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ENERGY CONSUMPTION AND ENERGY EFFICIENCY OF DIFFERENT TILLAGE SYSTEMS IN THE SEMI-ARID REGION OF AUSTRIA

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Abstract: Tillage in conventional cropping systems requires a high amount of direct energy in form of fuel and influences the energy efficiency of the production system. The fuel consumption was measured in three conventional tillage systems (plough, heavy cultivator and sub-soiler, integrated system) and two conservation tillage systems (mulch seeding, no-tillage) with a high-performance flow-meter, which was integrated in a four wheel driven tractor (92 kW). The tillage trials were carried out on a *Chernozem* soil with silty loam in the semiarid region of Austria (mean temperature: 9.8°C; mean rainfall: 546 mm). Moreover the total energy efficiency was calculated from the energy input (direct: fuel; indirect: seeds, fertilizer, pesticides and machines) and energy output (heat value) of winter wheat. The highest fuel consumption in the soil tillage was measured in the conventional tillage with plough (39.9 $l \cdot ha^{-1}$), where 18.8 $l \cdot ha^{-1}$ results from the plough. The lowest fuel consumption was in the no-tillage system, where 5.9 $l \cdot ha^{-1}$ fuel for seeding was required. The total fuel consumption can be reduced between 33% and 50% with conservation tillage in comparison to conventional tillage with plough. The best energetic parameters (energy and fuel intensity, net energy and energy efficiency) were realised in the conservation tillage systems.

Key words: *tillage system, fuel consumption, energy efficiency, energy intensity, plough, no-tillage*

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INTRODUCTION

Farming – from beef, pig, poultry or dairy and crops – has become increasingly mechanized and requires significant energy inputs at particular stages of the production cycle to achieve optimum yields. In accordance to Factor Five [16], the agricultural Sector has the potential to achieve a Factor 10 - 100 improvement in resource productivity. Due to increasing fuel prices, energy efficiency in plant production became an increasing awareness [12].The awareness in saving of direct energy has grown rapidly in this sector due to continues increase in energy prices (for example fuel) in the last couple of years. Reducing the fuel consumption in agriculture is a complex am multi-factorial process, where farm management plays a key factor in the fuel consumption reduction programs [13].

The energy input in plant cropping can be categorised into two main groups [6]: direct energy (fuel for machinery, heating oil and electricity for drying processes or conveyors) and indirect energy: (process energy for the production on “annual” facilities e.g. fertilizer, pesticides, seeds and “perennial” facilities e.g. farm machinery, farm buildings). In a conventional cropping system the greatest energy consumer is soil tillage [17]. Fuel consumption of soil tillage is correlated with the intensity of soil tillage. In comparison to conventional tillage systems with plough for primary tillage, the fuel consumption can be significantly reduced with conservation tillage systems [10]. Additional soil related parameters e.g. soil texture and organic matter content influences the fuel consumption in soil tillage [10, 9]. Depending on the soil constitution the fuel consumption increases per centimetre ploughing depth between 0.5 and 1.5 $l \cdot ha^{-1}$ [4, 7, 11]. Besides fuel saving in conservation tillage systems, there is a higher soil water storage capacity in semi-arid regions [3].

The aim of the research was to analyse the influence of three conventional tillage systems and two conservation tillage systems on the fuel consumption and energy efficiency for wheat production in a semiarid region of Austria (Marchfeld in Lower Austria).

MATERIAL AND METHODS

A long term trial for soil tillage since 1997 at the experimental station of the University of Natural Resources and Life Sciences - Vienna (BOKU) at the location Gross Enzersdorf (Tab. 1) was used for the measurement of fuel consumption and determination of energy efficiency. Each tillage system (Tab. 2) is designed in randomized plots in a fourfold repetition. The size of plots (60 m x 24 m) allows the cultivation with tillage implements, which are usually used on arable farms.

Table 1. Description of the trial locations in Lower Austria [15]

Location	*Gross Enzersdorf (lower Austria); 153 m above sea level*
Average temperature	*9.8 °C*
Average rainfall	*546 mm*
Classification of soil texture	*silty loam*
Type of soil	*chernozem*

Table 2. Tillage systems with operations

Tillage System	*Description*
Conventional tillage with plough (Conventional 1)	*Heavy cultivator for stubble field skimming (3 m, 5 cm*); 2x4-mouldboard plough (1.6 m, 25 cm); Power harrow (3 m, 5 cm); Seeding machine (3 m, 3 cm)*
Conventional tillage with heavy cultivator and subsoiler (Conventional 2)	*Heavy cultivator for Stubble field skimming (3 m, 5 cm); Subsoiler** (3 m, 35 cm); Heavy cultivator (3 m, 20 cm); Power harrow (3 m, 5 cm); Seeding machine (3 m, 3 cm)*
Conventional tillage –integrated Every four years: plough instead of cultivator (Conventional 3)	*Heavy cultivator for Stubble field skimming (3 m, 5 cm); Heavy cultivator (3 m, 10 – 15 cm); Resp. 2x4-mouldboard plough (1.6 m, 25 cm); Power harrow (3 m, 5 cm); Seeding machine (3 m, 3 cm)*
Conservation tillage – mulch seeding (Conservation 1)	*Heavy cultivator for Stubble field skimming (3 m, 5 cm); Heavy cultivator (3 m, 8 cm); Seeding machine (3 m, 3 cm)*
Conservation tillage – direct seeding (Conservation 2 – No tillage)	*Direct drilling machine with disc coulters (3 m, 2 cm)*

** first value: technical working width, second value: mean working depth*
***sub-soiler is used every fourth year*

For all experiments a four-wheel drive tractor (Steyr 9125, CNH, St. Valentin, Austria) with an engine power of 92 kW (DIN) was used. The measurement of the fuel consumption was done with a high-performance flow-meter (AVL PLU 116H[1]), which was integrated in the fuel system of the tractor. The volumetric fuel consumption was continuously measured with an error rate of 1 % without pressure drop between inlet and outlet (Δp = 0). The signals of the radar-sensor, transmission sensor, inductive sensor and flow-meter (Tab. 3) were scanned with a scan-rate of 1 Hz in a multi-channel data-logger (Squirrel Datenlogger 2020).

Table 3. Process parameters and their measurements

Process parameters	*Measurement engineering*
Vehicle speed v *[km·h^{-1}]*	*Radar sensor generates a rectangular signal (130 pulses m^{-1} = 27.8 Hz/[km·h^{-1}]*
Wheel speed v_0 *[km·h^{-1}]*	*Transmission sensor (inductive transducer), generates a 0.4 - 3.8 V AC signal*
Engine speed n_E *[rpm]*	*Inductive sensor generates a rectangular signal between 0 - 12 V AC signal*
Fuel consumption B *[l·h^{-1}]*	*Flow meter (PLU 116 H), generates a digital rectangular signal between 22 - 2800 Hz*

The area-specific fuel consumption (B_A) is defined by Eq. 1.

$$B_A = B \cdot T_A \tag{1}$$

where:
B_A [l·ha^{-1}] - area-specific fuel consumption,
B [l·h^{-1}] - fuel consumption,
T_A [h·ha^{-1}] - technical field operation time.

The calculated area-specific fuel consumption (B_A in l·ha^{-1}) does not consider the fuel consumption during turning at the headland. This parameter allows the comparison of soil tillage devices without influence of field shape and field size.

The technical field performance (C_A) is defined by Eq. 2.

$$C_A = b \cdot v \cdot 0.1 \tag{2}$$

where:
C_A [ha·h^{-1}] - technical field performance,
b [m] - technical working width,
v [km·h^{-1}] - vehicle speed,
0.1 [-] - conversion factor.

The technical field operation time (T_A) is defined by Eq. 3.

$$T_A = \frac{1}{C_A} \tag{3}$$

For the energy analysis, the energy inputs via fuel was calculated with the lower heat value of 35,2 MJ·l^{-1} diesel fuel. The energy equivalents for fertilizer, pesticides and machines were taken from [6, 2, 14]. The energy output of grain was energetically evaluated with the heat value of 18.3 MJ·kg^{-1} dry matter winter wheat.

RESULTS AND DISCUSSION

The measured technical parameters area-specific fuel consumption (l·ha^{-1}) and technical field performance (ha·h^{-1}) for the different soil tillage operations are shown in Tab. 4.

Soil tillage with plough has the highest fuel consumption of 18.8 l·ha^{-1}. With the cultivator can be reduced about 50 %. Turning at the headland was conventional done in the so-called „swallowtail-shape". The mean working time requires between 21 and 35 sec. with an average fuel consumption of 5.0 and 5.8 l·h^{-1}. This technical parameters allows the modeling of the fuel consumption in dependence of field size and field sharp.

The fuel consumption depends also on the soil texture. On a soil with loamy clay, the measured fuel consumption for ploughing was 35.6 l·ha^{-1} [10].

Table 4. Mean measured technical process parameter for different field operations

Field operations	*Fuel Consumption [l·ha^{-1}]*	*Technical field performance [ha·h^{-1}]*	*Working time requirement for one turning event* [s]	*Fuel consumption at turning [l·h^{-1}]*
Ploughing (25 cm)	*18.8*	*1.03*	*35*	*5.0*
Subsoiling (35 cm)	*9.4*	*2.16*	*30*	*5.8*
Cultivating (20 cm)	*9.4*	*2.19*	*26*	*5.0*
Cultivating (8 cm)	*6.7*	*2.71*	*23*	*5.0*
Power harrowing	*8.6*	*2.31*	*22*	*5.6*
Seeding	*6.3*	*2.46*	*33*	*5.3*
Stubble field skimming	*5.6*	*2.85*	*21*	*5.0*

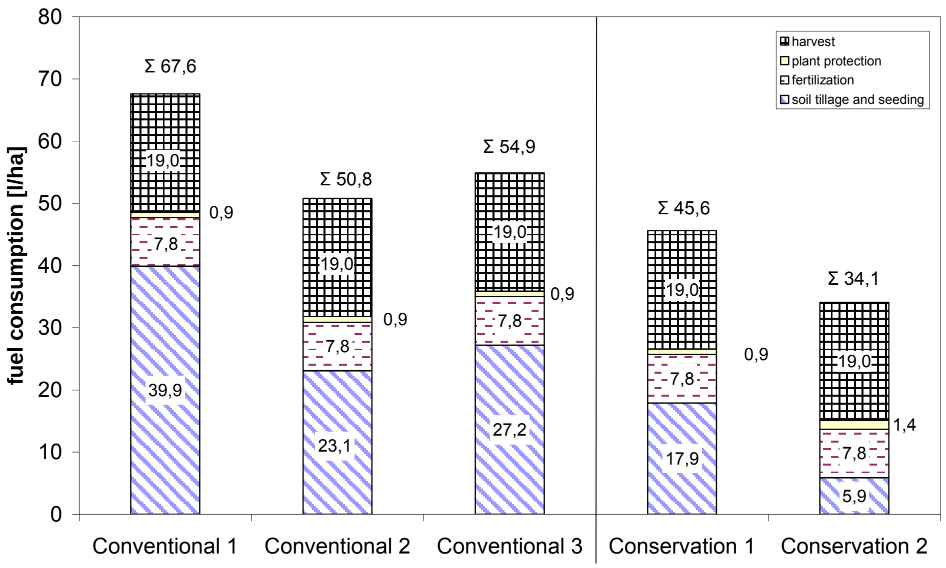

Figure 1. Fuel consumption of the different soil tillage systems for winter wheat cropping (Fuel consumption for fertilization, plant protection and harvest is calculated by means of data from The Association for Technology and Structures in Agriculture (KTBL), [8]

The total area-specific fuel consumption (l/ha), without consideration of the fuel consumption at the turning are shown in Fig. 1. For the tillage system with plough (Conventional 1), about 58 % of the total fuel consumption is caused by soil tillage and seeding. If the plough is substituted by an heavy cultivator (Conventional 2) the fuel consumption for soil tillage can be reduced by 42 % to 23.1 l/ha. The integrated tillage system (Conventional 3) is between Conventional 1 and 2. Conservation tillage systems have the lowest fuel consumption, which is caused by shallow soil tillage (Conservation

1) and no tillage (Conservation 2). Besides the reduction of the fuel consumption, also the working time requirement decreases with the shift from conventional tillage to conservation tillage [15]. For the conservation tillage systems, the working time requirement can be reduced between 48 and 81% [15].

The Tab. 5 about the energy analysis for winter-wheat indicates, that more than 75% of the total required energy belongs to the indirect energy form (seeds, fertilizer, herbicides and machine).

The main indirect energy consumer is the nitrogen fertilizers. This share of indirect energy to total energy was also found in the investigations for conventional crop production system in Canada [5].

Table 5. Energy analysis for wheat production in different soil tillage systems at the location Gross Enzersdorf (soil texture: silty loam)

	Conventional tillage			Conservation tillage	
	1	2	3	1	2
Direct Energy input [MJ·ha^{-1}]	2380	1788	1932	1605	1200
Fuel for soil tillage (Fig. 1)	1404	813	957	630	208
Fuel for fertilizer application	275	275	275	275	275
Fuel for pesticide application +1 glyphosate application in Conservation tillage 2	32	32	32	32	49
Fuel for harvest (combine)	669	669	669	669	669
Indirect Energy input [MJ·ha^{-1}]	7042	7030	7013	7033	7109
Seeds (160 kg·ha^{-1})	880	880	880	880	880
Fertilizers (Ø 120 kg N·ha^{-1})	4874	4874	4874	4874	4874
Herbicides + 1 glyphosate application (2 l·ha^{-1}) in Conservation tillage 2	675	675	675	675	805
Machines	612	600	583	603	550
Total Energy input [MJ·ha^{-1}]	9422	8818	8945	8638	8609
Ratio Direct Energy:Indirect Energy	25:75	20:80	22:78	19:81	14:86
Wheat yield*) [kg·ha^{-1}], 89 % DM	4636	4788	4969	4842	5117
Energy output_grain [MJ·ha^{-1}]	72964	75347	78205	76198	80539
Energy intensity [Input_ MJ·kg^{-1} wheat]	2.03	1.84	1.80	1.78	1.68
Fuel intensity [l fuel·t^{-1} wheat]	14.58	10.60	11.04	9.41	6.66
Output-Input = Net energy [MJ·ha^{-1}] (grain)	63542	66529	69260	67560	72230
Output/Input = Energy efficiency (grain)	7.70	8.54	8.74	8.82	9.69

*) mean wheat yield from the year 1998, 2000, 2002, 2004, 2007 and 2009

The tillage systems without plough (Conventional 2 and 3; Conservation 1 and 2) realized higher wheat yields in the investigated six years, which was explained by the improved water storage capacity especially in the periods of draught. The highest yield was measured in the no-tillage system.

The energy analysis for wheat production indicates that the conservation tillage systems had the best energetic parameters (energy and fuel intensity, net energy and energy efficiency) at this site with semi-arid climate. The lowest energy intensity of 1.68 $MJ \cdot kg^{-1}$ wheat was calculated in the no-tillage system, which is caused by the lower direct energy input of fuel and the highest mean yield of wheat (5.117 $kg \cdot ha^{-1}$). The conservation tillage system 1 with mulch seeding has the second best energy intensity and energy efficiency.

CONCLUSIONS

Fuel consumption in cereal cropping is significantly influenced by the soil tillage system. The reduction of tillage intensity in conservation soil tillage systems results in a decrease of fuel and working time. Conservation tillage systems conserve the soil structure and especially in the semi-arid region the soil water content, which is a adaptation contribution to climate change.

The shift from soil tillage systems with plough to conservation tillage systems reduces the direct energy input and improves the energy efficiency in the semi-arid region.

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POTROŠNJA ENERGIJE I ENERGETSKA EFIKASNIOST RAZLIČITIH SISTEMA OBRADE ZEMLJIŠTA U POLU-SUŠNOM REGIONU AUSTRIJE

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Sažetak: Obrada zemljišta u konvencionalnim sistemima ratarenja zahteva veliku količinu direktne energije iz goriva i utiče na energetsku efikasnost proizvodnog sistema. Potrošnja goriva je merena u tri konvencionalna sistema obrade (plug, teški kultivator i podrivač, integrisani sistem) i dva konzervacijska sistema obrade (malč setva, bez obrade) sa meračem protoka visokih performansi, koji je bio integrisan u traktor sa pogonom na sva četiri točka (92 kW). Probe obrade su izvedene na černozemu sa ilovastim sedimentom polu-aridnom regionu Austrije (srednja temperatura 9.8°C; srednji nivo padavina 546 mm). Ukupna energetska efikasnost je izračunata iz energetskih unosa (direktni: gorivo, indirektni: seme, đubrivo, pesticidi i mašine) i energetskih izlaza (toplotna vrednost) ozime pšenice. Najveća potrošnja goriva u obradi zemljišta je izmerena u konvencionalnoj obradi plugom (39,9 $l \cdot ha^{-1}$), gde je 18.8 $l \cdot ha^{-1}$ rezultat pluga. Najniži potrošnja goriva je u sistemu bez obrade, gde je bilo potrebno 5,9 $l \cdot ha^{-1}$ goriva za setvu . Ukupna potrošnja goriva može da se smanji između 33% i 50% sa konzervacijskom obradom u odnosu na konvencionalnu obradu plugom. Najbolji energetski parametri (energetski intenzitet i gorivo, neto energija i energetska efikasnost) realizovani su u konzervacijskim sistemima obrade zemljišta.

Ključne reči: *system obrade, potrošnja goriva, energetska efikasnost, energetski intenzitet, plug, bez obrade*

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