) Till	5-4, 5-9; 6-6, 6-7
4	Disk, 21 ft., Krause	5-8; 6-6, 6-7
4	Endgate seeder, 50 ft., 3 pt. hitch on IH 560, gasoline, tractor	6-5; 6-6
3	Cultivator, 4-38 in., Buffalo	6-6, 6-11; 6-15, 6-18

Table 1. (Continued)

Watershed No.	Equipment Used	Date Used
4	Cultivator, 4-38 in., Buffalo	6-11, 6-14; 6-27; 6-19,6-26; 7-1
3	Combine, 4-38 in., Deere 6600	10-24, 11-13
4	Combine, 4-38 in., Deere 6600	11-5, 11-12
4	Cornpicker, 2-38 in., mounted on IH 560	11-21, 11-22

were applied dry by a truck with a rotary spreader from Treynor. Anhydrous ammonia was put on by a diesel tractor with applicator from Underwood.

Field work on Watershed Four started with stalk shredding April 1 to April 23. The same fertilizer application procedure as Watershed Three followed.

Late Spring Work

Watersheds One and Two included a springtooth field operation directly before planting. Due to planting timeliness and a shortage of labor only 175 of the 201 acres were covered with the springtooth. Its field operations were from May 2 to May 16. A conventional (air) planter was used from May 1 to May 16. Following the planting operation, a boom type sprayer mounted on the tractor was used. Sprayer operation began on May 6 and ended May 17. These three operations, springtooth, plant, and spray, were conducted simultaneously during the first part of May over the acreage. Only one cultivation, June 7 to June 17, was performed.

A till planter was used from April 27 to May 3 on Watershed Three. A cultivator manufactured by the same company as the till planter and to be used in conjunction with it was used for two cultivations. Cultivation dates were from June 6 to June 11 for the first cultivation and June 15 to June 18 for the second cultivation.

Watershed Four also used the till planter May 4 to May 9. Some wet spots in ditches and low places, about 5 acres, were disked on May 8 prior to planting. Before the first cultivation, a cutworm infestation made it necessary to replant 40 acres of the watershed (See Figure 2). The 40 acres were first covered by an endgate seeder application of pesticide on June 5 and 6. Then disking and replanting followed June 6 and 7. The entire acreage was cultivated twice. Corn originally planted was cultivated the first time June 11 through June 14. The second cultivation was from June 19 to June 26. Replanted corn was cultivated first on June 27 and last on August 1.

Summer Work

No actual field work was done from July through September on the watersheds besides the second cultivation of the replant corn. Crop prospects were greatly affected, however, by an early summer drought. The watersheds received virtually no rainfall from about the second week of June to the first of August. Rainfall levels had already been below average in the spring. A week of temperatures exceeding 100°F was symbolic of a July heat wave. Hot and dry weather conditions were severe on the corn and contributed to an eventual crop failure.

Aerial spraying for cutworm control was done on Watershed Four in August. This operation was not included in the energy study.

Fall Work

The early summer drought caused a crop failure. All of the corn in the fields was soft and mushy and would not field dry. Since there was not much corn in the field and what corn was there was wet, harvest was delayed as long as possible to save expensive drying costs. Late October marked the start of harvest operations.

In yield checks in the field, Watersheds One and Two yielded only 6.6 bushels per acre. Since yields were low, only 65 acres were harvested out of 201 total acres. The combine was used between October 26 and November 5.

Watershed Three yielded 20.3 bushels per acre. A combine was also used for harvest on it between October 24 and November 13.

The yield on Watershed Four was 32.0 bushels per acre. The approximately 130 acres of originally planted corn was harvested by combine from November 5 to November 12. Forty acres of replanted corn was harvested by a cornpicker on November 21 and 22.

The author rode with both combine operators for a short time during harvest. Both combines operating on the watersheds had forward speeds of approximately 5.5 miles per hour, approximately twice as fast as normal operation. This speed was made necessary in order to keep the straw walkers in the back of the combine loaded enough for good separating. Yield was generally so low that each ear of corn could be heard as it entered the cylinder.

Two major factors, replanting and drought, affected the field data. A "normal" year probably would not be considered to include these two factors. Replanting among other things added more fuel and time use to Watershed Four. The crop failure would tend to more grossly affect results as the combines were run twice their normal speed and not over entire acreages or harvesting representative crops. Still data collected in the spring on primary tillage operations, planting, etc., should not be affected by the drought. Also, elimination of fuel and time in replanting would be possible.

ANALYSIS OF DATA

The analysis of data was begun by separating the field operation data for each tillage system. Then each field operation itself was broken down and separated from other field operations on that tillage system. Data tabulated for each field operation on each tillage system consisted of four different items. The first two were the total gallons of fuel used and total number of hours in the field. Third, starting and ending dates were recorded. Finally, the total number of acres covered if different from that expected was noted (e.g., the springtooth on Watersheds One and Two covered only 175 of the 201 acres).

Since the data contained both gasoline and diesel fuel values in gallons and it was desired to express all fuel values in gallons of diesel fuel, the gasoline values had to be converted to equivalent diesel values. The conversion procedure used was as outlined in Barger *et al.* (1963) using the low heating values of gasoline and diesel fuel. High or gross heating values, H_g, were

$$H_g \text{ gasoline} = 124{,}000 \text{ Btu/gal}$$
$$H_g \text{ no. 2 diesel} = 140{,}000 \text{ Btu/gal}$$

No. 1 diesel fuel (135,000 Btu/gal, high heat) is a slightly more volatile fuel than no. 2 diesel fuel and its use in agricultural applications is less common. These high heating values include the heat given up by condensation of water formed in the combustion process and are not representative of the chemical heating value of the fuel in an internal combustion engine since the heat of condensing water vapor cannot be used by the engine. Rather, the low heating value not including the heat of the condensing water is more representative of chemical energy available to the engine. The formula for this low heating value, H_n, is

$$H_n = H_g(0.7195) + 4310, \text{ Btu/gal}$$

Thus giving

$$H_n \text{ gasoline} = 93{,}530 \text{ Btu/gal}$$

$$H_n \text{ no. 2 diesel} = 105{,}000 \text{ Btu/gal}$$

The ratio of the low heating value of gasoline to that of diesel fuel, 0.8907, was used as a factor, which, when multiplied by a gasoline value changed it to diesel fuel value.

In addition, each of the fuel barrels was calibrated for accurate fuel meter readings. Five gallons of fuel was weighed to determine the apparent specific weight of fuel according to the fuel meter. Then actual specific gravity was checked with a hydrometer. After temperature corrections were made, the meters were calibrated.

Corrected fuel readings for total gallons of fuel used for each tillage system and field operation were thus obtained, all adjusted to diesel fuel.

Next basic measurements of fuel, time, and field efficiency were calculated. These measurements were calculated for each field operation in each tillage system.

The fuel measurement was calculated in gallons of diesel fuel per acre used for the field operation. The corrected fuel reading of the field operation was simply divided by the number of acres covered.

Time for each field operation was measured in hours per acre. As implied, the time spent for each field operation was divided by the number of actual acres covered (in most cases the field acreage).

Field efficiencies for each field operation were then determined as outlined in the 1973 Agricultural Engineers' Yearbook. Actual field capacity in acres per hour was calculated from the measured data. Theoretical field capacity, T.F.C., was determined as follows:

$$T.F.C. = \frac{S\ W}{8.25}\ \text{, acres/hour}$$

where S = speed of field implement, miles/hour
W = width of implement, feet

Implement speed was determined by using the nominal tractor speed suggested by the farmer and assuming 8% wheel slip.

Field efficiency was then the ratio of actual field capacity to theoretical field capacity.

Tables 2 and 3 list energy and time use and field efficiencies, respectively, for each field operation in each tillage system. In addition, field efficiencies from the time and motion study, the ratio of actual times working to total field times, are included wherever available. Figures 4, 5, 6, 7, 8, 9, 10, and 11 show relative fuel and time use for each tillage system. As illustrated on the graphs only, fuel figures are based on entire field acreages and not simply acres covered (e.g., on Watershed Four where fuel use for the combine was 1.959 gal/acre over 130 acres, fuel use based on 169 total acres was 1.496 gal/acre).

Total gallons per acre and hours per acre for each tillage system were determined by simply totaling the fuel and time used in each tillage system and dividing by the total number of acres in each tillage system.

Nine different cases for the three tillage systems are reported in the total. Since harvesting conditions with the crop failure were quite different from a normal year, all tillage systems are reported with and without harvest. (Results for fuel use per acre for combine harvest compare quite favorably, however, to those estimates made by Ayres, 1974.) In addition, Watersheds One and Two were only partially harvested. In the actual field data only 65 of the

Table 2. Energy and time use for field operations of three different tillage systems

Operation	Gal[a] / Acre	Kcal / Hectare	Hours / Acre	Hours / Hectare
Watersheds 1 and 2				
Disk	0.947	6.19×10^4	0.145	0.358
Disk	0.947	6.19	0.145	0.358
Fert. Truck	0.184	1.20	0.031	0.077
NH_3 Trac.	0.503	3.29	0.172	0.425
Springtooth	1.002	6.55	0.164	0.405
Plant	0.609	3.98	0.222	0.549
Spray	0.235	1.54	0.116	0.287
Cultivate	0.577	3.77	0.359	0.887
Combine	1.471	9.61	0.338	0.835
Watershed 3				
Shred	0.470	3.07	0.167	0.413
Fert. Truck	0.143	0.93	0.022	0.054
NH_3 Trac.	0.709	4.63	0.138	0.341
Plant	0.584	3.82	0.269	0.665
Cultivate #1	0.358	2.34	0.151	0.373
Cultivate #2	0.470	3.07	0.193	0.477
Combine	1.488	9.72	0.391	0.966
Watershed 4				
Shred	0.481	3.14	0.183	0.452
Fert. Truck	0.144	0.94	0.022	0.054
NH_3 Trac.	0.720	4.70	0.177	0.437
Plant	0.766	5.01	0.298	0.736
Disk	0.696	4.55	0.300	0.741
Endgate Seeder	0.173	1.13	0.175	0.432
Cultivate #1	0.332	2.17	0.165	0.408
Cultivate #2	0.403	2.63	0.187	0.462
Combine	1.959	12.80	0.336	0.830
Cornpicker	0.735	4.80	0.394	0.974

[a]Gallons per acre of no. 2 diesel fuel.

Table 3. Field efficiencies for field operations

Watersheds 1 and 2		Watershed 3		Watershed 4	
Operation	Field Eff.	Operation	Field Eff.	Operation	Field Eff.
Disk	0.498	Shred	0.765	Shred	0.696
Disk	0.498	Fert. Truck	0.897	Fert. Truck	0.891
Fert. Truck	0.649	NH_3 Trac.	0.740	NH_3 Trac.	0.577
NH_3 Trac.	0.404	Plant	0.527	Plant	0.476
Springtooth	0.465	Cultivate #1	0.743	Disk	0.257
Plant	0.639	Cultivate #2	0.734	Endgate Seeder	0.145
Spray	0.815	Combine	0.327	Cultivate #1	0.743[a]
Cultivate	0.466[b]			Cultivate #2	0.755
Combine	0.377[c]			Combine	0.380[d]
				Cornpicker	0.807

[a]Field efficiency in time and motion study was 0.970.

[b]Field efficiency in time and motion study was 0.967.

[c]Field efficiency in time and motion study was 0.899.

[d]Field efficiency in time and motion study was 0.651.

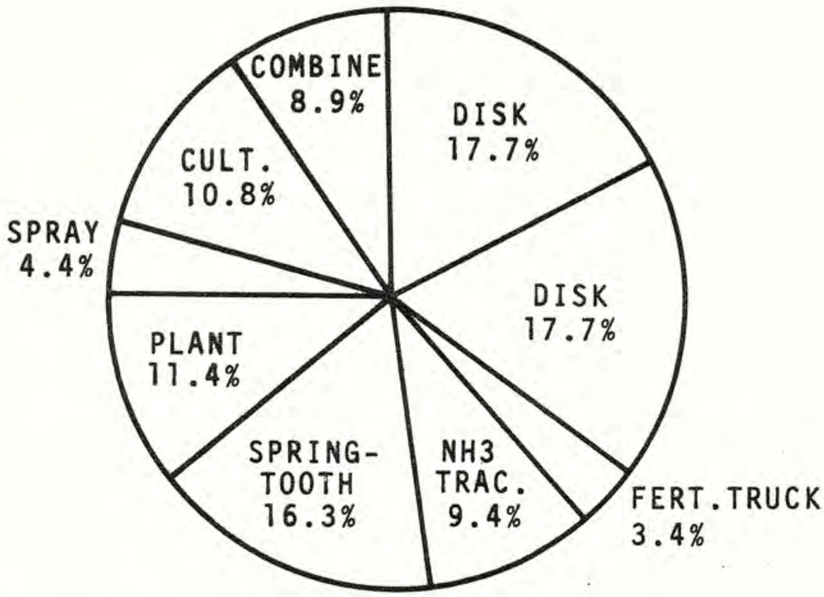

Figure 4. Relative fuel use for the tandem disk, contour tillage system (actual data from Watersheds One and Two)

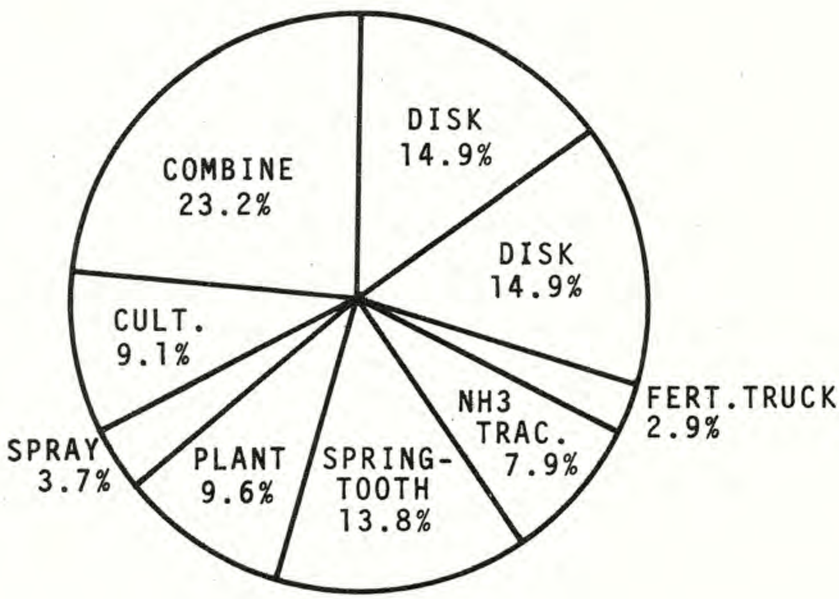

Figure 5. Relative fuel use for the tandem disk, contour tillage system (with normal harvest on Watersheds One and Two)

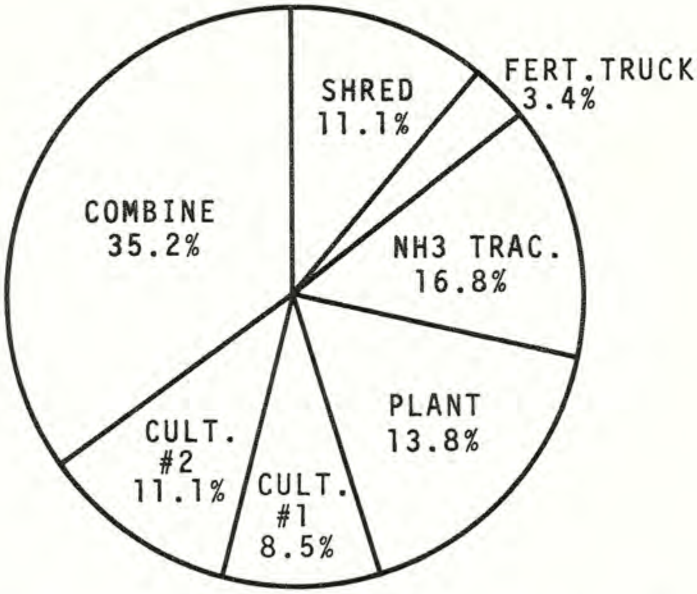

Figure 6. Relative fuel use for the till planter, contour tillage system (Watershed Three)

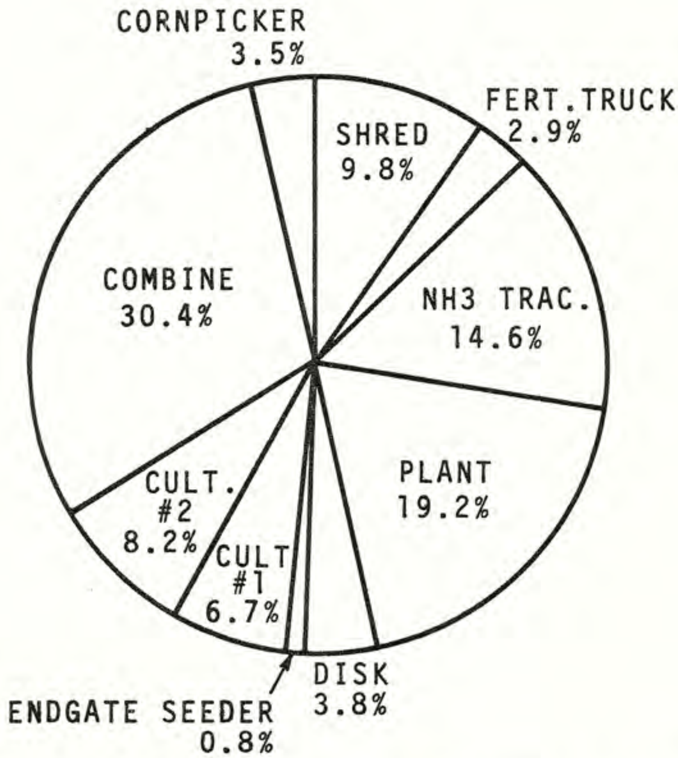

Figure 7. Relative fuel use for the till planter, terrace tillage system (Watershed Four)

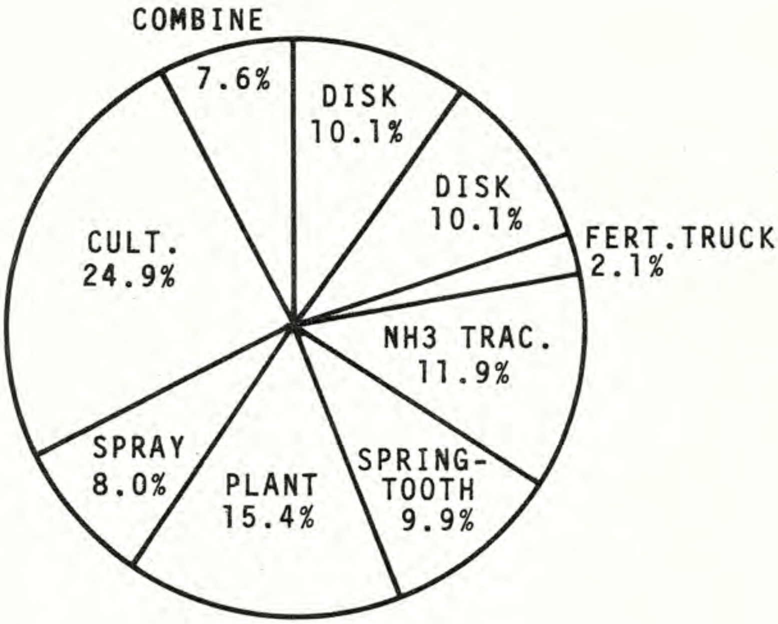

Figure 8. Relative time use for the tandem disk, contour tillage system (actual data from Watersheds One and Two)

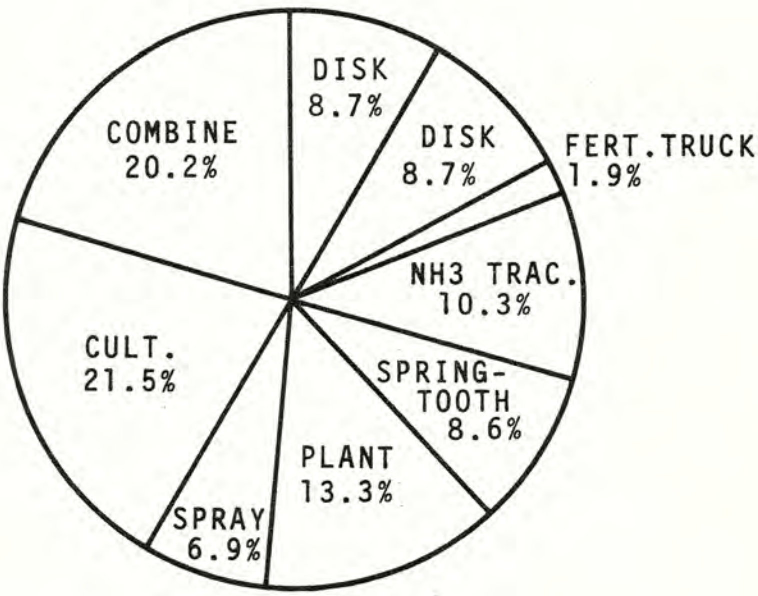

Figure 9. Relative time use for the tandem disk, contour tillage system (with normal harvest on Watersheds One and Two)

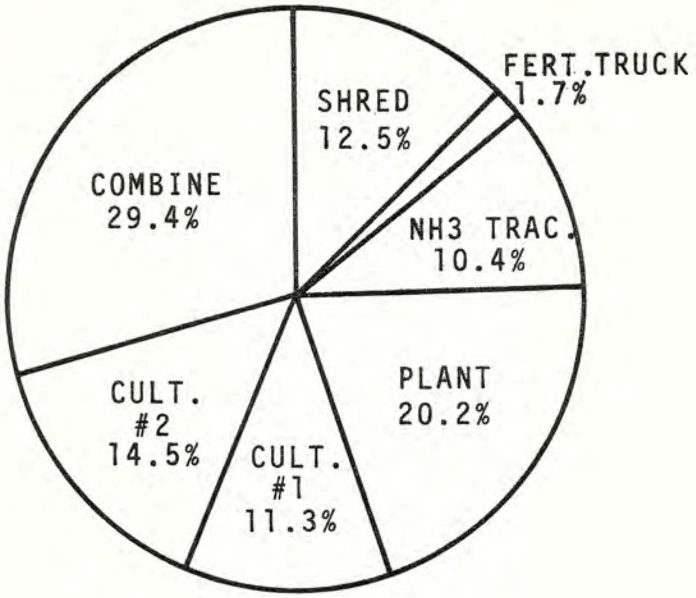

Figure 10. Relative time use for the till planter, contour tillage system (Watershed Three)

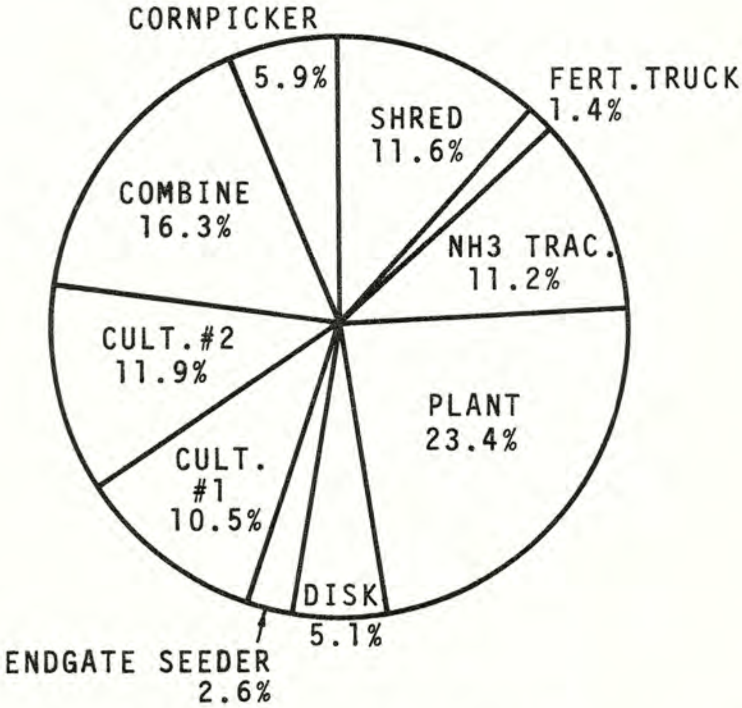

Figure 11. Relative time use for the till planter, terrace tillage system (Watershed Four)

201 acres were harvested. Harvest data for Watersheds One and Two were extrapolated for a full harvest. Extrapolated data for harvest should be used with caution however. The 65 acres that were harvested and used for the extrapolation were harvested by skipping around to different parts of the field. Poor time and fuel use undoubtedly resulted during the actual harvest.

Analysis of totals on Watershed Four presented some problems because of the replanting operation. Not only was replanting included in the actual data but also harvesting operations by both a combine on the originally planted corn and a cornpicker on the replanted corn. Four cases were reported in the totals for Watershed Four. These included actual data both with and without harvest. Next, the actual data were modified by removing the replant data and were extrapolated to have an entirely combined harvest (eliminating the use of the cornpicker on replanted corn harvesting). Again, extrapolated combine data may not be the true case as the combine skipped around replanted portions of the field. Finally, totals are reported both without replant and without harvest data. Totals for the different cases of the three tillage systems are shown in Table 4. Figures 12 and 13 illustrate the relative amounts of fuel and time needed per acre for each case.

Figure 14 shows the relative amounts of fuel required for field work each month of the cropping season.

Table 4. Total fuel and time use for three different tillage systems[a]

	Total Gallons	Gal/Acre	Kcal/Hectare	Total Hours	Hrs/Acre	Hrs/Hectare
Watersheds 1 and 2						
Actual	1074.5	5.351	34.96×10^4	289.5	1.442	3.563
With full harvest	1274.3	6.346	41.46	335.4	1.670	4.127
Without harvest	978.9	4.875	31.85	267.5	1.332	3.291
Watershed 3						
Actual	404.9	4.222	27.58	127.6	1.331	3.289
Without harvest	262.2	2.734	17.86	90.1	.940	2.323
Watershed 4						
Actual	833.9	4.923	32.16	266.6	1.574	3.889
Without harvest[b]	551.0	3.253	21.25	207.5	1.225	3.027
Without replant[b]	806.5	4.761	31.10	234.6	1.385	3.422
Without replant and harvest	474.6	2.802	18.31	177.7	1.049	2.592

[a]Fuel use in gallons per acre of no. 2 diesel fuel.

[b]Assumed to be harvested entirely by combine.

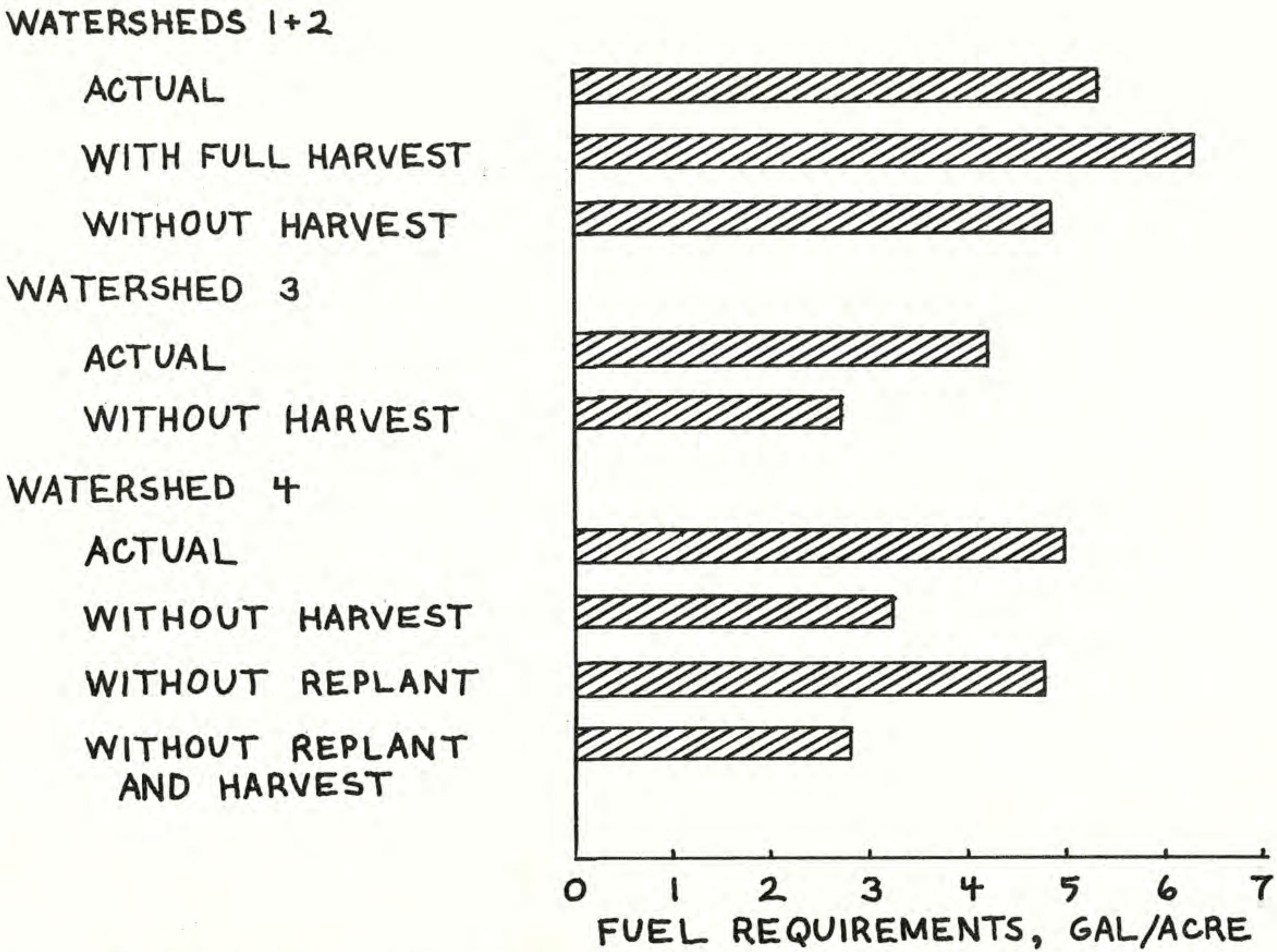

Figure 12. Relative amounts of fuel required per acre for each tillage system (see Table 4 for complete details)

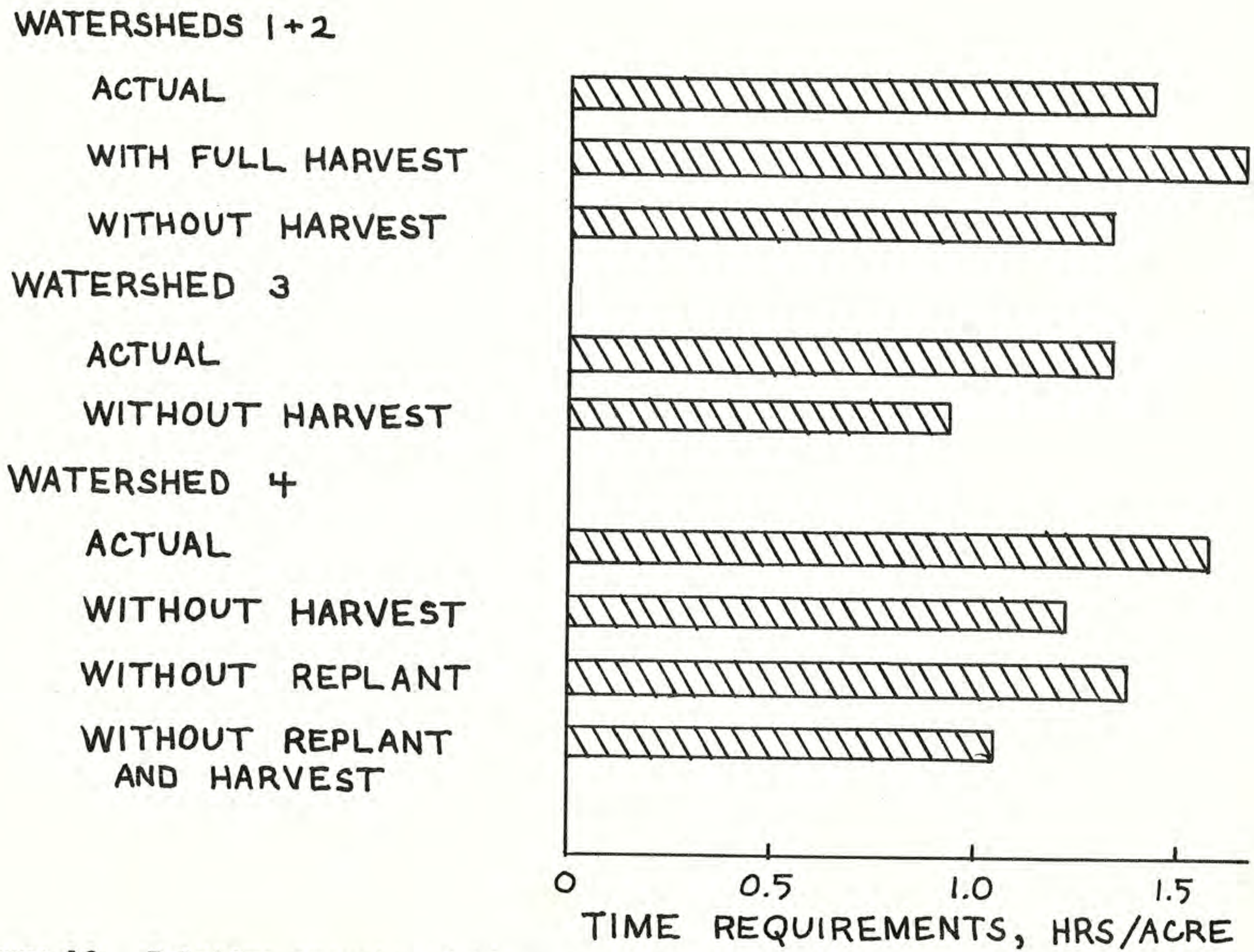

Figure 13. Relative amounts of time required per acre for each tillage system (see Table 4 for complete details)

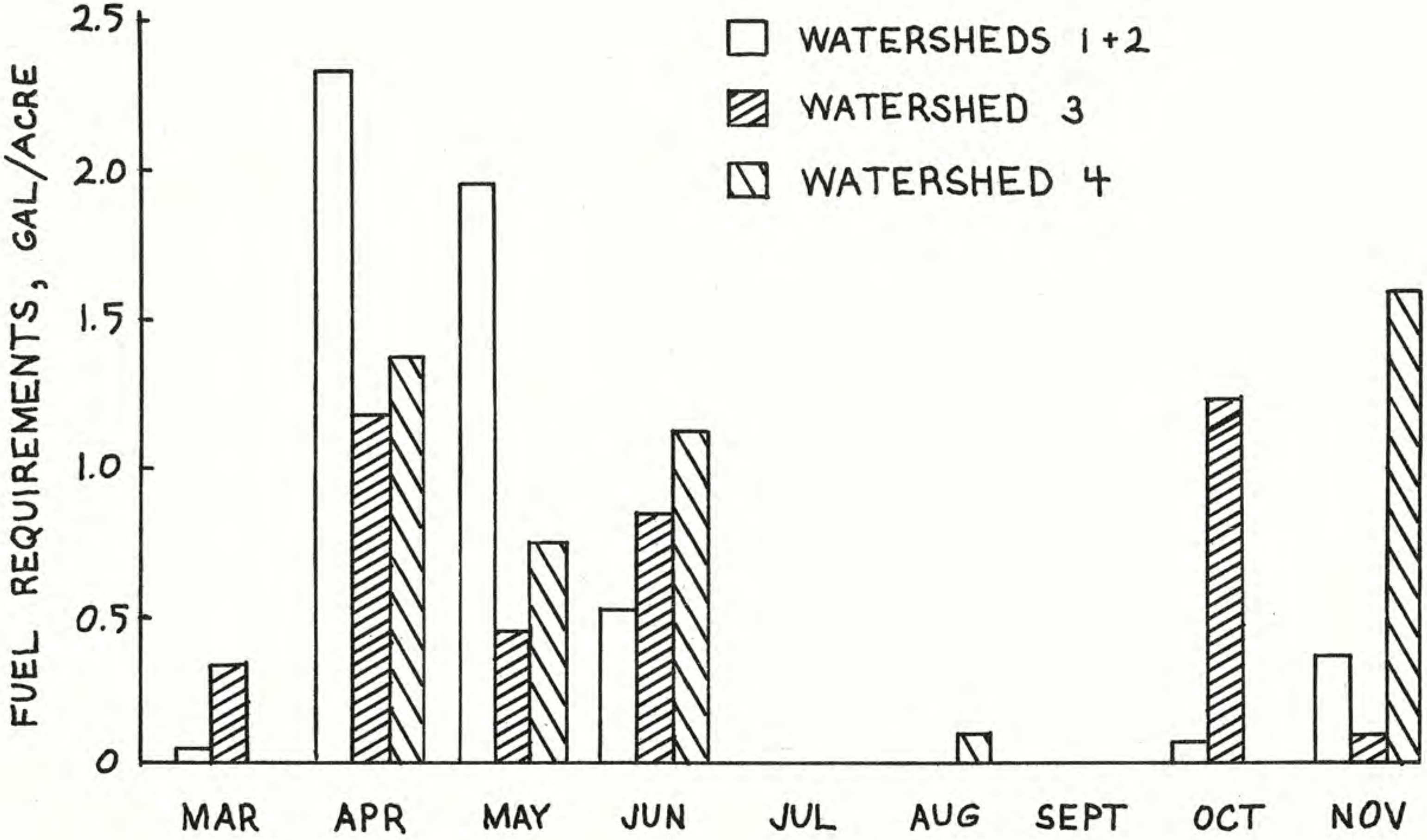

Figure 14. Relative amounts of fuel required per acre for the tillage systems during each month of the cropping season

In addition to energy needed as fuel for field operations, other forms of energy are necessary to supply inputs for corn production during the growing season. Energy is needed to produce herbicides, insecticides, fertilizer, and even the field machinery. An attempt was made to estimate the energy used in these corn production systems for supplying these goods.

Energy required for agricultural chemical production, herbicides and insecticides, has been estimated by Clark and Johnson (1974) to be 85,000 Btu/lb for wettable powders and 47,500 Btu/pint for liquids. A summary of the herbicide and insecticide data for the three tillage systems along with the energy needed to produce them is included in Table 5.

Energy for fertilizer production and delivery has been estimated by Pimentel _et al_. (1973) to be 8,400 kcal/lb for nitrogen, 1,520 kcal/lb for phosphorus, and 1,050 kcal/lb for potassium. A summary of the fertilizer data for each tillage system and the energy required for the fertilizer appears in Table 6. It should be noted that the abnormally heavy application of nitrogen on Watersheds One and Two (for another experiment) causes energy requirements on that tillage system to be unrealistically high.

Energy required in the production and delivery of farm machinery has been estimated by Clark and Johnson (1974) as 45,590 Btu/dollar of purchase price. An estimate of the

Table 5. Energy required for herbicide and insecticide[a]

	Application Rate	Gal[b] / Acre	Kcal / Hectare
Watersheds 1 and 2			
Aatrex	1.0 lb/acre	0.810	5.292×10^4
Lasso	1.0 qt/acre	0.905	5.913
Thimet[c]	7.0 lb/acre	1.133	7.405
Totals		2.848	18.610
Watershed 3			
Aatrex	0.5 lb/acre	0.405	2.646
Lasso	0.5 qt/acre	0.452	2.953
Thimet[c]	7.0 lb/acre	1.133	7.405
Totals		1.990	13.004
Watershed 4			
Aatrex	1.5 lb/acre	1.214	7.931
Lasso	1.5 qt/acre	1.357	8.866
Thimet[c]	7.0 lb/acre	1.133	7.405
Totals		3.704	24.202

[a]Based on 85,000 Btu/lb for wettable powders and 47,500 Btu/pint for liquids.

[b]Gallons per acre of no. 2 diesel fuel.

[c]Thimet based on 15% active ingredient.

Table 6. Energy required for fertilizer[a]

	Application Rate, lb/acre	Energy Required Gal[b]/Acre	Energy Required Kcal/Hectare
Watersheds 1 and 2			
Nitrogen	232.8	73.80	482.2×10^4
Phosphorus	34.9	2.00	13.1
Potassium	25.3	1.00	6.5
Totals		76.80	501.8
Watershed 3			
Nitrogen	167.8	53.19	347.5
Phosphorus	36.7	2.11	13.8
Potassium	31.1	1.23	8.0
Totals		56.53	369.3
Watershed 4			
Nitrogen	166.0	52.62	343.8
Phosphorus	36.7	2.11	13.8
Potassium	31.1	1.23	8.0
Totals		55.96	365.6

[a]Based on 8,400 kcal/lb N, 1,520 kcal/lb P, and 1,050 kcal/lb K.

[b]Gallons per acre of no. 2 diesel fuel.

purchase price value of each implement used in the field operations was made. Then by knowing the number of hours each implement was used and machinery life data from the 1973 Agricultural Engineers' Yearbook, it was possible to determine the energy use per acre of producing and transporting the field machinery to the farm. Table 7 illustrates this energy required for the supply of farm machinery.

No energy data for corn drying was collected. The abnormally low yields and wet corn which did not field dry would have given unrepresentative data. Transportation data of corn from the field to the farmstead was not recorded.

Table 7. Energy required for supply of farm machinery[a]

Equipment	Estimated Price	Hours Used	Life Hours	Energy Required: Gal[b]/Acre	Energy Required: Kcal/Hectare
Watersheds 1 and 2					
IH 1066	\$22,375	68.83	12,000	0.275	1.80×10^4
AC 190	13,190	62.75	12,000	1.149	0.97
Deere 730	6,125	95.25	12,000	0.105	0.69
19 ft. disk	5,990	58.32	2,500	0.302	1.97
18 ft. springtooth	1,200	28.75	2,500	0.030	0.20
4 row planter	4,000	44.50	1,200	0.321	2.10
6 row sprayer	980	23.25	1,200	0.041	0.27
4 row cultivator	1,100	72.00	2,500	0.069	0.45
4 row combine	30,000	22.00	2,000	0.714	4.66
Totals				2.006	13.11
Watersheds 3 and 4[c]					
IH 856	\$17,985	160.25	12,000	0.394	2.57
Deere 4020	17,000	103.91	12,000	0.241	1.57

[a]Based on 45,590 Btu/dollar of purchase price.

[b]Gallons of no. 2 diesel fuel.

[c]Equipment used on Watershed Three was identical to equipment used on Watershed Four with the exception of 21 ft. disk, endgate seeder, and cornpicker.

Table 7. (Continued)

Equipment	Estimated Price	Hours Used	Life Hours	Energy Required: Gal[b]/Acre	Energy Required: Kcal/Hectare
4 row shredder	$ 4,000	47.08	2,000	0.394	2.57 x 10^4
4 row till planter	5,000	88.08	1,200	0.602	3.93
21 ft. disk	3,680	13.50	2,500	0.033	0.22
Endgate seeder	1,600	7.00	1,200	0.015	0.10
4 row cultivator	1,200	92.75	2,500	0.073	0.48
4 row combine	35,000	80.92	2,000	2.323	15.18
2 row cornpicker	7,500	15.75	2,000	0.097	0.63
Totals				3.932	25.69

Total energy required for supply of farm machinery on Watersheds 1 and 2 = 2.006 gal/acre or 13.11 x 10^4 kcal/hectare.

Total energy required for supply of farm machinery on Watershed 3 = 3.787 gal/acre or 24.74 x 10^4 kcal/hectare.[c]

Total energy required for supply of farm machinery on Watershed 4 = 3.932 gal/acre or 25.69 x 10^4 kcal/hectare.

DISCUSSION

In this study the results were, of course, only as accurate as the records that were kept. The author made several trips to the watersheds during the year, visiting with the farmer operators and checking their records. The logbooks seemed to be in fairly good order. There were no gaps either in fuel or time data to be accounted for. Other energy inputs, herbicide, insecticide, fertilizer, and farm machinery, were based on data from the farms and the best energy parameters available at this time.

The study concerning how much fuel was used per acre for running the machinery brought up several important points. The amount of fuel needed to run the machinery in the field varies with the load on the engine, the tractive efficiency of the tractor or combine, soil type, and soil moisture, as well as basic energy conversion characteristics of the engine itself. Fortunately, diesel engines run at about the same energy conversion efficiency from half to full load. Gasoline engine efficiencies vary somewhat more than those of diesel engines under part load. Of more importance in fuel use during the study were soil type, surface, and moisture characteristics. Published figures for fuel use are generally for rather ideal conditions and often do not take into account the factors mentioned above. In addition often an engine is running in the field during loading or unloading operations, such as when planting or harvesting, and uses additional fuel as it is idling.

Several important items were noticed in the fuel study. On Watersheds One and Two both disk and springtooth fuel figures seem to be relatively high, 0.947 and 1.002 gal/acre, respectively. Both of these implements were run fairly deep. Disking was estimated to average about seven inches in depth; the springtooth was operated at an eight inch depth. On all three tillage systems travel fuel to and from Treynor was subtracted from the fertilizer truck data. Anhydrous ammonia application was done by two different tractors and applicators. On Watersheds One and Two a seven row applicator was operated at 0.503 gal/acre and on Watersheds Three and Four a five row applicator was operated at 0.709 and 0.720 gal/acre, respectively. Both applicators were run by custom operators. One of the widest set of variations was noted for the till planter. On Watershed Three (contour) the till planter used 0.584 gal/acre while on Watershed Four (terrace) the same implement used 0.766 gal/acre. Perhaps one reason for the additional fuel use per acre planted was the inefficiencies of extra turns in replanting forty acres on Watershed Four.

Although there are not enough data for a statistical analysis some generalizations can be made from the totals. As expected, the disk tillage system on contoured ground used more fuel than the till planter systems. More trips across the field, particularly with heavy tillage equipment, mean more fuel use. On the two till planter tillage systems the terraced ground seemed to use more fuel in general than the contoured ground, even after deducting the replanting operations.

The amount of time spent per acre for different field operations seemed to follow a pattern similar to that of fuel use. Again, the terraces seemed to take slightly more time than the contoured ground. This was particularly surprising considering that terrace spacing is double the recommended width. Disked ground took considerably more time with more field operations.

Field efficiencies were generally lower than expected. Watersheds One and Two were particularly low in field efficiency. Much of the early spring work was done in two and three hour time periods after school by the farmer's son. Small errors in starting and ending times in these short time periods would have a fairly large effect on these field efficiencies. As expected, field efficiencies for operations on the replanted corn area of Watershed Four were quite low. Also, as combines were operated faster during less than ideal harvesting conditions poor field efficiencies resulted. As indicated, some of these less than optimum field conditions together with maintenance and repair of equipment and starting and ending times that may not have exactly coincided with the beginning and ending of field operations all contributed toward lowering field efficiencies. It should be stressed that field efficiencies and times measured in this manner by logbook probably tend to exaggerate actual times during which field work was performed. Also, average field conditions do not lend themselves to optimum field efficiencies.

Other essentials for corn production were large energy consumers in the study. Fertilizers were by far the largest energy users with nitrogen leading the way. Anhydrous ammonia required much more energy per acre than any other input for corn production studied. Herbicide that was banded on Watershed Three appears to be an energy saver as compared to herbicide that was broadcast on Watershed Four. An extra cultivation may be justified in order to save herbicide if labor is available. Totals of all corn production inputs for each tillage system are not shown because of the excess amount of nitrogen used in another study on Watersheds One and Two.

Energy for machinery production and supply was perhaps the most difficult to estimate. Repairs were not included as an energy user so estimates may be somewhat low. Also, machinery supply energy per dollar has undoubtedly fluctuated greatly in the last two years. The limited combine use on Watersheds One and Two greatly lowered the energy requirement of that tillage system. It also points to the minimal use of an expensive machine in corn production. If the crop had been fully harvested on Watersheds One and Two, energy figures for machinery supply would be quite comparable. As far as total energy requirements, machinery supply takes almost as much energy as the fuel used by the machinery once it is in the field.

Drying energy, although not included in the study, has been shown to be a major energy user in corn production. Other investigators have made various estimates as to its energy requirements. Pimentel (1973) suggests that 12×10^4 kcal (4.53 gallons of no. 2 diesel fuel) per acre are needed as a nation-wide average for corn drying. Lane et al. (1973) estimated that the energy requirement for drying corn in Nebraska was 58.1×10^4 kcal (21.94 gallons of no. 2 diesel fuel) per acre. From actual measurements on a farm in Iowa Hurburgh (1974) lists the energy requirement as 25.2×10^4 kcal (9.52 gallons of no. 2 diesel fuel) per acre. Drying energy appears to rank second only to fertilizer energy.

SUMMARY

Energy inputs for corn production have recently come to be a major concern in agriculture. This study analyzes these inputs and time use for corn production on the Treynor Watersheds near Council Bluffs in western Iowa. Research was done on four large field sized watersheds including three different tillage systems. Field operations on Watersheds One and Two (200.8 acres) were done on an approximate contour and consisted of two passes with a tandem disk, custom fertilizer application, a springtooth operation, planting, spraying, cultivating, and a combine harvest. Watershed Three (95.9 acres) was also approximately contoured with field operations of shredding, custom fertilizer application, till planting, two cultivations, and a combine harvest. Watershed Four (169.4 acres) was terraced and had similar field operations as Watershed Three. They consisted of shredding, custom fertilizer application, till planting, disking, an endgate seeder application of pesticide, two cultivations, and harvest by both a combine and cornpicker. The disk, endgate seeder, and cornpicker were used because a cutworm infestation on forty acres necessitated replanting. The replanting and a drought caused crop failure and caused fuel and time inefficiencies.

As expected, more trips across the field with heavier tillage operations caused more fuel and time use. Fuel

(diesel) use for the field operation of farm machinery, as actually measured during the cropping season (excluding harvest and replant data), is as follows: tandem disk on contour system, 4.875 gal/acre, till planter on contour system, 2.734 gal/acre, and till planter on terrace system, 2.802 gal/acre. Time use followed a similar pattern (again excluding harvest and replant data): the tandem disk on contour system using 1.332 hrs/acre, till planter on contour system using 0.940 hrs/acre, and till planter on terrace system using 1.049 hrs/acre. Among other energy inputs into corn production, fertilizers were highest with nitrogen being by far the largest energy user of the study. Drying energy was not included.

Although low moisture conditions tended to favor the yields on the till planter systems, it appears that at least a gallon of fuel per acre and considerable time can be saved using the till planter tillage systems. More management is required with the reduced tillage systems, though, and careful attention is required during the cropping season. In this particular study terraced ground at double the recommended terrace spacing took slightly more fuel and time per acre than adjacent contoured ground.

Fuel requirements for the field operation of farm machinery in this study appear to be intermediate as compared to those fuel requirements estimated by other researchers. Pimentel *et al*. (1973) using the average of U.S. Department of Agriculture figures for all crops (i.e., they assumed corn to be an intermediate energy use crop) estimated that 30.1 gallons of diesel fuel per acre would be required for use by field machinery. Lane *et al*. (1973) estimated that tillage systems similar to those used on the watersheds would require between 2.56 and 5.25 gallons (including harvest) of diesel fuel per acre. Some of their estimates appear particularly low however, such as the combine which would require only 0.667 gal/acre of diesel fuel.

The fuel requirements compare favorably with other measured values. Hurburgh (1974) recorded values of 6.17 and 7.42 gallons per acre of diesel fuel required for field operations of similar tillage systems. These values represent actual farm records over four years (and include harvest).

SUGGESTIONS FOR FURTHER STUDY

1. More research is needed on the tillage systems as listed below:
   a. An on site observer weighing auxiliary fuel tanks similar to the Wald (1968) study to accurately check that data already measured at the fuel storage tanks.
   b. A check on the combine data with a harvest more representative of the area.
   c. Data measured on corn transportation from the field.
   d. Drying energy requirements.
2. Data are needed for other tillage systems and field operations of corn production.
3. Data are needed for field operations of other crops (soybeans, small grains, forage crops, etc.).
4. Better parameters for energy requirements of fertilizers, herbicides, insecticides, and production of machinery are needed.

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