

ENERGY ANALYSIS OF VARIOUS TILLAGE AND FERTILIZER TREATMENTS

ON

CORN SILAGE PRODUCTION

by

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## ABSTRACT

This analysis is used in-depth calculations of the energy sequestered in the inputs to corn silage production systems and actual yields of those production systems to determine the most efficient system in terms of resource depletion. The yields were also compared on the basis of the fuel consumed by each system to find the most productive in terms of fuel consumption. The costs were determined for each of the systems and were related to the yields produced to determine the most efficient system in terms of financial productivity. The production systems analysed included three levels of tillage, two types of fertilizer and two different soil types. The experiment was carried out during the 1983 growing season.

The highest yields were found in the conventionally tilled organically fertilized systems in both the sandy loam soil where the yield was 12520 kg dry matter per ha and the clay soil which produced 11280 kg/ha. The no-till plots achieved significantly lower yields in the sandy loam soil and were significantly lower than the conventionally tilled plots in the clay soil.

The most efficient system vis-a-vis resource depletion or total energy consumption was the no-till organic system which produced productivities of 0.83 kg/MJ in the sandy loam soil and 0.96 kg/MJ in the clay. Fertilizer had a

tremendous impact on the energy productivity because of the vast amount of energy used in the production of inorganic nitrogen sources. The inorganic systems were almost always nearly 50% less efficient than comparable organically fertilized systems. The inorganic fertilizers had little effect on the yield but accounted for over 10000 MJ/ha or nearly 50% of the total energy expended in these systems.

The most efficient system in terms of silage produced per diesel fuel input was the no-till inorganic system regardless of soil type. This system returned 112.9 kg/L in the sandy loam soil and 146.5 kg/L in the clay. The conventional tillage system returned the lowest yield per fuel input approximately 50% of that of the no-till systems.

The cost analysis was performed on the basis of a 14% interest, \$8.00 per hour labour charge and \$0.45 per litre diesel fuel costs. The expenses fell into four categories being machine, fuel, labour and input costs where the input costs included fertilizer, herbicide and seed costs.

The most productive system in terms of finances was the no-till organic combination in both soils which produced 12.02 kg of dry matter per each dollar spent in the clay soil and 10.59 kg/\$ in the sandy loam. The least productive was found to be the conventional inorganic system which produced an average of 9.14 kg/\$ across both soils.

## SOMMAIRE

Dans la présente analyse, nous avons fait appel à des calculs rigoureux de l'énergie absorbée dans les intrants des méthodes de production du fourrage de maïs ensilé et au rendement réel de ces méthodes de production, afin de déterminer la méthode la plus efficace en termes d'épuisement des ressources. Les productions ont également été comparées en fonction de la quantité de carburant consommée afin de déterminer le système le plus productif en termes de consommation de carburant. Après avoir précisé le coût de chacune de ces méthodes de production, nous avons établi le rapport coût-rendement de chacune, dans le but de déterminer la méthode la plus efficace en termes de productivité financière. Les systèmes de production soumis à notre analyse comportaient trois types de labourage, deux types d'engrais et deux types de sol. L'expérience a été menée à bien pendant la saison de culture de 1983.

Les méthodes de production faisant appel aux engrais organiques et au labourage conventionnel ont produit les taux de rendement les plus élevés, à la fois dans la terre grasse sableuse où le rendement s'est élevé à 12 520 kg de matière sèche par ha et dans la terre-glaise où le rendement s'est chiffré à 11 280 kg/ha. Les champs non labourés ont produit des taux de rendement substantiellement inférieurs dans la terre grasse sableuse et leur rendement a été

considérablement inférieur à celui des champs labourés conventionnellement, dans la terre-glaise.

La méthode organique sans labourage s'est révélée la méthode la plus efficace par rapport à l'épuisement des ressources ou à la consommation globale d'énergie. En effet, elle a produit un rendement de 0,83 kg/MJ, dans la terre grasse sableuse et de 0,96 kg/MJ dans la terre-glaise. L'engrais utilisé a exercé un impact considérable sur la productivité énergétique en raison de la vaste quantité d'énergie utilisée dans la production de sources inorganiques azotées. De façon générale, les méthodes inorganiques ont été presque la moitié moins efficaces que les méthodes comparables faisant appel aux engrais organiques. Bien que plus de 10 000 MJ/ha, soit presque la moitié de l'énergie consommée par ces méthodes, aient été attribuables aux engrais inorganiques, ces derniers n'ont eu que peu d'effet sur le rendement.

La méthode la plus efficace en termes de fourrage produit par unité de carburant diesel a été la méthode inorganique sans labourage, indépendamment du type de sol utilisé. En effet, cette méthode a donné un rendement de 112,9 kg/L dans la terre grasse sableuse et de 146,5 kg/L dans la terre-glaise. La méthode de labourage conventionnel, qui s'est révélée la méthode la moins efficace, à ce poste, a produit un taux de rendement par unité de carburant de quelque 50% inférieur à la méthode inorganique sans labourage.

L'étude des coûts a été fondée sur les paramètres suivants: taux d'intérêt de 14 p.c., frais de main-d'oeuvre établis à 8\$ l'heure et prix du carburant diesel fixé à 0,45\$ le litre. Quatre postes des dépenses ont été identifiés: les frais de machinerie, de carburant, de main-d'oeuvre et d'intrants, ces derniers faisant état des coûts de l'engrais, des herbicides et des semences.

La méthode la plus efficace en termes financiers a été la combinaison organique sans labourage, dans les deux types de sol; dans la terre-glaise, elle a produit 12,02 kg de matière sèche par dollar investi et dans la terre grasse sableuse, 10,59 kg/\$. En revanche, la méthode inorganique conventionnelle s'est révélée être la moins rentable, n'ayant produit, en moyenne, qu'un rendement de 9,14 kg/\$, dans les deux types de sol.

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## NOMENCLATURE

|     |                                                                    |
|-----|--------------------------------------------------------------------|
| AP  | Axle Power, kW                                                     |
| CCI | Conventional Tillage, Clay Soil, Inorganic Fertilizer System       |
| CCO | Conventional Tillage, Clay Soil, Organic Fertilizer System         |
| Cn  | Cone Index                                                         |
| CSI | Conventional Tillage, Sandy Loam Soil, Inorganic Fertilizer System |
| CSO | Conventional Tillage, Sandy Loam Soil, Organic Fertilizer System   |
| DBP | Draw Bar Power, kW                                                 |
| FC  | Annual Fixed Cost, \$                                              |
| I   | Annual Interest Rate, %                                            |
| Li  | Machine Life, yrs                                                  |
| P   | Rated Engine Power, kW                                             |
| PC  | Principle Cost, \$                                                 |
| PTO | Power Take Off Power, kW                                           |
| RCI | Reduced Tillage, Clay Soil, Inorganic Fertilizer System            |
| RCO | Reduced Tillage, Clay Soil, Organic Fertilizer System              |
| RR  | Rolling Resistance, kN                                             |
| RSI | Reduced Tillage, Sandy Loam Soil, Inorganic Fertilizer System      |
| RSO | Reduced Tillage, Sandy Loam Soil, Organic Fertilizer System        |
| TAR | Total Annual Repairs, %                                            |
| W   | Weight of Machine, kN                                              |

|     |                                                               |
|-----|---------------------------------------------------------------|
| X   | Ratio of Operational to Maximum PTO Power                     |
| ZCI | No-till Tillage, Clay Soil, Inorganic Fertilizer System       |
| ZCO | No-till Tillage, Clay Soil, Organic Fertilizer System         |
| ZSI | No-till Tillage, Sandy Loam Soil, Inorganic Fertilizer System |
| ZSO | No-till Tillage, Sandy Loam Soil, Organic Fertilizer System   |

# I

## INTRODUCTION

The increasing use of corn as an ensiled feed has prompted the examination of many aspects of its use and nature.

Silage corn has a relatively high return per acre and therefore has long been a valued crop in the United States. As varieties requiring lower values of heat units were developed, its use spread north to Canada.

At the same time, energy limitations and pesticide development have caused the re-evaluation of traditional tillage practices. Reduced and no-till tillage systems are becoming increasingly popular for corn silage due to the lower energy costs, reduced manpower and improved soil structure obtained with their use. Conservation tillage systems also reduce soil erosion and generally result in yields comparable with conventional methods. These reduced tillage systems do, however, require a higher level of management and control but have been shown to reduce costs if implemented correctly.

In order to fully understand the impact of the change caused by the use of no-till and reduced tillage, vis-a-vis energy, it is important to examine each system as a whole. Therefore each entire system must be evaluated in terms of the total resource depletion it causes or in other words,

the total amount of energy expended to make the system work.

This is accomplished by performing an energy analysis on each system including all the energy inputs to the system, direct and indirect. The systems can also be evaluated at the producer's energy spending level, however this is only part of the total energy expended to grow the corn. The hidden or indirect energy expenditures come from the manufacturing of machinery, fertilizers, pesticides, etc. The results of an energy analysis should be expressed in the units of kg dry matter (kg DM) per energy input, in order to show the most efficient production method in terms of yield and energy input.

The purpose of this study is to evaluate three different tillage treatments with two different fertilizers in two different soils for a total of twelve treatments under South Western Quebec climatic conditions. The report includes the different yields produced by each system determined experimentally as well as the total resource depletion caused by each system as determined by process analysis. The producer's energy expenditures and a financial comparison of the twelve systems are also given.

## II

### LITERATURE REVIEW

#### 2.1 Tillage

Traditional cultural practices have always included a high degree of tillage. The moldboard plow has been the basis of conventional tillage since its wide spread acceptance in the eighteenth century (Turner, 1983). Plowing and its associated secondary tillage treatments are used primarily for the control of weeds (CAST, 1977; Triplett and van Doren, 1977; Pidgeon, 1979). Additional benefits of conventional tillage are improved seed bed preparation (Triplett and van Doren, 1977; Bennett, 1977; Griffith et al., 1977a) and residue incorporation (Amemiya, 1977; Dull, 1979).

The advent of highly efficient herbicides in the 1960's cast doubts on the necessity of conventional tillage (plow, disk-harrow and cultivator) (Triplett and van Doren, 1977; Turner, 1983; Griffith et al., 1977a; Bennett, 1977). Although no-till or reduced tillage had been used sparingly but with some success since the 1940's (Triplett and van Doren, 1977), it did not come into commercial practice until the 1970's (Triplett and van Doren, 1977; Pidgeon, 1979). The use of reduced tillage is now becoming more and more accepted as a valuable cropping technique (Turner, 1983; Dull, 1979).

The advantages to be gained by the use of reduced tillage are as numerous as they are divergent. The major advantages that can be noted from Bennett (1977), Triplett and van Doren (1977), Barclay et al. (1983), Singh et al. (1979) are;

- reduction in on-farm fuel consumption
- effective control of wind and water erosion
- increased water infiltration
- improved timeliness of field operations
- reduction in field time and labour
- possibility of increased crop yield
- surface applied lime and fertilizer are more readily available to the plants
- possibility of double cropping each year
- utilization of marginal and sloping land
- reduction in field equipment needs.

The use of reduced tillage practices is often initiated for one or two of the above reasons and the additional benefits are seen as supplemental gains. The major impetus for the utilization of reduced tillage by commercial producers is the increased profits obtained (Hamlett et al., 1983; Ford and Kraft, 1977). However no cultivation system is without disadvantages. The major restraints concerning reduced tillage, as compiled from Bennet (1977), Barclay et al. (1983), Triplett and van Doren (1977) and Dull (1979) are;

- increased chemical costs

- increased dependency on herbicides
- possible residual build-up of chemicals in the soil
- leaching losses of nitrogen
- higher level of management required.

Turner (1983) states that the major reservation to reduced tillage is its perception by farmers. However, the increasing acceptance of reduced tillage by farmers would indicate that many of them feel it is to their advantage (Fluck and Baird, 1980; Turner, 1983; Doleski et al., 1981).

## 2.2) Energy Analysis

Energy analysis is a relatively young discipline which consists of the identification and measurement of energy flows sequestered in various goods and services (Fluck and Baird, 1980). The use of energy analysis is effective in the determination of the most efficient production systems and conservation practices vis-a-vis energy consumption (Fluck, 1981; Hill and Ramsay, 1977, Ozkan, 1981). Hill and Ramsay (1977) also stated that energy analysis is valuable for the determination of national policy on agricultural energy use.

The discipline of energy analysis is characterized by many divergent philosophies and concepts which are reflected by equally different approaches and methodologies. However most of these methods fall into one of two different schools of thought. Fluck and Baird (1980) presented the characteristics of the two, under the headings of eco-energetic and sequestered. The eco-energetic school is

concerned with developing complete models of systems including solar radiation and labour inputs as well as, in some cases, an energy theory of value. The sequestered energy school of thought is primarily concerned with the depletion of the earth's resources and therefore only non-renewable energy sources, or their equivalents, are considered. While an eco-energetic analysis is a useful practice to observe naturally occurring energy flows, it is evident that a sequestered energy analysis is more beneficial for the comparison of specific processes from the conservation point of view (Fluck, 1981).

Fluck and Baird (1980) predicted that over time, the differences in analyses will disappear and certain standard conventions will be agreed upon. However a major obstacle to unification is the differing objectives of the approaches which, while both being of worth, are decidedly distinct. Presently, the conventions most adhered to are those, or variations of those established by the 1974 International Federation of Institutes of Advanced Study which follows the sequestered energy procedure (Fluck, 1981). Pimmental (1980), in his Hand Book of Energy Utilization in Agriculture, used only sequestered energy analysis because of its superiority for use in developing management strategies. Fluck and Baird (1980) described the three methods for determining the sequestered energy in a service or good as follows:

- 1) Statistical Analysis - In statistical analysis, or

economic analysis, a quotient is created by dividing a nation's primary energy consumption by its gross national product. This quotient is then applied to the economic value of a service or good to determine its energy intensity. This method is suitable for quick estimates at the national level but is unreliable at the micro or system level (Fluck, 1981).

2) Input-Output Analysis - Input-output analysis divides the entire economy of a specified region, such as a nation or province, into a finite number of industries. The transactions between sections are then quantified and recorded in the selected, often monetary, units. An input-output analysis is best applied to large economies or societies as a whole. The results yielded by this form of analysis are more accurate than those of statistical analysis and its greatest ability is the demonstration of the effect felt in one section of the economy by changes applied to another. However, Fluck and Baird (1980) stated that it is of limited worth when applied to a specific process at the producers' level.

3) Process Analysis - Process analysis is the examination of a specific process or product on the basis of the summation of the energy requirements of all the inputs for that process or product. These inputs themselves are then analysed individually in the same manner, and this methodology is followed until all "upstream" inputs and hidden energy costs have been included (Fluck and Baird,

1980). The use of process analysis is best suited to a specific system (Fluck and Baird, 1980) and can be expected to yield the best results of the three methods although, it requires the most effort (Fluck, 1981).

The objectives of an energy analysis are to examine and determine the energy flows within a certain process or system. When process analysis is used, the eventual outcome is the comparison of certain practices and their effect on the process efficiency. This efficiency has been traditionally expressed in terms of an energy ratio, that is, output to input (Fluck and Baird, 1980). When dealing with agricultural subsistence societies, the energy ratio is a useful and logical reflection of the system (Fluck and Baird, 1980), however when dealing with industrialized agriculture, the use of such a ratio can be misleading (Ozkan, 1981; Connor, 1977).

The confusion develops over the utilization of the energy ratio for the determination of policy and strategy. Pasour and Bullock (1977) pointed out the fallacy in using the energy ratio by demonstrating the inequivalence of fossil fuel energy to food energy. Foods are obviously consumed for reasons other than their energy content and therefore an evaluation of a certain production system by its energy efficiency alone is certainly of limited merit. For this reason, Fluck and Baird (1980) proposed the use of a unit called energy productivity which relates a process to its output by means of a ratio of the quantity of output to

unit of input energy.

Fluck and Baird (1980) pointed out that energy productivity is specific for each agricultural product under given circumstances and therefore can only be used for the comparison of various production practices under the same specific circumstances. In no way can it be used to compare different crops or even the same crop in a different location or climate because they are simply incomparable under those terms. Although energy productivity is not without its limitations, it appears to be a more useful parameter than the energy ratio as an evaluator for comparative purposes (Fluck, 1981).

Fluck (1981) proposed a general methodology for performing an energy analysis as follows:

- 1) choose a boundary and the process to be analyzed.
- 2) identify and quantify all inputs with respect to time output.
- 3) assign energy requirements to all inputs.
- 4) identify and quantify all outputs.
- 5) relate inputs or sequestered energy to outputs.
- 6) apply results of the energy analysis to some useful purpose.

Although the application of an energy analysis would appear straight-forward, (Fluck and Baird, 1980) there are a number of problems which must be handled before proceeding. Fluck (1981) presented the problems which occur when applying energy analysis to agricultural systems and some

possible solutions. He recommends that the enthalpies of different/ primary energy sources be summarized alleviating the problem of non-homogeneity of energy sources. Pimmental (1980) handled this problem by employing an energy efficiency ratio to the primary energy source, thereby reducing its inherent worth. Fluck (1980) also recommended that systems involving multiple outputs should apportion the sequestered energy according to their relative economic worth. He also recommended that the boundaries around the system be based on physical or economic borders and that the energy theory of value should be ignored.

### 2.3) Examples of Energy Analysis

Energy analysis has been performed on a large number of crops under a number of different conditions. It would be impossible to list all of the available references, however a selected few are presented.

Pimmental (1980) listed an exhaustive compilation of various crops. While the data given is certainly of value, there are limitations to its usefulness. Little, if any, information is given concerning the natural constraints under which the systems were examined and no indications are given as to soil type, climate or any other system parameters.

Myers (1983) examined energy use in Tunisian wheat farms and found there to be three levels of mechanization. The report shows that the three levels had distinct

differences in labour and energy use, however in this context there was a direct comparison between fossil fuel energy and human consumed energy although the two are not equivalent (Connor, 1977).

Avlani and Chancellor (1977) intensely examined the energy requirements of the production, processing and consumption of wheat in California. The report was predominantly done using process analysis, however input/output and statistical analysis were also used. The problem of non-homogeneity of energy sources was handled in this case by maintaining a separation of energy sources. The units used throughout the report were predominantly BTU/ton or Mcal/tonne, however the energy ratio was used for the comparison of production methods and geographical locations. Labour in this case was not included because, on the basis of a whole economy, energy used in the economy and that used to support the lifestyle are the same, and hence double accounting would occur (Avlani and Chancellor, 1977).

Goering and Dougherty (1982) performed an energy analysis on eleven vegetable oil fuels and found that soybean oil had the highest energy ratio of the unirrigated crops, at 4.56. The most efficient oil crop tested was sunflower, which had a ratio of 1.96. The authors found that irrigation, when used, accounted for 58 percent of the total energy cost. The use of the output/input ratio was justified in this case because the production of this fuel is for the purpose of creating an energy source and a ratio of less

than unity would be causing a net loss (Spedding and Walsingham, 1975). Labour was included in this case using a ratio of energy consumed to hours worked per week.

Stanhill (1980) conducted an energy analysis of six different tomato cropping systems. The systems included open field unprotected production in California as well as other varying degrees of protection in Israel and England. The tomatoes were for consumption in England, thus transportation energy was included as an input as well as labour and all other upstream energy inputs. Stanhill (1980) found that the open field unprotected tomatoes of California were the least energy intensive and his results show a range of 1.4 to 137 MJ/kg for all of the systems.

#### 2.4) Energy Analysis and Tillage Systems

A number of works have been published in the area of energy used in tillage systems. German et al. (1977) performed a hypothetical energy analysis on conventional tillage, reduced tillage and no-till for soybean production. The authors used assumed crop yields for each of the three treatments as well as uniform fertilizer and herbicide applications. Hypothetical labour inputs and all others were shown in their physical units such as time and mass, and no conversion rates were presented. As well, no differences between soil types or between climates were shown, however the assumed production systems were listed in detail. The authors estimated a 20 to 30% energy saving by switching to

reduced or no-till with no-till being the better of the two. However, the authors also showed that reduced tillage is more profitable for the farmer and therefore more likely to be implemented. The validity of using an energy efficiency ratio (output/input) to evaluate production methods is questioned but used none the less.

Vaughan et al. (1977) performed an energy analysis on three soybean and grain corn production systems involving conventional tillage, reduced tillage and no-till. They found a possible diesel fuel equivalent reduction of 13.1 to 38.4 L/ha for corn and 11.2 to 47.6 L/ha for soybeans. These results may be misleading because treatment effects on yield were not considered. Therefore, although the L/ha value may be lower, the energy expended per yield may have been higher. The authors also assumed equal fertilization rates across the treatments and the cost of seed was not included in their analysis. All the inputs to their systems were expressed in their diesel fuel equivalence with the exception of labour which was not considered an energy input.

Rask and Forster (1977) performed an energy analysis on three different tillage treatments in three soils for corn production. The authors included all upstream energy costs by evaluating the economic worth of input energies to each system. This method of analysis allowed them to examine the net effect of energy price changes on producers in the short and long term. The authors showed the varying effects of

soil type on profit margins with the three treatments. From this they stated that energy price changes have little impact on the economic choice of tillage system in these soils.

Knapp (1980), in Pimmental (1980), presented an energy analysis of seven corn silage production systems. Included were inputs and outputs for five North American regions using conventional tillage, no-till and one system using manpower exclusively.

Within the conventional systems, Knapp (1980) included all inputs and upstream costs such as machinery production, however labour was not counted as an energy cost. This was because he was examining resource depletion using the sequestered school of thought.

The most efficient system in terms the energy output/input ratio was found to be the unmechanized manpower system with a ratio of 26.8, however at the same time this was also the least efficient in terms of production. The most efficient mechanized system was unirrigated corn grown in the cornbelt with a ratio of 6.17. The least efficient was irrigated corn grown in the western U.S. at 3.64. However, this was also the the most productive of all the systems tested with a dry matter yield of 12,360 kg/ha silage. For the production of unirrigated corn grown in the north-eastern U.S. and south-eastern Canada, Knapp (1980) showed a yield of 9400 kg/ha with a total energy input of 21796 MJ/ha and he gave the output/input ratio of this

region as 5.58.

Knapp (1980) gave no indication of soil type for any system although estimated yields were given to show relative productivity. Naturally the machinery requirements vary from system to system, but in his examples Knapp (1980) depreciated their costs over different field sizes making comparisons between systems virtually impossible. Knapp (1980) used only inorganic fertilizers in his calculations so no relative effect of manure use was given. Indeed, throughout the entire handbook, Pimmental (1980) never discussed manure or its use in agricultural production systems.

Griffith et al. (1977b) examined the effects of eight different tillage treatments on corn yields in four different soils. The report examined crop yield, plant height and soil temperature as well as the various energy consumptions for each system. The authors show that conventional tillage had the highest yields in all the soils tested, except for Tracey sandy loam in which no-till proved to be the most productive.

In the area of energy consumption, Griffith et al. (1977b) used a combination of actual measurements, process analysis and statistical analysis to calculate the fuel consumption of each system. This energy analysis measured the resource depletion caused by each system, and therefore all upstream costs were included but labour was excluded. Griffith et al. (1977b) estimated the indirect energy cost

of machinery as one half of the actual fuel consumption. The energy costs of insecticides and herbicides were included but inorganic fertilizer, which was used throughout, was excluded as it was applied in constant rates across all treatments. From their calculations the authors determined that the fuel use in all soils ranged from 32.8 L/ha for conventional tillage to 9.3 L/ha for one of the no-till treatments and that the total energy for tillage, planting and weed control ranged from 81.1 L/ha for conventional tillage to 55.8 L/ha for one of the no-till treatments. While from these estimates the authors postulated that 25.7 million litres of diesel fuel could be saved annually in Indiana, they also qualified their prediction due to a probable lack of farmer acceptance of a no-till system.

White (1980) compared the production costs of six different methods of forage production and processing. Regardless of the method used, White (1980) concluded that fertilizers, in particular N, accounted for more than 50 percent of the total energy costs. Two silage and four hay production methods were compared and the results indicated that silage had the lowest energy expenditure at 4.26 MJ/kg DM while high temperature dried grass was the most expensive at 22.8 MJ/kg DM.

Christenson (1977) reported on four different cropping systems with regard to their energy inputs. Corn silage, using conventional tillage, was one of the systems. Inorganic fertilizer was used throughout and human labour



was not included as an energy cost. Energy costs for machinery manufacturing were not included, however the upstream costs of fertilizer manufacturing were, thereby giving the corn silage system, including harvest, a slightly lower equivalent value of 428.7 L/ha diesel fuel, with fertilizer manufacturing costs accounting for 77 percent of that value. Christenson (1977) used an estimated wet yield of 50.2 Mg/ha silage to show a unit energy cost of 0.32 MJ/Mg of wet matter.

Allen et al. (1977) examined a number of different tillage-crop systems including irrigated and dry land farming. The authors also included the upstream cost of fertilizer but disregarded labour and machinery manufacturing costs. They estimated the tillage and planting fuel costs at 38.4, 14.0 and 9.3 L/ha for the conventional tillage, till-plant and slot plant systems respectively. They found that in terms of overall energy consumption, tillage and planting energy accounted for 3 to 7 percent of the total under irrigated production and 70 to 75 percent under dry land. They did however state that it would be possible to save 28.0 to 37.4 L/ha diesel fuel by reducing tillage and that this remains worthwhile even though it reflects a small amount of the total energy consumed under irrigated production.

#### 2.5) Computer Simulation

Computer models are now being applied to many aspects

of agriculture. Computer models generally use average crop production rates to evaluate different management strategies for a given farm in terms of their net energy return:

Ozkan (1981) described a computer model to evaluate the effects of certain practices in terms of their energy efficiencies for corn, soybean, wheat and alfalfa production. He found that while unirrigated, unfertilized corn resulted in the highest energy efficiency, fertilized corn had an increase in yield of 2,600 kg per hectare. By altering the initial conditions of the farm, as well as the strategy followed, Ozkan also found that the net energy return of his simulated farm could be increased by thirty percent.

Ozkan and Frisby (1980, 1981) applied a sensitivity analysis to the above model to determine the effects of changing supply levels of various production resources on the net energy return and energy efficiency of a multicrop farm. From their analysis the authors found that when the amount of land irrigated was reduced to zero, the net energy return and total energy output decreased by 20 and 19 percent respectively and more importantly, the overall energy efficiency of the system decreased by only 4 percent and corn was the only viable crop selected by the model. In the area of diesel fuel supply, the authors found that energy output and input and net energy return were affected identically by reductions in diesel fuel. Reducing the liquefied propane supply had the effect of recommending the

replacement of corn with other crops not requiring drying. Energy efficiency remained constant while the net energy return and the total energy output decreased linearly.

The reduction of nitrogen fertilizer had the effect of increasing the energy efficiency. This is of course because of the high energy cost of producing nitrogen fertilizer. The net energy input and output and the net energy return all decreased by the rate at which the efficiency increased. Finally, the model examined the effect of diesel fuel price increases and found that a 100 percent increase in the diesel fuel price would result in a 9.1 percent decrease in the net energy return of the farm.

Peart and Doering (1977) used another simulation model to evaluate different cultural practices with respect to their energy consumption. This model used the growing degree day method to estimate corn growth and maturity date based on 17 years of weather data. The entire analysis was done using the economic values of all inputs and the profit margin was used as the main indicator. Their results showed that a 40 percent decrease in corn prices would have the same effect as doubling drying fuel costs in determining the optimum system. The authors also stated that the most influential input to the profit/loss margin is the weather.

#### 2.6) On-Farm Fuel Consumption

A number of papers discuss the reduction in on-farm fuel consumption by altering tillage practices and ignore

the impact of the indirect energy costs.

Doleski et al. (1981) showed that there is a 70 percent saving in fuel expenditure by switching to no-till. The authors compared conventional tillage, minimum tillage and no-till and stated that they required 41.4, 23.4 and 1.32 L/ha of diesel fuel, respectively up to and including planting. They translate this into an average saving of 1,368.40 \$US fuel cost/ha.

Russell and Colwell (1981) examined the economics of energy conservation on Canadian prairie grain farms. In their report, the authors consider a number of different production systems in three soil types. They found that while implementing minimum tillage would result in a reduction in fuel use of 26 to 37 percent, the farmer's net income would also be reduced by up to 23 percent. The authors stated further, that while the potential to undertake economic fuel savings exists, it is limited at current energy prices and greater opportunities exist in reducing non-field fuel use, (e.g. in trucks and personal vehicles).

Peterson et al. (1983) examined a chisel-planter tillage system utilizing a special no-till planter for wheat. They compared the no-till system to conventionally planted wheat as well as reduced tillage using a chisel plow. They found that the no-till system reduced soil erosion by 75 percent while maintaining yields within 5 percent of conventionally planted wheat. They compared the

fuel consumptions of the three systems by simulation and found that the chisel planter method (no-till) used 70 percent less fuel and took 49 percent less time than did conventionally planted wheat and 52 percent less fuel and 22 percent less time than did the chisel plow system. It is interesting to note that these authors stated that the fuel savings alone would allow for a 100 kg/ha drop in yield and that on a 400 ha farm the actual savings would be a sizable portion of the profits.

Robertson and Mokma (1978) compared nine different tillage systems for the planting of corn in Michigan. The authors showed that no-till was the least fuel consuming, requiring only 6.92 L/ha to plant the corn. The other systems fell into two categories, namely conventional and reduced tillage, in which the respective fuel consumptions were in the range of 42.1 and 23.4 L/ha. The authors made no mention of the effects of tillage on yield, however there was a discussion of the erosion control benefits of the various systems.

There are many more papers concerning energy use in corn silage production systems, however the majority of those deal with a specific practice or aspect in a specific location.

The work reviewed above gives insight into the benefits and disadvantages associated with reduced tillage systems. The outline for performing energy analyses was examined and the results from various crops and systems was

observed.

Little mention is made in the literature concerning the combined effect of using inorganic or organic fertilizer in conjunction with different tillage treatments on the resource depletion or even the farmers' fuel cost. Although a number of authors have examined the energy use in the production of corn silage, none have evaluated the use of the different types of fertilizers in different soils with respect to the resource depletion and crop yield. There is also a definite lack of information concerning different production systems and their energy use in the western Quebec and eastern Ontario climatic region.

### III

#### OBJECTIVES AND SCOPE

The objectives of this study were:

- 1) To determine the resource depletion of twelve different corn silage production systems with variations in tillage, fertilizer and soil by performing an energy analysis.
- 2) To determine the producers' fuel use for each of the twelve systems by performing an energy analysis.
- 3) To determine the economic cost to producers for each of the twelve systems.
- 4) To use the measured yields from the twelve different systems to evaluate each system's efficiency.
- 5) To compare the systems and determine the most efficient in terms of resource depletion, producers energy cost and economics.

The scope of this thesis is limited to the analysis of corn silage grown under South-Western Quebec climatic conditions using either a conventional (moldboard plow, disk-harrow), reduced (chisel plow) or no-till tillage system, in conjunction with organic or inorganic fertilizer in either a St. Benoit sandy loam or a Macdonald clay soil.

## MATERIALS AND METHODS

4.1) Field Experimental Procedure

## 4.1.1 History of the Plots

The experimental results in this report come from a study which began in 1981. At that time, two sites were selected at the Macdonald College Research Station of McGill University located in Ste. Anne de Bellevue, Quebec just west of Montreal. The sites consisted of a Macdonald clay and a St. Benoit sandy loam. These two soils were selected in order to determine the results of the experiment in two distinctly different soils.

Immediately prior to the establishment of the trial plots, the Macdonald clay site had been in alfalfa (Medicago sativa) during the years 1976 to 1981. Preceding that was continuous corn (Zea mays) cultivated under conventional tillage. The St. Benoit sandy loam site had previously been subjected to 20 years of continuous corn (Zea mays) using conventional tillage.

## 4.1.2 Experimental Design

In the fall of 1981 a 3x2 factorial experiment was established at each site. The three tillage treatments and two fertilizer types were set up in a randomized complete

block design with three replicates. This resulted in a total of 18 plots at each site. The treatments and their labels are shown in Table 1.

The plots were instituted in the fall of 1981 and received consistent treatments in the 1982 and 1983 growing seasons. The plots measured 10 m by 12 m and contained 12 corn rows 12 m in length. The middle four rows were essentially untouched during the growing season and only these were used for the harvest data. The outer four rows were used as a buffer between the plots and the inner four were used for data collection for experiments not included in this report. The plot separation was one corn row and the edge effects were reduced by the planting of four rows of corn at both ends of each replicate.

The data included in this report are from the 1983 growing season. Severe mechanical problems arose during seeding in 1982 and germination in the clay plots was extremely poor. Because of this it was felt that comparisons between years would be inappropriate.

#### 4.1.3 Tillage Treatments

The six plots in each replicate were subjected to one of three tillage systems labelled conventional, reduced and no-till and herbicide applications replaced inner-row cultivation in all systems.

The conventional plots were fall plowed using a moldboard plow at a depth of 20 cm. These plots were then

TABLE 1. Experimental Coding System for the Tillage, Soil and Fertilizer Treatments.

| Tillage Treatment | Soil Type   | Fertilizer Type | Code |
|-------------------|-------------|-----------------|------|
| Conventional      | sandy loam* | Inorganic       | CSI  |
| Conventional      | sandy loam  | Organic         | CSO  |
| Conventional      | clay**      | Inorganic       | CCI  |
| Conventional      | clay        | Organic         | CCO  |
| Reduced           | sandy loam  | Inorganic       | RSI  |
| Reduced           | sandy loam  | Organic         | RSO  |
| Reduced           | clay        | Inorganic       | RCI  |
| Reduced           | clay        | Organic         | RCO  |
| No-till           | sandy loam  | Inorganic       | ZSI  |
| No-till           | sandy loam  | Organic         | ZSO  |
| No-till           | clay        | Inorganic       | ZCI  |
| No-till           | clay        | Organic         | ZCO  |

\* St. Benoit Sandy Loam

\*\* Macdonald Clay

disk harrowed twice in the spring to create a conventional seed bed for spring planting.

The reduced tillage plots were treated with chisel plowing in the fall of 1982. The chisel plow was a five shank plow with narrow spear-pointed shovels spaced at 30 cm and operated at a depth of 20 cm. This was followed by one pass of the disk harrow in order to break up the clods created by the chisel and to incorporate the previous year's stubble. All tillage treatments were performed using a Massey-Ferguson MF-165 D tractor with a rated PTO power of 39 kW.

The no-till plots were seeded directly into the previous year's stubble with no seed bed preparation of any kind.

#### 4.1.4 Seeding

All plots were mechanically seeded with Warwick (Trojan) 844 brand silage seed on May 22, 1983. The seeding rate of 80,000 plants/ha was achieved by planting with a spacing of 16.5 cm in 76 cm rows. A four row International Harvester 800 conservation air planter was used because of its ability to plant through the stubble in the no-till plots and the hard ground surface in the clay soil. This was operated with a Massey-Ferguson MF-165 D tractor.

#### 4.1.5 Fertilizer

Quebec Ministry of Agriculture, Food and Fisheries

recommendations of 170, 75 and 80 kg/ha application rates of N,  $P_2O_5$  and  $K_2O$  respectively were followed. These rates were based on initial soil test results which revealed background levels of 322 kg  $P_2O_5$ /ha and 289 kg  $K_2O$ /ha in the Macdonald clay and 479 kg  $P_2O_5$ /ha and 386 kg  $K_2O$ /ha in the St. Benoit sandy loam.

In the inorganic plots which had been subjected to a conventional or reduced tillage system, the nitrogen was applied in the form of urea (46-0-0). This was then incorporated into the soil by one or two passes of the disk harrow depending on the system. The no-till inorganic plots were treated with ammonium nitrate which was broadcast and then left on the surface. Ammonium nitrate (34-0-0) replaced the urea in those plots because with no incorporation the urea would be susceptible to heavy losses through volatilization. Both the ammonium nitrate and the urea were spread by hand to ensure proper distribution throughout the test plots.

For all of the organic plots the rate of dairy cow manure was such that an equivalent rate of 170 kg N/ha was applied. This equivalency was based on a semi-micro Kjeldahl analysis performed two days before application. Although the manure was incorporated by disk harrowing in the conventional and reduced plots, it was left on the surface in the no-till plots. The manure was spread manually with pitch forks to prevent clumping and to ensure proper distribution.

The potassium source for the inorganic plots was muriate of potash. This was broadcasted by hand and then incorporated along with the urea in the conventional and reduced tillage plots. In the no-till plots it was simply broadcasted on the surface and left unincorporated. The organic plots received no potassium other than that which was in the manure.

Due to a phosphorous deficiency in the manure, triple superphosphate was applied to both the organic and inorganic plots, regardless of tillage treatment. This was accomplished by banding the triple superphosphate 5 cm below and 5 cm away from the seed at the time of planting.

#### 4.1.6 Herbicide

The conventional tillage plots received a preplant application of atrazine and alachlor at rates of 1.5 kg/ha and 2.5 kg/ha respectively. This was incorporated into the soil by the disk harrowing. The same herbicides were applied at the same rates pre-emergence in the reduced and no-till plots but were not incorporated. Post-emergence treatment consisted of two applications of Bentazon and Citowett at 0.84 kg/ha separated by eight days. All plots received the same treatment and were sprayed using a PTO driven sprayer mounted on a Massey-Ferguson MF-165 D.

Volunteer grain presented a problem in some plots and this was treated by spraying, wherever necessary, with Atrazine at 2 kg/ha mixed with Kornoil. Dandelions

(Taraxacum officinale) also presented problems in some areas and these were dealt with by spot spraying with Killex brand herbicide.

#### 4.1.7 Harvest

Harvest of the corn was performed on September 13, 1983 at the clay site and September 20 at the sand site. Harvest was performed with a John Deere one row forage harvester mounted on a Massey-Ferguson MF-165 D tractor. The four middle rows of each plot were collected and weighed giving the total wet weight of those four rows. From these, 500 gm samples were taken and dried in a grain oven for 48 hours at 50°C. This then gave the final moisture content of the four rows and from that the corresponding dry matter yields were calculated and converted to Mg/ha. Further description and analysis of these results can be found in Kelly (1985).

#### 4.2) Analytical Procedure of Energy Consumption

The energy analysis was performed utilizing the sequestered school of thought so that the resource depletion of each system could be determined. A reasonable management strategy, in terms of energy consumption, could then be selected from the results of the experiment. The methods used were primarily process analysis although statistical analysis was applied if no specific information could be found.

Following Fluck's (1981) previously discussed

methodology, the boundary of the process was considered to be the field gate. All energy inputs occurring within the field were accounted for directly while those outside were handled in the manners described below. Inputs, other than those occurring in the field were not included because of the many variations in transportation and storage methods.

The inputs to all of the systems fell under six categories; machinery, fuel, seed, fertilizer, herbicide and labour.

#### 4.2.1 Machinery

To understand the effects of the different systems on family sized farms, the machinery for the analysis was selected based on 25 ha of corn silage production. The selected machines for the three tillage systems are shown in Tables 2, 3 and 4. In an effort to maintain relative continuity between systems, equivalent sizes of machines were selected.

The obsolescence lives are from Kepner et al. (1978) and they reflect the useful life of the machine. The number of hours or hectares worked per year is required to depreciate the capital, energy and financial costs on a per hour basis. In the case of the tractor, the annual use is meant to include all farm operations of which it is a part.

The various parameters associated with each machine are listed in Table 5. These include the annual use, operating speed, efficiency, operating width, effective field

**TABLE 2. Machinery Requirements for the Conventional Tillage Systems, Inorganic and Organic.**

| SYSTEM | MACHINE           | OBSOLESCENCE <sup>a</sup><br>yrs. | ANNUAL USE<br>Units/yr. | WIDTH<br>Units. |
|--------|-------------------|-----------------------------------|-------------------------|-----------------|
| I,0*   | 97 kW Tractor     | 10                                | 600 h                   | ---             |
| I,0    | 47 kW Tractor     | 10                                | 400 h                   | ---             |
| I,0    | Planter           | 15                                | 25 ha                   | 4 row           |
| I,0    | Moldboard Plow    | 15                                | 25 ha                   | 5 bot.          |
| I,0    | Disk-harrow       | 15                                | 50 ha**                 | 6 m             |
| I,0    | Sprayer           | 8                                 | 75 ha***                | 8 m             |
| I      | Broadcaster       | 8                                 | 25 ha                   | 8 m             |
| O      | Manure Spreader   | 8                                 | 25 ha                   | 4 m             |
| I,0    | Forage Chopper    | 10                                | 25 ha                   | 2 row           |
| I,0    | Forage Wagons (3) | 15                                | 25 ha                   | ---             |

\* I = Inorganic Fertilizer  
O = Organic Fertilizer

\*\* Operation performed twice

\*\*\* Operation performed three times

<sup>a</sup> Kepner et al. (1978).

**TABLE 3. Machinery Requirements for the Reduced Tillage Systems, Inorganic and Organic.**

| SYSTEM | MACHINE           | OBSOLESCENCE <sup>a</sup><br>yrs. | ANNUAL USE<br>Units/yr. | WIDTH<br>Units |
|--------|-------------------|-----------------------------------|-------------------------|----------------|
| I,O*   | 97 kW Tractor     | 10                                | 600 h                   | ---            |
| I,O    | 47 kW Tractor     | 10                                | 400 h                   | ---            |
| I,O    | Planter           | 15                                | 25 ha                   | 4 row          |
| I,O    | Chisel Plow       | 15                                | 25 ha                   | 2.1 m          |
| I,O    | Disk-harrow       | 15                                | 25 ha                   | 6 m            |
| I,O    | Sprayer           | 8                                 | 75 ha**                 | 8 m            |
| I      | Broadcaster       | 8                                 | 25 ha                   | 8 m            |
| O      | Manure Spreader   | 8                                 | 25 ha                   | 4 m            |
| I,O    | Forage Chopper    | 10                                | 25 ha                   | 2 row          |
| I,O    | Forage Wagons (3) | 15                                | 25 ha                   | ---            |

\* I = Inorganic Fertilizer  
O = Organic Fertilizer

\*\* Operation performed three times

<sup>a</sup> Kepner et al. (1978).

**TABLE 4. Machinery Requirements for the No-till Tillage Systems, Inorganic and Organic.**

| SYSTEM | MACHINE           | OBSOLESCENCE <sup>a</sup><br>yrs. | ANNUAL USE<br>Units/yr. | WIDTH<br>Units |
|--------|-------------------|-----------------------------------|-------------------------|----------------|
| I,O*   | 97 kW Tractor     | 10                                | 600 h                   | ---            |
| I,O    | 47 kW Tractor     | 10                                | 400 h                   | ---            |
| I,O    | Planter           | 15                                | 25 ha                   | 4 row          |
| I,O    | Sprayer           | 8                                 | 75 ha**                 | 8 m            |
| I      | Broadcaster       | 8                                 | 25 ha                   | 8 m            |
| O      | Manure Spreader   | 8                                 | 25 ha                   | 4 m            |
| I,O    | Forage Chopper    | 10                                | 25 ha                   | 2 row          |
| I,O    | Forage Wagons (3) | 15                                | 25 ha                   | ---            |

\* I = Inorganic Fertilizer  
O = Organic Fertilizer

\*\* Operation performed three times

<sup>a</sup> Kepner et al. (1978).

**Table 5. Parameters of Typical Machinery Used for the Analysis.**

| MACHINE           | MASS<br>kg | AN USE<br>h | LIFE <sup>a</sup><br>yrs | COST<br>\$ | TRACTOR<br>POWER, kW |
|-------------------|------------|-------------|--------------------------|------------|----------------------|
| 97 kW Tractor     | 7156       | 600.00      | 10                       | 56800      | NA                   |
| 47 kW Tractor     | 4382       | 400.00      | 10                       | 23000      | NA                   |
| Planter           | 1700       | 24.88       | 15                       | 10750      | 97                   |
| Moldboard Plow    | 1137       | 24.63       | 15                       | 10200      | 97                   |
| Chisel Plow       | 1050       | 29.76       | 15                       | 6250       | 97                   |
| Disk-harrow*      | 1750       | 8.68        | 15                       | 10600      | 97                   |
| Disk-harrow**     | 1750       | 17.36       | 15                       | 10600      | 97                   |
| Sprayer           | 50         | 21.86       | 8                        | 3290       | 47                   |
| Broadcaster       | 1052       | 3.24        | 8                        | 2750       | 47                   |
| Manure Spreader   | 1725       | 14.58       | 8                        | 9200       | 97                   |
| Forage Chopper    | 1200       | 44.80       | 10                       | 20600      | 97                   |
| Forage Wagons (3) | 3945       | 44.80       | 15                       | 19980      | 47                   |

| MACHINE           | AN USE<br>ha | SPEED <sup>a</sup><br>km/h | EFF. <sup>a</sup><br>% | WIDTH<br>m | CAPACITY<br>ha/h |
|-------------------|--------------|----------------------------|------------------------|------------|------------------|
| 97 kW Tractor     | NA           | NA                         | NA                     | NA         | NA               |
| 47 kW Tractor     | NA           | NA                         | NA                     | NA         | NA               |
| Planter           | 25           | 5.00                       | 0.67                   | 3.00       | 1.01             |
| Moldboard Plow    | 25           | 7.25                       | 0.80                   | 1.75       | 1.02             |
| Chisel Plow       | 25           | 5.00                       | 0.80                   | 2.10       | 0.84             |
| Disk-harrow*      | 25           | 6.00                       | 0.80                   | 6.00       | 2.88             |
| Disk-harrow**     | 50           | 6.00                       | 0.80                   | 6.00       | 2.88             |
| Sprayer           | 75           | 6.40                       | 0.67                   | 8.00       | 3.43             |
| Broadcaster       | 25           | 6.40                       | 0.67                   | 18.00      | 7.72             |
| Manure Spreader   | 25           | 6.40                       | 0.67                   | 4.00       | 1.72             |
| Forage Chopper    | 25           | 6.00                       | 0.62                   | 1.50       | 0.56             |
| Forage Wagons (3) | 25           | 6.00                       | 0.62                   | 1.50       | 0.56             |

\* One Pass  
\*\* Two Passes

<sup>a</sup> Kepner et al. (1978).

capacity, life in hours, mass and cost. Two listings are shown for the disk-harrow. The first one represents its use in the reduced tillage system (one pass) and the second is for the conventional tillage system (two passes). The three forage wagons required for harvest in all systems are treated as a unit with respect to mass and cost.

The machinery energy of each machine is the total amount of energy expended to fabricate and maintain that machine. It includes the energy used in manufacturing, repairs and transportation as well as the energy embodied in the materials used. Detailed calculations of the total machinery energy are shown in the Results and Discussion and Appendix A.

#### 4.2.2 Fuel

Fuel consumption was determined by following ASABE (1983) D230.3 recommendations. Equivalent PTO power, including draft and rolling resistance was found for each field operation.

The rolling resistance was calculated using the ASABE (1983) equation;

$$RR = W (1.2/C_n + 0.04) \quad (1)$$

where RR = rolling resistance (kN)

W = Weight of machine (kN)

C<sub>n</sub> = Cone index value (dimensionless)

The  $C_n$  value was assumed to vary with different soils and treatments. The general values shown in Table 6 are from ASAE (1983) and are listed in Appendix B by system and operation. The Draw Bar Power to Axle Power ratio, shown in Table 6 was found from ASAE (1983) by assuming optimum slip for each soil. The Tractive and Transmission Coefficient is the ratio of the power developed at the PTO to the power available at the draw bar and is determined by multiplying the DBP/Axle Power ratio by the Axle Power/PTO ratio. A table of the Tractive and Transmission Coefficients, as listed by system and operation, is shown in Appendix B.

The rolling resistances of the tractors were calculated by the above equation and then incorporated into the calculations of the fuel consumption for each system. These are also shown in Appendix B.

The ratio of operational to maximum PTO power was then calculated and fuel consumption was determined from the equation;

$$L/kW h \text{ (diesel)} = 2.64X + 3.91 - 0.2738X + 173 \quad (2)$$

where  $X$  = the ratio of operational to maximum PTO power.

Oil consumption was calculated using the following equation taken from ASAE D230.3 (1983).

$$L/h = 0.00059P + 0.02169 \quad (3)$$

**Table 6. Soil and Machinery Coefficients.**

| SOIL           | Cn    | DBP/AP <sup>a</sup> | AP/PTO <sup>b</sup> | T and T <sup>c</sup> |
|----------------|-------|---------------------|---------------------|----------------------|
| Tilled SL*     | 15.00 | 0.52                | 0.95                | 0.49                 |
| Par. Tilled SL | 20.00 | 0.64                | 0.95                | 0.61                 |
| Untilled SL    | 25.00 | 0.72                | 0.95                | 0.68                 |
| Tilled C**     | 20.00 | 0.64                | 0.95                | 0.61                 |
| Par. Tilled C  | 25.00 | 0.72                | 0.95                | 0.68                 |
| Untilled C     | 30.00 | 0.78                | 0.95                | 0.74                 |

\* Sandy Loam Soil

\*\* Clay Soil

<sup>a</sup> Draw Bar Power / Axle Power (ASAE, 1983).

<sup>b</sup> Axle Power / PTO Power (ASAE, 1983).

<sup>c</sup> Total Tractive and Transmission Coefficient.

where  $P$  = the rated engine power.

Although oil consumption proves to be insignificant in relation to fuel consumption, it is included in any case.

The fuel and oil were assumed to have an energy worth of 47.8 MJ/L, of which 9.12 MJ/L is the production and processing energy (Cervinka, 1980).

The detailed calculations of fuel and oil consumption for each operation under the various conditions are shown in Appendix B along with a table detailing the fuel energy consumption of each system listed by operation.

#### 4.2.3 Seed

The energy cost of the seed is the total amount of energy sequestered in the production of corn as seed. The value used in this analysis is from Heichel (1980) who found, by statistical analysis, that the seed cost was 103.86 MJ/kg seed. This value was then applied to the initial seeding rate of 80 000 plants/ha or 28 kg/ha of seed.

#### 4.2.4 Fertilizer

Because of the wide variety of production methods of different types of fertilizer, the average values as defined by Lockertz (1980) were applied.

For urea, the value of 59.87 MJ/kg of nitrogen was used as the total energy cost, including transportation and

packaging. Ammonium nitrate, another nitrogen source, had an energy cost of 61.55 MJ/kg of N. Triple superphosphate, the phosphorous source, had a value of 12.56 MJ/kg of  $P_2O_5$  and 6.7 MJ/kg of  $K_2O$  was the value associated with the muriate of potash. The calculations for the fertilizer embodied energy are shown in Appendix C.

The energy cost of the manure is assumed to be only the embodied energy in the spreader and the fuel used to spread it which are accounted for in their respective sections. This is because the manure is a by-product of the overall production system, within the dairy farm gate, and would be produced regardless of the silage production system chosen.

#### 4.2.5 Herbicide

Pimmentel (1980) found that Atrazine, as an oil, had an embodied energy value of 369 MJ/kg including production, formulation and transportation. The industry average of 418 MJ/kg was applied to Alachlor in the form of an emulsifiable concentrate. Bentazon and Citowett were assumed to have the industry average of 362 MJ/kg for a solution. These calculations are also shown in Appendix C.

#### 4.2.6 Labour

Human labour, while a necessary component of the systems, is not included as an energy input. This is because the purpose of the analysis is to evaluate the resource depletion of each system and human labour neither

contributes nor detracts from that depletion. Although human labour can reduce the amount of energy required, the two are not truly interchangeable in modern industrialized agriculture.

However, when considering different management strategies, the required time per system is of as great an interest as the energy efficiency or the financial costs of each production system. This time relates to the cost and efficiency in terms of human input. The total time required for each system was calculated using the effective field capacity and this is shown in Appendix D.

#### 4.2.7 Cost Analysis

The basic method for the cost analysis was that which is outlined by the ASAE (1983). The interest, depreciation and minor fixed costs were calculated from the following equation assuming a 10% salvage value;

$$FC = (PC - 0.1PC)/Li + ((PC + 0.1PC)/2)I + 0.02PC \quad (4)$$

where FC = annual fixed cost (\$/yr)

PC = principle cost (\$)

Li = life (yrs)

I = interest rate (%)

Repair and maintainence costs were calculated using the method and values given by Kepner et al (1980).

The productivity of each system was examined by

calculating the cost per hectare and the yield per cost. The values were calculated with labour values of \$8.00 per hour, fuel costs of \$0.45 per liter and an interest rate of 14% per annum. The machinery prices used in the calculations, shown in Table 5, are the average typical price as given by five eastern Ontario dealers as shown in Appendix E. All costs are calculated using the 1984 prices and are expressed in 1984 dollars and the calculations are shown in Appendix E.

## RESULTS AND DISCUSSION

### 5.1) Yield

The field experiment was performed in order to evaluate the productivity of each system and to relate it to the energy consumed. The experiment consisted of three tillage treatments, two fertilizer treatments and two different soil types as applied to corn silage production. The results of the experiment were analysed using the SAS statistical package and reported by Kelly (1985). The mean yield results for the sandy loam and clay sites are shown in Table 7 segregated according to soil type. The combined results are expressed as a histogram in Figure 1.

The results of each soil type were analysed separately, using the Duncan's New Multiple Range test at the 0.05 level of significance. These analyses revealed an absence of interaction among the treatments and therefore allowed them to be examined individually. Blocks proved to be significantly different in the clay soil but had no effect in the sandy loam. The details of the analysis are shown in Appendix F.

The results obtained from the sandy loam site (St. Benoit sandy loam) show very definite trends. The no-till plots achieved a significantly lower yield at 9597 kg/ha of dry matter while the conventional and reduced plots produced

Table 7. Mean Plant Yield Results of the Sandy Loam and Clay Sites.

| SYSTEM | YIELD<br>kg/ha | SYSTEM | YIELD<br>kg/ha |
|--------|----------------|--------|----------------|
| CSI    | 10100          | CCI    | 11860          |
| CSO    | 11280          | CCO    | 12520          |
| RSI    | 10820          | RCI    | 11960          |
| RSO    | 11060          | RCO    | 11530          |
| ZSI    | 9620           | ZCI    | 11560          |
| ZSO    | 9570           | ZCO    | 10830          |

| TREATMENT<br>SANDY LOAM | MEAN*<br>kg/ha | TREATMENT<br>CLAY | MEAN*<br>kg/ha |
|-------------------------|----------------|-------------------|----------------|
| Conventional            | 10646 a        | Conventional      | 12192 a        |
| Reduced                 | 10938 a        | Reduced           | 11748 ab       |
| No-till                 | 9597 b         | No-till           | 11200 b        |
| Inorganic               | 10148 a        | Inorganic         | 11796 a        |
| Organic                 | 10640 a        | Organic           | 11631 a        |

\* Treatments followed by the same letter not significantly different at the 0.05 level of the Duncan's New Multiple Range Test.

## DRY MATTER YIELD

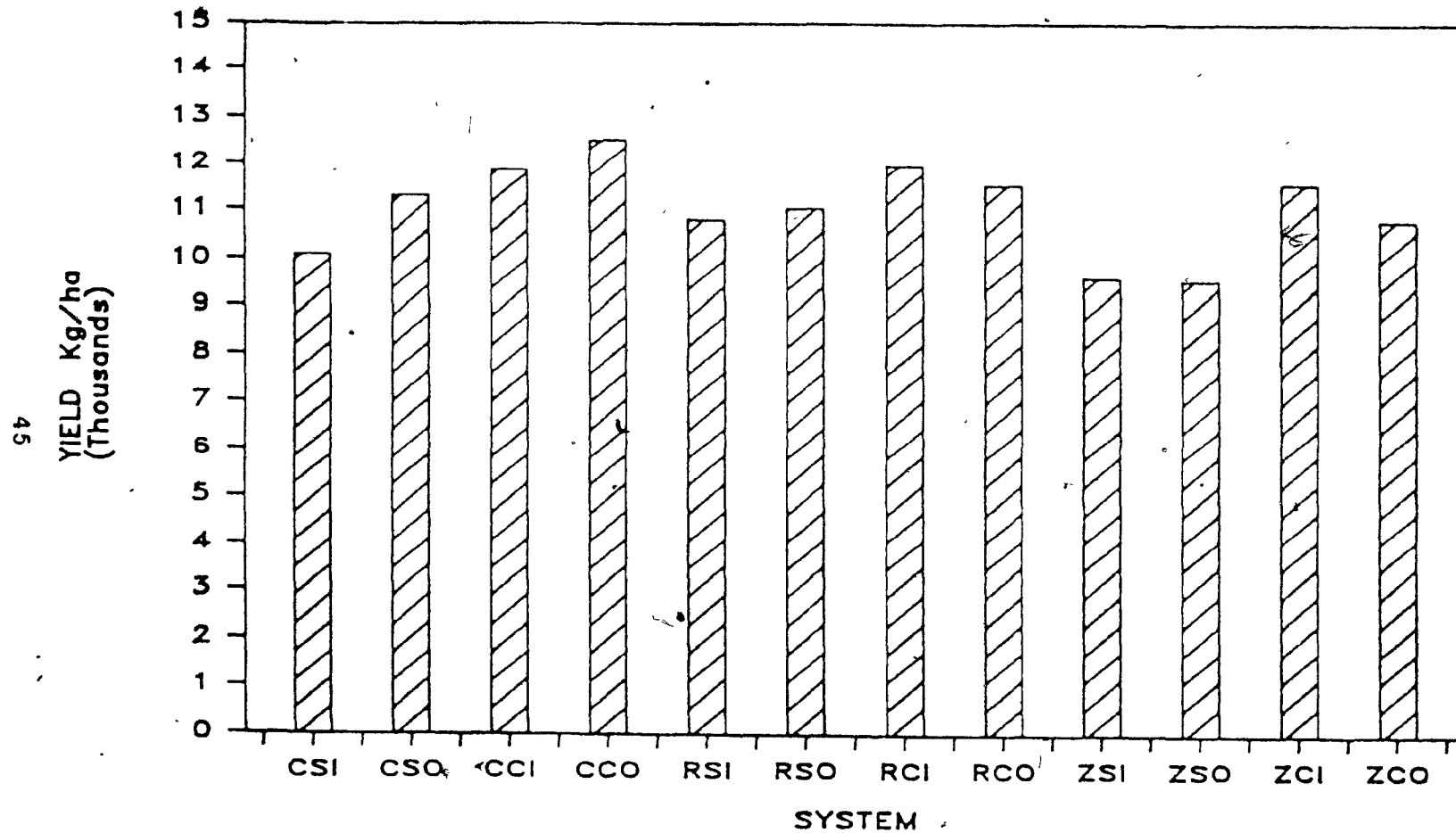


Figure 1. Histogram of the dry matter yields of all systems.

10846 and 10938 kg/ha respectively.

This indicates that the no-till systems would require approximately 10% more land to produce the same amount of silage as the conventional and reduced systems. Given an unlimited land base, this is of little consequence. However, if the farmer is working with a fixed area of land then the reduced yield, caused by the no-till system, may be the most important consequence associated with no-till use regardless of the potential benefits in the areas of cost, reduced labour or energy consumption.

The effect of fertilizer type on yield was not significant in the sandy loam site although, in general, the organic fertilizer did marginally better with an average yield of 10640 kg/ha as compared to 10148 kg/ha in the inorganic plots. Other aspects associated with fertilizer choice will be closely examined in later sections.

The results obtained from the clay (Macdonald Clay) field show that the no-till systems did significantly poorer than did the conventional tillage systems with final average yields of 11200 kg/ha as compared to 12192 kg/ha. However, in the clay field, the reduced tillage plots resulted in yields marginally lower than the conventional treated plots and only marginally better than the no-till plots.

The effect of the reduced yields caused by the no-till systems on land requirements for a fixed volume of silage is less pronounced in the clay soil but could still amount to an additional 9% land requirement if no-till was the chosen

production method.

The results of fertilizer treatments in the clay field were also insignificant with the inorganic plots performing slightly better than the organic plots at 11796 kg/ha compared to 11631 kg/ha, a reverse of the trend observed in the sandy loam soil.

Figure 1, which illustrates the combined results, shows that the results of similar treatments are higher in the clay soil than in the sandy loam for all treatments. This was to be expected in a year such as 1983. Rainfall during the 1983 growing season, as recorded by Barclay et al. (1983), was abnormally low compared to the 1952-1982 average, particularly during the tasseling and silking stages. The clay, with its increased water retention capabilities, would be better able to supply the plant during the drier periods thus reducing the effects of drought. Overall, the system which performed the best was the conventionally tilled and inorganically fertilized system in a clay soil with an average yield of 12520 kg/ha of dry matter. The worst system, overall, was the no-till, organically fertilized system in a sandy loam soil, with an average yield of 9570 kg/ha dry matter.

The yield produced by each system is of great importance but to be properly evaluated it must be determined at what cost, in energy or money, this yield is produced. An increased yield at a much greater expense is of little benefit to the farmer or society.

## 5.2) Machinery Energy

The machinery energy is the total energy used in the construction, lifetime maintenance and repair of the machines. The values are derived in order to place a value on the individual machines in terms of the energy expended due to their existence and to incorporate the machines into the total resource depletion values for each system.

The results of the machinery energy calculations are shown in Table 8. These values were calculated using the methods outlined by Doering (1980) and are based on the typical mass values for the selected machines as shown in Table 5. As outlined by Doering, each machine has a different value based on the production methods used and the actual types of material included in construction of the product. Therefore, these values are meant to represent typical values for the types of machines used in the systems.

Table 8 includes two listings for the embodied energy of the disk-harrow. The first listing represents the disk-harrow's use in the reduced system (one pass) whereas the second represents the conventional system (two passes). The values shown for the wagons represent the total values for all three wagons. This was done because the wagons, although independent units, work simultaneously and therefore, can be treated as one machine. Detailed calculations of the machinery energy are shown in Appendix A.

The embodied energy, shown in Table 8, represents the

**Table 8. Machinery Energy Results of All Machines Included in the Analysis**

| MACHINE           | TYPICAL<br>MASS<br>kg  | EMBODIED<br>ENERGY<br>MJ | FABRIC.<br>ENERGY<br>MJ  | COMBINED<br>ENERGY<br>MJ  |
|-------------------|------------------------|--------------------------|--------------------------|---------------------------|
| 97 kW Tractor     | 7156                   | 354938                   | 104692                   | 376897                    |
| 47 kW Tractor     | 4382                   | 217347                   | 64109                    | 230793                    |
| Planter           | 1700                   | 106760                   | 14671                    | 99573                     |
| Moldboard Plow    | 1137                   | 71404                    | 9812                     | 66597                     |
| Chisel Plow       | 1050                   | 65940                    | 9061                     | 61501                     |
| Disk-harrow (1)   | 1750                   | 109900                   | 14612                    | 102100                    |
| Disk-harrow (2)   | 1750                   | 109900                   | 14612                    | 102100                    |
| Sprayer           | 50                     | 3140                     | 369                      | 2877                      |
| Broadcaster       | 1052                   | 66066                    | 7764                     | 60540                     |
| Manure Spreader   | 1725                   | 108330                   | 12730                    | 99270                     |
| Forage Chopper    | 1200                   | 75360                    | 15708                    | 74676                     |
| Forage Wagons (3) | 3945                   | 247746                   | 24775                    | 223467                    |
| MACHINE           | REPAIR<br>ENERGY<br>MJ | TOTAL<br>ENERGY<br>MJ    | TOTAL*<br>ENERGY<br>MJ/h | TOTAL*<br>ENERGY<br>MJ/ha |
| 97 kW Tractor     | 134993                 | 511890                   | NA                       | NA                        |
| 47 kW Tractor     | 82664                  | 313457                   | NA                       | NA                        |
| Planter           | 30455                  | 130028                   | 159.55                   | 158.75                    |
| Moldboard Plow    | 24925                  | 91522                    | 87.80                    | 86.50                     |
| Chisel Plow       | 23018                  | 84519                    | 85.00                    | 101.19                    |
| Disk-harrow (1)   | 38213                  | 140313                   | 107.31                   | 37.26                     |
| Disk-harrow (2)   | 38213                  | 140313                   | 107.31                   | 74.52                     |
| Sprayer           | 880                    | 3757                     | 33.22                    | 29.06                     |
| Broadcaster       | 22171                  | 82711                    | 100.27                   | 12.99                     |
| Manure Spreader   | 18377                  | 117647                   | 149.23                   | 87.00                     |
| Forage Chopper    | 18332                  | 93008                    | 97.69                    | 175.08                    |
| Forage Wagons (3) | 68348                  | 291815                   | 179.36                   | 321.44                    |

\* Tractor energy included.

energy associated with the material used in the construction of the machine. The 97 kW tractor has the highest embodied energy value, at 354938 MJ, due to its greater mass. However, the tractors were converted using 49.6 MJ/kg as compared to 62.8 MJ/kg for the other machines as suggested by Doering (1980).

The fabrication energy is the energy required at the factory to shape and form the materials into the machine. The values were determined using the conversion values given by Doering (1980). Detailed calculations and conversion rates are shown in Appendix A. Naturally, the tractors have the highest values, at 104692 and 64109 MJ, because of their masses. It is interesting to note that they also have the highest conversion rates, as determined by Doering (1980), at 14.63 MJ/kg as compared to the forage chopper, the second highest at 13.09 MJ/kg. The other machines were converted at rates of less than 9.00 MJ/kg as shown in Appendix A.

The combined energy is the adjusted total of the embodied and fabrication energies and represents the total amount of energy used to construct the machine. The adjustment factor of 82% is used to reflect the useful life of the machine. This adjustment is discussed further by Doering (1980).

The repair energy value represents the energy used to maintain and repair the machine during its useful life. The total accumulated repair values (TAR), as determined by

ASAE (1983), are the total repairs for each machine for its entire life expressed as a percentage of the initial investment in the machine. In this case, the TAR value is applied to the energy cost of the machines. Each type of machine has a specific TAR value as shown in Appendix A. These values are reduced by the 82% adjustment factor and then applied to the sum of the fabrication and embodied energy values. This gives the amount of energy expended during the useful life of the machine including the embodied and fabrication energies of the replacement parts. Again, the tractors have the highest values as is to be expected. The wagons also have a very high repair energy value which can be attributed to the fact that there are three wagons in total.

The total energy value, shown in Table 8, is the summation of the combined energy and the repair energy. This value represents the total amount of energy expected to be expended because of the creation and use of the machine excluding any additional inputs such as fuel, etc. For example if a 97 kW tractor was not built, then approximately 511890 MJ of energy would not have been consumed and would be available for other uses.

However, to best see the efficiency of a given machine, it is necessary to express its energies as related to its outputs. This is done by depreciating its total energies over its expected life as outlined by Doering (1980). The values shown in Table 8, as the total energy in MJ/h, are

the depreciated energies of the individual machines summed with the depreciated energy of the associated tractor. Of the individual machines, the wagons have the highest energy per hour value followed closely by the planter which, again, can be attributed to the fact that all three wagons are lumped together.

Another observation of machine output is on the basis of unit area worked. This is accomplished by multiplying the hours worked by the effective field capacity, as shown in Appendix A. When comparing the machines on an energy per hectare basis, the wagons including the 47 kW tractor, have the highest values at 321 MJ/ha. The forage chopper, with the 97 kW tractor, also has a high value, at 175 MJ/ha, due to its low effective field capacity. The field capacity has the opposite effect on the broadcaster by moving it from the fifth highest in terms of energy per hour to the lowest, of all the machines, in energy per hectare.

Table 9 and Figure 2 show the total machinery energy requirements for each of the twelve corn silage systems. Each value includes the depreciated embodied, fabrication and repair energies for all machines used in that system. Similar systems across the different soil types have equal values because the machine requirements are the same. Detailed calculations and the inputs into each system are shown in Appendix A.

The highest total machinery energy value is found in the conventional-organic combination at 932 MJ/ha. This

Table 9. Total Machinery Energy of Each System.

| SYSTEM | ENERGY<br>MJ/ha |
|--------|-----------------|
| CSI    | 858             |
| CSO    | 932             |
| CCI    | 858             |
| CCO    | 932             |
| RSI    | 836             |
| RSO    | 910             |
| RCI    | 836             |
| RCO    | 910             |
| ZSI    | 697             |
| ZSO    | 771             |
| ZCI    | 697             |
| ZCO    | 771             |

## TOTAL MACHINERY ENERGY

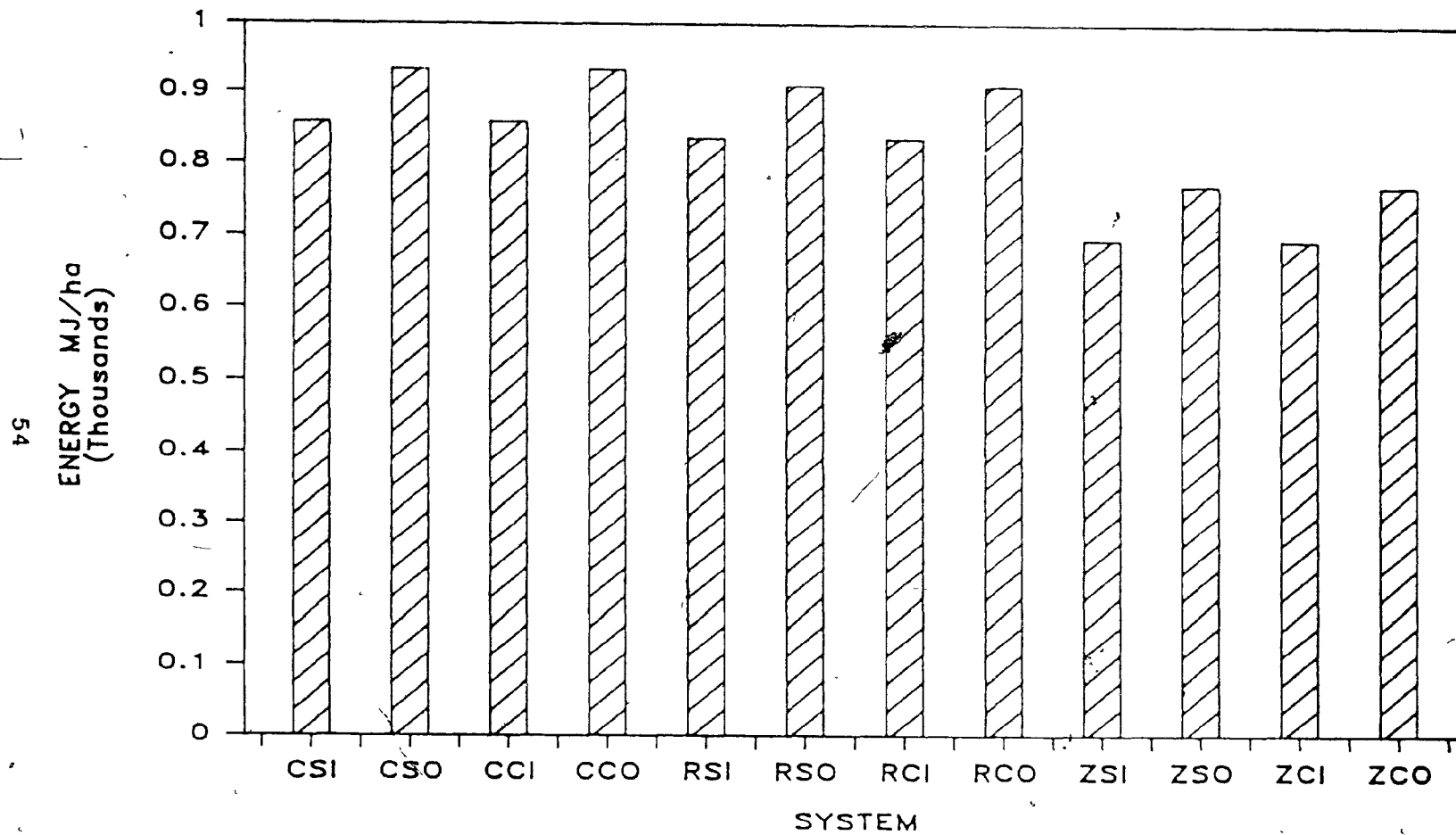


Figure 2. Histogram of the total machine energies of all systems.

value differs from the conventional-inorganic, at 858 MJ/ha, because of the higher energy value attached to the manure spreader as compared to that of the broadcaster (see Table 8). The lowest values are associated with the no-till systems at 697 and 771 MJ/ha for the inorganic and organic systems respectively. This was to be expected because of the lower machinery requirements of the no-till systems.

When comparing across the tillage treatments, the reduced and no-till systems have respective average machinery energy savings over the conventional system of 2 and 18%. Soil type, however, has no effect on machinery energy requirements.

These results demonstrate the lower initial machinery energy requirements of the no-till system as compared to the reduced and conventional systems. Although the organic systems require slightly more machinery, other factors must be considered besides the machinery energy for a complete energy analysis.

### 5.3) Fuel Consumption

The fuel consumption associated with the different production systems is of great importance, especially to the farmer. It is the major on farm energy expenditure for corn silage production in terms of both finances and the amount of energy used. The fuel consumption has particular importance to the farmer during times of fluctuating fuel costs and may be of prime importance when choosing tillage

#### methods.

The derived diesel fuel consumptions for the various systems are shown in Table 10 in the units of L/ha and MJ/ha. These values are the summations of the fuel consumptions for all of the field operations included in each production system. Also shown in Table 10 are the productivities of the systems based on the amount of fuel consumed and the yield of each system.

The highest consumption, at 184.64 L/ha, was determined to be in the conventional-sand-organic system. This was due, in most part, to the high machinery use associated with the conventional tillage system. The lowest consumption was found to be in the no-till-clay-inorganic system at 78.89 L/ha.

Table 10 also shows the percent savings over conventional tillage with all other parameters being equal. Overall, The best tillage method on a fuel use per hectare basis was the no-till method with an average fuel consumption of just over 88 L/ha. The no-till systems had an average fuel reduction of 48% over the conventional systems whereas the reduced tillage systems gave only an 11% reduction. The reduced tillage systems showed limited improvement over the conventional systems because the total number of passes was reduced by only one.

The no-till systems gave the greatest reductions not only because of the fewer passes over the field but also because of the expected improved traction on the undisturbed

Table 10. Total Diesel Fuel Use of Each System.

| SYSTEM | FUEL USE<br>L/ha | ENERGY<br>MJ/ha | YIELD<br>kg/ha | PRODUCTIVITY<br>kg/L |
|--------|------------------|-----------------|----------------|----------------------|
| CSI    | 166.15           | 7969            | 10100          | 60.8                 |
| CSO    | 184.64           | 8853            | 11280          | 61.1                 |
| CCI    | 157.17           | 7539            | 11860          | 75.5                 |
| CCO    | 172.24           | 8260            | 12520          | 72.7                 |
| RSI    | 150.43           | 7217            | 10820          | 71.9                 |
| RSO    | 165.50           | 7938            | 11060          | 66.8                 |
| RCI    | 138.87           | 6665            | 11960          | 86.1                 |
| RCO    | 152.65           | 7323            | 11530          | 75.5                 |
| ZSI    | 85.18            | 4099            | 9620           | 112.9                |
| ZSO    | 98.96            | 4757            | 9570           | 96.7                 |
| ZCI    | 78.89            | 3798            | 11560          | 146.5                |
| ZCO    | 91.85            | 4417            | 10830          | 117.9                |

| SYSTEM | PERCENT SAVING<br>OVER CONVENTIONAL |
|--------|-------------------------------------|
| CSI    | -                                   |
| RSI    | 9.5                                 |
| ZSI    | 48.7                                |
| CSO    | -                                   |
| RSO    | 10.3                                |
| ZSO    | 46.4                                |
| CCI    | -                                   |
| RCI    | 11.6                                |
| ZCI    | 49.8                                |
| CCO    | -                                   |
| RCO    | 11.3                                |
| ZCO    | 46.7                                |

soil. The detailed calculations, including a breakdown of each operation on the different soils, are shown in Appendix B along with a listing of the operations in each system.

While the no-till systems did have the best performance with respect to fuel consumption, they also returned the lowest yields as demonstrated previously. However, the reduction in yield was only in the area of 10% for both soils and as such, the potential benefits of applying no-till techniques vis-a-vis fuel consumption are considerable if the additional land base is available to the farmer. The almost 50% savings in fuel consumption is felt by the farmer directly and hence, is a strong motive for the implementation of a no-till system.

Across fertilizer types, the inorganic systems gave an average savings of 11% over the organic systems with the highest savings being in the no-till systems at 14%. The difference between fertilizer types can be explained by the fact that the manure spreader, with its thin swath, is required to make more trips over the field than is the fertilizer broadcaster. However the potential savings in fuel consumption by the use of inorganic fertilizer is not truly justified when all energy expenditures are included. This shall be discussed further in later sections.

When comparing across soil types, it was found that the clay systems had an average reduction in fuel consumption of 7% compared to the sandy-loam systems. Although the clay soil causes greater draft during plowing and hence greater

fuel consumption, this is more than compensated for during the rest of the field operations by the improved traction in the clay.

A histogram of the fuel use associated with each system is shown in Figure 3. The trend of reduced fuel use with reduced tillage, as shown in Figure 3, is quite obvious. The reduction in fuel consumption with the inorganic fertilizer is also easily seen in this figure.

The fuel productivities of the systems, shown in Table 10, express the amount of silage produced per unit input of fuel. This value allows comparison of the systems at the level of the farmer's energy expenses. The most productive system, overall, was found to be the no-till inorganic system in the clay soil. This system returned 146.5 kg of silage for every litre of fuel consumed. The least productive was the conventional inorganic system in a sandy loam soil which gave a productivity of 60.8 kg/L.

Within the soil types, the most productive system was the no-till inorganic system which gave 146.5 and 112.9 kg/L in the clay and sandy loam soils respectively. These results indicate the tremendous potential savings in on-farm fuel consumption associated with the no-till system while maintaining equivalent production levels.

In terms of the farmer, the reduction in fuel consumption caused by no-till is one of the most important factors associated with its use. The monetary gains associated with these savings will be examined in detail in

## FUEL CONSUMPTION

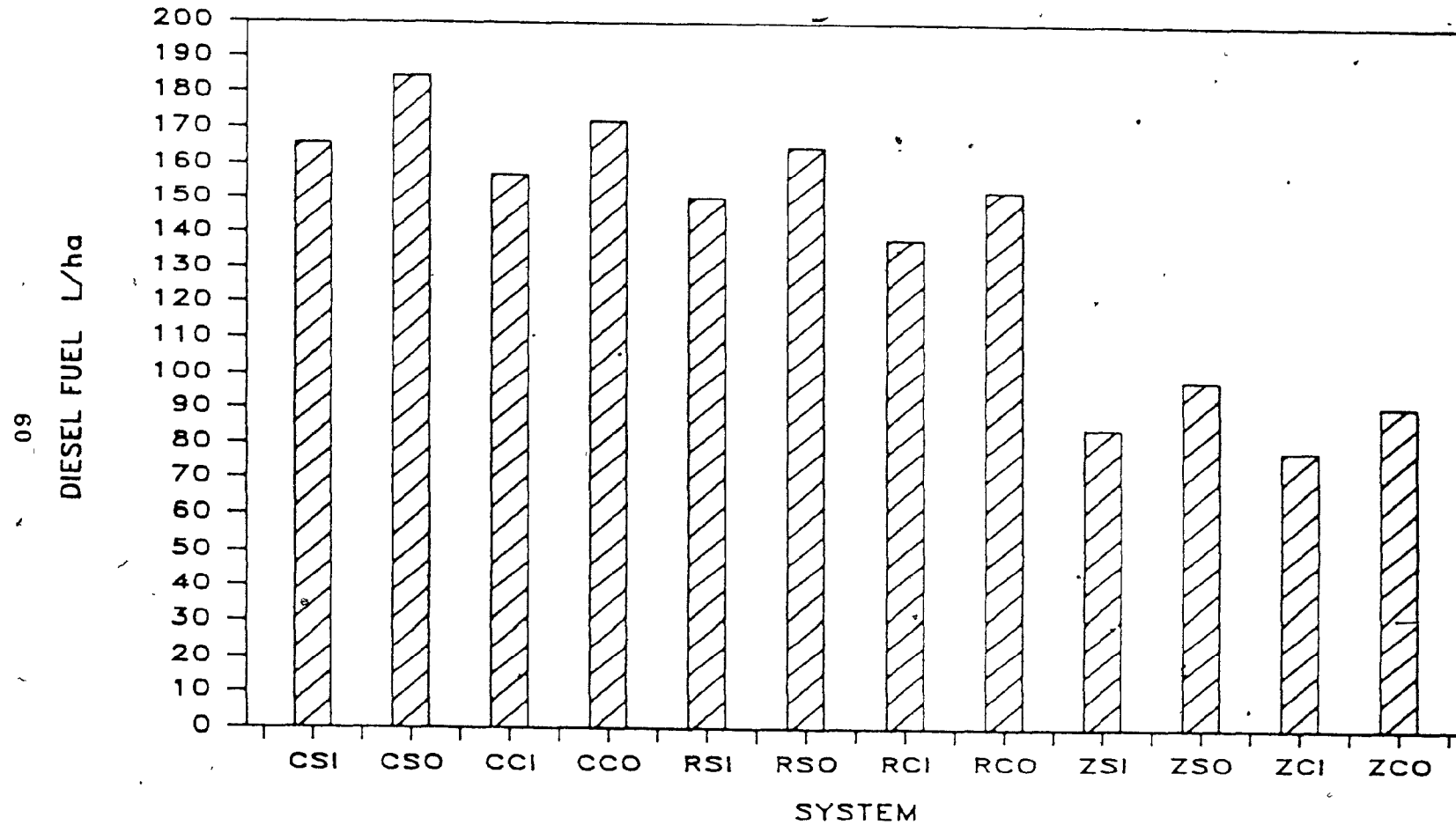


Figure 3. Histogram of the fuel consumptions of all systems.

the Cost Analysis section.

#### 5.4) Fertilizer Energy

The importance of fertilizer type on the total amount of energy used by each system is very dramatic. The results of the analysis on fertilizer energy are shown in Table 11. The nitrogen sources, urea and ammonium nitrate, had the highest inputs at 10177 and 10463 MJ/ha respectively. Comparatively, the triple super phosphate and potash had very low energy values at 942 and 536 MJ/ha respectively.

The highest total fertilizer energy use was found to be in the no-till-inorganic treatments at 11941 MJ/ha. The rest of the inorganic treatments gave values of 11655 MJ/ha, the difference being attributable to the difference in nitrogen sources. The organic systems, without the inorganic nitrogen and potassium sources, consumed only the 942 MJ/ha used by the triple super phosphate. This amounts to a savings of approximately 92% for all systems. The detailed calculations are shown in Appendix C.

The use of manure as organic fertilizer, can potentially save almost 11000 MJ/ha. of sequestered energy. The manure does require additional fuel and machinery energy because of the distribution method but this amounts to approximately 1000 MJ/ha for all systems, giving the organic systems a net energy saving of 10000 MJ/ha. This shows the great advantage to the use of manure as the nitrogen source.

However, also associated with organic fertilizer use is

Table 11. Fertilizer Energy of Each System.

| SYSTEM | UREA <sup>a</sup> | AMMONIUM <sup>a</sup><br>NITRATE | TRIPLE <sup>b</sup><br>SUPER<br>PHOSPHATE | POTASH <sup>c</sup> | TOTAL |
|--------|-------------------|----------------------------------|-------------------------------------------|---------------------|-------|
|        | MJ/ha             | MJ/ha                            | MJ/ha                                     | MJ/ha               | MJ/ha |
| CSI    | 10178             | 0                                | 942                                       | 536                 | 11656 |
| CSO    | 0                 | 0                                | 942                                       | 0                   | 942   |
| CCI    | 10178             | 0                                | 942                                       | 536                 | 11656 |
| CCO    | 0                 | 0                                | 942                                       | 0                   | 942   |
| RSI    | 10178             | 0                                | 942                                       | 536                 | 11656 |
| RSO    | 0                 | 0                                | 942                                       | 0                   | 942   |
| RCI    | 10178             | 0                                | 942                                       | 536                 | 11656 |
| RCO    | 0                 | 0                                | 942                                       | 0                   | 942   |
| ZSI    | 0                 | 10464                            | 942                                       | 536                 | 11942 |
| ZSO    | 0                 | 0                                | 942                                       | 0                   | 942   |
| ZCI    | 0                 | 10464                            | 942                                       | 536                 | 11942 |
| ZCO    | 0                 | 0                                | 942                                       | 0                   | 942   |

<sup>a</sup> applied at the rate of 170 kg N/ha

<sup>b</sup> applied at the rate of 75 kg P<sub>2</sub>O<sub>5</sub>/ha

<sup>c</sup> applied at the rate of 80 kg K<sub>2</sub>O/ha

a 6% increase in the labour requirements. Although this may be a very small increase, the nature of manure makes it unpleasant to work with as compared to inorganic fertilizer and this may prove to be one of the deciding factors in the selection of fertilizer type. At the same time, manure disposal is an ever-present concern on most dairy farms and the use of manure as fertilizer would alleviate much of that problem. Even with the use of such new technology as a digester, the manure must still be disposed of and its use as fertilizer is the obvious solution.

The results of this study indicate that inorganic fertilizer use, other than as a supplement to manure, is a very costly procedure in terms of energy consumption. The financial aspect of fertilizer use will be examined in later sections.

#### 5.5) Herbicide and Seed Energy

The herbicide treatments for all systems were the same and as such the energy sequestered in the herbicide was the same for all systems. The Atrazine applications required a total of 553 MJ/ha, the Alachlor was found to use 1045 MJ/ha and the Bentazon and Citowett, together, consumed 609 MJ/ha for a grand total of 2208 MJ/ha. This value represents the the energy used in the production, packaging and distribution of the herbicides. Detailed calculations are shown in Appendix C.

In terms of the overall energy use by each system, the

herbicide costs amount to only 10 - 20% of the total and is certainly beneficial for the maintenance of yield levels. Any reduction in herbicide energy could lead to reduced yields therefore herbicide energy is not an area of great potential with respect to energy conservation. This is particularly true concerning the no-till treatments where weed management is of great concern.

The seed energy is the amount of energy required to produce the seed used by the system. The amount of energy associated with the seed is 2908 MJ/ha for a seeding rate of 80000 plants/ha and was the same for all systems. Any potential savings gained from the reduction of seed planted would produce lower yield levels and would not necessarily reduce the energy productivity of the system. Therefore, seed energy is a basic input and no true savings are possible in this area but the seed and herbicide energy still contribute to the resource depletion caused by each silage production method.

#### 5.6) Resource Depletion

The resource depletion caused by each system is the total amount of energy required to produce the corn. It can be assumed that if the corn were not grown, then this energy would be available for other sectors of the economy albeit in the form in which it originated. Table 12 and Figure 4 show the total amount of energy expended by each system, in MJ/ha of corn grown, as well as the values of the various

Table 12. Resource Depletion Caused by Each System.

| SYSTEM | MACHINERY<br>ENERGY<br>MJ/ha | FUEL<br>ENERGY<br>MJ/ha | FERTILIZER<br>ENERGY<br>MJ/ha |
|--------|------------------------------|-------------------------|-------------------------------|
| CSI    | 858                          | 7969                    | 11656                         |
| CSO    | 932                          | 8853                    | 942                           |
| CCI    | 858                          | 7539                    | 11656                         |
| CCO    | 932                          | 8260                    | 942                           |
| RSI    | 836                          | 7217                    | 11656                         |
| RSO    | 910                          | 7938                    | 942                           |
| RCI    | 836                          | 6665                    | 11656                         |
| RCO    | 810                          | 7323                    | 942                           |
| ZSI    | 697                          | 4099                    | 11942                         |
| ZSO    | 771                          | 4757                    | 942                           |
| ZCI    | 697                          | 3798                    | 11942                         |
| ZCO    | 771                          | 4417                    | 942                           |

| SYSTEM | HERBICIDE<br>ENERGY<br>MJ/ha | SEED<br>ENERGY<br>MJ/ha | TOTAL<br>ENERGY<br>MJ/ha |
|--------|------------------------------|-------------------------|--------------------------|
| QSI    | 2208                         | 2908                    | 25599                    |
| CSO    | 2208                         | 2908                    | 15843                    |
| CCI    | 2208                         | 2908                    | 25170                    |
| CCO    | 2208                         | 2908                    | 15251                    |
| RSI    | 2208                         | 2908                    | 24825                    |
| RSO    | 2208                         | 2908                    | 14906                    |
| RCI    | 2208                         | 2908                    | 24273                    |
| RCO    | 2208                         | 2908                    | 14292                    |
| ZSI    | 2208                         | 2908                    | 21854                    |
| ZSO    | 2208                         | 2908                    | 11587                    |
| ZCI    | 2208                         | 2908                    | 21553                    |
| ZCO    | 2208                         | 2908                    | 11247                    |

# TOTAL RESOURCE DEPLETION

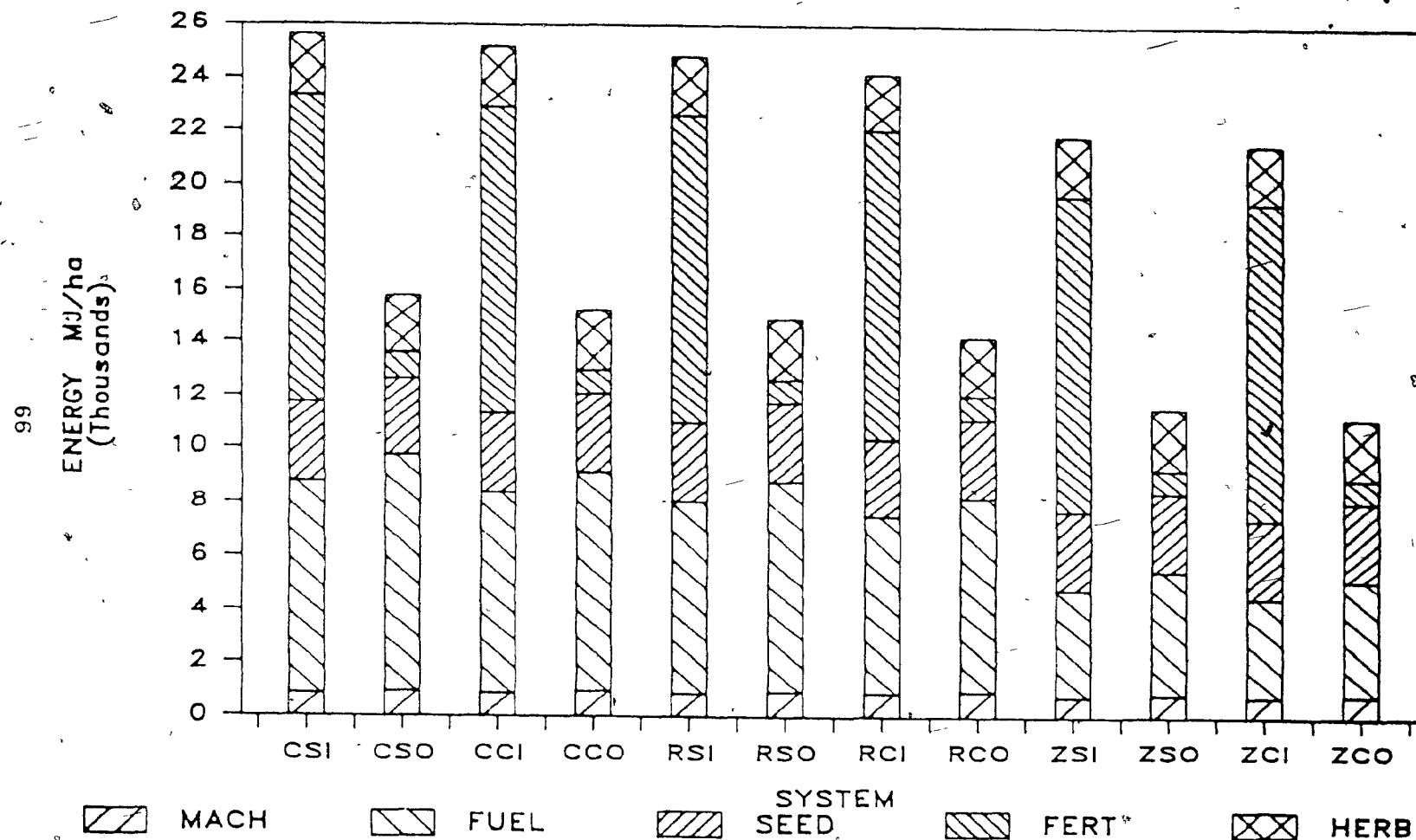


Figure 4. Stacked bar histogram of the total resource depletions of all systems.

inputs to the systems.

The maximum energy consumed was 25599 MJ/ha for the conventional-sand-inorganic system. The minimum was expended by the no-till-clay-organic system at 11247 MJ/ha. The difference is attributable, in the most part, to the energy embodied in the inorganic fertilizer as was previously examined.

The potential savings by changing tillage systems is due, in the most part, to the associated reduction in the fuel consumption. The average potential saving, over the conventional system, in total energy expended was 3% by switching to reduced tillage and 19% by the use of no-till. The potential savings of no-till over reduced tillage amounted to 3014 MJ/ha or 15% of the reduced tillage energy. These values indicate the substantial savings in energy by the use of no-till.

The most dramatic savings observed was due to the effect of fertilizer. With all other factors held constant, the average potential savings by switching to organic fertilizer from inorganic fertilizer was 40% in those systems using urea as the nitrogen source. This amounts to a savings of approximately 10000 MJ/ha across all similar systems. The potential savings when ammonium nitrate is the nitrogen source, averaged 47% which again amounts to approximately 10000 MJ/ha. The difference in total energy expended, which is due solely to the difference in fertilizer energy, demonstrates the great energy consumption

of the nitrogen fertilizers.

The influence of soil type was very limited in all cases and only gave variations of less than 2% or about 471 MJ/ha. This indicates that soil type has little effect on the energy used for the production of corn silage. The effect of soil type is felt by the reduction in yield and therefore has a direct effect on the energy productivity but is of limited consequence when evaluating the resource depletion.

The most dramatic savings, while maintaining the same soil type, is achieved by the use of the no-till-organic system as compared to the conventional-inorganic. In the sandy loam soil, the possible savings by using no-till and organic fertilizer was 14012 MJ/ha or 55% of the original energy expenditure. In the clay soil, the maximum possible savings was 13923 MJ/ha or, again, 55%. This would indicate that the potential savings of energy, at a national or provincial level, by the use of the no-till and organic fertilizer combination, is very great. This energy would not all be in the same form and can not therefore be expressed as a direct savings in petroleum. Nor would these savings all appear at the same level in the economy. However, these values represent the potential reduction in the energy used by the agriculture industry as whole for the production of corn silage.

Figure 4 shows the resource depletion of each system as expressed on a per hectare basis. The distinctive trend

associated with the fertilizer use is very noticeable along with the reduction of energy associated with the reduction of tillage.

While the resource depletion caused by each system is of interest, the maximum corn silage production based on energy input is an even more important parameter if energy consumption is to be reduced with constant or increased production levels. This is examined in the next section, by the comparison of the energy productivities of each system.

#### 5.7) Energy Productivity

The energy productivity is the relationship between the output of each system and a unit of input energy. It is used to compare the systems in terms of their relative productivities and to determine the most efficient system vis-a-vis energy use. The calculated energy productivities of the systems are shown in Table 13 and Figure 5. Also shown in Table 13 are the output to input ratios for all of the systems. The output is determined by converting the yield of silage to energy using 12.9 MJ/kg (Knapp, 1980).

The highest energy productivity of all of the systems examined was found to be that of the no-till organically fertilized system in a clay soil at 0.96 kg/MJ. The lowest return for energy input, at 0.39 kg/MJ, was found to be the productivity of the conventionally tilled inorganically fertilized system in the sandy loam soil.

In general, energy productivity was found to increase

Table 13. Energy Productivity of Each System.

| SYSTEM | YIELD<br>kg/ha | ENERGY<br>MJ/ha | PRODUCTIVITY<br>kg/MJ | OUTPUT/INPUT |
|--------|----------------|-----------------|-----------------------|--------------|
| CSI    | 10100          | 25599           | 0.39                  | 5.11         |
| CSQ    | 11280          | 15843           | 0.71                  | 9.22         |
| CCI    | 11860          | 25170           | 0.47                  | 6.10         |
| CCO    | 12520          | 15251           | 0.82                  | 10.63        |
| RSI    | 10820          | 24825           | 0.44                  | 5.64         |
| RSO    | 11060          | 14906           | 0.74                  | 9.61         |
| RCI    | 11960          | 24273           | 0.49                  | 6.38         |
| RCO    | 11530          | 14292           | 0.81                  | 10.45        |
| ZSI    | 9620           | 21854           | 0.44                  | 5.70         |
| ZSO    | 9570           | 11587           | 0.83                  | 10.69        |
| ZCI    | 11560          | 21553           | 0.54                  | 6.94         |
| ZCO    | 10830          | 11247           | 0.96                  | 12.46        |

## ENERGY PRODUCTIVITY

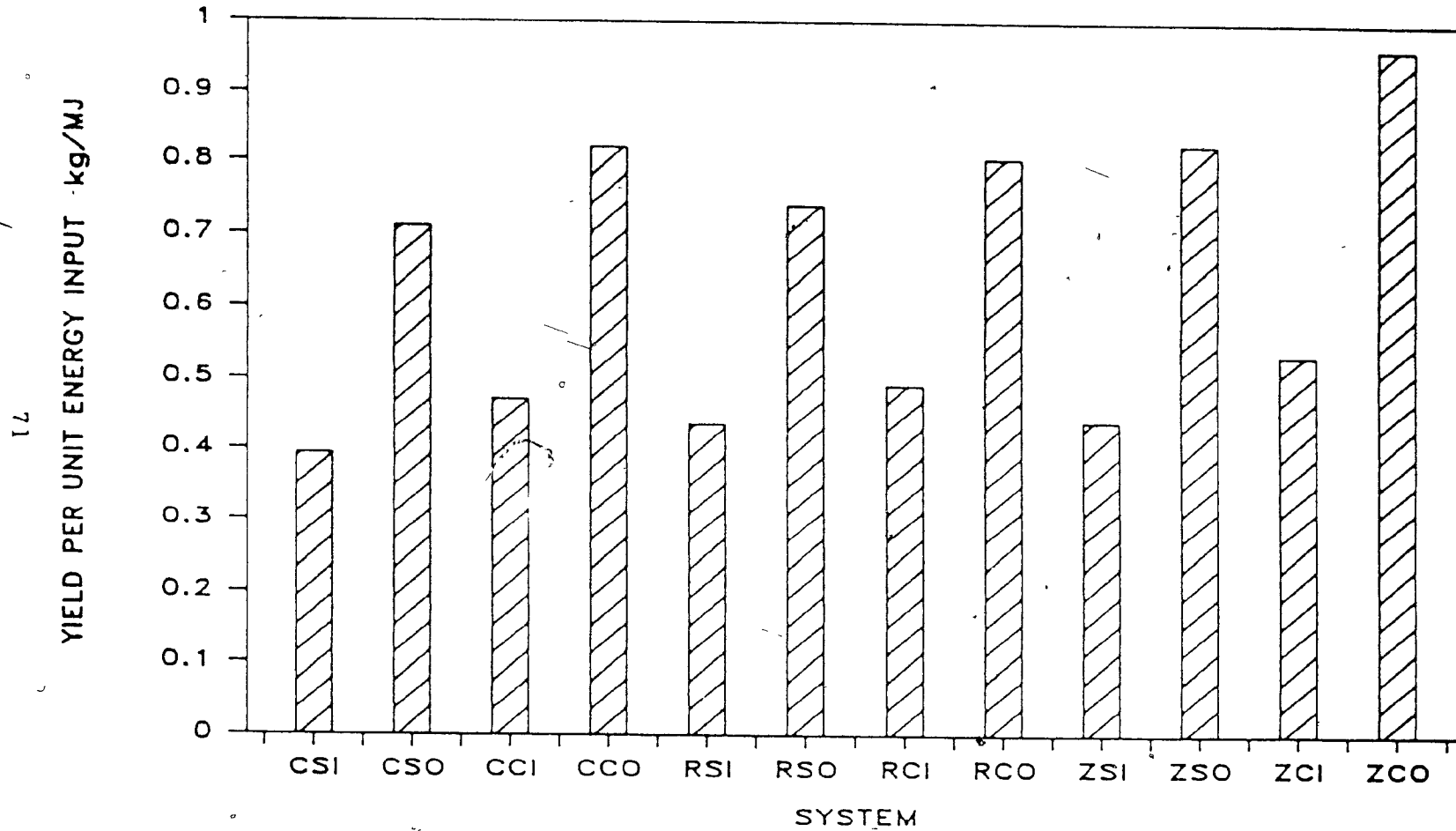


Figure 5. Histogram of the energy productivity of all systems.

with decreasing tillage. The poorest productivities were calculated to be those associated with the conventional tillage systems which had an average productivity of 0.60 kg/MJ. The reduced and no-till systems did better with average values of 0.62 and 0.69 kg/MJ respectively.

All other parameters being equal, switching from conventional to reduced tillage gave an average improvement in the productivity of 5%. The greatest increase, at 13%, was found to be in the inorganically fertilized sandy loam system. The least effect was found to be in the organically fertilized clay combination where productivity actually decreased by 1% when the reduced system was applied. This reduction can be explained by the fact that the conventionally tilled organically fertilized clay system had the highest yield of all treatments and the reduction in energy use associated with the reduced tillage system was insufficient, in comparison to the reduction in yield, in order to increase the productivity.

When comparing conventional to no-till, the no-till gave productivities that were an average of 16% higher. The biggest improvement in productivity was found to be in the organic systems where the use of no-till increased the productivity by 17%. The smallest improvement was in the inorganically fertilized sandy loam system in both soils where the increase in productivity was 13%, still a respectable improvement. The productivities of the no-till systems as compared to those of the conventional are much

better even after accounting for the reduction in yields caused by the use of no-till. In the most part, these improvements in the productivity are due to the reduced fuel consumptions associated with the no-till systems. The machinery energy is also lower in the no-till system which again contributes to its superior productivities.

The no-till system was, on the average 10% more productive than the reduced tillage system. The maximum improvement was determined to be in the organically fertilized clay soil system where the use of no-till produced a 18% improvement in the productivity. This dramatic improvement can be attributed to the reduction in fuel and machinery energy with no significant differences in the yields. The lowest improvement in productivity by the use of no-till over reduced tillage was in the inorganically fertilized sandy loam system where the productivity showed no change. This lack of improvement in the productivity is explained by the reduced yields associated with the use of no-till in the sandy loam soil.

These results show that the use of a no-till system can improve the energy productivity of corn silage regardless of the type of fertilizer or soil. This would indicate that on a greater scale, provincially or nationally, the trend towards no-till should be encouraged if energy conservation in corn silage production is to be realized.

Fertilizer type caused the most dramatic change in the energy productivity. The average energy productivity for

systems using inorganic fertilizer was found to be 0.46 kg/MJ while the organic systems gave an average productivity of 0.81 kg/MJ. This tremendous discrepancy can be explained by the vast amount of energy sequestered in the nitrogen fertilizers as described in previous sections.

Across systems of similar treatments, the average increase in the energy productivity caused by using organic fertilizer was 76%. The greatest improvement was found to be in the no-till system in the sandy loam soil where the productivity was found to be 0.44 kg/MJ for inorganic fertilizer and 0.83 kg/MJ for the organic system. This amounts to an improvement of 88% in the productivity. The least improvement was found in the reduced tillage system in the clay soil where the productivity was still increased by a substantial 65%.

The energy productivities illustrate the tremendous energy cost of using inorganic nitrogen sources. The yields of the two fertilizer types were shown to have no significant differences and as such the effect of the inorganic fertilizer only serves to reduce the productivity of comparable systems. These results would indicate that the use of inorganic nitrogen should be severely scrutinized if energy consumption is to be lowered during the production of corn silage.

The effect of soil type on the energy productivity was such that the production of corn silage was more efficient in the clay soil. The average productivity was found to be

0.68 kg/MJ, in the clay soil whereas the sandy loam soil returned an average of 0.59 kg/MJ. The differences in the results are attributable to the superior yields in the clay soil, as shown in Tables 7 and 13.

The average improvement in the productivities of similar systems across soil type was found to be 16%. The greatest increase was in the inorganically fertilized conventionally tilled and no-till systems where the clay soil performed more than 20% better than did the sandy loam. The least improvement was in the reduced organic combination where soil type only created a 10% difference in the energy productivity. The differences between the soil types can be explained by the lower yields associated with the sandy loam soil.

The differences in the productivities, caused by soil type, are of limited value because the farmer rarely has the option of selecting soil type to any great extent. Within soil types, the most energy efficient production method was found to be the no-till organically fertilized combination which gave productivities of 0.83 kg/MJ in the sandy loam and 0.96 kg/MJ in the clay soil.

Overall, these results indicate that the use of no-till in conjunction with organic fertilizer has tremendous potential for the conservation of energy while producing equal amounts of silage. The energy productivity of a no till organic fertilizer system is an average of 108% better than a conventionally tilled inorganic system regardless of

soil type. The adoption of the no-till system would require a 10% increase in the land worked as well as additional labour but at a national level the implications with respect to energy conservation are tremendous.

Naturally the implementation of no-till or organic fertilizer is a decision made by the farmer. This decision is not made on the basis of energy use but on economics. Therefore, the finances of the various systems will be examined in the following sections in order to find the system most likely to be implemented. Examined first are the labour requirements of the individual systems and the impact of the tillage systems and/or fertilizer choice.

#### 5.8) Labour

The labour associated with a particular system is of great importance to the farmer as it is one of his major inputs and is, therefore, a factor when deciding on the production methods to be used. The calculated labour values for all of the systems are shown in Table 14 and Figure 6. Detailed calculations are shown in Appendix D.

The results of the calculations indicate that the maximum amount of labour is associated with the conventional tillage and organic fertilizer combination with 7.72 h/ha required to complete all the tasks in both soils. The least labour intensive production method was found to be the no till inorganically fertilized system at 5.58 h/ha.

The amount of labour required was found to increase

**Table 14. Labour Requirements of Each System Based on One and 25 ha of Corn.**

| SYSTEM | LABOUR<br>h/ha | LABOUR FOR 25 ha.<br>h |
|--------|----------------|------------------------|
| CSI    | 7.26           | 181.58                 |
| CSO    | 7.72           | 192.91                 |
| CCI    | 7.26           | 181.58                 |
| CCO    | 7.72           | 192.91                 |
| RSI    | 7.12           | 178.03                 |
| RSO    | 7.57           | 189.36                 |
| RCI    | 7.12           | 178.03                 |
| RCO    | 7.57           | 189.36                 |
| ZSI    | 5.58           | 139.58                 |
| ZSO    | 6.04           | 150.92                 |
| ZCI    | 5.58           | 139.58                 |
| ZCO    | 6.04           | 150.92                 |

## LABOUR REQUIREMENTS

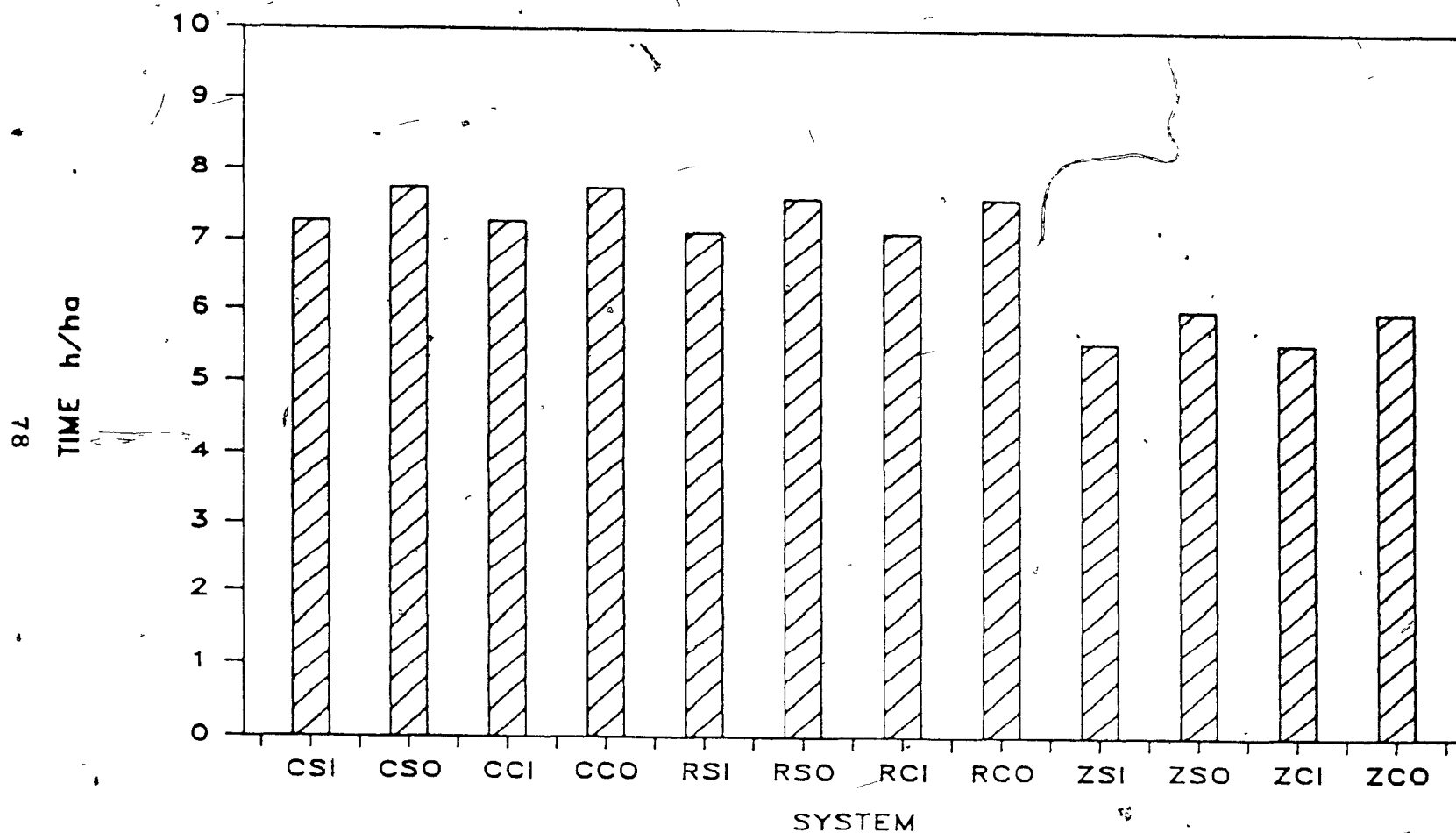


Figure 6. Histogram of the labour requirements of all systems.

with increasing tillage. The conventional systems were calculated to require an average of 7.49 h/ha as compared to the reduced and no-till systems which required averages of 7.34 and 5.81 h/ha respectively.

Comparing across similar systems, the reduced tillage systems were found to save only 2% of the labour required for the conventional systems. This can be explained by the reduction of only one pass in the reduced systems compared to the conventional. The potential labour savings by implementing no-till as compared to conventional tillage were found to be approximately 22%. This is due to the substantially reduced field work associated with the no-till system. The benefits of applying no-till are almost as great when it is compared to reduced tillage. The no-till labour requirements were found to be 20% less than those of reduced tillage.

Although the benefits of no-till in the area of labour are great, the reduced yields of the no-till systems would necessitate the working of approximately 10% more land thereby decreasing the savings in labour. However, even after applying the additional land requirements, the no-till systems still have an approximate 10% saving in labour over the conventional and reduced systems.

The use of organic fertilizer was found to increase the labour requirements. The average labour requirement for the inorganic systems was 6.65 h/ha while the organic systems were found to require an average of 7.11 h/ha. The increase

in labour for organic fertilization over similar inorganically fertilized systems was found to amount to approximately 6%. This difference is due to the greater time required in the field with the manure spreader as compared to the broadcaster

These values only include the actual field time because the manure would require disposal regardless of fertilizer type.

Soil was determined to have no effect on labour requirements in that the working times of the various implements would be the same regardless of soil type

The least labour intensive corn silage production method was found to be the no till inorganic combination at 5.58 h/ha. However, labour is only part of the total inputs from the perspective of the farmer. The labour requirements discussed above, are included as part of the total costs associated with each production method which are dealt with in the next section.

#### 5.9) Cost Analysis

The total financial cost incurred during the production of the corn silage is of great interest to the farmer and is often used as a principle consideration for the determination of the production method to be used. The yield per dollar input is an additional parameter for the farmer and is examined in the next section. The total costs for each system were calculated, as shown in Appendix E, and the

each system were calculated, as shown in Appendix E, and the results are listed in Table 15 as well as Figure 7. The total costs were broken down into four distinct groups being machine, fuel, labour and inputs. The inputs grouping includes the costs of the fertilizer, herbicide and seed.

The machine costs were the most expensive input, accounting for almost 70% of the total costs in all systems. The machine costs consist of the total amount of capital spent for the machines depreciated over their lives, the repair and maintenance costs, interest and taxes and insurance. Salvage values of 10% were assumed and an interest rate of 14% was used. Taxes and insurance were calculated as 2% of the principle cost of the machine annually.

The machine costs ranged from \$784.30/ha to \$531.82/ha for the conventional-organic and the no-till-inorganic systems respectively. The major differences were due to the increased machinery requirements of the conventional system.

The average machine costs for the conventional tillage systems was found to be approximately \$748/ha while the reduced was slightly less at around \$714/ha. This difference is because of the lower cost of the chisel plow as compared to the moldboard plow and the lower use of the disk harrow. The no-till system showed the least machinery expenditure, at approximately \$567/ha. The savings is a result of the reduced capital expenditure required for the machinery in the no-till system.

Table 15. Total Financial Costs of Each System (1984 dollars).

| SYSTEM | MACHINE<br>COSTS<br>\$/ha | FUEL<br>COSTS<br>\$/ha | LABOUR<br>COSTS<br>\$/ha | INPUT<br>COSTS<br>\$/ha | TOTAL<br>COSTS<br>\$/ha |
|--------|---------------------------|------------------------|--------------------------|-------------------------|-------------------------|
| CSI    | 713.30                    | 74.77                  | 58.10                    | 356.96                  | 1203.13                 |
| CSO    | 784.30                    | 83.09                  | 61.73                    | 208.34                  | 1137.46                 |
| CCI    | 713.30                    | 70.72                  | 58.10                    | 356.96                  | 1199.09                 |
| CCO    | 784.30                    | 77.51                  | 61.73                    | 208.34                  | 1131.88                 |
| RSI    | 678.94                    | 67.69                  | 56.97                    | 356.96                  | 1160.56                 |
| RSO    | 749.94                    | 74.47                  | 60.60                    | 208.34                  | 1093.35                 |
| RCI    | 678.94                    | 62.49                  | 56.97                    | 356.96                  | 1155.36                 |
| RCO    | 749.94                    | 68.69                  | 60.60                    | 208.34                  | 1087.56                 |
| ZSI    | 531.82                    | 38.33                  | 44.67                    | 378.01                  | 992.83                  |
| ZSO    | 602.82                    | 44.53                  | 48.29                    | 208.34                  | 903.99                  |
| ZCI    | 531.82                    | 35.50                  | 44.67                    | 378.01                  | 990.00                  |
| ZCO    | 602.82                    | 41.33                  | 48.29                    | 208.34                  | 900.79                  |

# TOTAL FINANCIAL COSTS

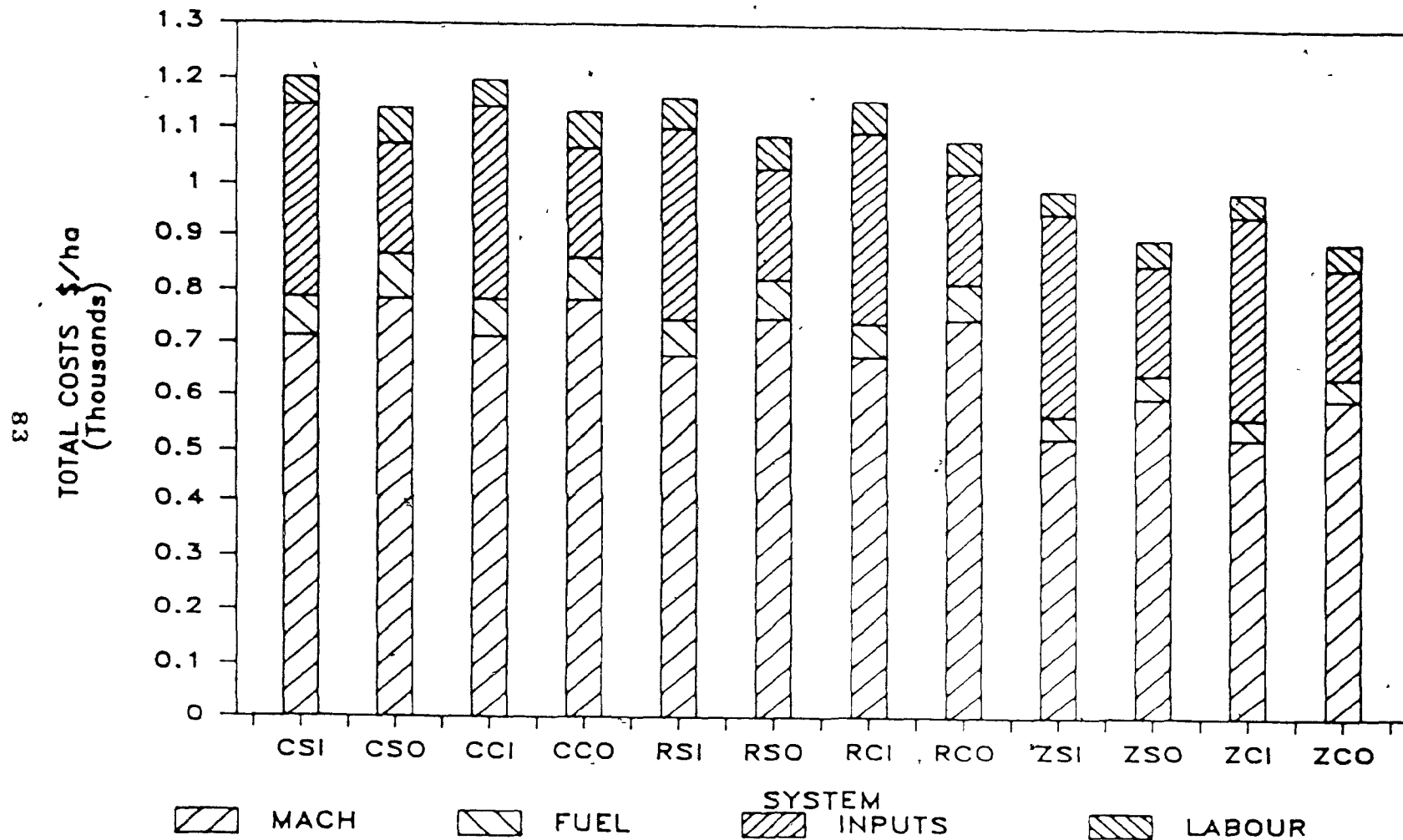


Figure 7. Stacked bar histogram of the total financial costs of all systems.

The inorganic systems had an average machine cost of \$641/ha while the organic systems were found to need \$712/ha of machinery. The difference here is attributable to the greater capital cost of the manure spreader as compared to the broadcaster, shown in Table 5.

Similar systems across soil type had equivalent machine costs because the machinery required is dependent on the production method used and is not influenced by soil type.

The fuel costs were calculated using a unit price of \$0.45/L. The fuel costs accounted for only about 3 to 7% of the total costs. The differences in fuel consumptions were discussed in a previous section.

The labour costs also had little effect on the total costs as labour accounted for only about 5% of the total costs for all systems.

The inputs, including all fertilizers, herbicides and seed were the second most important contributor and also had great variations between systems. The detailed calculations of the input costs along with the unit prices are shown in Appendix E.

The input costs had two distinct groups, the inorganically fertilized and the organically. The organic inputs, at \$208.34/ha amounted to approximately 20% of the total costs for all organic systems. The additional costs incurred through the use of inorganic fertilizer amounted to a 75% increase in the input costs. The inorganic systems had total input costs of either \$356.96/ha or \$378.01/ha,

depending on the nitrogen source, and this accounted for approximately 35% of the total costs in those systems.

The most costly system, overall, was determined to be the conventional tillage and inorganic fertilizer combination in a sandy loam with total expenditures of \$1203.13 per ha of corn grown. The least expensive production system was the no-till organic in a clay soil which required only \$900.79 per ha from planting to harvest. The major reasons for these differences are the lower machine costs associated with the no-till and the reduced amount of purchased inputs.

The average per hectare costs varied very little from the conventional systems to the reduced, \$1170/ha as compared to \$1148/ha. The no-till systems cost substantially less with average total expenditures of \$946/ha. The reduction in costs associated with the no-till system is the combined effect of lower machinery requirements, lower fuel costs and reduced labour input.

The inorganic systems averaged \$1116/ha and the organic systems \$1042/ha. The apparent gains in reducing the fertilizer costs in the organic systems were almost nullified by the increased machinery, fuel and labour costs associated with manure use and accounted for the only 6% difference between fertilizer types. The difference caused by fertilizer type was more pronounced in the no-till systems where the total costs were lower and the inorganic fertilizer costs slightly higher. The result being that the

organic fertilizer no-till systems were an average of 10% less costly than the inorganic systems.

Soil type had almost no effect on the total cost incurred by each system as the sandy loam systems averaged total costs of \$1081/ha and the clay systems cost \$1077/ha.

The least expensive systems, overall, were the no-till organic system at \$903.99/ha in the sandy loam and \$900.79 in the clay.

Total cost is not, in itself, a valid parameter for the selection of a production system. The effect of the production method on yield must be accounted for and as such the next section combines the two to determine the most productive system in terms of kilograms produced per unit dollar input.

#### 5.10) Financial Productivity

The financial productivity should be the parameter used by the farmer to select his production method. This value shows the most profitable system to produce the required amount of corn silage and is found by dividing the yield by the total costs associated with the system.

Table 16 and Figure 8 show the results of the calculations of financial productivity. The least expensive corn silage was produced by the no-till organic system in a clay soil which was found to have a productivity of 12.02 kg/\$. The most expensive silage was produced by the conventional inorganic system where only 8.39 kg of silage

**Table 16. Financial Productivity of Each System Based on  
\$ 0.45/ Litre Fuel, \$ 8/hr Labour Cost and 14%  
Interest.**

| SYSTEM | YIELD<br>kg/ha | COST<br>\$/ha | PRQDUCTIVITY<br>kg/\$ |
|--------|----------------|---------------|-----------------------|
| CSI    | 10100          | 1203.13       | 8.39                  |
| CSO    | 11280          | 1137.46       | 9.92                  |
| CCI    | 11860          | 1199.09       | 9.89                  |
| CCO    | 12520          | 1131.88       | 11.06                 |
| RSI    | 10820          | 1160.56       | 9.32                  |
| RSO    | 11060          | 1093.35       | 10.12                 |
| RCI    | 11960          | 1155.36       | 10.35                 |
| RCO    | 11530          | 1087.56       | 10.60                 |
| ZSI    | 9620           | 992.83        | 9.69                  |
| ZSO    | 9570           | 903.99        | 10.59                 |
| ZCI    | 11560          | 990.00        | 11.68                 |
| ZCO    | 10830          | 900.79        | 12.02                 |

## FINANCIAL PRODUCTIVITY

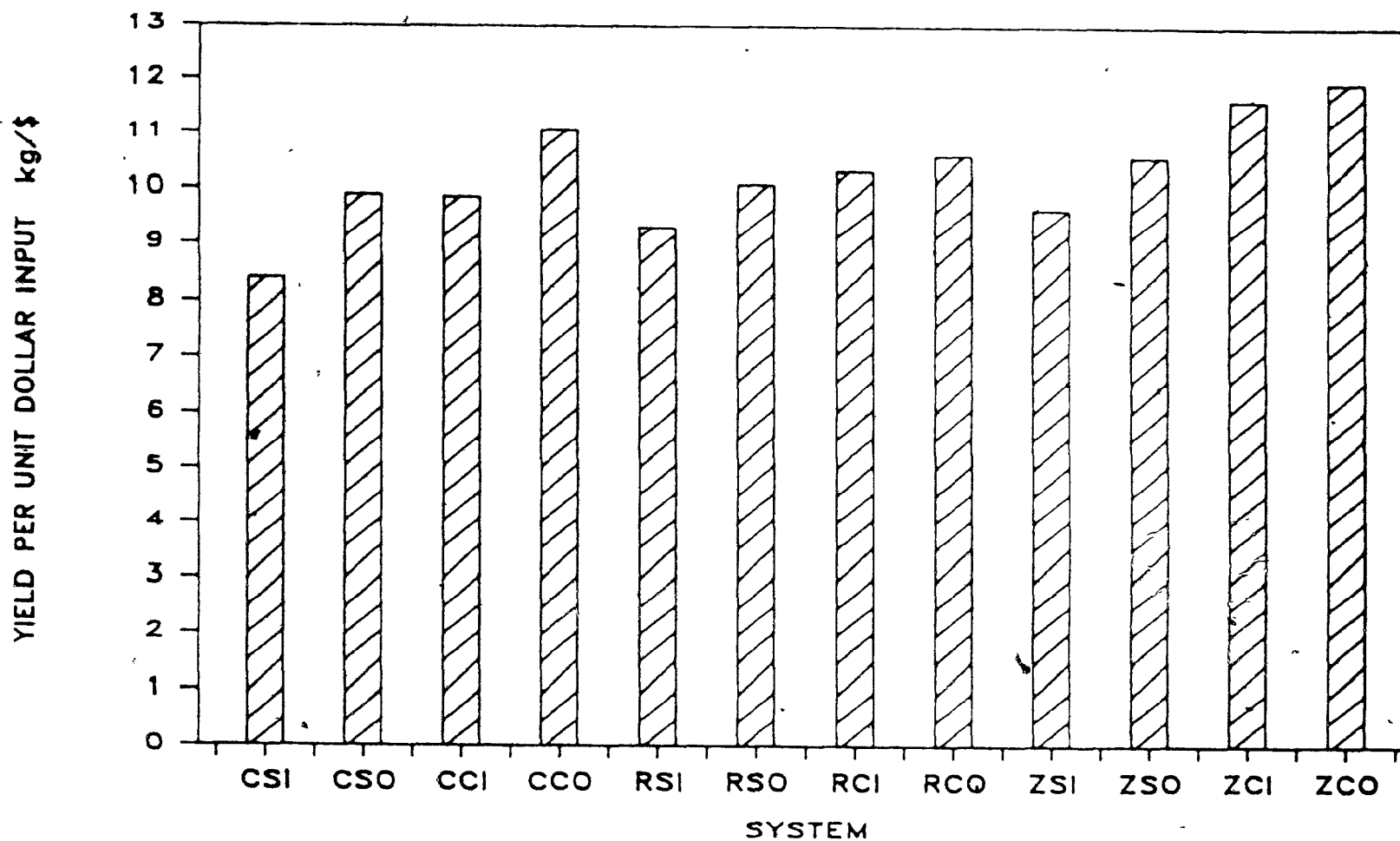


Figure 8. Histogram of the financial productivity of all systems.

was produced for each dollar put into the system.

Across tillage treatments, the productivity rose with decreasing tillage. The conventional systems produced an average of 9.82 kg of silage for each dollar while the reduced and no-till systems produced averages of 10.10 and 11.00 kg/\$ respectively. This indicates that the no-till systems can produce 12% more silage, than the conventional systems, for every dollar spent in production costs. This, in turn, is translatable directly into profits for the farmer. The superiority of the no-till is again evident when cost is the major concern.

The effect of fertilizer type on the financial productivity was that the organic systems were slightly more productive than the inorganic systems based on average productivities of 10.72 to 9.89 kg/\$. The difference here is due mostly to the differences in the yields as was previously observed.

The clay soils, with their higher yields, returned an average productivity that was higher than that of the sandy loam system. The clay systems produced an average of 10.93 kg of silage for every dollar spent while the sandy loam systems only produced an average of 9.67 kg/\$. The difference here was due primarily to the difference in the yields as the total costs of the two soils were almost equal.

Within the soils, the no-till organic system was the most productive in terms of the money spent to grow the

corn. In the clay soil, the no-till organic system produced 12.02 kg/\$ and the second most productive system was the no-till inorganic system which produced 11.68 kg/\$. The least productive system was the conventional inorganic which returned 9.89 kg/\$.

In the sandy loam soil, the no-till organic system was found to have a productivity of 10.59 kg/\$ and the reduced organic system was the second most productive at 10.12 kg/\$. The worst system, in the sandy loam soil, was the conventional inorganic system which returned only 8.39 kg of silage for each dollar put in to the system.

These results show that farmers should consider no-till as a viable, if not superior, tillage system for the production of corn silage. When used in conjunction with organic fertilizer, no-till can reduce production costs by up to 20% over conventional inorganic while producing the same amount of silage. The benefits of no-till and organic fertilizer in the area of finances are directly related to the profitability of the operation as a whole.

The use of no-till and organic fertilizer is only possible when the additional land required is available at no added expense. If the additional land must be rented or purchased then the financial benefits of no-till and organic fertilizer may not be observed. This is, of course, totally dependent on the operation of the farm as a whole and the decision on tillage system must be made accordingly.

## VI

### SUMMARY AND CONCLUSIONS

This analysis used in-depth calculations of the energy sequestered in the inputs into corn silage production and actual yields of those production systems to determine the most efficient system in terms of resource depletion. The yields were also compared on the basis of the fuel consumption of each system. The costs were determined for each of the systems and were related to the yields produced to determine the most efficient system based on financial productivity. The production systems analysed included three levels of tillage, two types of fertilizer and two different soil types. The field experiment was performed during the 1983 growing season.

The energy inputs were broken down into individual sections under the headings of machinery, fuel, seed, fertilizer, and herbicide. The machinery energy consisted of three inputs which were embodied, fabrication and repair energy. These values were added together to find the total energy incorporated into each machine throughout its entire life and this energy was then depreciated over the life of the machine. The depreciated energies of the operations were added together to find the total machinery energy required for each system on a per hectare basis.

The fuel consumption was calculated for each operation,

in each soil. From this, the total fuel requirement for each system was found and converted to energy using a standard conversion rate of 47.8 MJ/L (Cervinka, 1980).

The seed, fertilizer and herbicide energies were found by converting each application rates into the net energy sequestered in each substance. Manure was assumed to have no net energy cost because it is a by product of the farm and the energy sequestered in it would be accounted for elsewhere.

All of the above energies were summed to give the total resource depletion caused by each system. The energy productivities were calculated by dividing the yield obtained from each system by the resource depletion it caused.

The most efficient system vis-a-vis energy consumption was the no-till organic system which produced productivities of 0.83 kg/MJ in the sandy loam soil and 0.96 kg/MJ in the clay. The least efficient system was the conventional tillage and inorganic fertilizer system which gave productivities of less than 50% of those from the no-till organic combination.

Fertilizer had a tremendous impact on the energy productivity because of the vast amount of energy used in the production of inorganic nitrogen sources. The inorganically fertilized systems were almost always 50% less efficient than comparable organically fertilized systems. The use of inorganic fertilizers had little effect on the

yield but accounted for over 10000 MJ/ha or nearly 50% of the total energy expended.

In terms of energy use, the no-till systems showed great potential for the conservation of energy while maintaining yield levels. The use of manure as the nitrogen source has fantastic potential for conserving the energy required to produce corn silage while, at the same time, eliminating disposal problems and improving the soil structure.

The most efficient system in terms of silage produced per diesel fuel input was the no-till inorganic system regardless of soil type. This system returned 112.9 kg/L in the sandy loam soil and 146.5 kg/L in the clay. The second most efficient system was the no-till system in conjunction with organic fertilizer. The conventional tillage system returned the lowest yield per fuel input at approximately 50% of that of the no-till systems. The reduced tillage system performed slightly better than the conventional system but was quite poor when compared to the no-till system.

The results indicate that substantial reductions in on farm fuel consumption are possible with the use of a no-till tillage system. However, the use of organic fertilizer caused an average increase in the fuel consumption of 11% indicating a drawback to the implementation of organic fertilizer systems.

The cost analysis was performed on the basis of a 14%

interest rate, \$8.00 per hour labour costs and \$0.45 per litre diesel fuel costs. The expenses fell into four categories being machine, fuel, labour and input costs where the input costs included fertilizer, herbicide and seed costs. Manure was assumed to be a by product of the farm.

The machine costs were found by taking an average of prices as quoted by five eastern Ontario dealers and depreciating these costs over the life of the machine. The machine costs accounted for 70% of the total expenses for all systems studied and averaged \$676.83 per hectare of corn grown (based on 25 ha). The no-till systems had the lowest machine costs at \$567/ha while the conventional was the most expensive at \$748/ha. The fuel costs amounted to only about 6% of the total costs and labour was even less than that. The inputs amounted to just over \$350/ha for the inorganic system and the organic systems had input costs of a little over \$200/ha.

The most productive system in terms of finances, assuming zero-manure cost, was the no-till organic combination which produced 12.02 kg of dry matter per each dollar spent in the clay soil and 10.59 kg/\$ in the sandy loam. The least productive was found to be the conventional inorganic system which produced an average of 9.14 kg/\$ across both soils.

Based on the results of all three criteria, the no till organic fertilizer combination proved to be the most efficient. These results indicate that substantial amounts

of energy can be saved by the implementation of a no-till tillage system and organic fertilizer. The energy saved would be in various forms; natural gas from the production of inorganic fertilizer, electricity from the machinery fabrication plants and diesel fuel from the farm. Regardless of the form of the energy the savings would still be available to other sectors of the economy and would therefore reduce the amount of irreplaceable fossil fuel consumed.

The major impetus for the implementation of these systems by the farmer is the potential reduction in production costs. The results show that the combination of no-till and manure can indeed save the farmer money while producing the same amount of corn silage. Although the financial benefits are the major draw to the implementation of these systems, the farmer will also receive the additional benefits associated with no till and organic fertilizer use such as improved soil structure, reduced soil erosion and improved timeliness for the field operations.

The major constraint associated with the no-till and organic system is the reduced yields achieved. The implementation of these systems implies the working of more land to produce the same amount of silage at reduced cost and energy. If the additional land is present and available then the no-till organic combination is the most productive system in terms of money or energy.

## VII

### SUGGESTIONS FOR FURTHER RESEARCH

The results of this analysis are very promising for the use of no-till tillage treatments and organic fertilizer. However the results are based on the yields obtained during the 1983 growing season only and can only reflect upon growing seasons such as that. This would indicate that additional yield results are required in order to better evaluate the different production systems vis-a-vis the amount of silage produced.

Another benefit of further field studies would be the indication of the long term effects of no-till on the yields. The results of this study were based on yields produced during the second year of production with a given system and the long term effects of a given tillage practice or fertilizer treatment need to be investigated. These effects include the soil temperature and humidity and any additional disease or insect problem associated with no-till use. Some problems were encountered with seeding in the first year of this project and investigation into the problems of no-till planting should be examined.

There is limited benefit in the closer examination of the fuel consumptions associated with the various treatments because of its limited effect on the overall energy consumption of each system.

An area of great potential is the use of manure as the nitrogen source for the plants. Further research in this area could include the examination of the use of digesters whereby the manure produces energy and the effluent from the digester is used as the nitrogen source for the plants. This system would have the manure serving two roles with regard to energy conservation. The first being the elimination of energy intensive inorganic fertilizers and secondly the production of methane which could in turn reduce the diesel fuel requirements.

The effects of price changes could be examined in order to observe the the effect on the financial productivity and to determine at what prices the no-till inorganic ceases to be the most efficient system overall. This would then create the situation whereby one production system may be the most efficient in terms of energy but unlikely to be implemented because of economics. From that one could investigate the use of subsidies or tariffs on certain inputs which would ensure that the most energy efficient was also the most cost effective thereby promoting its use.

An identical experiment could be run on grain corn employing the same techniques applied here. This would demonstrate the effect of tillage, fertilizer and soil type on the efficiency of grain corn production and may indicate that the most efficient silage corn production system may not be the most efficient for grain corn.

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## APPENDICES

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## Appendix A

### Machinery Energy Calculations

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TABLE A.1 Total Machinery Energy.

| MACHINE           | MASS<br>kg     | CONV.EMB*<br>MJ/kg | EMB.ENR.<br>MJ     | CONV.FAB.*<br>MJ/kg |
|-------------------|----------------|--------------------|--------------------|---------------------|
| 97 kW Tractor     | 7156.00        | 49.60              | 354937.60          | 14.63               |
| 47 kW Tractor     | 4382.00        | 49.60              | 217347.20          | 14.63               |
| Planter           | 1700.00        | 62.80              | 106760.00          | 8.63                |
| Moldboard Plow    | 1137.00        | 62.80              | 71403.60           | 8.63                |
| Chisel Plow       | 1050.00        | 62.80              | 65940.00           | 8.63                |
| Disk-harrow       | 1750.00        | 62.80              | 109900.00          | 8.35                |
| Sprayer           | 50 00          | 62 80              | 3140.00            | 7.38                |
| Broadcaster       | 1052.00        | 62.80              | 66065.60           | 7.38                |
| Manure Spreader   | 1725.00        | 62 80              | 108330.00          | 7 38                |
| Forage Chopper    | 1200.00        | 62.80              | 75360 00           | 13.09               |
| Forage Wagons(3)  | 3945.00        | 62.80              | 247746 00          | 6.28                |
|                   | FAB.ENR.<br>MJ | EMB.+FAB.<br>MJ    | ADJUST.<br>FACTOR* | ADJ.TOTAL<br>MJ     |
| 97 kW Tractor     | 104692.28      | 459629.88          | 0 82               | 376896.50           |
| 47 kW Tractor     | 64108.66       | 281455 86          | 0 82               | 230793 81           |
| Planter           | 14671.00       | 121431 00          | 0.82               | 99573 42            |
| Moldboard Plow    | 9812 31        | 81215.91           | 0 82               | 66597.05            |
| Chisel Plow       | 9061.50        | 75001.50           | 0 82               | 61501.23            |
| Disk-harrow       | 14612.50       | 124512.50          | 0 82               | 102100 25           |
| Sprayer           | 369 00         | 3509.00            | 0 82               | 2877 38             |
| Broadcaster       | 7763.76        | 73829.36           | 0 82               | 60540.08            |
| Manure Spreader   | 12730.50       | 121060.50          | 0 82               | 99269.61            |
| Forage Chopper    | 15708.00       | 91068.00           | 0.82               | 74675.76            |
| Forage Wagons(3)  | 24774.60       | 272520 60          | 0 82               | 223466.89           |
|                   | TAR**          | CONV REP<br>MJ/kg  | REP ENR.<br>MJ     | TOTAL ENR<br>MJ     |
| 97 kW Tractor     | 0.89           | 0.33               | 134993.30          | 511889.80           |
| 47 kW Tractor     | 0.89           | 0.33               | 82663.59           | 313457.39           |
| Planter           | 0.76           | 0.33               | 30454.89           | 130028.31           |
| Moldboard Plow    | 0.93           | 0.33               | 24925.16           | 91522.21            |
| Chisel Plow       | 0.93           | 0.33               | 23017.96           | 84519.19            |
| Disk-harrow       | 0.93           | 0.33               | 38212.89           | 140313.14           |
| Sprayer           | 0.76           | 0.33               | 880.06             | 3757.44             |
| Broadcaster       | 0.91           | 0.33               | 22170.96           | 82711.03            |
| Manure Spreader   | 0.46           | 0.33               | 18376.98           | 117646 59           |
| Forage Chopper    | 0.61           | 0.33               | 18331.99           | 93007 75            |
| Forage Wagons(3). | 0.76           | 0.33               | 68348.17           | 291815.06           |

\* Doering (1980)

\*\* Total Annual Repair. ASAE (1983).

TABLE A.2 Unit Machinery Energy.

| MACHINE          | TOTAL ENR.<br>MJ | LIFE*<br>h | UNIT ENR.<br>MJ/h |
|------------------|------------------|------------|-------------------|
| 97 kW Tractor    | 511889.80        | 10000.00   | 51.19             |
| 47 kW Tractor    | 313457.39        | 10000.00   | 31.35             |
| Moldboard Plow   | 91522.21         | 2500.00    | 36.61             |
| Chisel Plow      | 84519.19         | 2500.00    | 33.81             |
| Disk-harrow(1)   | 140313.14        | 2500.00    | 56.13             |
| Disk-harrow(2)   | 140313.14        | 2500.00    | 56.13             |
| Sprayer          | 3757.44          | 2000.00    | 1.88              |
| Broadcaster      | 82711.03         | 1200.00    | 68.93             |
| Manure Spreader  | 117646.59        | 1200.00    | 98.04             |
| Forage Chopper   | 93007.75         | 2000.00    | 46.50             |
| Forage Wagons(3) | 291815.06        | 5000.00    | 58.36             |

|                  | TRACTOR<br>kW | TOTAL ENR.<br>MJ/h** | CAP.<br>ha/h | TOTAL ENR.<br>MJ/ha |
|------------------|---------------|----------------------|--------------|---------------------|
| 97 kW Tractor    | NA            | NA                   | NA           | NA                  |
| 47 kW Tractor    | NA            | NA                   | NA           | NA                  |
| Planter          | 97.00         | 159.55               | 1.01         | 158.75              |
| Moldboard Plow   | 97.00         | 87.80                | 1.02         | 86.50               |
| Chisel Plow      | 97.00         | 85.00                | 0.84         | 101.19              |
| Disk-harrow(1)   | 97.00         | 107.31               | 2.88         | 37.26               |
| Disk-harrow(2)   | 97.00         | 107.31               | 2.88         | 74.52               |
| Sprayer          | 47.00         | 33.22                | 3.43         | 29.06               |
| Broadcaster      | 47.00         | 100.27               | 7.72         | 12.99               |
| Manure Spreader  | 97.00         | 149.23               | 1.72         | 87.00               |
| Forage Chopper   | 97.00         | 97.69                | 0.56         | 175.08              |
| Forage Wagons(3) | 47.00         | 179.36               | 0.56         | 321.44              |

Note: MJ/ha refers to ha's of corn planted.

\* Kepner et al. (1978).

\*\* includes appropriate tractor energy.

TABLE A.3 System Machinery Energy Listed by Operation.

| MACHINE          | CSI    | CSO    | CCI    | CCO    |
|------------------|--------|--------|--------|--------|
| 97 kw Tractor    | NA     | NA     | NA     | NA     |
| 47 kW Tractor    | NA     | NA     | NA     | NA     |
| Planter          | 158.75 | 158.75 | 158.75 | 158.75 |
| Moldboard Plow   | 86.50  | 86.50  | 86.50  | 86.50  |
| Chisel Plow      | NA     | NA     | NA     | NA     |
| Disk-harrow      | 74.52  | 74.52  | 74.52  | 74.52  |
| Sprayer          | 29.06  | 29.06  | 29.06  | 29.06  |
| Broadcaster      | 12.99  | NA     | 12.99  | NA     |
| Manure Spreader  | NA     | 87.00  | NA     | 87.00  |
| Forage Chopper   | 175.08 | 175.08 | 175.08 | 175.08 |
| Forage Wagons(3) | 321.44 | 321.44 | 321.44 | 321.44 |
| TOTAL MJ/ha      | 858.34 | 932.35 | 858.34 | 932.35 |

| MACHINE          | RSI    | RSO    | RCI    | RCO    |
|------------------|--------|--------|--------|--------|
| 97 kw Tractor    | NA     | NA     | NA     | NA     |
| 47 kW Tractor    | NA     | NA     | NA     | NA     |
| Planter          | 158.75 | 158.75 | 158.75 | 158.75 |
| Moldboard Plow   | NA     | NA     | NA     | NA     |
| Chisel Plow      | 101.19 | 101.19 | 101.19 | 101.19 |
| Disk-harrow      | 37.26  | 37.26  | 37.26  | 37.26  |
| Sprayer          | 29.06  | 29.06  | 29.06  | 29.06  |
| Broadcaster      | 12.99  | NA     | 12.99  | NA     |
| Manure Spreader  | NA     | 87.00  | NA     | 87.00  |
| Forage Chopper   | 175.08 | 175.08 | 175.08 | 175.08 |
| Forage Wagons(3) | 321.44 | 321.44 | 321.44 | 321.44 |
| TOTAL MJ/ha      | 835.76 | 909.78 | 835.76 | 909.78 |

| MACHINE          | ZSI    | ZSO    | ZCI    | ZCO    |
|------------------|--------|--------|--------|--------|
| 97 kw Tractor    | NA     | NA     | NA     | NA     |
| 47 kW Tractor    | NA     | NA     | NA     | NA     |
| Planter          | 158.75 | 158.75 | 158.75 | 158.75 |
| Moldboard Plow   | NA     | NA     | NA     | NA     |
| Chisel Plow      | NA     | NA     | NA     | NA     |
| Disk-harrow      | NA     | NA     | NA     | NA     |
| Sprayer          | 29.06  | 29.06  | 29.06  | 29.06  |
| Broadcaster      | 12.99  | NA     | 12.99  | NA     |
| Manure Spreader  | NA     | 87.00  | NA     | 87.00  |
| Forage Chopper   | 175.08 | 175.08 | 175.08 | 175.08 |
| Forage Wagons(3) | 321.44 | 321.44 | 321.44 | 321.44 |
| TOTAL MJ/ha      | 697.32 | 771.33 | 697.32 | 771.33 |

## Appendix B

### Fuel Consumption Calculations

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TABLE B.1 Cone Index Values

| OPERATION       | CSI   | CSO   | CCI   | CCO   |
|-----------------|-------|-------|-------|-------|
| Planter         | 15.00 | 15.00 | 20.00 | 20.00 |
| Moldboard Plow  | 25.00 | 25.00 | 30.00 | 30.00 |
| Chisel Plow     | NA    | NA    | NA    | NA    |
| Disk-harrow     | 20.00 | 20.00 | 25.00 | 25.00 |
| Sprayer         | 15.00 | 15.00 | 20.00 | 20.00 |
| Broadcaster     | 15.00 | NA    | 20.00 | NA    |
| Manure Spreader | NA    | 15.00 | NA    | 20.00 |
| Forage Chopper  | 15.00 | 15.00 | 20.00 | 20.00 |
|                 | RSI   | RSO   | RCI   | RCO   |
| Planter         | 20.00 | 20.00 | 25.00 | 25.00 |
| Moldboard Plow  | NA    | NA    | NA    | NA    |
| Chisel Plow     | 25.00 | 25.00 | 30.00 | 30.00 |
| Disk-harrow     | 20.00 | 20.00 | 25.00 | 25.00 |
| Sprayer         | 20.00 | 20.00 | 25.00 | 25.00 |
| Broadcaster     | 20.00 | NA    | 25.00 | NA    |
| Manure Spreader | NA    | 20.00 | NA    | 25.00 |
| Forage Chopper  | 20.00 | 20.00 | 25.00 | 25.00 |
|                 | ZSI   | ZSO   | ZCI   | ZCO   |
| Planter         | 25.00 | 25.00 | 30.00 | 30.00 |
| Moldboard Plow  | NA    | NA    | NA    | NA    |
| Chisel Plow     | NA    | NA    | NA    | NA    |
| Disk-harrow     | NA    | NA    | NA    | NA    |
| Sprayer         | 25.00 | 25.00 | 30.00 | 30.00 |
| Broadcaster     | 25.00 | NA    | 30.00 | NA    |
| Manure Spreader | NA    | 25.00 | NA    | 30.00 |
| Forage Chopper  | 25.00 | 25.00 | 30.00 | 30.00 |

Note: Values from ASAE (1983).

TABLE B.2 Tractive and Transmission Coefficients.

| OPERATION       | CSI  | CSO  | CCI  | CCO  |
|-----------------|------|------|------|------|
| Planter         | 0.49 | 0.49 | 0.61 | 0.61 |
| Moldboard Plow  | 0.68 | 0.68 | 0.74 | 0.74 |
| Chisel Plow     | NA   | NA   | NA   | NA   |
| Disk-harrow     | 0.61 | 0.61 | 0.68 | 0.68 |
| Sprayer         | 0.49 | 0.49 | 0.61 | 0.61 |
| Broadcaster     | 0.49 | NA   | 0.61 | NA   |
| Manure Spreader | NA   | 0.49 | NA   | 0.61 |
| Forage Chopper* | 0.49 | 0.49 | 0.61 | 0.61 |
|                 | RSI  | RSO  | RCI  | RCO  |
| Planter         | 0.61 | 0.61 | 0.68 | 0.68 |
| Moldboard Plow  | NA   | NA   | NA   | NA   |
| Chisel Plow     | 0.68 | 0.68 | 0.74 | 0.74 |
| Disk-harrow     | 0.61 | 0.61 | 0.68 | 0.68 |
| Sprayer         | 0.61 | 0.61 | 0.68 | 0.68 |
| Broadcaster     | 0.61 | NA   | 0.68 | NA   |
| Manure Spreader | NA   | 0.61 | NA   | 0.68 |
| Forage Chopper* | 0.61 | 0.61 | 0.68 | 0.68 |
|                 | ZSI  | ZSO  | ZCI  | ZCO  |
| Planter         | 0.68 | 0.68 | 0.74 | 0.74 |
| Moldboard Plow  | NA   | NA   | NA   | NA   |
| Chisel Plow     | NA   | NA   | NA   | NA   |
| Disk-harrow     | NA   | NA   | NA   | NA   |
| Sprayer         | 0.68 | 0.68 | 0.74 | 0.74 |
| Broadcaster     | 0.68 | NA   | 0.74 | NA   |
| Manure Spreader | NA   | 0.68 | NA   | 0.74 |
| Forage Chopper* | 0.68 | 0.68 | 0.74 | 0.74 |

\* Includes Forage Wagons.

Note: Values determined from ASAE (1983).

TABLE B.3 Tractor Rolling Resistance Calculations.

| CN    | TRACTOR<br>kW | WEIGHT<br>kN | RR<br>kN |
|-------|---------------|--------------|----------|
| 15.00 | 97.00         | 70.20        | 8.42     |
| 20.00 | 97.00         | 70.20        | 7.02     |
| 25.00 | 97.00         | 70.20        | 6.18     |
| 30.00 | 97.00         | 70.20        | 5.62     |
| 15.00 | 47.00         | 42.99        | 5.16     |
| 20.00 | 47.00         | 42.99        | 4.30     |
| 25.00 | 47.00         | 42.99        | 3.78     |
| 30.00 | 47.00         | 42.99        | 3.44     |

Note: Values determined from  $W(1.2/Cn + 0.04)$ , ASAE (1983).

TABLE B.4.1 Fuel Consumptions for the Planter and Sprayer.

PLANTER

|                  |         |         |        |        |
|------------------|---------|---------|--------|--------|
| Cn               | 15.00   | 20.00   | 25.00  | 30.00  |
| Ave. Weight kN   | 11.78   | 11.78   | 11.78  | 11.78  |
| RR kN            | 1.41    | 1.18    | 1.04   | 0.94   |
| Tractor kW       | 97.00   | 97.00   | 97.00  | 97.00  |
| Tractor RR kN    | 8.42    | 7.02    | 6.18   | 5.62   |
| Total RR kN      | 9.84    | 8.20    | 7.21   | 6.56   |
| Mach. Draft kN   | 6.20    | 6.20    | 6.20   | 6.20   |
| Total kN         | 16.04   | 14.40   | 13.41  | 12.76  |
| Speed km/h       | 5.00    | 5.00    | 5.00   | 5.00   |
| DrawBarPower kW  | 22.27   | 20.00   | 18.63  | 17.72  |
| T and T coef.    | 0.49    | 0.61    | 0.68   | 0.74   |
| PTO Equiv kW     | 45.46   | 32.78   | 27.40  | 23.95  |
| PTO Oper. kW*    | NA      | NA      | NA     | NA     |
| PTO Equiv. kW    | 45.46   | 32.78   | 27.40  | 23.95  |
| Total PTO req kW | 45.46   | 32.78   | 27.40  | 23.95  |
| Max. PTO Av. kW  | 97.38   | 97.38   | 97.38  | 97.38  |
| PTO REQ./MAX PTO | 0.47    | 0.34    | 0.28   | 0.25   |
| Fuel Use l/h*    | 26.94   | 22.72   | 20.57  | 19.01  |
| Oil Use l/h*     | 0.08    | 0.08    | 0.08   | 0.08   |
| Total Fuel l/h   | 27.02   | 22.79   | 20.65  | 19.08  |
| conv. MJ/l#      | 47.80   | 47.80   | 47.80  | 47.80  |
| TOTAL MJ/h       | 1291.50 | 1089.59 | 987.03 | 912.24 |

SPRAYER

|                  |        |        |        |        |
|------------------|--------|--------|--------|--------|
| Cn               | 15.00  | 20.00  | 25.00  | 30.00  |
| Ave. Weight kN   | NA     | NA     | NA     | NA     |
| RR kN            | NA     | NA     | NA     | NA     |
| Tractor kW       | 47.00  | 47.00  | 47.00  | 47.00  |
| Tractor RR kN    | 5.16   | 4.30   | 3.78   | 3.44   |
| Total RR kN      | 5.16   | 4.30   | 3.78   | 3.44   |
| Mach. Draft kN   | NA     | NA     | NA     | NA     |
| Total kN         | 5.16   | 4.30   | 3.78   | 3.44   |
| Speed km/h       | 6.40   | 6.40   | 6.40   | 6.40   |
| DrawBarPower kW  | 9.17   | 7.64   | 6.73   | 6.11   |
| T and T coef.    | 0.49   | 0.61   | 0.68   | 0.74   |
| PTO Equiv. kW    | 18.72  | 12.53  | 9.89   | 8.26   |
| PTO Oper. kW*    | 1.86   | 1.86   | 1.86   | 1.86   |
| PTO Equiv. kW    | 18.72  | 12.53  | 9.89   | 8.26   |
| Total PTO req kW | 20.58  | 14.39  | 11.75  | 10.12  |
| Max. PTO Av. kW  | 46.62  | 46.62  | 46.62  | 46.62  |
| PTO REQ./MAX PTO | 0.44   | 0.31   | 0.25   | 0.22   |
| Fuel Use l/h*    | 12.53  | 10.37  | 9.23   | 8.42   |
| Oil Use l/h*     | 0.05   | 0.05   | 0.05   | 0.05   |
| Total Fuel l/h   | 12.58  | 10.42  | 9.28   | 8.47   |
| conv. MJ/l#      | 47.80  | 47.80  | 47.80  | 47.80  |
| TOTAL MJ/h       | 601.09 | 498.18 | 443.75 | 405.02 |

\* ASAE (1983).

# Cervinka (1980).

TABLE B.4.2 Fuel Consumptions for the Moldboard Plow.

MOLDBOARD PLOW; SANDY LOAM

|                            |         |         |         |         |
|----------------------------|---------|---------|---------|---------|
| Cn                         | 15.00   | 20.00   | 25.00   | 30.00   |
| Ave. Weight kN             | NA      | NA      | NA      | NA      |
| RR kN                      | NA      | NA      | NA      | NA      |
| Tractor kW                 | 97.00   | 97.00   | 97.00   | 97.00   |
| Tractor RR kN              | 8.42    | 7.02    | 6.18    | 5.62    |
| Total RR kN                | 8.42    | 7.02    | 6.18    | 5.62    |
| Mach. Draft kN             | 12.19   | 12.19   | 12.19   | 12.19   |
| Total kN                   | 20.61   | 19.21   | 18.37   | 17.81   |
| Speed km/h                 | 7.25    | 7.25    | 7.25    | 7.25    |
| DrawBarPower kW            | 41.51   | 38.69   | 36.99   | 35.86   |
| T <sub>f</sub> and T coef. | 0.49    | 0.61    | 0.68    | 0.74    |
| PTO Equiv. kW              | 84.72   | 63.42   | 54.40   | 48.46   |
| PTO Oper. kW*              | NA      | NA      | NA      | NA      |
| PTO Equiv. kW              | 84.72   | 63.42   | 54.40   | 48.46   |
| Total PTO req kW           | 84.72   | 63.42   | 54.40   | 48.46   |
| Max. PTO Av. kW            | 97.38   | 97.38   | 97.38   | 97.38   |
| PTO REQ./MAX PTO           | 0.87    | 0.65    | 0.56    | 0.50    |
| Fuel Use l/h*              | 42.10   | 32.73   | 29.72   | 27.87   |
| Oil Use l/h*               | 0.08    | 0.08    | 0.08    | 0.08    |
| Total Fuel l/h             | 42.18   | 32.81   | 29.80   | 27.95   |
| conv. MJ/l*                | 47.80   | 47.80   | 47.80   | 47.80   |
| TOTAL MJ/h                 | 2016.32 | 1568.31 | 1424.34 | 1335.87 |

MOLDBOARD PLOW CLAY

|                  |         |         |         |         |
|------------------|---------|---------|---------|---------|
| Cn               | 15.00   | 20.00   | 25.00   | 30.00   |
| Ave. Weight kN   | NA      | NA      | NA      | NA      |
| RR kN            | NA      | NA      | NA      | NA      |
| Tractor kW       | 97.00   | 97.00   | 97.00   | 97.00   |
| Tractor RR kN    | 8.42    | 7.02    | 6.18    | 5.62    |
| Total RR kN      | 8.42    | 7.02    | 6.18    | 5.62    |
| Mach. Draft kN   | 21.22   | 21.22   | 21.22   | 21.22   |
| Total kN         | 29.64   | 28.24   | 27.40   | 26.84   |
| Speed km/h       | 7.25    | 7.25    | 7.25    | 7.25    |
| DrawBarPower kW  | 59.70   | 56.87   | 55.18   | 54.04   |
| T and T coef.    | 0.49    | 0.61    | 0.68    | 0.74    |
| PTO Equiv. kW    | 121.84  | 93.23   | 81.14   | 73.03   |
| PTO Oper. kW*    | NA      | NA      | NA      | NA      |
| PTO Equiv. kW    | 121.84  | 93.23   | 81.14   | 73.03   |
| Total PTO req kW | 121.84  | 93.23   | 81.14   | 73.03   |
| Max. PTO Av. kW  | 97.38   | 97.38   | 97.38   | 97.38   |
| PTO REQ./MAX PTO | 1.25    | 0.96    | 0.83    | 0.75    |
| Fuel Use l/h*    | 71.98   | 47.18   | 40.22   | 36.46   |
| Oil Use l/h*     | 0.08    | 0.08    | 0.08    | 0.08    |
| Total Fuel l/h   | 72.06   | 47.26   | 40.30   | 36.54   |
| conv. MJ/l*      | 47.80   | 47.80   | 47.80   | 47.80   |
| TOTAL MJ/h       | 3444.48 | 2259.06 | 1926.49 | 1746.73 |

\* ASAE (1983).

# Cervinka (1980).

TABLE B.4.3 Fuel Consumptions for the Chisel Plow.

CHISEL PLOW; SANDY LOAM

|                  | Cn      | 15.00   | 20.00   | 25.00   | 30.00   |
|------------------|---------|---------|---------|---------|---------|
| Ave. Weight kN   | NA      | NA      | NA      | NA      | NA      |
| RR kN            | NA      | NA      | NA      | NA      | NA      |
| Tractor kW       | 97.00   | 97.00   | 97.00   | 97.00   | 97.00   |
| Tractor RR kN    | 8.42    | 7.02    | 6.18    | 5.62    | 5.62    |
| Total RR kN      | 8.42    | 7.02    | 6.18    | 5.62    | 5.62    |
| Mach. Draft kN   | 31.43   | 31.43   | 31.43   | 31.43   | 31.43   |
| Total kN         | 39.85   | 38.45   | 37.61   | 37.05   | 37.05   |
| Speed km/h       | 5.00    | 5.00    | 5.00    | 5.00    | 5.00    |
| DrawBarPower kW  | 55.35   | 53.40   | 52.23   | 51.45   | 51.45   |
| T and T coef.    | 0.49    | 0.61    | 0.68    | 0.74    | 0.74    |
| PTO Equiv. kW    | 112.96  | 87.55   | 76.81   | 69.53   | 69.53   |
| PTO Oper. kW*    | NA      | NA      | NA      | NA      | NA      |
| PTO Equiv. kW    | 112.96  | 87.55   | 76.81   | 69.53   | 69.53   |
| Total PTO req kW | 112.96  | 87.55   | 76.81   | 69.53   | 69.53   |
| Max. PTO Av. kW  | 97.38   | 97.38   | 97.38   | 97.38   | 97.38   |
| PTO REQ./MAX PTO | 1.16    | 0.90    | 0.79    | 0.71    | 0.71    |
| Fuel Use l/h*    | 62.87   | 43.69   | 38.14   | 35.02   | 35.02   |
| Oil Use l/h*     | 0.08    | 0.08    | 0.08    | 0.08    | 0.08    |
| Total Fuel l/h   | 62.95   | 43.77   | 38.22   | 35.10   | 35.10   |
| conv. MJ/l*      | 47.80   | 47.80   | 47.80   | 47.80   | 47.80   |
| TOTAL MJ/h       | 3009.05 | 2092.07 | 1826.73 | 1677.91 | 1677.91 |

CHISEL PLOW; CLAY

|                  | Cn      | 15.00   | 20.00   | 25.00   | 30.00   |
|------------------|---------|---------|---------|---------|---------|
| Ave. Weight kN   | NA      | NA      | NA      | NA      | NA      |
| RR kN            | NA      | NA      | NA      | NA      | NA      |
| Tractor kW       | 97.00   | 97.00   | 97.00   | 97.00   | 97.00   |
| Tractor RR kN    | 8.42    | 7.02    | 6.18    | 5.62    | 5.62    |
| Total RR kN      | 8.42    | 7.02    | 6.18    | 5.62    | 5.62    |
| Mach. Draft kN   | 29.57   | 29.57   | 29.57   | 29.57   | 29.57   |
| Total kN         | 37.99   | 36.59   | 35.75   | 35.19   | 35.19   |
| Speed km/h       | 5.00    | 5.00    | 5.00    | 5.00    | 5.00    |
| DrawBarPower kW  | 52.77   | 50.82   | 49.65   | 48.87   | 48.87   |
| T and T coef.    | 0.49    | 0.61    | 0.68    | 0.74    | 0.74    |
| PTO Equiv. kW    | 107.69  | 83.31   | 73.01   | 66.04   | 66.04   |
| PTO Oper. kW*    | NA      | NA      | NA      | NA      | NA      |
| PTO Equiv. kW    | 107.69  | 83.31   | 73.01   | 66.04   | 66.04   |
| Total PTO req kW | 107.69  | 83.31   | 73.01   | 66.04   | 66.04   |
| Max. PTO Av. kW  | 97.38   | 97.38   | 97.38   | 97.38   | 97.38   |
| PTO REQ./MAX PTO | 1.11    | 0.86    | 0.75    | 0.68    | 0.68    |
| Fuel Use l/h*    | 58.09   | 41.35   | 36.46   | 33.68   | 33.68   |
| Oil Use l/h*     | 0.08    | 0.08    | 0.08    | 0.08    | 0.08    |
| Total Fuel l/h   | 58.17   | 41.42   | 36.53   | 33.76   | 33.76   |
| conv. MJ/l*      | 47.80   | 47.80   | 47.80   | 47.80   | 47.80   |
| TOTAL MJ/h       | 2780.53 | 1980.08 | 1746.33 | 1613.81 | 1613.81 |

\* ASAE (1983).

\* Cervinka (1980).

TABLE B.4.4 Fuel Consumptions for the Disk-harrow.

DISK-HARROW; SANDY LOAM

|                  |         |         |         |         |
|------------------|---------|---------|---------|---------|
| Cn               | 15.00   | 20.00   | 25.00   | 30.00   |
| Ave. Weight kN   | NA      | NA      | NA      | NA      |
| RR kN            | NA      | NA      | NA      | NA      |
| Tractor kW       | 97.00   | 97.00   | 97.00   | 97.00   |
| Tractor RR kN    | 8.42    | 7.02    | 6.18    | 5.62    |
| Total RR kN      | 8.42    | 7.02    | 6.18    | 5.62    |
| Mach. Draft kN   | 13.65   | 13.65   | 13.65   | 13.65   |
| Total kN         | 22.07   | 20.67   | 19.83   | 19.27   |
| Speed km/h       | 6.00    | 6.00    | 6.00    | 6.00    |
| DrawBarPower kW  | 36.79   | 34.45   | 33.05   | 32.11   |
| T and T coef.    | 0.49    | 0.61    | 0.68    | 0.74    |
| PTO Equiv. kW    | 75.08   | 56.48   | 48.60   | 43.39   |
| PTO Oper. kW*    | NA      | NA      | NA      | NA      |
| PTO Equiv. kW    | 75.08   | 56.48   | 48.60   | 43.39   |
| Total PTO req kW | 75.08   | 56.48   | 48.60   | 43.39   |
| Max. PTO Av. kW  | 97.38   | 97.38   | 97.38   | 97.38   |
| PTO REQ./MAX PTO | 0.77    | 0.58    | 0.50    | 0.45    |
| Fuel Use l/h*    | 37.35   | 30.38   | 27.91   | 26.29   |
| Oil Use l/h*     | 0.08    | 0.08    | 0.08    | 0.08    |
| Total Fuel l/h   | 37.43   | 30.46   | 27.99   | 26.37   |
| conv. MJ/l#      | 47.80   | 47.80   | 47.80   | 47.80   |
| TOTAL MJ/h       | 1789.30 | 1456.12 | 1337.91 | 1260.65 |

DISK-HARROW; CLAY

|                  |         |         |         |         |
|------------------|---------|---------|---------|---------|
| Cn               | 15.00   | 20.00   | 25.00   | 30.00   |
| Ave. Weight kN   | NA      | NA      | NA      | NA      |
| RR kN            | NA      | NA      | NA      | NA      |
| Tractor kW       | 97.00   | 97.00   | 97.00   | 97.00   |
| Tractor RR kN    | 8.42    | 7.02    | 6.18    | 5.62    |
| Total RR kN      | 8.42    | 7.02    | 6.18    | 5.62    |
| Mach. Draft kN   | 25.73   | 25.73   | 25.73   | 25.73   |
| Total kN         | 34.15   | 32.75   | 31.90   | 31.34   |
| Speed km/h       | 6.00    | 6.00    | 6.00    | 6.00    |
| DrawBarPower kW  | 56.92   | 54.58   | 53.17   | 52.24   |
| T and T coef.    | 0.49    | 0.61    | 0.68    | 0.74    |
| PTO Equiv. kW    | 116.15  | 89.47   | 78.19   | 70.59   |
| PTO Oper. kW*    | NA      | NA      | NA      | NA      |
| PTO Equiv. kW    | 116.15  | 89.47   | 78.19   | 70.59   |
| Total PTO req kW | 116.15  | 89.47   | 78.19   | 70.59   |
| Max. PTO Av. kW  | 97.38   | 97.38   | 97.38   | 97.38   |
| PTO REQ./MAX PTO | 1.19    | 0.92    | 0.80    | 0.72    |
| Fuel Use l/h*    | 65.99   | 44.82   | 38.78   | 35.45   |
| Oil Use l/h*     | 0.08    | 0.08    | 0.08    | 0.08    |
| Total Fuel l/h   | 66.07   | 44.90   | 38.86   | 35.53   |
| conv. MJ/l#      | 47.80   | 47.80   | 47.80   | 47.80   |
| TOTAL MJ/h       | 3158.01 | 2146.29 | 1857.54 | 1698.17 |

\* ASAE (1983).

# Cervinka (1980).

**TABLE B.4.5 Fuel Consumptions for the Fertilizer Equipment.**

**BROADCASTER**

|                  |        |        |        |        |
|------------------|--------|--------|--------|--------|
| Cn               | 15.00  | 20.00  | 25.00  | 30.00  |
| Ave. Weight kN   | 33.97  | 33.97  | 33.97  | 33.97  |
| RR kN            | 4.08   | 3.40   | 2.99   | 2.72   |
| Tractor kW       | 47.00  | 47.00  | 47.00  | 47.00  |
| Tractor RR kN    | 5.16   | 4.30   | 3.78   | 3.44   |
| Total RR kN      | 9.23   | 7.70   | 6.77   | 6.16   |
| Mach. Draft kN   | NA     | NA     | NA     | NA     |
| Total kN         | 9.23   | 7.70   | 6.77   | 6.16   |
| Speed km/h       | 6.40   | 6.40   | 6.40   | 6.40   |
| DrawBarPower kW  | 16.42  | 13.68  | 12.04  | 10.95  |
| T and T coef.    | 0.49   | 0.61   | 0.68   | 0.74   |
| PTO Equiv. kW    | 33.51  | 22.43  | 17.71  | 14.79  |
| PTO Oper. kW*    | 2.00   | 2.00   | 2.00   | 2.00   |
| PTO Equiv. kW    | 33.51  | 22.43  | 17.71  | 14.79  |
| Total PTO req kW | 35.51  | 24.43  | 19.71  | 16.79  |
| Max. PTO Av. kW  | 46.62  | 46.62  | 46.62  | 46.62  |
| PTO REQ./MAX PTO | 0.76   | 0.52   | 0.42   | 0.36   |
| Fuel Use l/h*    | 17.69  | 13.72  | 12.25  | 11.27  |
| Oil Use l/h*     | 0.05   | 0.05   | 0.05   | 0.05   |
| Total Fuel l/h   | 17.74  | 13.77  | 12.30  | 11.32  |
| conv. MJ/l*      | 47.80  | 47.80  | 47.80  | 47.80  |
| TOTAL MJ/h       | 847.91 | 658.26 | 587.86 | 541.15 |

**MANURE SPREADER**

|                  |         |         |         |         |
|------------------|---------|---------|---------|---------|
| Cn               | 15.00   | 20.00   | 25.00   | 30.00   |
| Ave. Weight kN   | 64.11   | 64.11   | 64.11   | 64.11   |
| RR kN            | 7.69    | 6.41    | 5.64    | 5.13    |
| Tractor kW       | 97.00   | 97.00   | 97.00   | 97.00   |
| Tractor RR kN    | 8.42    | 7.02    | 6.18    | 5.62    |
| Total RR kN      | 16.12   | 13.43   | 11.82   | 10.74   |
| Mach. Draft kN   | NA      | NA      | NA      | NA      |
| Total kN         | 16.12   | 13.43   | 11.82   | 10.74   |
| Speed km/h       | 6.40    | 6.40    | 6.40    | 6.40    |
| DrawBarPower kW  | 28.65   | 23.88   | 21.01   | 19.10   |
| T and T coef.    | 0.49    | 0.61    | 0.68    | 0.74    |
| PTO Equiv. kW    | 58.48   | 39.14   | 30.90   | 25.81   |
| PTO Oper. kW*    | 12.70   | 12.70   | 12.70   | 12.70   |
| PTO Equiv. kW    | 58.48   | 39.14   | 30.90   | 25.81   |
| Total PTO req kW | 71.18   | 51.84   | 43.60   | 38.51   |
| Max. PTO Av. kW  | 97.38   | 97.38   | 97.38   | 97.38   |
| PTO REQ./MAX PTO | 0.73    | 0.53    | 0.45    | 0.40    |
| Fuel Use l/h*    | 35.69   | 28.92   | 26.36   | 24.72   |
| Oil Use l/h*     | 0.08    | 0.08    | 0.08    | 0.08    |
| Total Fuel l/h   | 35.77   | 29.00   | 26.44   | 24.80   |
| conv. MJ/l*      | 47.80   | 47.80   | 47.80   | 47.80   |
| TOTAL MJ/h       | 1709.62 | 1385.99 | 1263.78 | 1185.51 |

\* ASAE (1983).

# Cervinka (1980).

TABLE B.4.6 Fuel Consumptions for the Harvesting Equipment.

FORAGE CHOPPER

|                  |         |         |         |         |
|------------------|---------|---------|---------|---------|
| Cn               | 15.00   | 20.00   | 25.00   | 30.00   |
| Ave. Weight kN   | NA      | NA      | NA      | NA      |
| RR kN            | NA      | NA      | NA      | NA      |
| Tractor kW       | 97.00   | 97.00   | 97.00   | 97.00   |
| Tractor RR kN    | 9.84    | 8.20    | 7.21    | 6.56    |
| Total RR kN      | 9.84    | 8.20    | 7.21    | 6.56    |
| Mach. Draft kN   | 6.16    | 5.13    | 4.51    | 4.10    |
| Total kN         | 15.99   | 13.33   | 11.73   | 10.66   |
| Speed km/h       | 6.00    | 6.00    | 6.00    | 6.00    |
| DrawBarPower kW  | 26.65   | 22.21   | 19.55   | 17.77   |
| T and T coef.    | 0.49    | 0.61    | 0.68    | 0.74    |
| PTO Equiv. kW    | 54.40   | 36.41   | 28.74   | 24.01   |
| PTO Oper. kW*    | 10.00   | 10.00   | 10.00   | 10.00   |
| PTO Equiv. kW    | 54.40   | 36.41   | 28.74   | 24.01   |
| Total PTO req kW | 64.40   | 46.41   | 38.74   | 34.01   |
| Max. PTO Av. kW  | 97.38   | 97.38   | 97.38   | 97.38   |
| PTO REQ./MAX PTO | 0.66    | 0.48    | 0.40    | 0.35    |
| Fuel Use l/h*    | 33.08   | 27.24   | 24.80   | 23.17   |
| Oil Use l/h*     | 0.08    | 0.08    | 0.08    | 0.08    |
| Total Fuel l/h   | 33.16   | 27.31   | 24.88   | 23.25   |
| conv. MJ/l*      | 47.80   | 47.80   | 47.80   | 47.80   |
| TOTAL MJ/h       | 1585.01 | 1305.65 | 1189.17 | 1111.13 |

FORAGE WAGONS

|                  |        |        |        |        |
|------------------|--------|--------|--------|--------|
| Cn               | 15.00  | 20.00  | 25.00  | 30.00  |
| Ave. Weight kN   | 51.30  | 51.30  | 51.30  | 51.30  |
| RR kN            | 6.16   | 5.13   | 4.51   | 4.10   |
| Tractor kW       | 47.00  | 47.00  | 47.00  | 47.00  |
| Tractor RR kN    | 5.16   | 4.30   | 3.78   | 3.44   |
| Total RR kN      | 11.31  | 9.43   | 8.30   | 7.54   |
| Mach. Draft kN   | NA     | NA     | NA     | NA     |
| Total kN         | 11.31  | 9.43   | 8.30   | 7.54   |
| Speed km/h       | 6.00   | 6.00   | 6.00   | 6.00   |
| DrawBarPower kW  | 18.86  | 15.71  | 13.83  | 12.57  |
| T and T coef.    | 0.49   | 0.61   | 0.68   | 0.74   |
| PTO Equiv. kW    | 38.48  | 25.76  | 20.34  | 16.99  |
| PTO Oper. kW*    | NA     | NA     | NA     | NA     |
| PTO Equiv. kW    | 38.48  | 25.76  | 20.34  | 16.99  |
| Total PTO req kW | 38.48  | 25.76  | 20.34  | 16.99  |
| Max. PTO Av. kW  | 46.62  | 46.62  | 46.62  | 46.62  |
| PTO REQ./MAX PTO | 0.83   | 0.55   | 0.44   | 0.36   |
| Fuel Use l/h*    | 19.08  | 14.14  | 12.45  | 11.34  |
| Oil Use l/h*     | 0.05   | 0.05   | 0.05   | 0.05   |
| Total Fuel l/h   | 19.13  | 14.19  | 12.50  | 11.39  |
| conv. MJ/l*      | 47.80  | 47.80  | 47.80  | 47.80  |
| TOTAL MJ/h       | 914.20 | 678.19 | 597.48 | 544.48 |

\* ASAE (1983).

# Cervinka (1980).

**TABLE B.5 Fuel Energy Listed by System and Operation.**

| OPERATION        | CSI     | CSO     | CCI     | CCO     |
|------------------|---------|---------|---------|---------|
| Planter          | 1278.71 | 1278.71 | 1078.81 | 1078.81 |
| Moldboard Plow   | 1396.41 | 1396.41 | 1712.48 | 1712.48 |
| Chisel Plow      | NA      | NA      | NA      | NA      |
| Disk-harrow      | 1011.19 | 1011.19 | 1289.96 | 1289.96 |
| Sprayer          | 525.73  | 525.73  | 435.73  | 435.73  |
| Broadcaster      | 109.83  | NA      | 85.27   | NA      |
| Manure Spreader  | NA      | 993.96  | NA      | 805.81  |
| Forage Chopper   | 2830.38 | 2830.38 | 2331.51 | 2331.51 |
| Forage Wagons(3) | 816.25  | 816.25  | 605.52  | 605.52  |
| TOTAL MJ/ha      | 7968.51 | 8852.64 | 7539.28 | 8259.82 |
|                  | RSI     | RSO     | RCI     | RCO     |
| Planter          | 1078.81 | 1078.81 | 977.26  | 977.26  |
| Moldboard Plow   | NA      | NA      | NA      | NA      |
| Chisel Plow      | 2174.68 | 2174.68 | 1921.20 | 1921.20 |
| Disk-harrow      | 505.60  | 505.60  | 644.98  | 644.98  |
| Sprayer          | 435.73  | 435.73  | 388.12  | 388.12  |
| Broadcaster      | 85.27   | NA      | 76.15   | NA      |
| Manure Spreader  | NA      | 805.81  | NA      | 734.76  |
| Forage Chopper   | 2331.51 | 2331.51 | 2123.52 | 2123.52 |
| Forage Wagons(3) | 605.52  | 605.52  | 533.46  | 533.46  |
| TOTAL MJ/ha      | 7217.11 | 7937.65 | 6664.69 | 7323.30 |
|                  | ZSI     | ZSO     | ZCI     | ZCO     |
| Planter          | 977.26  | 977.26  | 903.21  | 903.21  |
| Moldboard Plow   | NA      | NA      | NA      | NA      |
| Chisel Plow      | NA      | NA      | NA      | NA      |
| Disk-harrow      | NA      | NA      | NA      | NA      |
| Sprayer          | 388.12  | 388.12  | 354.25  | 354.25  |
| Broadcaster      | 76.15   | NA      | 70.10   | NA      |
| Manure Spreader  | NA      | 734.76  | NA      | 689.25  |
| Forage Chopper   | 2123.52 | 2123.52 | 1984.16 | 1984.16 |
| Forage Wagons(3) | 533.46  | 533.46  | 486.14  | 486.14  |
| TOTAL MJ/ha      | 4098.51 | 4757.12 | 3797.85 | 4417.01 |

## Appendix C

### Fertilizer and Herbicide Energy Calculations

|                             | page |
|-----------------------------|------|
| C.1) Fertilizer Energy..... | 119  |
| C.2) Herbicide Energy.....  | 120  |

TABLE C.1 Fertilizer Energy Calculations

| Type             | Amount<br>kg/ha | Conv.*<br>MJ/kg | Energy<br>MJ/ha |        |
|------------------|-----------------|-----------------|-----------------|--------|
| Urea             | 170.00          | 59.87           | 10177.90        |        |
| Ammonium Nitrate | 170.00          | 61.55           | 10463.50        |        |
| 3-superphosphate | 75.00           | 12.56           | 942.00          |        |
| Muriate Potash   | 80.00           | 6.70            | 536.00          |        |
|                  |                 |                 |                 |        |
|                  | CSI             | CSO             | CCI             | CCO    |
| Urea             | 10177.90        | NA              | 10177.90        | NA     |
| Ammonium Nitrate | NA              | NA              | NA              | NA     |
| 3-superphosphate | 942.00          | 942.00          | 942.00          | 942.00 |
| Muriate Potash   | 536.00          | NA              | 536.00          | NA     |
| TOTAL MJ/ha      | 11655.90        | 942.00          | 11655.90        | 942.00 |
|                  |                 |                 |                 |        |
|                  | RSI             | RSO             | RCI             | RCO    |
| Urea             | 10177.90        | NA              | 10177.90        | NA     |
| Ammonium Nitrate | NA              | NA              | NA              | NA     |
| 3-superphosphate | 942.00          | 942.00          | 942.00          | 942.00 |
| Muriate Potash   | 536.00          | NA              | 536.00          | NA     |
| TOTAL MJ/ha      | 11655.90        | 942.00          | 11655.90        | 942.00 |
|                  |                 |                 |                 |        |
|                  | ZSI             | ZSO             | ZCI             | ZCO    |
| Urea             | NA              | NA              | NA              | NA     |
| Ammonium Nitrate | 10463.50        | NA              | 10463.50        | NA     |
| 3-superphosphate | 942.00          | 942.00          | 942.00          | 942.00 |
| Muriate Potash   | 536.00          | NA              | 536.00          | NA     |
| TOTAL MJ/ha      | 11941.50        | 942.00          | 11941.50        | 942.00 |

\* Lockertz (1980).

TABLE C.2 Herbicide Energy Calculations.

| Type        | Amount<br>kg/ha | Conv.*<br>MJ/kg | Energy<br>MJ/ha |         |
|-------------|-----------------|-----------------|-----------------|---------|
| Atrazine    | 1.50            | 369.00          | 553.50          |         |
| Alachlor    | 2.50            | 418.30          | 1045.75         |         |
| Bent & Cit  | 1.68            | 362.60          | 609.17          |         |
|             |                 |                 |                 |         |
|             | CSI             | CSO             | CCI             | CCO     |
| Atrazine    | 553.50          | 553.50          | 553.50          | 553.50  |
| Alachlor    | 1045.75         | 1045.75         | 1045.75         | 1045.75 |
| Bent & Cit  | 609.17          | 609.17          | 609.17          | 609.17  |
| TOTAL MJ/ha | 2208.42         | 2208.42         | 2208.42         | 2208.42 |
|             |                 |                 |                 |         |
|             | RSI             | RSO             | RCI             | RCO     |
| Atrazine    | 553.50          | 553.50          | 553.50          | 553.50  |
| Alachlor    | 1045.75         | 1045.75         | 1045.75         | 1045.75 |
| Bent & Cit  | 609.17          | 609.17          | 609.17          | 609.17  |
| TOTAL MJ/ha | 2208.42         | 2208.42         | 2208.42         | 2208.42 |
|             |                 |                 |                 |         |
|             | ZSI             | ZSO             | ZCI             | ZCO     |
| Atrazine    | 553.50          | 553.50          | 553.50          | 553.50  |
| Alachlor    | 1045.75         | 1045.75         | 1045.75         | 1045.75 |
| Bent & Cit  | 609.17          | 609.17          | 609.17          | 609.17  |
| TOTAL MJ/ha | 2208.42         | 2208.42         | 2208.42         | 2208.42 |

\* Pimmental (1980).

**Appendix D**  
**Labour Requirements**

|                                                                | page |
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| D.1) Time Required for Each Operation....                      | 122  |
| D.2) Time Required for Each System Listed<br>by Operation..... | 123  |
| D.3) Time Required for 25 ha.....                              | 124  |

TABLE D.1 Time Required for Each Operation.

| OPERATION        | CAPACITY*<br>ha/h | # of PASSES | CORN<br>ha | TIME<br>h |
|------------------|-------------------|-------------|------------|-----------|
| Planter          | 1.01              | 1.00        | 1.00       | 1.00      |
| Moldboard Plow   | 1.02              | 1.00        | 1.00       | 0.99      |
| Chisel Plow      | 0.84              | 1.00        | 1.00       | 1.19      |
| Disk-harrow(1)   | 2.88              | 1.00        | 1.00       | 0.35      |
| Disk-harrow(2)   | 2.88              | 2.00        | 1.00       | 0.69      |
| Sprayer          | 3.43              | 3.00        | 1.00       | 0.87      |
| Broadcaster      | 7.72              | 1.00        | 1.00       | 0.13      |
| Manure Spreader  | 1.72              | 1.00        | 1.00       | 0.58      |
| Forage Chopper   | 0.56              | 1.00        | 1.00       | 1.79      |
| Forage Wagons(3) | 0.56              | 1.00        | 1.00       | 1.79      |

(1) Disk-harrow use in the reduced tillage system.

(2) Disk-harrow use in the conventional tillage system.

(3) Forage wagons operated simultaneously

\* Capacity from Appendix A.

TABLE D.2 Time Required for Each System Listed by Operation.

| OPERATION        | CSI  | CSO  | CCI  | CCO  |
|------------------|------|------|------|------|
| Planter          | 1.00 | 1.00 | 1.00 | 1.00 |
| Moldboard Plow   | 0.99 | 0.99 | 0.99 | 0.99 |
| Chisel Plow      | NA   | NA   | NA   | NA   |
| Disk-harrow      | 0.69 | 0.69 | 0.69 | 0.69 |
| Sprayer          | 0.87 | 0.87 | 0.87 | 0.87 |
| Broadcaster      | 0.13 | NA   | 0.13 | NA   |
| Manure Spreader  | NA   | 0.58 | NA   | 0.58 |
| Forage Chopper   | 1.79 | 1.79 | 1.79 | 1.79 |
| Forage Wagons(3) | 1.79 | 1.79 | 1.79 | 1.79 |
| TOTAL MAN-HOURS  | 7.26 | 7.72 | 7.26 | 7.72 |

| OPERATION        | RSI  | RSO  | RCI  | RCO  |
|------------------|------|------|------|------|
| Planter          | 1.00 | 1.00 | 1.00 | 1.00 |
| Moldboard Plow   | NA   | NA   | NA   | NA   |
| Chisel Plow      | 1.19 | 1.19 | 1.19 | 1.19 |
| Disk-harrow      | 0.35 | 0.35 | 0.35 | 0.35 |
| Sprayer          | 0.87 | 0.87 | 0.87 | 0.87 |
| Broadcaster      | 0.13 | NA   | 0.13 | NA   |
| Manure Spreader  | NA   | 0.58 | NA   | 0.58 |
| Forage Chopper   | 1.79 | 1.79 | 1.79 | 1.79 |
| Forage Wagons(3) | 1.79 | 1.79 | 1.79 | 1.79 |
| TOTAL MAN-HOURS  | 7.12 | 7.57 | 7.12 | 7.57 |

| OPERATION        | ZSI  | ZSO  | ZCI  | ZCO  |
|------------------|------|------|------|------|
| Planter          | 1.00 | 1.00 | 1.00 | 1.00 |
| Moldboard Plow   | NA   | NA   | NA   | NA   |
| Chisel Plow      | NA   | NA   | NA   | NA   |
| Disk-harrow      | NA   | NA   | NA   | NA   |
| Sprayer          | 0.87 | 0.87 | 0.87 | 0.87 |
| Broadcaster      | 0.13 | NA   | 0.13 | NA   |
| Manure Spreader  | NA   | 0.58 | NA   | 0.58 |
| Forage Chopper   | 1.79 | 1.79 | 1.79 | 1.79 |
| Forage Wagons(3) | 1.79 | 1.79 | 1.79 | 1.79 |
| TOTAL MAN-HOURS  | 5.58 | 6.04 | 5.58 | 6.04 |

TABLE D.3 Time Required for 25 ha.

| OPERATION        | CSI    | CSO    | CCI    | CCO    |
|------------------|--------|--------|--------|--------|
| Planter          | 24.88  | 24.88  | 24.88  | 24.88  |
| Moldboard Plow   | 24.63  | 24.63  | 24.63  | 24.63  |
| Chisel Plow      | NA     | NA     | NA     | NA     |
| Disk-harrow      | 17.36  | 17.36  | 17.36  | 17.36  |
| Sprayer          | 21.86  | 21.86  | 21.86  | 21.86  |
| Broadcaster      | 3.24   | NA     | 3.24   | NA     |
| Manure Spreader  | NA     | 14.58  | NA     | 14.58  |
| Forage Chopper   | 44.80  | 44.80  | 44.80  | 44.80  |
| Forage Wagons(3) | 44.80  | 44.80  | 44.80  | 44.80  |
| TOTAL MAN-HOURS  | 181.58 | 192.91 | 181.58 | 192.91 |

| OPERATION        | RSI    | RSO    | RCI    | RCO    |
|------------------|--------|--------|--------|--------|
| Planter          | 24.88  | 24.88  | 24.88  | 24.88  |
| Moldboard Plow   | NA     | NA     | NA     | NA     |
| Chisel Plow      | 29.76  | 29.76  | 29.76  | 29.76  |
| Disk-harrow      | 8.68   | 8.68   | 8.68   | 8.68   |
| Sprayer          | 21.86  | 21.86  | 21.86  | 21.86  |
| Broadcaster      | 3.24   | NA     | 3.24   | NA     |
| Manure Spreader  | NA     | 14.58  | NA     | 14.58  |
| Forage Chopper   | 44.80  | 44.80  | 44.80  | 44.80  |
| Forage Wagons(3) | 44.80  | 44.80  | 44.80  | 44.80  |
| TOTAL MAN-HOURS  | 178.03 | 189.36 | 178.03 | 189.36 |

| OPERATION        | ZSI    | ZSO    | ZCI    | ZCO    |
|------------------|--------|--------|--------|--------|
| Planter          | 24.88  | 24.88  | 24.88  | 24.88  |
| Moldboard Plow   | NA     | NA     | NA     | NA     |
| Chisel Plow      | NA     | NA     | NA     | NA     |
| Disk-harrow      | NA     | NA     | NA     | NA     |
| Sprayer          | 21.86  | 21.86  | 21.86  | 21.86  |
| Broadcaster      | 3.24   | NA     | 3.24   | NA     |
| Manure Spreader  | NA     | 14.58  | NA     | 14.58  |
| Forage Chopper   | 44.80  | 44.80  | 44.80  | 44.80  |
| Forage Wagons(3) | 44.80  | 44.80  | 44.80  | 44.80  |
| TOTAL MAN-HOURS  | 139.58 | 150.92 | 139.58 | 150.92 |

**Appendix E**  
**Cost Analysis Calculations**

|                                                              | page |
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TABLE E.1 Average Machinery Prices.

| DEALER           | GIL BEAUDRY<br>FARM SUPPLIES<br>WINCHESTER<br>ONT. | TIBBEN<br>EQUIPMENT<br>IROQUOIS<br>ONT. | ALFRED FARM<br>EQUIPMENT<br>ALFRED<br>ONT. |
|------------------|----------------------------------------------------|-----------------------------------------|--------------------------------------------|
| MACHINE          | \$                                                 | \$                                      | \$                                         |
| 97 kw Tractor    | 75000.00                                           | 45000.00                                | 60000.00                                   |
| 47 kW Tractor    | 35000.00                                           | 17000.00                                | 24000.00                                   |
| Planter          | 15000.00                                           | 8000.00                                 | 11000.00                                   |
| Moldboard Plow   | 12000.00                                           | 8000.00                                 | 8000.00                                    |
| Chisel Plow      | 6000.00                                            | 5000.00                                 | 11000.00                                   |
| Disk-harrow(1)   | 8000.00                                            | 9000.00                                 | 9500.00                                    |
| Disk harrow(2)   | 8000.00                                            | 9000.00                                 | 9500.00                                    |
| Sprayer          | 5500.00                                            | 2250.00                                 | 2200.00                                    |
| Broadcaster      | 1500.00                                            | 2500.00                                 | 2000.00                                    |
| Manure Spreader  | 10000.00                                           | 7000.00                                 | 10000.00                                   |
| Forage Chopper   | 17000.00                                           | 18000.00                                | 22000.00                                   |
| Forage Wagons(3) | 16500.00                                           | 18000.00                                | 20400.00                                   |

MARTIN & MUIR    GARY SMITH  
EQUIPMENT    SALES & SERVICE  
MAXVILLE    MAXVILLE  
ONT.    ONT.

|                  | \$       | \$       | AVERAGE<br>\$ |
|------------------|----------|----------|---------------|
| 97 kw Tractor    | 54000.00 | 50000.00 | 56800.00      |
| 47 kW Tractor    | 21000.00 | 18000.00 | 23000.00      |
| Planter          | NA       | 9000.00  | 10750.00      |
| Moldboard Plow   | 11000.00 | 12000.00 | 10200.00      |
| Chisel Plow      | NA       | 3000.00  | 6250.00       |
| Disk-harrow(1)   | 16500.00 | 10000.00 | 10600.00      |
| Disk-harrow(2)   | 16500.00 | 10000.00 | 10600.00      |
| Sprayer          | 4000.00  | 2500.00  | 3290.00       |
| Broadcaster      | NA       | 5000.00  | 2750.00       |
| Manure Spreader  | 11000.00 | 8000.00  | 9200.00       |
| Forage Chopper   | 21000.00 | 25000.00 | 20600.00      |
| Forage Wagons(3) | 22500.00 | 22500.00 | 19980.00      |

NA: Not Available.

- (1) Disk-harrow use in the reduced tillage system.
- (2) Disk-harrow use in the conventional tillage system.
- (3) Three forage wagons in total.

Note: For additional machine parameters see Table 5.

**TABLE B.2 Machinery Cost Calculations.**

| MACHINE          | PERCENT<br>SALVAGE | INT.<br>RATE | AVG COST<br>\$ | FC*<br>\$/year | FC<br>\$/h |
|------------------|--------------------|--------------|----------------|----------------|------------|
| 97 kw tractor    | 0.10               | 0.14         | 56800.00       | 10621.60       | 17.70      |
| 47 kw tractor    | 0.10               | 0.14         | 23000.00       | 4301.00        | 10.75      |
| Planter          | 0.10               | 0.14         | 10750.00       | 1687.75        | 67.85      |
| Moldboard Plow   | 0.10               | 0.14         | 10200.00       | 1601.40        | 65.02      |
| Chisel Plow      | 0.10               | 0.14         | 6250.00        | 981.25         | 32.97      |
| Disk-harrow(1)   | 0.10               | 0.14         | 10600.00       | 1664.20        | 191.72     |
| Disk-harrow(2)   | 0.10               | 0.14         | 10600.00       | 1664.20        | 95.86      |
| Sprayer          | 0.10               | 0.14         | 3290.00        | 689.26         | 31.53      |
| Broadcaster      | 0.10               | 0.14         | 2750.00        | 576.13         | 177.87     |
| Manure Spreader  | 0.10               | 0.14         | 9200.00        | 1927.40        | 132.24     |
| Forage Chopper   | 0.10               | 0.14         | 20600.00       | 3852.20        | 85.98      |
| Forage Wagons(3) | 0.10               | 0.14         | 19980.00       | 3136.86        | 70.01      |

| MACHINE          | AVG REP**<br>% | TOTAL<br>\$/h | TRACTOR<br>kW | OPERATION<br>\$/h | TOT.<br>\$/ha |
|------------------|----------------|---------------|---------------|-------------------|---------------|
| 97 kw tractor    | 0.010          | 23.38         | NA            | NA                | NA            |
| 47 kw tractor    | 0.010          | 13.05         | NA            | NA                | NA            |
| Planter          | 0.075          | 75.91         | 97.00         | 99.29             | 98.80         |
| Moldboard Plow   | 0.080          | 73.18         | 97.00         | 96.56             | 95.13         |
| Chisel Plow      | 0.048          | 35.97         | 97.00         | 59.35             | 70.66         |
| Disk harrow(1)   | 0.048          | 196.80        | 97.00         | 220.19            | 76.45         |
| Disk-harrow(2)   | 0.048          | 100.95        | 97.00         | 124.33            | 86.34         |
| Sprayer          | 0.100          | 34.82         | 47.00         | 47.87             | 41.86         |
| Broadcaster      | 0.100          | 180.62        | 47.00         | 193.67            | 25.09         |
| Manure Spreader  | 0.100          | 141.44        | 97.00         | 164.82            | 96.09         |
| Forage Chopper   | 0.040          | 94.22         | 97.00         | 117.60            | 210.76        |
| Forage Wagons(3) | 0.018          | 73.61         | 47.00         | 86.66             | 155.31        |

(1) Disk-harrow use in the reduced tillage system.

(2) Disk-harrow use in the conventional tillage system.

(3) Three forage wagons in total.

\* Fixed Costs, ASAE (1983).

\*\* Average hourly repairs, Kepner et al. (1978).

**TABLE E.3 Machinery Costs Listed by System and Operation.**

| MACHINE          | CSI    | CSO    | CCI    | CCO    |
|------------------|--------|--------|--------|--------|
| 97 kw Tractor    | NA     | NA     | NA     | NA     |
| 47 kW Tractor    | NA     | NA     | NA     | NA     |
| Planter          | 98.80  | 98.80  | 98.80  | 98.80  |
| Moldboard Plow   | 95.13  | 95.13  | 95.13  | 95.13  |
| Chisel Plow      | NA     | NA     | NA     | NA     |
| Disk-harrow      | 86.34  | 86.34  | 86.34  | 86.34  |
| Sprayer          | 41.86  | 41.86  | 41.86  | 41.86  |
| Broadcaster      | 25.09  | NA     | 25.09  | NA     |
| Manure Spreader  | NA     | 96.09  | NA     | 96.09  |
| Forage Chopper   | 210.76 | 210.76 | 210.76 | 210.76 |
| Forage Wagons(3) | 155.31 | 155.31 | 155.31 | 155.31 |
| TOTAL \$/ha      | 713.30 | 784.30 | 713.30 | 784.30 |

| MACHINE          | RSI    | RSO    | RCI    | RCO    |
|------------------|--------|--------|--------|--------|
| 97 kw Tractor    | NA     | NA     | NA     | NA     |
| 47 kW Tractor    | NA     | NA     | NA     | NA     |
| Planter          | 98.80  | 98.80  | 98.80  | 98.80  |
| Moldboard Plow   | NA     | NA     | NA     | NA     |
| Chisel Plow      | 70.66  | 70.66  | 70.66  | 70.66  |
| Disk-harrow      | 76.45  | 76.45  | 76.45  | 76.45  |
| Sprayer          | 41.86  | 41.86  | 41.86  | 41.86  |
| Broadcaster      | 25.09  | NA     | 25.09  | NA     |
| Manure Spreader  | NA     | 96.09  | NA     | 96.09  |
| Forage Chopper   | 210.76 | 210.76 | 210.76 | 210.76 |
| Forage Wagons(3) | 155.31 | 155.31 | 155.31 | 155.31 |
| TOTAL \$/ha      | 678.94 | 749.94 | 678.94 | 749.94 |

| MACHINE          | ZSI    | ZSO    | ZCI    | ZCO    |
|------------------|--------|--------|--------|--------|
| 97 kw Tractor    | NA     | NA     | NA     | NA     |
| 47 kW Tractor    | NA     | NA     | NA     | NA     |
| Planter          | 98.80  | 98.80  | 98.80  | 98.80  |
| Moldboard Plow   | NA     | NA     | NA     | NA     |
| Chisel Plow      | NA     | NA     | NA     | NA     |
| Disk-harrow      | NA     | NA     | NA     | NA     |
| Sprayer          | 41.86  | 41.86  | 41.86  | 41.86  |
| Broadcaster      | 25.09  | NA     | 25.09  | NA     |
| Manure Spreader  | NA     | 96.09  | NA     | 96.09  |
| Forage Chopper   | 210.76 | 210.76 | 210.76 | 210.76 |
| Forage Wagons(3) | 155.31 | 155.31 | 155.31 | 155.31 |
| TOTAL \$/ha      | 531.82 | 602.82 | 531.82 | 602.82 |

(3) Three forage wagons in total.

TABLE E.4 Cost Calculations of the Various Inputs.

| INPUT             |            | TOTAL<br>RATE kg/ha<br>ACTIVE INGR. | TOTAL<br>RATE |
|-------------------|------------|-------------------------------------|---------------|
| UREA              | 46-0-0     | 170.00                              | 369.57 kg/ha  |
| AMMONIUM NITRATE  | 34-0-0     | 170.00                              | 500.00 kg/ha  |
| 3-SUPERPHOSPHATE  | 0-44-0     | 75.00                               | 170.45 kg/ha  |
| MURIATE OF POTASH | 0-0-60     | 80.00                               | 133.33 kg/ha  |
| ATRAZINE          |            | 1.50                                | 1.50 kg/ha    |
| ALACHLOR          |            | 2.50                                | 5.22 L/ha     |
| KORNOIL           |            | NA                                  | 5.60 L/ha     |
| BENTAZON          |            | 1.68                                | 2.92 L/ha     |
| CITOWETT          |            | NA                                  | 0.01 L/ha     |
|                   |            |                                     |               |
|                   | UNIT*      |                                     | COST          |
|                   | COST       |                                     | \$/ha         |
| UREA              | 0.33 \$/kg |                                     | 121.96        |
| AMMONIUM NITRATE  | 0.29 \$/kg |                                     | 143.00        |
| 3-SUPERPHOSPHATE  | 0.32 \$/kg |                                     | 53.86         |
| MURIATE OF POTASH | 0.20 \$/kg |                                     | 26.67         |
| ATRAZINE          | 5.55 \$/kg |                                     | 8.33          |
| ALACHLOR          | 6.40 \$/L  |                                     | 33.39         |
| KORNOIL           | 1.60 \$/L  |                                     | 8.96          |
| BENTAZON          | 25.25 \$/L |                                     | 73.77         |
| CITOWETT          | 4.80 \$/L  |                                     | 0.04          |
| HERB TOTAL *      |            |                                     | 124.48        |
| SEED *            |            |                                     | 30.00         |

\* Price as quoted by Kemptville Co-op, Kemptville, Ontario, fall, 1984.

TABLE E.5 Input Cost Listed by System.

| SYSTEM | SEED<br>\$/ha | UREA<br>\$/ha | AM. NIT.<br>\$/ha | 3-PHOS<br>\$/ha |
|--------|---------------|---------------|-------------------|-----------------|
| CSI    | 30.00         | 121.96        | 0.00              | 53.86           |
| CSO    | 30.00         | 0.00          | 0.00              | 53.86           |
| CCI    | 30.00         | 121.96        | 0.00              | 53.86           |
| CCO    | 30.00         | 0.00          | 0.00              | 53.86           |
| RSI    | 30.00         | 121.96        | 0.00              | 53.86           |
| RSO    | 30.00         | 0.00          | 0.00              | 53.86           |
| RCI    | 30.00         | 121.96        | 0.00              | 53.86           |
| RCO    | 30.00         | 0.00          | 0.00              | 53.86           |
| ZSI    | 30.00         | 0.00          | 143.00            | 53.86           |
| ZSO    | 30.00         | 0.00          | 0.00              | 53.86           |
| ZCI    | 30.00         | 0.00          | 143.00            | 53.86           |
| ZCO    | 30.00         | 0.00          | 0.00              | 53.86           |

|     | POTASH<br>\$/ha | HERBICIDE<br>\$/ha | TOTAL<br>\$/ha |
|-----|-----------------|--------------------|----------------|
| CSI | 26.67           | 124.48             | 356.96         |
| CSO | 0.00            | 124.48             | 208.34         |
| CCI | 26.67           | 124.48             | 356.96         |
| CCO | 0.00            | 124.48             | 208.34         |
| RSI | 26.67           | 124.48             | 356.96         |
| RSO | 0.00            | 124.48             | 208.34         |
| RCI | 26.67           | 124.48             | 356.96         |
| RCO | 0.00            | 124.48             | 208.34         |
| ZSI | 26.67           | 124.48             | 378.01         |
| ZSO | 0.00            | 124.48             | 208.34         |
| ZCI | 26.67           | 124.48             | 378.01         |
| ZCO | 0.00            | 124.48             | 208.34         |

TABLE E.6 Labour and Fuel Cost Calculations.

| SYSTEM | LABOUR  | LABOUR*        | LABOUR        |
|--------|---------|----------------|---------------|
|        | h/ha    | CHARGE<br>\$/h | COST<br>\$/ha |
| CSI    | 7.26    | 8.00           | 58.10         |
| CSO    | 7.72    | 8.00           | 61.73         |
| CCI    | 7.26    | 8.00           | 58.10         |
| CCO    | 7.72    | 8.00           | 61.73         |
| RSI    | 7.12    | 8.00           | 56.97         |
| RSO    | 7.57    | 8.00           | 60.60         |
| RCI    | 7.12    | 8.00           | 56.97         |
| RCO    | 7.57    | 8.00           | 60.60         |
| ZSI    | 5.58    | 8.00           | 44.67         |
| ZSO    | 6.04    | 8.00           | 48.29         |
| ZCI    | 5.58    | 8.00           | 44.67         |
| ZCO    | 6.04    | 8.00           | 48.29         |
|        | FUEL    | FUEL*          | FUEL          |
|        | CONSUMP | PRICE          | COST          |
|        | L/ha    | \$/L           | \$/ha         |
| CSI    | 166.15  | 0.45           | 74.77         |
| CSO    | 184.64  | 0.45           | 83.09         |
| CCI    | 157.17  | 0.45           | 70.72         |
| CCO    | 172.24  | 0.45           | 77.51         |
| RSI    | 150.43  | 0.45           | 67.69         |
| RSO    | 165.50  | 0.45           | 74.47         |
| RCI    | 138.87  | 0.45           | 62.49         |
| RCO    | 152.65  | 0.45           | 68.69         |
| ZSI    | 85.18   | 0.45           | 38.33         |
| ZSO    | 98.96   | 0.45           | 44.53         |
| ZCI    | 78.89   | 0.45           | 35.50         |
| ZCO    | 91.85   | 0.45           | 41.33         |

\* Eastern Ontario prices, fall 1984.

## Appendix F

### Statistical Analysis of Plant Yields

page

F.1) Yield Results from the Sandy Loam  
Site..... 133

F.2) Yield Results from the Clay Site.... 134

TABLE F.1 Yield Results from the Sandy Loam Site.

Note: These values were determined by Kelly (1985).

| SOURCE  | DF | SUM<br>OF<br>SQUARES | MEAN<br>SQUARE | F VALUE | PR > F   | R-SQUARE | C.V.    |
|---------|----|----------------------|----------------|---------|----------|----------|---------|
| Model   | 7  | 11.2966              | 1.6138         | 3.1400  | 0.0499   | 0.6871   | 6.9006  |
| Error   | 10 | 5.1442               | 0.5144         |         | ROOT MSE |          | MEAN    |
| Cor. To | 17 | 16.4409              |                |         | 0.7172   |          | 10.3937 |

| SOURCE  | DF | ANOVA<br>SS | F    | PR > F |
|---------|----|-------------|------|--------|
| Block   | 2  | 2.7824      | 2.70 | 0.1151 |
| Fert    | 1  | 1.0898      | 2.12 | 0.1762 |
| Till    | 2  | 5.9738      | 5.81 | 0.0212 |
| Till*Fe | 2  | 1.4507      | 1.41 | 0.2880 |

Duncan's Multiple Range Test for yield.

Alpha 0.05 DF=10 MSE=0.5144

Means with the same grouping are not significantly different

| TILLAGE | N | MEAN   | GROUPING |
|---------|---|--------|----------|
| Reduced | 6 | 10.938 | A        |
| Conven. | 6 | 10.646 | A        |
| No-till | 6 | 9.597  | B        |

| FERT.   | N | MEAN   | GROUPING |
|---------|---|--------|----------|
| Organic | 9 | 10.640 | A        |
| Inorgan | 9 | 10.148 | A        |

| BLOCK | N | MEAN   | GROUPING |
|-------|---|--------|----------|
| 3     | 6 | 10.891 | A        |
| 1     | 6 | 10.360 | A        |
| 2     | 6 | 9.930  | A        |

TABLE F.2 Yield Results from the Clay Site.

Note: These values were determined by Kelly (1985).

| SOURCE  | DF | SUM<br>OF<br>SQUARES | MEAN<br>SQUARE | F VALUE | PR > F   | R-SQUARE | C.V.    |
|---------|----|----------------------|----------------|---------|----------|----------|---------|
| Model   | 7  | 17.2739              | 2.4677         | 8.4500  | 0.0016   | 0.8552   | 4.6128  |
| Error   | 10 | 2.9195               | 0.2919         |         | ROOT MSE |          | MEAN    |
| Cor. To | 17 | 20.1934              |                |         | 0.5403   |          | 11.7134 |

| SOURCE  | DF | ANOVA<br>SS | F     | PR > F |
|---------|----|-------------|-------|--------|
| Block   | 2  | 12.5829     | 21.55 | 0.0002 |
| Fert    | 1  | 0.1214      | 0.42  | 0.5336 |
| Till    | 2  | 2.9651      | 5.08  | 0.0301 |
| Till*Fe | 2  | 1.6045      | 2.75  | 0.1119 |

Duncan's Multiple Range Test for yield.

Alpha=0.05 DF=10 MSE=0.5144

Means with the same grouping are not significantly different

| TILLAGE | N | MEAN   | GROUPING |
|---------|---|--------|----------|
| Conven. | 6 | 12.192 | A        |
| Reduced | 6 | 11.748 | AB       |
| No-till | 6 | 11.200 | B        |

| FERT.   | N | MEAN   | GROUPING |
|---------|---|--------|----------|
| Inorgan | 9 | 11.796 | A        |
| Organic | 9 | 11.631 | A        |

| BLOCK | N | MEAN   | GROUPING |
|-------|---|--------|----------|
| 3     | 6 | 12.759 | A        |
| 1     | 6 | 11.668 | B        |
| 2     | 6 | 10.713 | C        |