ENGLISH 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), Tripplett 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 Foster (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-
97-kW tractor
47-kW tractor
Planter
Moldboard plow
Chisel plow
Disk harrow
Sprayer
Broadcast
Manure spreader
Forage chopper
Three wagons

Clay

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) 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 P2O5 in triple superphosphate and 6.7 MJ/kg of K2O 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 $8.00/h, $0.45/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

<table>
<thead>
<tr>
<th>System</th>
<th>Tillage treatment</th>
<th>Fertilizer application</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional inorganic</td>
<td>Fall plowing to 20 cm</td>
<td>170 kg/ha N as urea</td>
</tr>
<tr>
<td></td>
<td>Two spring diskings</td>
<td>75 kg/ha P₂O₅ at seeding</td>
</tr>
<tr>
<td></td>
<td></td>
<td>80 kg/ha K₂O</td>
</tr>
<tr>
<td>Reduced inorganic</td>
<td>Fall chisel plowing</td>
<td>170 kg/ha N as urea</td>
</tr>
<tr>
<td></td>
<td>One spring diskings</td>
<td>75 kg/ha P₂O₅ at seeding</td>
</tr>
<tr>
<td></td>
<td></td>
<td>80 kg/ha K₂O</td>
</tr>
<tr>
<td>Zero inorganic</td>
<td>No tillage</td>
<td>170 kg/ha N, ammonium nitrate</td>
</tr>
<tr>
<td></td>
<td></td>
<td>75 kg/ha P₂O₅ at seeding</td>
</tr>
<tr>
<td></td>
<td></td>
<td>80 kg/ha K₂O</td>
</tr>
<tr>
<td>Conventional organic</td>
<td>Fall plowing to 20 cm</td>
<td>Dairy cow manure†</td>
</tr>
<tr>
<td></td>
<td>Two spring diskings</td>
<td>75 kg/ha P₂O₅ at seeding</td>
</tr>
<tr>
<td>Reduced organic</td>
<td>Fall chisel plowing</td>
<td>Dairy cow manure†</td>
</tr>
<tr>
<td></td>
<td>One spring diskings</td>
<td>75 kg/ha P₂O₅ at seeding</td>
</tr>
<tr>
<td>Zero organic</td>
<td>No tillage</td>
<td>Dairy cow manure†</td>
</tr>
<tr>
<td></td>
<td></td>
<td>75 kg/ha P₂O₅ at seeding</td>
</tr>
</tbody>
</table>

†Application rate equivalent to 176 kg/ha N.

TABLE VII. MEAN SILAGE CORN DRY MATTER YIELDS

<table>
<thead>
<tr>
<th>Soil</th>
<th>Tillage system</th>
<th>Fertilizer source</th>
<th>Dry matter yield (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sandy loam</td>
<td>Conventional</td>
<td>Inorganic</td>
<td>10 100</td>
</tr>
<tr>
<td></td>
<td>Reduced</td>
<td>Inorganic</td>
<td>10 820</td>
</tr>
<tr>
<td></td>
<td>Zero</td>
<td>Inorganic</td>
<td>9 620</td>
</tr>
<tr>
<td>Clay</td>
<td>Conventional</td>
<td>Inorganic</td>
<td>11 860</td>
</tr>
<tr>
<td></td>
<td>Reduced</td>
<td>Inorganic</td>
<td>11 960</td>
</tr>
<tr>
<td></td>
<td>Zero</td>
<td>Inorganic</td>
<td>11 560</td>
</tr>
<tr>
<td></td>
<td>Reduced</td>
<td>Organic</td>
<td>12 520</td>
</tr>
<tr>
<td></td>
<td>Zero</td>
<td>Organic</td>
<td>10 830</td>
</tr>
</tbody>
</table>

†From Kelly (1985).

TABLE VIII. LABOR REQUIREMENTS OF DIFFERENT SYSTEMS FOR 25 HA

<table>
<thead>
<tr>
<th>Tillage system</th>
<th>Fertilizer source</th>
<th>Unit labor (h/ha)</th>
<th>Labor for 25 ha (h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional</td>
<td>Inorganic</td>
<td>7.26</td>
<td>181.6</td>
</tr>
<tr>
<td>Reduced</td>
<td>Inorganic</td>
<td>7.12</td>
<td>178.0</td>
</tr>
<tr>
<td>Zero</td>
<td>Inorganic</td>
<td>5.58</td>
<td>139.6</td>
</tr>
<tr>
<td>Conventional</td>
<td>Organic</td>
<td>7.72</td>
<td>192.9</td>
</tr>
<tr>
<td>Reduced</td>
<td>Organic</td>
<td>7.57</td>
<td>189.4</td>
</tr>
<tr>
<td>Zero</td>
<td>Organic</td>
<td>6.94</td>
<td>150.9</td>
</tr>
</tbody>
</table>

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 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.
1.5

Machinery Fuel Inputs Labor

ZIZ1 E3

Total

costs

1000$/ha

CI RI ZI CO RO ZO

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.

Dollar Productivity

kg/$

Clay

Organic

Inorganic

Sandy loam

Organic

Inorganic

Conventional Reduced Tillage Zero

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 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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