ENERGY ANALYSIS MODEL OF VARIOUS TILLAGE AND FERTILIZER TREATMENTS ON CORN SILAGE PRODUCTION

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An energy model analysis was performed on conventional, reduced and zero tillage practices, as well as on the use of manufactured and manure fertilizers for silage corn production. The energy evaluation followed process analysis and included all energy inputs through the farm gate, including indirect energy sequestered in the machines and materials used. This analysis was integrated with observations of large plot experiments of the same tillage and fertilizer systems conducted in 1983 on a sandy loam and a clay soil in Quebec. The results showed that reduced or zero tillage can save estimated input energy and costs without losing productivity, and that the application of manure as a nitrogen source considerably increases the energy productivity of the operation.

INTRODUCTION

Because corn has a relatively high yield and financial return per hectare, it has long been a valued crop in the United States, and has enjoyed a great increase in popularity in Canada over the past 30 yr. At the same time, energy costs and the availability of improved pesticides have led to a re-evaluation of traditional tillage practices. Reduced tillage and no-till systems are becoming increasingly popular for both grain and silage corn, especially in North America. Some of the advantages of reduced tillage are a saving in mechanical energy input, reduced time and manpower costs, possibly improved yields in some regions and the conservation of soil and water, especially in drier areas. Hamlett et al. (1983) and Ford and Kraft (1977) have demonstrated that commercial feed producers adopt reduced or zero tillage practices mainly for an increase in overall profitability of operations.

Yet, no cultivation system is without disadvantages. Bennett (1977), Triplett and van Doren (1977), Dull (1979) and Barclay et al. (1983) have pointed out some of the drawbacks of reduced tillage. They include an increase in chemical costs, more difficulty in weed control, the possibility of a residual buildup of chemicals in the soil, potential leaching losses of nitrogen, a higher required level of management and a danger of excessive soil compaction.

The purposes of this particular study were twofold, namely to analyze the energy inputs and observe the productivity of reduced and zero tillage practices in Western Quebec for silage corn production, and to determine the feasibility of such systems for commercial operations in that region.

ENERGY AND COST ANALYSIS PROCEDURES

The method of analysis of energy inputs which was chosen for this study was Process Analysis. Fluck and Baird (1980) have shown that this method is best suited to the examination of a specific production system on a small regional scale, compared to other possible techniques such as a statistical or input-output analyses. All inputs are analyzed individually on the basis of their energy requirements in order to include the total of direct and hidden energy costs entering the system. Fluck and Baird (1980) also pointed out the inadvisability of using the energy value of crops as the representative output quantity, since food energy is not equivalent to fossil fuel and other forms of input energies. Instead, they proposed that the mass of output should be the appropriate quantity, and that an energy productivity quotient can be calculated through dividing this mass by the total of input energies used in producing a specific crop.

Some studies have been conducted using process analysis to evaluate the energy productivity of particular crops with differing tillage systems, such as German et al. (1977) on soybeans, Vaughan et al. (1977) on soybeans and grain corn and Rask and Forster (1977) on corn. However, few studies have been made in association with actual physical experiments in which yield results can be observed concretely. Knapp (1980), for instance, conducted a comprehensive analysis of seven silage corn production systems, but used estimated yields from different regions in North America. One exception was a study by Griffith et al. (1977) wherein corn yields were observed in response to eight different tillage management schemes on four soil types. All energy sources which were sequestered in the production systems were included in order to estimate the net resource depletions caused by the operations. The indirect energy cost involved in the manufacture of the appropriate machinery was not calculated directly, but was estimated as one-half of the actual machinery fuel consumption. Energy costs of pesticides were included also, but not those of manure fertilizers which were applied at constant rates for all systems. When inorganic fertilizers are used in agricultural production, they can easily account for half of total energy costs (White 1980).

In the study presented here, it was desired to include in the model all energy costs of items and materials entering the farm gate, including fuel, pesticides, manufactured fertilizers and a reasonable estimate of machinery manufacture energy costs. With reference to Doering (1980), the figures used to estimate the embodied energy costs of machinery were 49.6 MJ/kg mass for tractors, and 62.8 MJ/kg for all other implements. Different conversion factors were used also to estimate the energies of fabrication during manu-

TABLE I. TOTAL MACHINERY ENERGY INPUTS

Machine	Mass (kg)	Embodied energy (GJ)	Fabrication (GJ)	Repairs (GJ)	Total (GJ)
97-kW tractor	7156	291	86	135	512
47-kW tractor	4382	178	53	83	313
Planter	1700	87	12	30	130
Moldboard plow	1137	59	8	25	92
Chisel plow	1050	54	7	23	85
Disk harrow	1750	90	12	38	140
Sprayer	50	2.5	0.3	0.9	3.7
Broadcaster	1052	54	7	22	83
Manure spreader	1725	54	10	18	117
Forage chopper	1200	62	13	18	93
Three wagons	3945	203	20	68	291

TABLE II. FIELD PERFORMANCE OF TRACTORS

Soil	Tillage treatment	Cn	Coefficient of power transmission	Rolling resistance (kN) 47 kW	Rolling resistance (kN) 97 kW
Sandy loam	Conventional	15	0.49	5.2	8.4
	Reduced	20	0.61	4.3	7.0
	Zero	25	0.68	3.8	6.2
Clay	Conventional	20	0.61	4.3	7.0
	Reduced	25	0.68	3.8	6.2
	Zero	30	0.74	3.4	5.6

TABLE III. FERTILIZER EMBODIED ENERGY

Fertilizer	Rate (kg/ha)	Specific energy† (MJ/kg)	Energy rate (MJ/ha)
Urea	170	59.87	10178
Ammonium nitrate	170	61.55	10464
3-superphosphate	75	12.56	942
Muriate potash	80	6.70	536

†Lockertz (1980).

TABLE IV. HERBICIDE EMBODIED ENERGY

Herbicide	Rate (kg/ha)	Specific energy† (MJ/kg)	Energy rate (MJ/ha)
Atrazine	1.50	369.0	554
Alachlor	2.50	418.3	1046
Bentazon & Citowett	1.68	362.6	609

†Pimmental (1980).

TABLE V. MACHINERY COSTS EXCLUDING FUEL AND OIL

Machine	Annual use	Average price ($)	Fixed cost† ($/h)	Total cost‡ ($/h)	Specific area cost ($/ha)
97-kW tractor	600 h	56800	17.70	23.38	NA§
47-kW tractor	400 h	23000	10.75	13.05	NA
Planter	25 ha	10750	67.85	75.91	98.80
Moldboard plow	25 ha	10200	65.02	73.18	95.13
Chisel plow	25 ha	6250	32.97	35.97	70.66
Disk harrow	50 ha	10600	95.86	100.95	86.34
Sprayer	75 ha	3290	31.53	34.82	41.86
Broadcaster	25 ha	2750	177.87	180.62	25.09
Manure spreader	25 ha	9200	132.24	141.44	96.09
Forage chopper	25 ha	20600	85.98	94.22	210.76
Three wagons	25 ha	19980	70.01	73.61	155.31

†At 10% annual depreciation and 14% annual interest rate.
‡Including repairs at rates estimated by Kepner et al. (1978).
§Tractor operating costs are included in those of the machines below.

facture, and for repairs (Table I). The sizes of machines selected for the analysis were based on a corn silage production operation of 25 ha, employing one 97 kW tractor and another of 47 kW. The annual uses of these two machines were estimated as 600 and 400 h per year, respectively, for this crop, and the other necessary implements were sized accordingly.

Fuel consumption during each year was determined following the American Society of Agricultural Engineers (ASAE) (1983) D230.3 recommendations, using dimensionless cone index strength values, Cn, of 15−30 for the test soil surfaces ranging from tilled sandy loam to untilled clay (Table II). Fuel specific energy values and tractor efficiency values were also taken from ASAE Recommendation D230.3. According to the estimated field performance figures for the two tractors used, and the draft requirements of implements, detailed calculations were carried out for the various tractor and implement combination consumptions of fuel and oil (Owen 1985).

The energy cost of seed was calculated at 103.86 MJ/kg (Heickel 1980) at an application rate of 28 kg/ha for 80 000 plants/ha. Average energy expenses for inorganic fertilizer components were taken from Lockertz (1980) as 59.87 MJ/kg of nitrogen for urea, 61.55 MJ/kg of nitrogen in ammonium nitrate, 12.56 MJ/kg of P_2O_5 in triple superphosphate and 6.7 MJ/kg of K_2O in muriate of potash, all including transporation and packaging. The calculations of the embodied energy in the applied inorganic fertilizers are shown in Table III. The energy cost of dairy cow manure, which was used in some of the systems studied, was assumed to comprise only that in the machinery and fuel required to spread it, since the manure was not designated as an input through the farm gate, but as a by-product which is always present in dairy production.

Herbicide components were taken from Pimmental (1980) to have energy contents of 369 MJ/kg for Atrazine, 418 MJ/kg for Alachlor and 362 MJ/kg for Bentazon and Citowett in solution (Table IV). Human labor was not considered as an energy input into the cultivation systems because it was not classified among the resource depleting inputs. The time required for various operations in the different systems is, however, of interest.

In addition to the energy process analysis, a cost analysis of the cultivation systems considered was conducted, using the interest, depreciation and minor fixed costs as calculated by ASAE (1983) management data, and procedures outlined by Kepner et al. (1978). The values of labor, fuel and interest rates were taken as $C8.00/h, $C0.45/L and 14% per annum, respectively. Machinery prices were averaged from those reported by five Eastern Canadian dealers in 1984 as shown in Table V. Land costs were not included in the analysis as they were considered to be equal for all of the systems modelled.

FIELD PRODUCTION EXPERIMENTS

The energy analysis of different tillage and fertilization systems was applied in particular to a physical study which was conducted in 1983 (Kelly et al. 1984; Kelly 1985). This experiment comprised 36 field plots of 10 × 12 m each established on a sandy loam and a clay field. On each soil, there were three replicates of six combinations of tillage and fertilization practices for silage corn production, as shown in Table VI. All of the plots received the same herbicide treatment, which consisted of 1.5 kg/ha of Atrazine and 2.5 kg/ha of Alachlor before seeding, incorporated into the soil except in the zero-till situation, followed by two spray applications of 0.84 kg/ha of Ben-

TABLE VI. TILLAGE AND FERTILIZER TREATMENTS FOR SILAGE CORN STUDIES

System	Tillage treatment	Fertilizer application
Conventional inorganic	Fall plowing to 20 cm Two spring diskings	170 kg/ha N as urea 75 kg/ha P_2O_5 at seeding 80 kg/ha K_2O
Reduced inorganic	Fall chisel plowing One spring disking	170 kg/ha N as urea 75 kg/ha P_2O_5 at seeding 80 kg/ha K_2O
Zero inorganic	No tillage	170 kg/ha N, ammonium nitrate 75 kg/ha P_2O_5 at seeding 80 kg/ha K_2O
Conventional organic	Fall plowing to 20 cm Two spring diskings	Dairy cow manure† 75 kg/ha P_2O_5 at seeding
Reduced organic	Fall chisel plowing One spring disking	Dairy cow manure† 75 kg/ha P_2O_5 at seeding
Zero organic	No tillage	Dairy cow manure† 75 kg/ha P_2O_5 at seeding

†Application rate equivalent to 170 kg/ha N.

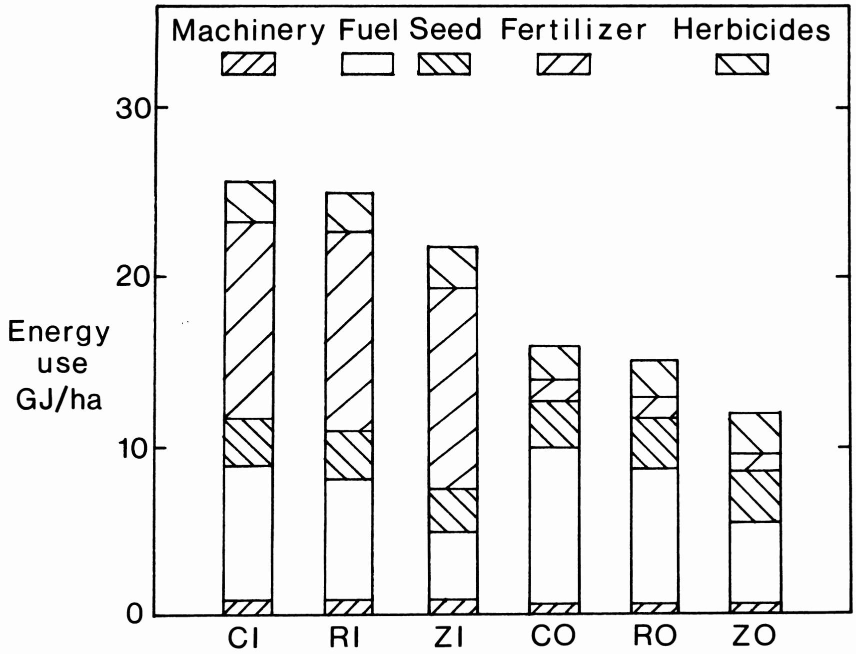

Figure 1. Components and sum of energy use in different cultivation systems. C = conventional, R = reduced, Z = zero tillage; I = inorganic, O = organic fertilizer.

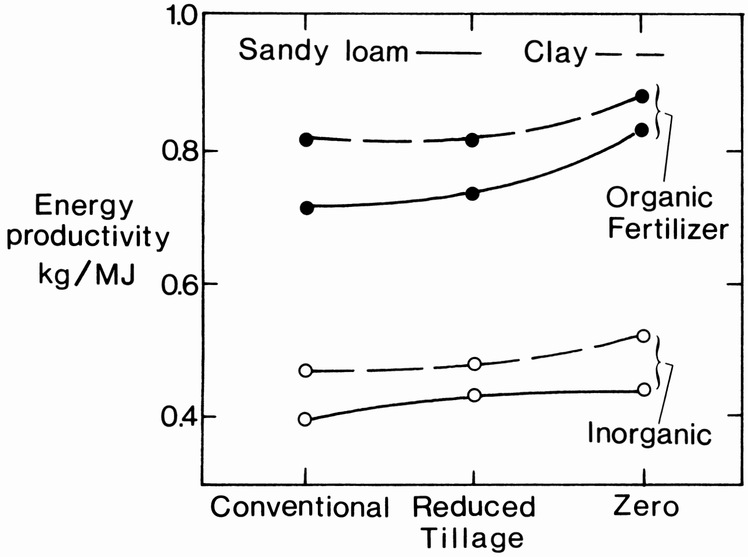

Figure 2. Energy productivity of silage corn production with three tillage systems, two sources of fertilizer and on two soils.

TABLE VII. MEAN SILAGE CORN DRY MATTER YIELDS

Soil	Tillage system	Fertilizer source	Dry matter yield (kg/ha)
Sandy loam	Conventional	Inorganic	10 100
	Reduced	Inorganic	10 820
	Zero	Inorganic	9 620
	Conventional	Organic	11 280
	Reduced	Organic	11 060
	Zero	Organic	9 570
Clay	Conventional	Inorganic	11 860
	Reduced	Inorganic	11 960
	Zero	Inorganic	11 560
	Conventional	Organic	12 520
	Reduced	Organic	11 530
	Zero	Organic	10 830

†From Kelly (1985).

TABLE VIII. LABOR REQUIREMENTS OF DIFFERENT SYSTEMS FOR 25 HA

Tillage system	Fertilizer source	Unit labor (h/ha)	Labor for 25 ha (h)
Conventional	Inorganic	7.26	181.6
Reduced	Inorganic	7.12	178.0
Zero	Inorganic	5.58	139.6
Conventional	Organic	7.72	192.9
Reduced	Organic	7.57	189.4
Zero	Organic	6.04	150.9

tazon and Citowett separated by 8 days. Certain systems, particularly the zero-till with applied manure, presented problems of volunteer grain emergence and dandelion growth, which were treated with an additional 2 kg/ha of Atrazine mixed with Kornoil, and spot applications of Killex, respectively. With the possible exception of the spot herbicide applications, these procedures were considered quite practical on the farm scale of operation.

In September 1983, the plots were harvested with a one-row forage harvester mounted on a 40-kW tractor. Samples of the harvested silage were dried for 48 h at a temperature of 50°C to determine average moisture contents and calculate dry matter yields per unit field area.

RESULTS AND DISCUSSION

The total amounts of energy used in the model by the different tillage and fertilizer systems for silage corn production are summarized in Fig. 1 as a bar graph including the individual components of machinery embodied and fabrication energy, fuel and oil used, seed, fertilizer and herbicides. Figure 1 represents the calculations for the sandy loam field, but the clay field had nearly identical results save for a small reduction in the amount of fuel due to reduced rolling resistance on the latter surface. A saving in fuel energy is evident by the use of reduced or zero tillage compared to the conventional system, but never more than 19% of overall energy

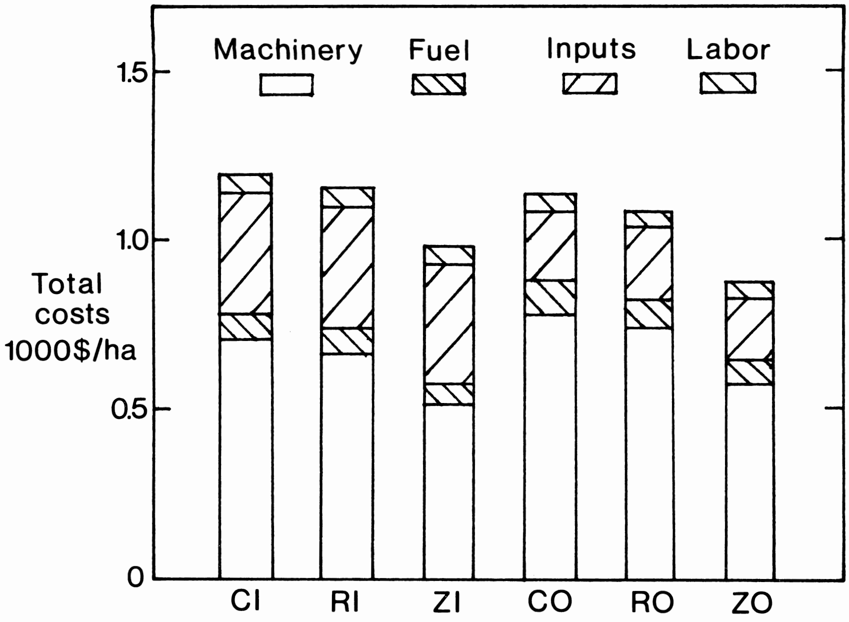

Figure 3. Total costs of the different tillage and fertilization schemes. C = conventional, R = reduced, Z = zero tillage; I = inorganic, O = organic fertilizer.

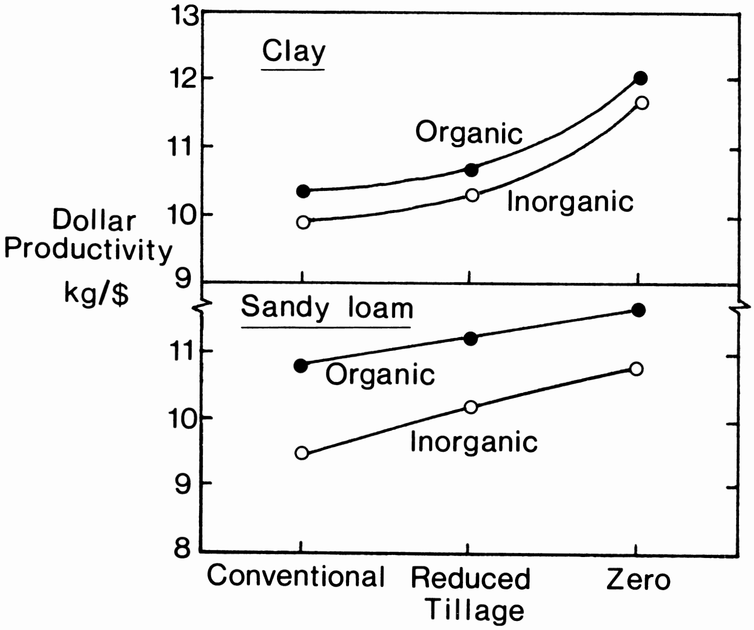

Figure 4. Dollar productivity of silage corn production with three tillage systems, two sources of fertilizer and on two soils.

inputs are saved. The larger reductions in energy consumption result from the application of manure instead of manufactured fertilizer, and they amounted to between 38 and 43% of the overall energy input.

The yields of silage corn dry matter for the 1983 study are given in Table VII for the various combinations of tillage systems and fertilizers used. On the sandy loam and clay fields separately, there were no significant yield differences due to the source of fertilizer. On the same soils, however, a significantly lower yield resulted for the zero-till treatment of approximately 8−10% of the conventional tillage yield. In this case, also, the clay plots yielded an average of 11% more dry matter than those on sandy loam soil. In other years, there could well be variations due to the interactions among climatic conditions, energy requirements and crop yields.

In order to compare the energy productivities of the different cultivation systems, the dry matter yield per unit field area is divided by the specific energy input per hectare from all off-farm sources. Figure 2 shows these results in graphical form. As the total energy inputs would indicate, organically fertilized treatments are much more productive per unit energy input. The clay soil was more productive than the sandy loam, and reduced and zero tillage better than conventional tillage by average amounts of 3 and 12%, respectively.

In order to examine the financial aspects of choosing various systems of production, the total costs of machinery, fuel, labor and other expendables were calculated and are presented in Fig. 3. The ownership or rental of land has not been included here. From the viewpoint of costs, the zero tillage system offers potential savings of 19% over conventional soil preparation, while the use of manure as a fertilizer saved only 4% on the average. The dollar productivities of the systems are compared graphically in Fig. 4, in which it is evident that reducing tillage and employing manure as fertilizer are both measures which can increase financial productivity by 10−20% or so.

The labor requirements of the systems examined are also of interest, and are listed in Table VIII. The largest difference in labor needs was between the conventional cultivation method with manure, and zero-till with inorganic fertilizer, and that was a saving in the latter case of some 2.1 h/ha, or about 28%.

CONCLUSIONS

(1) The most efficient cultivation system examined in this study, from the point of view of energy productivity, was zero tillage using manure as the fertilizer. The least efficient system was conventional soil preparation using inorganic fertilizers. The fertilizer source had a very strong impact on the energy productivity of silage corn because of the large quantities of energy needed principally to produce nitrogen fertilizer. The use of manure was observed to have no significant effect on crop yields in this experiment, but saved over 10 000 MJ/ha of off-farm energy requirements, or nearly 50% of total energy requirements.

(2) Zero-till cultivation had the lowest inherent costs of the systems tried in the study. Although no tillage led to a minor reduction in the yield of silage corn dry matter, it still produced the best dollar productivities of all the schemes. Zero tillage also offers the possibility of saving up to 28% in labor in the production process.

(3) It appears from the energy analyses conducted in this study, and the observations of silage corn yields in field scale experiments, that reduced or zero tillage are viable alternatives to be considered in commercial feed production in Eastern Canada.

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