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# TILLAGE AND PLANTING ENERGIES FOR CORN PRODUCTION UNDER THREE TILLAGE SYSTEMS ON A CLAY-LOAM SOIL

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**ABSTRACT** Diesel fuel for field operations represents a major portion of total energy input for crop production. Of these, fuel for tillage is generally the largest. Energy measurements for tillage and planting were made on the corn phase of an existing field experiment with a corn-soybean-winter wheat rotation on a clay-loam soil. Three tillage treatments were used, conventional till, zone till and no till. Conventional till consisted of fall moldboard plow followed by two cultivations in the spring. For zone till, 200 mm wide strips spaced on 760 mm centers were tilled in the fall and the 560 mm wide strips between the tilled zones were left untilled. In the following spring, corn was planted directly into the tilled strips without additional tillage. For no till, corn was planted directly into the previous year's winter wheat stubble. Drawbar energy data for tillage and planting operations were acquired with an instrumented research tractor over a three year period. Total drawbar energy consumption over the three year period ranged from 185 to 266 MJ/ha for conventional till, 54 to 83 MJ/ha for zone till, and 12 to 16 MJ/ha for no till. Tillage and planting energy represents only part of the total energy input for corn production, but nevertheless, the data reveal opportunities for substantial energy savings by selecting energy efficient tillage systems. Other energy intensive inputs (e.g. fertilizer and grain drying), and the resultant yields need to be included to determine the total energy cost per ton of corn produced.

**Keywords:** zone till, conventional till, no till, moldboard plow, field cultivator, drawbar energy

**INTRODUCTION** Diesel fuel for tillage and planting is a key input, and represents a significant portion of the total input cost for crop production in mechanized agriculture. Traditional field crop production in Eastern Canada includes fall moldboard plowing, two or more spring cultivations with discs or field cultivators, and planting in May. One obvious method of reducing fossil fuel costs is by reducing the number and intensity of tillage operations, either by adopting energy efficient conservation tillage systems, or by adopting no till crop production where tillage is eliminated entirely and the crop is planted directly into residue from the previous crop. No till has been successfully practiced by many producers on coarse or medium textured soils. However, it is more difficult to consistently achieve good yields on cohesive fine textured soils. Yields for no till show more variability among years than for conventional till in fine textured soils, and yield appears to be influenced by the weather and soil water content both before and shortly after spring planting. Many producers are not willing to take the risk of lower yields with no till in an unfavorable year.

Zone till is a relatively new tillage system which is well adapted to crops such as corn which are normally planted in rows spaced at 760 mm. Other terms such as strip till and band till have been used to describe the concept (Morrison, 2002). For consistency, the term zone till will be used in this paper. In zone till, only a narrow strip or zone of soil is tilled, and the soil between the zones is left untilled. In the following spring, corn is planted directly into the tilled zones. Zone till can be thought of as a combination of conventional till and no till. Since the untilled strips between the zones are usually much wider than the tilled zones, zone till usually meets the definition of conservation tillage where at least 30% of the soil surface is covered by plant residue (ASABE Standards, 2007). A number of machinery manufacturing companies have recently introduced equipment for zone till. Most of the zone till equipment employs a leading plain or notched coulter for cutting crop residue, which is followed by some combination of chisels and fluted coulters for tillage in a narrow zone or strip. Residue clearing or row cleaning wheels are often used move residue off the zone for more effective tillage.

No till and zone till have fewer field operations than conventional till, and therefore, total energy input would be expected to be lower. However, no till planters need to be much heavier, and therefore more expensive than conventional till planters, to cut residue and penetrate untilled soil. Counter arguments against no till are sometimes made that much of the machinery cost and energy saved by not tilling is consumed by pulling the more expensive and heavier planter in the tougher untilled soil. Also, well timed tillage is an effective weed control strategy, and was the sole weed control method prior to introduction of herbicides. Clearly, actual data on energy and input costs are required to properly assess the contrasting tillage systems.

The objective of this paper was to measure the tillage and planting energy requirements for corn production on a clay-loam soil under conventional till, zone till, and no till. The same no-till planter was used for all 3 tillage treatments.

**MATERIALS AND METHODS** Field experiments were carried out at the Agriculture and Agri-Food Canada Hon. Eugene F. Whalen Experimental Station, Woodslee, Ontario, Canada (Lat 42°13′ N, Long 82°44′ W). The soil was a Brookston clay loam with an average of 28% sand, 35% silt and 37% clay in the Ap horizon (0-200 mm). The soil was classified as an Orthic-Humic Gleysol in the Canadian soil classification system, and as a fine loamy mixed mesic Typic Argiaquoll in the U.S. soil classification system. The soil is moderately expansive (shrinkage limit ≈ 18 %, specific surface area ≈ 100-150 $m^2$ $g^{-1}$), and when cropped it is poorly structured, poorly drained and poorly aerated (Reynolds et al., 2009). Topography was flat with slope < 1%.

**Tillage Treatments** The energy measurements were conducted on an existing field experiment established in 1996 with a corn-soybean-winter wheat rotation and three tillage treatments. Three fields in close proximity were utilized such that each phase of the three year rotation was present in one of the fields in each year. The experimental design was a randomized complete block with three tillage treatments (conventional till, zone till and no till) and four replicates. The same plot layout was used in each field. Plot size was 9 m wide x 20 m long.

The zone tillage treatment was applied only to the winter wheat stubble at the start of the corn phase of the rotation. The conventional tillage treatment was applied to conventional tilled plots on both the winter wheat and corn stubble at the start of the corn and soybean phases respectively. No till treatment was applied to the no till plots in all three phases of the rotation. No till was also applied to the entire experiment following the soybean phase where winter wheat was seeded directly into the soybean stubble without any form of tillage, and to the zone till plots at the beginning of the soybean phase. Descriptions of the tillage and planting equipment are given in Table 1.

Table 1. Specifications of tillage and planting equipment used in the field experiment.

| Implement | Manufacturer | Description | Width (m) | Ground Speed (km/h) |
|---|---|---|---|---|
| Moldboard plow | Kongskilde, Strathroy, ON | Semi-mount, five bottom, 300 mm width | 1.52 | 5.6 |
| Field Cultivator | Kongskilde, Strathroy, ON | Triple K vibrating spring tooth | 3.81 | 7.5 |
| Zone Till | Row-Tech Inc., Snover, MI | Trans Till, six row, 760 mm row spacing | 4.57 | 7.3 |
| Corn Planter | Kinze Manufacturing, Williamsburg, IA | Model 3000 no till, four row | 3.05 | 6.1 |

The conventional tillage treatment included fall moldboard plow, and secondary cultivation in the following spring. A Kongskilde five bottom semi-mount moldboard plow was used with furrow width set at 300 mm. Nominal plowing depth was 180 mm. Spring cultivation consisted of two passes of a Kongskilde Triple K field cultivator.

Zone till, sometimes called strip till or band till (Morrison, 2002), was done with a 4.57 m wide Trans Till machine (Table 1). This implement tilled six strips or zones, each 200 mm wide and 150-200 mm deep. The tilled zones were spaced 760 mm on centre, with a 560 mm untilled space between the zones. Each zone tillage unit consisted of a single leading plain coulter to cut residue, then two fluted coulters on either side of a narrow chisel with a 30 mm wide point, and finally a trailing pair of opposing concave discs to bring the loosened soil into a slight ridge. Each tillage unit was attached to a toolbar via a parallel arm linkage allowing each tillage unit to "float" independently from the other units. Tillage depth was controlled with a depth band on the leading coulter. The 760 mm spacing of the tillage zones was the same as the corn rows; corn was planted in the tilled zones the following spring without secondary tillage. Winter freezing and thawing, and rain tended to disintegrate the clods (or mound) of soil resulting from the fall zone till making the tilled zones difficult to see the following spring. The tilled zones were thus marked with flags to aid in finding them at planting. This would not be practical on a commercial scale, but use of a precision GPS tractor guidance system for both fall zone tillage and spring planting would eliminate the need to visually identify the tilled zones at planting time.

The no till treatment consisted of planting corn directly into the winter wheat stubble. A Kinze 3000 four row no till corn planter (Kinze Manufacturing, Williamsburg, IA) was used to plant all three tillage treatments.

**Energy Measurements** Energy measurements for tillage and planting were made with the Agriculture and Agri-Food Canada instrumented research tractor (McLaughlin et al. 1993). This tractor was fitted with a set of instruments and an onboard data logger to allow tractor operational parameters such as engine, wheel and ground speed, fuel consumption, and implement draft to be measured and recorded as the tractor is doing normal field work.

Stakes were established in the centre of each pass of the tractor in each plot to provide the tractor operator a sight line for driving to ensure that there was no overlap or gaps between adjacent passes of the particular tillage implement. The tractor transmission gear and no-load engine speed (high idle) was set with the tractor stopped in the roadways between the plots. The tractor was brought up to speed in the roadway, and the speed was not adjusted while in the plot. Stake lines at either end of the plot provided a visual cue for the data logger operator to start and stop the data logger at either end of the plot while the tractor was in motion. Data were logged at 100 Hz while the implement was in the plot. The tractor was stopped at the end of the plot, the data were saved to the hard disk, and the data logger was set up for the next plot. Data for each pass in each plot were saved in separate files with the implement, plot and pass coded in the file name.

The implement was periodically unhitched from the tractor, and a ‘zero’ or tare file was logged with no load on the tractor hitch. Apparent draft from these zero files was subtracted from draft in the data files to correct for minor drift in the instrumentation offset.

Tillage depth was measured with a depth probe resembling a large tire tread depth gage (McLaughlin et al. 2008). Moldboard plow depth was measured in the open furrow left after each pass of the plow and before the next pass was made. Mean tillage depth data are given in Table 2.

**Data Analysis** Data were logged for 22 m of travel which is two m longer than the 20 m plot length. Three m of data were trimmed from either end of the data file to ensure that the entire length of the implement was within the plot boundary. Data were corrected for drift in the instrumentation offset by subtracting the weighted mean draft calculated from the nearest before and after zero file. The drift was assumed to be linear with time, and apparent draft data determined from the before and after zero files were weighted according to elapsed time between when the data for the plot and the corresponding before and after zero files were logged. Means were calculated from the corrected data for the central 16 m of the plot. These means were considered as the dependent variable for each pass in each plot.

Table 2. Mean and standard deviation of the mean depth (mm) for different tillage and planting operations in conventional till, zone till and no till cropping systems.

| Tillage Operation | 2007 | 2008 | 2009 | Mean |
|---|---|---|---|---|
| Moldboard Plow (Previous Fall) | 166 (6) | 194 (5) | 174 (10) | 178 |
| Zone Till (Previous Fall) | 195 (6) | 154 (6) | 157 (14) | 169 |
| Field Cultivator First Pass (Spring) | 72 (8) | 68 (4) | N/A | 70 |
| Plant (Conventional Till) | 70 (4) | 59 (6) | N/A | 65 |
| Plant (Zone Till) | 74 (4) | 58 (6) | N/A | 66 |
| Plant (No Till) | 73 (3) | 49 (9) | N/A | 61 |

The corrected draft data were converted to drawbar energy and expressed in Mega Joules per hectare by dividing the implement draft in Mega Newtons by the implement width in meters, and multiplying by the number of square meters per hectare (10,000). Using draft data instead of tractor fuel consumption removes the effect of the tractor from the energy data. Conversion of the total implement draft to drawbar energy compensates for the different widths of the various implements, and allows direct comparison of total energy for the different implements in each tillage system. Drawbar energy is dimensionally equivalent to, and numerically 10 times the draft expressed in kilo Newtons per meter width which was used by (McLaughlin et al. 2008) and in the ASABE standards (ASABE 2006). We chose to use drawbar energy in this paper to provide a more intuitive vision of total energy for several field operations (primary tillage, secondary tillage and planting) with different implements of different widths in a particular tillage system.

**RESULTS AND DISCUSSION** Energy for the different components of each tillage system are given in Table 3. Mean total energy over the three years was 235, 67 and 14, MJ/ha for the conventional till, zone till and no till systems respectively. A wide range was expected since the conventional till, zone till and no till systems have respectively four, two and one separate field operations.

The drawbar energy data were fairly consistent over the three years. A notable exception was the much lower drawbar energy for both passes with the field cultivator in 2007 compared to 2008 and 2009. The reason for this difference was not determined, but may reflect differences in soil water content, or differences in soil reconsolidation by rain and freeze-thaw cycles over the winter. Tractor fuel consumption for cultivating in 2007 was also lower than either 2008 or 2009 (data not shown).

Drawbar energy for planting was almost identical for the three tillage systems. At first, this seems a bit surprising as one would expect higher energy for the planter operating in the no till system where the soil had not been loosened by previous cultivation. Planter draft is the sum of rolling resistance of the planter wheels, and draft of the row units which cut the soil and open and close the seed furrow. One possibility for similar planter draft among tillage treatments might be that the rolling resistance of the planter wheels was lower on the harder no till soil than on the soil loosened by the cultivator in the conventional till system, and this largely compensated for the difference in the draft of the planter row units. In the zone till system, the cultivator wheels were running on no till soil between the rows, while the planter row units were in soil that had been tilled the previous fall and then re-consolidated by time, rain, and freeze-thaw cycles. Hence, the lower rolling resistance of the planter wheels on the no till part of the soil may have compensated for the higher draft of the planting units in the reconsolidated tilled zones.

Table 3. Drawbar energy mean and standard deviation (MJ/ha, four replicates) for tillage and planting operations in conventional till, zone till and no till cropping systems.

| Tillage System | Implement | Year | | | |
|---|---|---|---|---|---|
| | | 2007 | 2008 | 2009 | 3 year mean |
| Conventional Till | Moldboard Plow | 122 (10.7) | 133 (4.2) | 108 (10.6) | 121 (12.6) |
| | Cultivate 1 | 27 (0.5) | 66 (1.6) | 76 (7.6) | 56 (25.7) |
| | Cultivate 2 | 22 (1.0) | 55 (2.5) | 59 (6.0) | 45 (20.3) |
| | Plant | 15 (0.2) | 12 (0.5) | 13 (0.1) | 13 (1.2) |
| | Total | **185** | **266** | **256** | **235 (43.6)** |
| Zone Till | Zone Till | 68 (5.2) | 42 (4.7) | 51 (10.5) | 54 (13.2) |
| | Plant | 15 (0.3) | 12 (0.2) | 13 (0.2) | 13 (1.7) |
| | Total | **83** | **54** | **64** | **67 (14.9)** |
| No Till | Plant | 16 (0.3) | 12 (0.6) | 13 (0.4) | 14 (1.8) |
| | **Total** | **16** | **12** | **13** | **14 (1.8)** |

The drawbar energy for the second pass with the field cultivator was always lower than that for the first pass (Table 3). This was expected as the first pass is in soil which was moldboard plowed the previous fall, while the second pass was in soil which was partially loosened by the first pass with the field cultivator.

The mean drawbar energy for the moldboard plow and zone till of 121 and 54 MJ/ha is in good agreement with McLaughlin et al. (2008), who obtained a four year average of 123 and 50 MJ/ha respectively for the same implements on the same soil type but in different fields. The moldboard plow energy is in good agreement with the energy of 144 MJ/ha calculated for the same operating depth from data provided by the ASABE (ASABE 2006).

The energy data presented here are only for pulling the respective implements while engaged in the soil which implies a field efficiency of 100%. Field efficiency for any agricultural field operation is always less than 100% due to time and energy lost by turning on headlands, tractor idling while adjusting equipment or refilling planters, and travel to and from the field etc. The field efficiency can vary widely among farms (depends on shape, size, topography and location of fields), among operators, and among types of field equipment. No attempt was made to adjust the numbers to include field efficiency, but the reader is reminded to include this factor when estimating total energy inputs for a particular situation.

As the term implies, drawbar energy is the energy produced at the tractor drawbar (e.g. drawbar force times distance traveled) and imparted to the implement. Fuel energy can be three to five times higher than the drawbar energy, and can be estimated by dividing drawbar energy by tractor total efficiency which is the product of the engine efficiency and power delivery efficiency. Both tractor engine efficiency and power delivery efficiency depend on tractor-implement match. Both efficiencies can vary widely, but under the same operating conditions (i.e. the same tractor-implement match), the ratios in fuel energy would be approximately the same as ratios in drawbar energy for the different tillage systems. Drawbar energy provides a means of comparing implements without the effect of the tractor, but energy input calculations for crop production or life cycle analysis need to include the tractor as well.

The data in Table 3 show standard deviations of the means for the three years ranging from about 10% of the mean for the moldboard plow to nearly 50% of the mean for the field cultivator. The large value for the field cultivator was mainly due to much lower drawbar energy in 2007. ASABE indicates that a range in draft of +/- 25 to 50% is to be expected for various tillage implements (ASABE 2006).

The data show substantial differences in input energy among the tillage systems, with conventional till requiring over 16 times the energy input for no till over a three year period. However, these numbers are only for tillage and planting. Energy for other inputs including fertilizer and herbicide production and application, harvesting machinery, and grain drying need to be included to determine the total energy input for the different tillage systems. Previous work has shown that energy for production of N fertilizer represents approximately 30 to 50% of total energy cost for corn production. The yields are different among the tillage systems, and total energy input data need to be combined with final yield to determine energy input per tonne of grain produced. We have the agronomic data for the experimental site and plan to do this type of analysis.

**CONCLUSION** Field experiments were carried out over a three year period to measure the energy inputs required for tillage and corn planting on a clay-loam soil under conventional till, zone till and no till. Tillage and planting were conducted using field scale equipment, and drawbar energy in Mega Joules per hectare was measured with an instrumented research tractor. The three year mean drawbar energy input was 235, 67 and 14 MJ/ha for conventional till, zone till and no till respectively. The differences are substantial, but can be misleading. Tractor fuel and other energy inputs (most notably manufacture of N fertilizer and grain drying) need to be included to calculate the total energy costs for corn production using the three tillage systems. As the other inputs (e.g. fertilizer, pesticides) are approximately the same for each tillage system, the ratios of the energy inputs obtained above are expected to decrease when all inputs are taken into account. Including yield data in the analysis would permit calculation of energy cost for production of a unit mass of corn for each tillage system. In spite of the limitation of not including all energy inputs, the data do show opportunity for substantial reduction in energy inputs by selecting energy efficient tillage systems.

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