# Modeling fuel use for specific farm machinery and operations of wheat production

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**ABSTRACT**

This paper presents the approach used to develop a model predicting fuel consumption according to the different agricultural practices and the results obtained for wheat production. Results showed that the largest variations were caused, not by production systems, but by soil preparation and fertilization operations. Average fuel consumption was 55.6 L/ha regardless of the production system, the soil preparation and fertilization strategies and the type of wheat. On average, soil preparation consumes 32% of the fuel, but it can reach more than 50% if conventional tillage is used. Grouped by tillage system, instead of production systems, no-till plots consume 39.6 L/ha, reduce tillage 55.6 L/ha and conventional 76.0 L/ha. Fuel consumption due to fertilization varies according to the type of fertilizer used. The amount of fuel used seems to be related to the concentration of nitrogen in the fertilizer. Winter wheat production used less fuel than spring wheat.

Keywords: life cycle assessment, wheat production, greenhouse gas, environmental impact, fuel consumption

## 1. Introduction

Life cycle assessment (LCA) performed on agricultural products generally use average values of fuel, fertilizer and pesticide consumption per hectare of land. These average values are close to reality when the LCA results are used to inform consumers about the environmental impact of products like milk or flour that have been produced on more than one farm using different agricultural practices. Such values are, however, less relevant for agricultural producers who want to improve the environmental impact of their farm.

Several factors may influence fuel consumption: production systems, soil and fertilizer management and technical factors such as the width and weight of equipment, as well as the power of the tractor used during farm operations.

A model predicting fuel used for specific farm machinery and operation was developed while performing a “cradle-to-farm gate” LCA of wheat production. The aim of this LCA was to assess the environmental impact of four production systems (intensive, conventional, integrated and organic) for spring and winter wheat.

This paper focuses on the approach used to develop the model and the results obtained for fuel consumption according to the different agricultural systems.

## 2. Methods

### 2.1. Inventory data

Four production systems for spring and winter wheat were considered in this study. Difference in production systems were observed in the management of fertilizer and pesticide use. Organic producers had to be accredited by a certified organic body. Integrated producers were obliged to follow a book of specifications provided by the grain buyer. They were not restricted with the use of mineral fertilizer alongside manure, but they were encouraged to respect a fertilization management plan. They were only allowed to use herbicide before seeding, but not during the growing season. Conventional and intensive producers were not restricted in the use of fertilizers or pesticides. Intensive producers tended to use more pesticides in combination with a growth regulator. Regardless of the production system, soil management practices were not limited.

Data used in the project come from plots established on farms that were accustomed to sell their wheat to a grain buyer. Producers provided data for soil cultivation, like tillage, seedbed preparation, seeding, fertilizers and pesticides application, harvesting and on-farm transportation. They were asked to provide, for every operation, the main characteristics of the implement (e.g., width and weight), the tractor used (e.g., type and power) and the working conditions (e.g., yield, soil texture, travel speed and working depth). Producers with information such as fuel consumption and field capacity, recorded by the GPS of their tractor or combine were invited to provide them. These values were thereafter used to validate the model.

Based on the list of equipment provided by the producers, a data base of equipment has been developed alongside the model. This database includes the following equipment:

- Chisel
- Combine (auger or draper head, rigid or flexible)
- Disk gang
- Disk harrow
- Field cultivator
- Grain drill (rows or no-till)
- Grain wagon
- Loader
- Manure pump
- Manure spreader (solid and liquid)
- Mounted fertilizer spreader
- Plow (semi-mounted and mounted)
- Rod weeder
- Roller packer
- Sweep plow
- Pesticides sprayer (trailed)

2.2. Fuel consumption

The methodology used for the calculation of fuel consumption was based on the equations presented in the following two standards produced by the American Society of Agricultural and Biological Engineers: Agricultural Machinery Management Data (ASAE D497.7 Mar2011; ASABE, 2011) and Agricultural Machinery Management (ASAE EP496.3 FEB2006; ASABE, 2006). The methodology estimates fuel consumption of an operation using the equipment characteristics (e.g., width, mass and tillage depth) as well as the characteristics of the tractor used (e.g., mass and travel speed).

The methodology has been simplified according to the available data. A summary of the main calculation is presented here. The calculation of fuel consumption can be summarized by the following equation:

$$Q_{fuel} = \frac{P_{total} \times Q_{sfc}}{C_{field}} \qquad \text{Eq. 1}$$

Where $Q_{fuel}$ is the fuel consumption (L/ha), $P_{total}$ is total power requirement for an operation (kW), $Q_{sfc}$ is specific fuel consumption (L/kWh) and $C_{field}$ is field capacity (ha/h).

Total power ($P_{total}$) requirement for operating implements is the sum of implement power components (Eq. 2).

$$P_{total} = \frac{P_{db}}{E_m E_t} + P_{pto} + P_{hyd} + P_{el} \qquad \text{Eq. 2}$$

Drawbar power ($P_{db}$) is power developed by the drive wheels or tracks and transmitted through the hitch or drawbar to move an implement through or over the crop or soil (ASABE, 2006). It is primarily a function of the width of the implement and the speed at which it is pulled. It also depends upon soil texture, depth and geometry of the tool. Drawbar power is the sum of motion resistance and soil and crop resistance multiply by the travel speed. Mechanical efficiency ($E_m$) and tractive efficiency ($E_t$) are coefficients specific to tractor characteristics.

Power-takeoff power ($P_{pto}$) is the power required by the implement from the PTO shaft of the tractor or engine and it is a function of the width of the implement and the material feed rate or yield.

Hydraulic power ($P_{hyd}$) is the fluid power required by the implement from the hydraulic system of the tractor or engine. Electric power ($P_{el}$) is required to operate components of implements. Hydraulic and electric power are difficult to assess and were not considered in the survey, they were replaced by a factor ($F_{Phyd\ +\ Pel}$) representing an additional 25% of the power requirement.

Total engine power must be greater than the total implement power required. Additional power is required to accelerate and overcome changes in topography, soil and crop conditions (ASABE, 2006). An additional 20% of the power requirement has been allowed for reserve power ($F_{Pres}$).

For the purpose of the project, Equation 2 has been simplified and can be presented as:

$$P_{total} = \left(\frac{P_{db}}{E_m E_t} + P_{pto}\right) \times F_{P_{hyd}\,+\,P_{el}} \times F_{P_{res}} \qquad \text{Eq. 3}$$

Specific fuel consumption ($Q_{sfc}$) is the fuel requirement based on the actual power required. For a particular operation it can be found by multiplying specific fuel consumption volume by current power delivery. It takes into account the ratio of equivalent PTO power required by the current operation to rated power available and the ratio of partial throttle engine speed to full throttle engine speed.

Effective field capacity ($C_{field}$) is a function of field speed, machine working width, field efficiency and unit yield of the field.

## 3. Results

Average fuel consumption was 55.6 L/ha with a standard deviation of 21 L/ha for the 80 plots regardless of the production system, the soil preparation and fertilization strategies and the type of wheat. There was lot of variation in the results, the minimum value was 27.5 L/ha and the maximum value was 108.0 L/ha. Table 1 presents the average fuel used per operation according to production and tillage systems. Results showed that the largest variations in fuel consumption were caused, not by production systems, but by soil preparation and fertilization operations.

Table 1. Average fuel used for wheat cultivation per operation in function of production and tillage systems

| Production and tillage systems | n | Yield (t/ha) | Soil preparation (l/ha) | Fertilization (l/ha) | Pulverization (l/ha) | Seeding (l/ha) | Harvesting (l/ha) | Transportation (l/ha) | Total (l/ha) |
|---|---|---|---|---|---|---|---|---|---|
| Organic | | | | | | | | | |
| No-till | 3 | 4.2 | - | 4.7 | - | 11.2 | 9.4 | 4.3 | 29.7 |
| Reduce | 9 | 2.3 | 33.3 | 4.4 | - | 4.5 | 12.1 | 2.3 | 56.6 |
| Conventional | 3 | 3.0 | 34.0 | 5.6 | - | 7.6 | 11.9 | 3.1 | 62.2 |
| Average | | 2.8 | 26.8 | 4.7 | - | 6.5 | 11.5 | 2.9 | 52.3 |
| Integrated | | | | | | | | | |
| No-till | 8 | 3.8 | - | 4.1 | 1.7 | 14.9 | 13.5 | 3.9 | 38.1 |
| Reduce | 6 | 3.6 | 12.8 | 13.2 | 0.6 | 8.6 | 13.8 | 3.7 | 52.6 |
| Conventional | 6 | 3.5 | 41.0 | 6.7 | 0.9 | 9.2 | 16.1 | 3.6 | 77.5 |
| Average | | 3.6 | 16.3 | 7.6 | 1.1 | 11.3 | 14.4 | 3.7 | 54.5 |
| Conventional | | | | | | | | | |
| No-till | 8 | 4.4 | - | 4.3 | 2.4 | 14.9 | 13.5 | 4.5 | 39.6 |
| Reduce | 5 | 4.0 | 14.2 | 15.5 | 2.3 | 9.1 | 14.1 | 4.1 | 59.4 |
| Conventional | 6 | 4.2 | 41.0 | 6.7 | 2.5 | 9.2 | 16.1 | 4.3 | 79.8 |
| Average | | 4.2 | 16.9 | 8.0 | 2.4 | 11.6 | 14.5 | 4.3 | 57.8 |
| Intensive | | | | | | | | | |
| No-till | 8 | 5.0 | - | 4.7 | 4.9 | 14.9 | 13.5 | 5.2 | 43.2 |
| Reduce | 12 | 4.4 | 10.7 | 13.5 | 5.0 | 7.9 | 13.3 | 4.5 | 54.9 |
| Conventional | 6 | 4.9 | 37.4 | 7.5 | 3.9 | 8.7 | 15.0 | 5.0 | 77.5 |
| Average | | 4.7 | 13.7 | 9.4 | 4.7 | 10.2 | 13.7 | 4.8 | 56.7 |
| Average | | 4.0 | 17.6 | 7.7 | 2.4 | 10.1 | 13.7 | 4.1 | 55.6 |

On average, soil preparation consumes 32% of the fuel, or 17.6 L/ha, but it can reach more than 50% or 41 L/ha. Grouped by tillage system instead of production systems, no-till plots consume 39.6 L/ha, reduce tillage 55.6 L/ha and conventional 76.0 L/ha. Conventional tillage system used roughly the same amount of fuel regardless of the production system. Soil preparation consisted, on average, of 2.3 operations, using a plow and one or two passes of field cultivator. For integrated, conventional and intensive production systems, reduce tillage consumed approximately one third of the fuel used by conventional tillage. An average of 1.6 operations was done by the producers combining a chisel, a field cultivator, a disk harrow or a rod weeder. Soil preparation was performed with an average of 3.8 operations for organic producers using reduce tillage. They consumed approximately the same quantity of fuel than those using conventional tillage (33.3 L/ha vs 34.0 L/ha). The exact reason for all these operations was not specified, but it may be due to a related operation such as weed control.

Fuel consumption due to fertilization varies according to the type of fertilizer used. Fertilization with ammonium nitrate averaged 1.8 L/ha or 0.9 l/ha per pass. Spreading of liquid cow manure averaged 14.7 L/ha while mixing and loading accounted for 16.4 L/ha for a total of 31.1 L/ha. Spreading of liquid pig manure averaged 7.7 L/ha while loading accounted for 4.8 L/ha for a total of 12.5 L/ha. Spreading of solid poultry manure averaged 3.6 L/ha while loading accounted for 2.1 L/ha for a total of 5.7 L/ha. The amount of fuel used seems to be related to the concentration of nitrogen in the fertilizer (Figure 1).

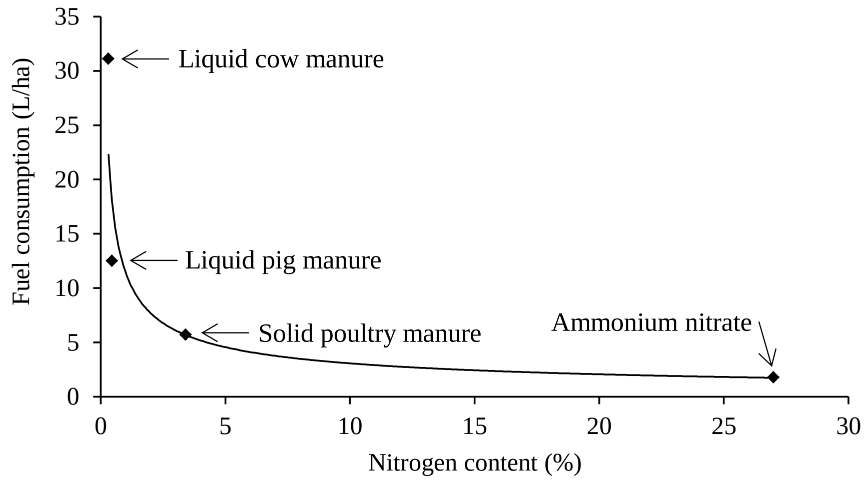

Figure 1. Fuel consumption of fertilization operations according to the concentration of nitrogen in the fertilizer

Winter wheat production used less fuel than spring wheat. Major differences were observed because more producers used no-till and fertilized with manure. Average fuel consumption for winter wheat was 53.6 L/ha with no-till representing 60% of the plots. Fertilization consume 11.4 L/ha and seeding 11.8 L/ha. Average spring wheat fuel consumption was 57.5 L/ha with no-till representing only 3 plots out of 40. Fertilization consume 4.1 L/ha and seeding 8.4 L/ha.

Pesticides pulverization consumed less fuel than any other operation. Integrated production system consumed 1.1 L/ha, conventional 2.4 L/ha and intensive 4.7 L/ha.

No-till seeding consumed approximately 5 litres more per hectare than seeding done after reduce or conventional tillage. Organic farming consumed less fuel for seeding because, for most of the plots, the operation was done using a tractor smaller than 100 kW. The same conclusion can be drawn for harvesting; the combines used in the organic plots were smaller.

## 4. Discussion

Sensitivity analysis should be performed to investigate the impact of farm equipment use. Efforts to reduce fuel use during farm operations would contribute to reduce greenhouse gas emissions, but this parameter has little influence on the whole farm emissions. Fuel consumption of 55 L/ha is equivalent to approximately 150 kg $CO_2$e/ha, which is not an important parameter compare to the emissions produced on a hectare of land. Furthermore, results observed in this study showed a variation corresponding roughly to 20 L/ha or 50 kg $CO_2$e/ha. In another vein, at the end of the year, an economy of 20 L/ha can represents a substantial amount of money for a producer.

If the objective is to reduce the environmental impact, the choice to use a machine or another must take into account all the operations of the farm. For example, the use of manure instead of mineral fertilizer increase greenhouse gas produced by the use of machinery on the farm but may contribute to reduce greenhouse gas outside the farm.

It should be considered to use the method to evaluate the impact of agricultural operations on more than a year in order to cover an entire rotation. The sequence of crops in the rotation has an impact on the operations and ultimately on greenhouse gas emissions and other impact categories. For example, analyzing operations for an entire rotation could solve interrogations like, in what year and on what culture is associated the environmental impact of seeding a cover crop?

## 5. Conclusion

This paper presented the approach used to develop a model predicting fuel consumption according to the different agricultural practices and the results obtained for wheat production.

Results showed that the largest variations were caused, not by production systems, but by soil preparation and fertilization operations. Average fuel consumption was 55.6 L/ha regardless of the production system, the soil preparation and fertilization strategies and the type of wheat. On average, soil preparation consumes 32% of the fuel, but it can reach more than 50% if conventional tillage is used. Grouped by tillage system, instead of production systems, no-till plots consume 39.6 L/ha, reduce tillage 55.6 L/ha and conventional 76.0 L/ha. Fuel consumption due to fertilization varies according to the type of fertilizer used. The amount of fuel used seems to be related to the concentration of nitrogen in the fertilizer. Winter wheat production used less fuel than spring wheat. Differences were observed because more producers used no-till and fertilized with manure.

## 6. References

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