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# SPECIFIC MEASURES FOR ENERGY SAVING IN SOIL TILLAGE

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**Abstract:** In this study, it is examined that the specific measures for energy saving in soil tillage applications. The fuel consumption can be reduced by 39% for stubble processing, basic and secondary processing and also sowing, if the method is changed from conventional cultivation with a plough to mulching including soil loosening. By combining single working operations the number of operations can be reduced. The requirement for energy and therefore also the fuel consumption are fluctuating by about 30% depending on the working intensity. An increasing driving speed for reaching a higher power output is definitely responsible for higher fuel consumption.
**Keywords:** soil, tillage, energy, saving, measures

## 1. INTRODUCTION

Approximately one third of the total energy consumption in agriculture is realized as a result of fuel use alone. Annual diesel fuel consumption for different products varies between 60–210 liters/ha, depending on the intensity of maintenance operations. The fuel costs of a tractor processing 450 ha per year constitute approximately 40% of the total costs (Handler and Nadlinger, 2012).

Depending on the working process, an agricultural tractor provides torque (PTO) and hydraulic power as well as drawbar power. For example, when a total of 25 L/ha of fuel is used in towing, only about 5 L/ha (20%) of the total fuel consumption can be converted into effective drawbar power. Most of the energy used is lost in the form of cooling or exhaust gases. Under poor pulling conditions, very large gearbox–related gear losses can occur due to slip and rolling resistance. When operating the tractor in the field, only 20% of the fuel energy is actually transferred to an effective drawbar power. Efficiency can even drop below 20%. The efficiency in working with the power take–off shaft (PTO) is about 25% (Kutzbach, 1989).

Table 1. Fuel consumption for different agricultural works (Holz, 2006)

| Working process | Fuel consumption (L/ha) | | Remarks |
|---|---|---|---|
| | Average value | Variation | |
| Stuble processing | 9.1 | 5.0–18.0 | 3.0–6.0 m |
| Disc harrow | 10.0 | 7.2–12.0 | 3.0–6.0 |
| Spade rotary harrow | 6.0 | – | 6.0 m |
| Soil loosening | 19.8 | 18.3–21.3 | 35–38 cm deep |
| Ploughing | 21.8 | 15.0–30.0 | 18–30 cm deep |
| Milling | 15.9 | 20.0 | 2.3–3.0 m |
| Rotary harrow solo | 12.7 | 8.0–22.0 | 3.0 m |
| Mulching | 12.9 | 10.0–17.6 | 2.3–3.0 m |
| Rotary tiller + drilling machine | 14.2 | 10.0–20.0 | 3.0–4.0 m |

Due to varying power requirements, there are also significant differences in fuel consumption for various agricultural operations. The results of a study conducted on 540 farms in Germany are given in Table 1. However, when performing the same production operations, fuel consumption is changed depending on the soil type or condition, humidity, working speed, working intensity, harvest amount, tool/machine type, tool/machine adjustment and maintenance, parcel shape and size, and distance between field and farm. effects. Therefore, variations of ± 50% from the mean value are possible. In this study, it is examined that the specific measures for energy saving in soil tillage applications.

## 2. SPECIFIC MEASURES FOR ENERGY SAVING IN SOIL TILLAGE

### Tillage Methods

Fuel consumption can be efficiently reduced by mulch or direct sowing. By replacing the traditional tillage practice with plows, fuel consumption can be reduced by 39% (Figure 1). If the soil is not loosened, 20% more savings can be achieved. The direct sowing method only needs 11% of the amount of fuel required for plowing. To apply the mulch and direct sowing method, some basic principles need to be taken into account. In particular, precautions should be taken to prevent Fusarium diseases.


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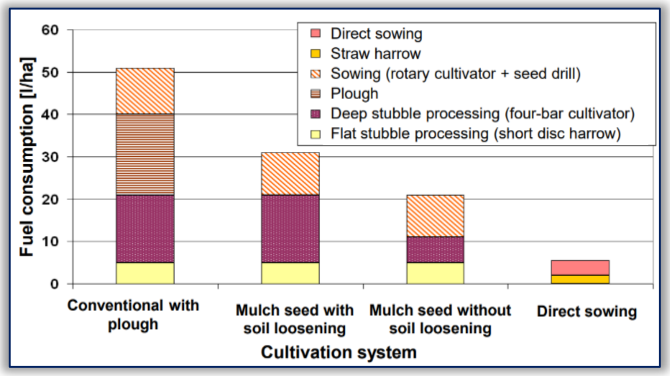


Figure 1 – Fuel consumption for different cultivation methods (Brunette and Korte 2003)

Cavalaris and Gemtos (2002) obtained data of the real absorbed energy with each implement are presented in Table 2. The data are the average values from the six years measurements. As it can be seen, the mouldboard plough had the greater energy consumption through traction, followed by the chisel plough and the heavy cultivator. These implements however worked on the greater depth. The rotary cultivator absorbed little energy from traction but had great energy demands through the PTO. As a result, it presented the greater energy consumption. Combined with a much shallower working depth, the implement was proved to be the most intensive (in terms of energy spent in the soil per cultivated volume). The disk harrow and the field cultivator presented the lower energy demands but also had the shallower tillage depth. Considering the equivalent PTO power (Table 2) an apparent advantage for the rotary cultivator can be seen due to the greater efficiency of power transmission through the PTO. Thus the rotary cultivator had lower energy demands than moulboard and chisel plough and greater demands than the heavy cultivator.

Table 2. Energy consumption with the tillage implements (Cavalaris and Gemtos, 2002)

| Tillage implement | Absorbed energy on traction (MJ/ha) | Energy consumed on turning edges (MJ/ha) | Coefficient of traction efficiency ($C_t$) | Equivalent PTO energy (MJ/ha) | Fuel and lubricant energy (MJ/ha) | Reduction of machinery sequestered energy (MJ/ha) | Total energy (MJ/ha) |
|---|---|---|---|---|---|---|---|
| Plough | 189 | 9 | 0.53 | 367 | 1930 | 225 | 2155 |
| Heavy cultivator | 111 | 5 | 0.53 | 216 | 1085 | 105 | 1190 |
| Chisel plough | 162 | 7 | 0.52 | 318 | 1594 | 184 | 1778 |
| Rotary cultivator | 22 | 5 | 0.49 | 266 | 1407 | 147 | 1554 |
| Disk harrow | 17 | 3 | 0.43 | 43 | 242 | 59 | 301 |
| Field cultivator | 19 | 2 | 0.43 | 47 | 242 | 36 | 283 |
| Croskill cylinder | 0.3 | 2 | 0.07 | 7 | 37 | 30 | 67 |

By examing the total energy consumed (the energy of fuel and lubricants as well as the reduction of the machinery sequestered energy) it can be noticed that the moalboard plough was the most energy consuming implement. With the chisel plough, energy savings of 18% were achieved. The rotary cultivator provided savings of 28% and the heavy cultivator savings of 45%. The disk harrow and the field cultivator were 86–87% less energy consuming (Cavalaris and Gemtos, 2002).

Energy consumption during fieldwork is one of the most important factors that affect the production cost so that measurement of energy consumption is necessary. Moreover knowledge of power requirements of a tractor leads to the right choice of its size which can optimize the initial investment. Conclusively knowing energy consumption and power requirements of a tractor for a particular agricultural work could minimize the production cost. Moreover agricultural implements could be properly designed and economic for the farmers. Papathanassiou et al., (2002) obtained that the energy consumption to cultivate 1000 m$^2$ with several agricultural implements (Figure 2).

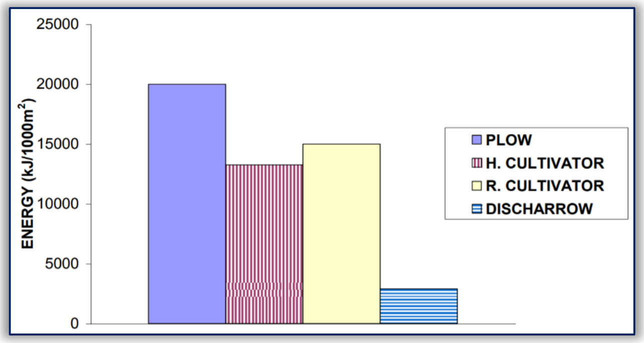


Figure 2 – Energy consumption for several tillage implements (Papathanassiou et al., 2002)


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### Reducing Working Times – Consolidating Transactions

Unnecessary operations should be avoided. For example, only one operation for seedbed preparation requires 5–9 liters of diesel fuel per hectare (KTBL, 2006). Other reference values for fuel consumption for processes can be found in Table 3.

Table 3. Fuel saving by combining of operations (KTBL, 2006)

| Operation | Operation method | Mechanization | Fuel consumption (L/ha) |
|---|---|---|---|
| Sowing of cereals | separated | seedbed combination (5 m, 67 kW, 2 treatments), seed drill (3 m, 45 kW) | 14.8 |
| | combined | rotary harrow with seed drill (3m, 67 kW) | 11.6 |
| | | | % –20 |
| Preparation of wilted silage | separated | mower (2.8 m, 54 kW) and rotary tedder (5.5 m, 45 kW, one treatment) | 7.8 |
| | combined | mower with conditioner (2.8 m, 67 kW) | 5.9 |
| | | | % –24 |

Some operations can easily be combined when choosing operating methods. Fuel savings can be achieved under optimal conditions. For example, if grain is planted in two separate work steps and therefore the field has to be prepared twice with a seedbed combination, a new method of combined sowing with a rotary harrow can save 20% in fuel (Table 3). The number of applications can be reduced by combining self–study applications. However, it is necessary to take into account that the weight will increase as well as the power required by the equipment.

### Prevention of Soil Compaction

Soil compaction also increases the required power and therefore fuel consumption. Table 4 illustrates the effects of soil compaction during tillage. Skid is increased from 3.6% to 5.4% and driving speed is reduced from 6.8 to 6.4 km/h. Fuel consumption increases from an average of 13.2 L/ha to 15.3 L/ha.

The support capacity and moisture of the soil, as well as the technology used (wheel load, contact surface pressure), are decisive factors for the formation of soil compaction. Successful mulching or direct sowing are the most important prerequisites to avoid soil compaction. The best prerequisite for a healthy soil is not to compact the soil. Soil compaction requires more engine power and fuel.

Table 4. Impact of soil compaction during ploughing (Moitzi, 2006)

| Parameter | Soil not compacted | Soil compacted |
|---|---|---|
| Speed (km/h) | 6.8 | 6.4 |
| Slipping (%) | 3.6 | 5.4 |
| Fuel consumption (L/h) | 15.3 | 16.7 |
| Fuel consumption (L/ha) | 13.2 | 15.3 |

Remark: 4–furrows reversible plough – 1,70 m working width, 20 cm working depth, autumnal tilling after grain maize, soil type: sandy loam with 14 % moisture

### Improvement of Soil Structure

If the soil structure is improved, the drawbar requirement during planting as well as fuel consumption can be reduced. Research in Canada has shown that a perennial organic fertilization reduces the draft force requirement during tillage by up to 38% (Moitzi, 2006). This successful saving effect has been attributed to the reduced specific earth resistance.

Increased soil activity also provides soil loosening and biological stabilization of the soil and all its components. The latter is also a prerequisite for a solid brittle structure. A balanced biological activity of the soil especially needs a suitable source of oxygen and organic matter. An active soil structure is responsible for the biological loosening of the soil. Therefore, it can also reduce fuel consumption.

One of the most important factors for the supporting ability and workability of the soil is moisture, among other factors. Therefore, the optimal time point for cultivation and therefore the organization of all working processes must be optimized. For example, the risk of soil compaction, work intensity, number of treatments and draft power demand can be minimized by choosing the most suitable time for work and optimum soil moisture. Improving soil structure and stimulating soil activity reduces draft power requirement and fuel consumption. An active soil and better soil structures reduce fuel consumption. The best time to work should be chosen. The best time to reduce tillage depends on the following factors:

- risk of soil compaction
- work intensity
- number of transactions
- traction power requirement


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### Tillage Depth

During tillage, approximately 150 tons of soil should be transported per cm of working depth and per hectare. Therefore, the higher the working depth, the higher the fuel consumption. Depending on soil conditions, 0.5 to 1.4 liters more fuel per hectare is consumed for this process (Kalk and Hülsbergen, 1999).

When cultivating the soil, increased fuel consumption is in a similar range (Figure 3). Therefore, the seed should never be planted deeper than the soil and crop require. By adapting the working depth, fuel savings can be achieved even as soil conditions change and yields remain constant. On a farm or field with heterogeneous soil conditions, more than 50% fuel savings can be achieved if sandy soils are planted more deeply and loamy and clayey soils are worked more shallowly (Sommer and Vosshenrich, 2004). When the depth of tillage increases by 1 cm, diesel fuel consumption increases by 0.5–1.4 L (Handler and Nadlinger, 2012).

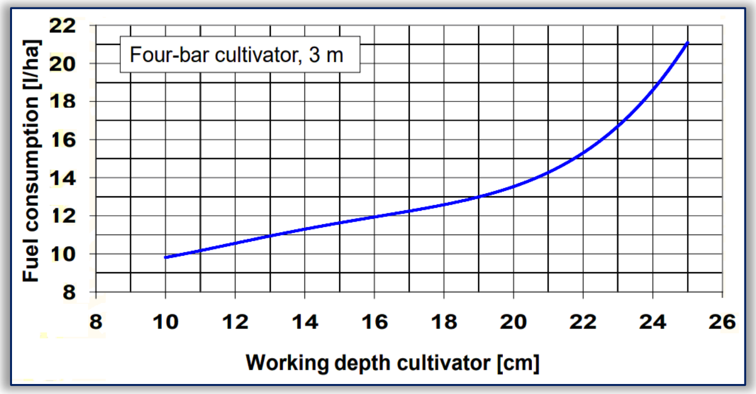


Figure 3 – Influence of working depth on fuel consumption (Mumme, 2007)

### Adjusting Working Intensity

Different soil conditions and crops allow for different working intensities. In the PTO–operated seed drill, the working intensity can be adjusted depending on the PTO rotation speed, the driving speed and the gear box of the equipment. The energy requirement, and thus the fuel consumption, varies by about 30% depending on the working intensity. Therefore, an optimal working intensity results in a corresponding fuel reduction. If the soil is worked too deeply, the risk of muddy silting increases, especially in silty soils.

The intensity of work depends on the following factors:

- Rotation speed of the equipment
- Diameter of equipment
- Driving speed

The higher the operating intensity, the more fuel is required. Work intensity should be adjusted according to specific needs.

### Working Width, Speed and Engine Power Adjustment

The larger the working width, the shorter the distance that must be traveled to treat a particular parcel. Thus, a higher operating speed and lower fuel consumption are possible. Larger working widths have the disadvantage that the equipment weighs more. The increased driving speed to achieve a higher power output is certainly responsible for a higher power and drawbar power demand and correspondingly higher fuel consumption. For example, the traction force requirement increases with the square of the driving speed (Moitzi, 2006). Therefore, in order to increase the working speed, the working width should be increased, not the speed.

If the working width is too large:

- The routes on the parcel are shorter.
- Turnaround times are less.
- Working speed is higher.
- Fuel consumption is less.

If the operating speed is high:

- Power and drawbar power requirement is high.
- Fuel consumption is higher.
- Working width should be adjusted according to the power of the tractor.
- To increase the working speed, the working width – not the speed – should be increased.

### Equipment Setting

For many agricultural mechanization vehicles, tuning has a significant impact on power requirements and thus fuel consumption. Incorrect adjustment of the plow (wrong drawbar point or plow slope) can increase the drawbar power requirement by approximately 10% to 30%. An incorrectly adjusted drawbar can increase


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the drawbar power requirement by 19%. If this happens together with an incorrect slope (plow slope), the drawbar power requirement will increase by 33% compared to the optimal setting of the equipment (Höner, 2004).

### Equipment Maintenance

Optimally maintained seed drills have a positive fuel–saving effect. Often times, an attempt is made to prolong the service life of these equipment by melting scrap metal parts on a plowshare, another unit, or a slatted die board. This often results in soil sticking, resulting in increased traction and fuel demand. Also, rust on work tools causes soil to stick. Therefore, the most important measures for successful rust protection should be taken immediately after the equipment is used.

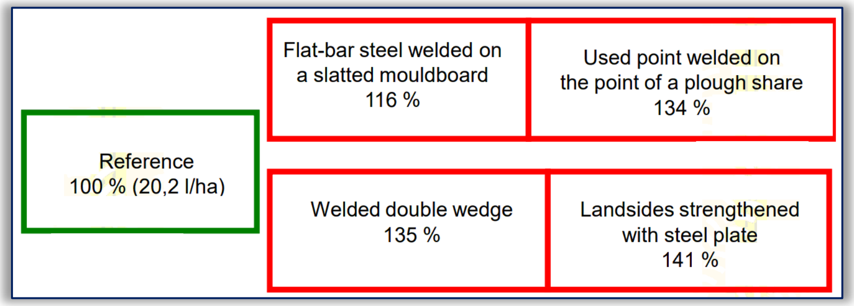


Figure 4 – Diesel consumption of four–furrows–plough with new wearing parts in comparison to unchanged plough body (Weiss 2003)

## 3. CONCLUSIONS

Direct sowing reduce fuel consumption. If possible, tillage with plows should be avoided. Unnecessary operations should be avoided. Merging processes should be attempted. A single operation with a seedbed combination requires 5–9 liters of diesel fuel per hectare. The best prerequisite for preventing soil compaction is a healthy soil. A compacted soil requires more engine power and fuel. An improved soil structure reduces fuel consumption. More soil activity and a more fragile and loose structure also reduce fuel consumption. The best time to work should be chosen. The greater the working depth, the higher the fuel consumption. Approximately 150 tons of soil per hectare is transported per cm working depth. When plowing with a plow, approximately + 0.5 to 1.4 L/ha more diesel fuel is required for a working depth of +1 cm. It should not be worked deeper than the soil and culture require. The higher the rotation speed of the cultivation equipment and the slower the operating speed, the higher the power and fuel consumption. Working intensity should be adjusted according to specific needs. Working width should be adjusted according to engine power. To increase the working speed, it is necessary to increase the working width, not the speed. The wrong traction point and the wrong plow slope require approximately 20–33% more diesel fuel. A full adjustment of the working equipment must be made for each individual working phase. Worn parts must not be improperly repaired but replaced. Parts simply welded to the tillage equipment lead to increased fuel consumption.

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**References**

[1] Brunotte, J., & Korte K. (2003), Bewertung von Systemen der Bodenbearbeitung in Fruchtfolgen mit Körnerraps und Körnerleguminosen. Jahresbericht der Bundesforschungsanstalt für Landwirtschaft (FAL) 2003, Bundesforschungsanstalt für Landwirtschaft, Bundesallee 50, 38116 Braunschweig, ISSN 0171–5801.
[2] Cavalaris, C.C. & Gemtos, T.A. (2002), Evaluation of tillage efficiency and energy requirements for five methods of soil preparation in the sugar beet crop. EE&AE'2002 – International Scientific Conference – 04–06.04.2002, Rousse, Bulgaria.
[3] Demmel, M., Kirchmeier, H., & Geischeder, R. (2004), Untersuchung des Leistungsbedarfes und der Zerkleinerungswirkung von Kreiseleggen mit unterschiedlichen Kreiseldurchmessern. Institut für Landtechnik, Bauwesen und Umwelttechnik, Vöttinger Str. 36, 85354 Freising.
[4] Handler, F., & Nadlinger, M. (2012), D 3.8 Strategies for saving fuel with tractors Trainer handbook Version 12/2012. Efficient 20. IEE/09/764/SI2.558250.
[5] Holz, W. (2006), Möglichkeiten zur Kraftstoffeinsparung in der Landwirtschaft. Sonderdruck aus der Kartei für Rationalisierung 2.1.2.1, RKL, 24768 Rendsburg, Juli 2006.

[6] Höner, G. (2004), Besser Pflügen und 30% Kraftstoff sparen. Top Agrar, Heft 10, 2004.
[7] Kalk, W.D., & Hülsbergen, K.J., (1999), Dieselkraftstoffeinsatz in der Pflanzenproduktion. Landtechnik 54 (6), 332–333.
[8] KTBL (2006), Betriebsplanung Landwirtschaft 2006/07. KTBL, Bartningstr. 49, 64289 Darmstadt, ISBN13: 978–3–939371–07–6Kutzbach, H.D. (1989), Lehrbuch Agrartechnik Band 1: Allgemeine Grundlagen – Ackerschlepper – Fördertechnik; Verlag Paul Parey 1989.
[9] Moitzi, G. (2006), Möglichkeiten zur Kraftstoffeinsparung – Richtiger Einsatz von Maschinen und Geräten im Ackerbau. Ländlicher Raum – Online–Fachzeitschrift des Bundesministeriums für Land– und Forstwirtschaft, Umwelt und Wasserwirtschaft, Jahrgang 2006.
[10] Mumme, M. (2007), Kraftstoffverbrauch und Schlagkraft bei verschiedenen Bodenbearbeitungs– und Bestellverfahren. DLG–Testzentrum Groß–Umstadt, Manuskript zum Vortrag, Strickhof Ackerbautag 15.08.2007.
[11] Papathanassiou, I., Kavalaris, Ch., Karamoutis, Ch., Gemtos, T.A. (2002), Design, Construction and Testing of an Instrumented Tractor to Measure Forces on Agricultural Implements and Energy Consumption During Field Work 1 st Conference of Hellenic Association of ICT in Agriculture (HAICTA), Food and Environment, Athens 2002, 144153.
[12] Sommer, C., & Vosshenrich, H.H. (2004), Bodenbearbeitung und Bestellung. Kapitel 4.5 in Precision Agriculture – Ergebnisse des Verbundprojektes pre agro, KTBL, Bartningstr. 49, 64289 Darmstadt.
[13] Weiss, J. (2003), Zugkraftbedarf bei verschiedenen Pflugscharen und gängigen Abwandlungen an Verschleissteilen. RKL–Schrift, Rationalisierungs–Kuratorium für Landwirtschaft, Am Kamp 13, 24768 Rendsburg, April 2003.

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