Energy Use and Energy Efficiency in Selected Arable Farms in Central and South Eastern Europe

Gerhard MOITZI [1] (✉), Milan MARTINOV [2], Ladislav NOZDROVICKY [3],
Alexandru NAGHIU [4], Andreas GRONAUER [1]

Summary

The main objective of the project "Mechanization and Energy use in selected arable farms in Central and South Eastern Europe (CASEE)" was to analyse energy characteristics of arable farming in Slovak Republic, Romania, Serbia and Austria, to compare results and identify possibilities of its improvements. The large scale farms are: the university farm of the Slovak University of Agriculture (SK) with 1.112 ha arable land, a cooperative farm in Risnovice (SK) with an arable land of 1.266 ha, a family farm in Apahida-Transylvania (RO) with 400 ha, a farm in Viisoara-Transylvania (RO) with 600 ha, a family farm in Sremska Mitrovica (SRB) with an arable land of 115 ha, a family farm near Novi Sad (SRB) with an arable land of 450 ha and a family farm in Ansfelden/Linz (A) with 368 ha. The farms were visited by the interviewer once or more times and the relevant data, used machinery, quantity of inputs, e.g. fuel, pesticides, fertilizer, seed and yields of harvested crops, were recorded, for the production season 2012. After collection of the basic data all energy inputs and outputs, energy content of crops, were calculated in accordance with data and procedure defined by CIGR (International Commission of Agricultural and Biosystems Engineering), Handbook Volume V – Energy and Biomass Engineering (1999). Energy input and net energy gain, expressed in MJ/ha, were used to calculate energy characteristics of crops' production: energy productivity - kg/MJ, energy efficiency index, energy ratio, energy intensity - MJ/kg, fuel intensity - L/kg. The intensity of all used farm inputs (fuel, seeds, fertilizer and pesticide) in crop production systems influences the energy efficiency. The fuel consumption for winter wheat production of the analysed farms ranges between 54 and 91 l/ha. The mean energy ratio (energy-output/energy-input) for winter wheat is 5.6 with ranges between 4.8 and 7.1. Besides the fuel consumption the energy-input via the nitrogen-fertilizer is the main energy consumer in cropping systems. It is clearly identified that the highest possible energy savings are possible by reduction of fertilizers, first of all nitrogen.

Key words

arable farming, energy characteristics, Central and South Eastern Europe (CASEE), fuel consumption

[1] University of Natural Resources and Life Sciences (BOKU),
Department of Sustainable Agricultural Systems; Division of Agricultural Engineering,
Peter Jordan-Strasse 82; 1190 Vienna, Austria
✉ e-mail: gerhard.moitzi@boku.ac.at
[2] University of Novi Sad, Faculty of Technical Sciences, Department of Environmental Engineering, Chair of Biosystems Engineering, Trg Dositeja Obradovica 6, 21000 Novi Sad, Serbia
[3] The Slovak Agricultural University in Nitra, Faculty of Engineering,
Tr. A. Hlinku 2, 949 76 Nitra, Slovak Republic
[4] University of Agricultural Sciences and Veterinary Medicine - Cluj-Napoca (USAMV),
Faculty of Agriculture, Str. Manastur, nr. 3, RO-3400 Cluj-Napoca, Romania

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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 (Von Weizsäcker et al. 2009), the agricultural Sector has the potential to achieve a Factor 10-100 improvement in resource productivity. The awareness in saving of direct energy has grown rapidly in this sector due to continues increase in energy prices (for example fuel prices) in the last couple of years. The increase of the photosynthetic yield in plant cropping systems requires external facilities. The energy input in plant cropping can be categorised into two main groups (Hülsbergen 2008):

- Direct energy: fuel for machinery, heating oil and electricity for drying processes or conveyors
- Indirect energy: process energy for the production on "annual" facilities e.g. fertilizer, pesticides, seeds and "perennial" facilities e.g. farm machinery, farm buildings

Due to increasing fuel prices, energy efficiency in plant production became an increasing awareness (Pimentel et al. 1998). In a conventional cropping systems soil tillage is a large energy consumer (Zimmer et al. 2004). Additional soil related parameters e.g. soil texture and organic matter content influences the fuel consumption in soil tillage (McLaughlin et al. 2002). Depending on the soil constitution the fuel consumption increases per centimetre ploughing depth between 0.5 and 1.5 l/ha (Moitzi et al. 2006; Kalk and Hülsbergen 1999, Filipovic et al. 2004).

The intensity of production in arable farms is correlated with farm facility consumption. In conventional cropping systems the energy input via fertilizers are high (Hoeppner et al. 2004). Analysed conventional arable farms in Austria show, that the main energy inputs on the farm level are fertilizer and fuel. The total energy input of the five arable farms ranges between 8.5 and 12.2 GJ/ha (Moitzi et al. 2010).

The main objective of this paper was to analyse selected arable farms in Central and South Eastern Europe (Slovak Republic, Romania, Serbia and Austria) in respect of energy efficiency.

Materials and methods

The seven farms (two farms in Romania -Transylvanian Plateau, two farms the Slovak Republic - Kolinany and Risnovce, two farms in Serbia - Sremska Mitrovica and Novi Sad and one farm in Austria Ansfelden/Linz, Table 1) were visited in the year 2012 one or two times. The data are collected for the cropping season 2012.

In a questionnaire basic farm description (size, crop rotation,...), the amount of used facilities (fuel, pesticides, fertilizer, and seed) and the yearly harvested crops were recorded for the cropping season 2011. The stocks of facilities and harvested crops were converted with energy equivalents (Table 2) into energy units (MJ or GJ).

Table 2. Energy-equivalents of farm facilities

		Energy-equivalent	Source
Direct-use Energy	Diesel, Heating oil	44.3 MJ/l	CIGR, 1999
	Electricity	12 MJ/kWh	
Indirect-use Energy			
Fertilizers	Nitrogen	60 MJ/kg N	CIGR, 1999
	Phosphorus	14 MJ/kg P_2O_5	
	Potassium	12 MJ/kg K_2O	
Pesticides	Herbicide	250 MJ/kg[1]	CIGR, 1999
	Fungicide	180 MJ/kg[1]	
	Insecticide	300 MJ/kg[1]	
Seed	Cereals	15 MJ/kg	CIGR, 1999
	Corn hybrid	100 MJ/kg	Hülsbergen, 2008
	Potato	93 MJ/kg	
	Oil seed rape	200 MJ/kg	
	Sunflower	20 MJ/kg	
	Sugarbeet	54 MJ/kg	
	Soybean	34 MJ/kg	
Machinery	Farm size (50 ha)	3000 MJ/ha	Biedermann 2009
	Farm size (100 ha)	1700 MJ/ha	
	Farm size (200 ha)	1170 MJ/ha	

[1] active ingredient (for calculation: use factor 0.6 because about 60 % of pesticide volume is active ingredient)

The amount of energy used in the setting up of farm buildings was not considered. The energy output of crops was calculated with the amount of harvested crops (without straw) and the lower heat value (MJ/kg DM). The lower heat values are for wheat 18.3 MJ/kg DM, for rye 17.9 MJ/kg DM, for barely 18.2 MJ/kg DM, for oat 18.8 MJ/kg DM, for corn 18.5 MJ/kg DM, for sugar beet 17.0 MJ/kg DM for soybean 23.8 MJ/kg DM for rapeseed 28.3 MJ/kg DM.

For the energetic evaluation of the production systems different energetic parameters can be used (CIGR 1999, Hülsbergen 2008, Naghiu et al. 2003):

Table 1. Description of the farms

	Romania		Slovak Republic		Serbia		Austria
	RO 1	RO 2	SK 1	SK 2	SRB 1	SRB 2	A 1
Location	Transylvanian Plateau A	Transylvanian Plateau B	Kolinany	Risnovce	Sremska Mitrovica	Novi Sad	Ansfelden
Arable land (ha)	400	600	1112	1266	115	450	368
Mean temperature (°C)	8.4	9.0	9.7	10.3	11.0	11.5	9.1
Precipitation (mm)	628-733	557-600	631	550-600	650-700	550-600	848
Average field size (ha)	8.0	10.0	39.5	27.0	5.0	8.5	8.8
Soil	clay-silty, chernozem	clay-silty, chernozem	brown soil type	brown soil type	clay-silty chernozem	clay-silty chernozem	silty loam; brown soil type
Soil tillage	with plough	with plough	with plough	with plough	with plough	ploughless	ploughless

a.) Energy Ratio = *Eo/Ei*
b.) Energy Intensity (MJ/kg) = *Ei/Y*
c.) Fuel Intensity (l/t) = *FI/Y*
d.) Net Energy Gain (GJ/ha) = *Eo-Ei*
e.) Energy Productivity (kg/MJ) = *Y/Ei*
f.) Energy Efficiency Index (%) η_E

$$\eta_E = \frac{E_o - E_i}{E_o} \; [\%]$$

where:

Ei - Energy input (fuel, seeds, fertilizer, pesticide, farm machinery); MJ/ha
Eo - Energy output of the harvested crop; MJ/ha
Y - harvested crop; kg/ha

Results and discussion

Fuel consumption

The fuel consumption in plant cropping is determined by the kind of crop, soil tillage system (conventional or conservation tillage), soil parameter (e.g. content of moisture, humus, clay), field size, production intensity (amount of mineral fertilizer and pesticides), machinery parameter (engine power, kind of transmission etc.) and human factors (e.g. operating strategy of the engine). For the analysed crops and farms the mean fuel consumption per hectare are shown in figure 1. For wheat production, the mean fuel consumption ranges between 54 and 81 l/ha. An outlier is the SK_1 Farm, where the mean fuel consumption for winter wheat was 54 l/ha although ploughing was used (Table 3). One of the reasons is the degression effect of fuel consumption through the large fields with an average field size of 39.5 ha.

The area based fuel consumption (l/ha) with the consideration of the crop yield represents the fuel intensity (l/t, Figure 2).

The mean fuel intensity for winter wheat is 13.4 l/t with an range of 8 l/t to 18 l/t. For corn the mean fuel intensity is 15.2 l/t but with an larger range of 6 l/t to 28 l/t. The high fuel intensity value in Romania are caused by the low yields of corn (3000 t/ha). The lowest fuel intensity values are shown in sugarbeet (3 and 2 l/t). For soybean the mean fuel intensity is 23 l/t which ranges between 19 and 28 l/t. For rape the range is between 17 and 33 l/t with an average fuel intensity of 26 l/t.

Energy analyses for winterwheat

In Table 4 the crop specific data for winterwheat production from seven arable farms are shown.

The results for energy analysis are shown in table 5. The mean energy ratio is 5.6 and ranges between 4.8 and 7.1. It must be mentioned that only the harvested grain is considered in the energy output (table 5). The energy ratio is higher, if also the stored solar in the straw and root biomass is considered. Plant cropping systems are photosynthetic energy storage systems. The increase of the photosynthetic yield in plant cropping systems required external farm facilities (e.g. fertilizers). Energy analysis for conventional farms show that, that the energy input via the fertilizer takes the highest share of the total energy input (Moitzi et al. 2010). The calculated mean energy intensity is 2.93 MJ/kg and ranges between 2.27 and 3.59. The mean fuel intensity is 15 l/t and ranges between 8.06 l/t and 18.3 l/t. The lowest values are explained by the conservation tillage system on the Serbian farm (SRB 2) and Austrian Farm (A1). The low fuel intensity of 9.0 l/ha on the Slovakian farm in Kolinany (SK 1) is mainly explained by the degression effect of fuel consumption.

The mean net energy gain of winterwheat of the seven farms is 77.96 GJ/ha and ranges between 51.67 and 110.64 GJ/ha. The high net energy gain values and also the energy efficiency index

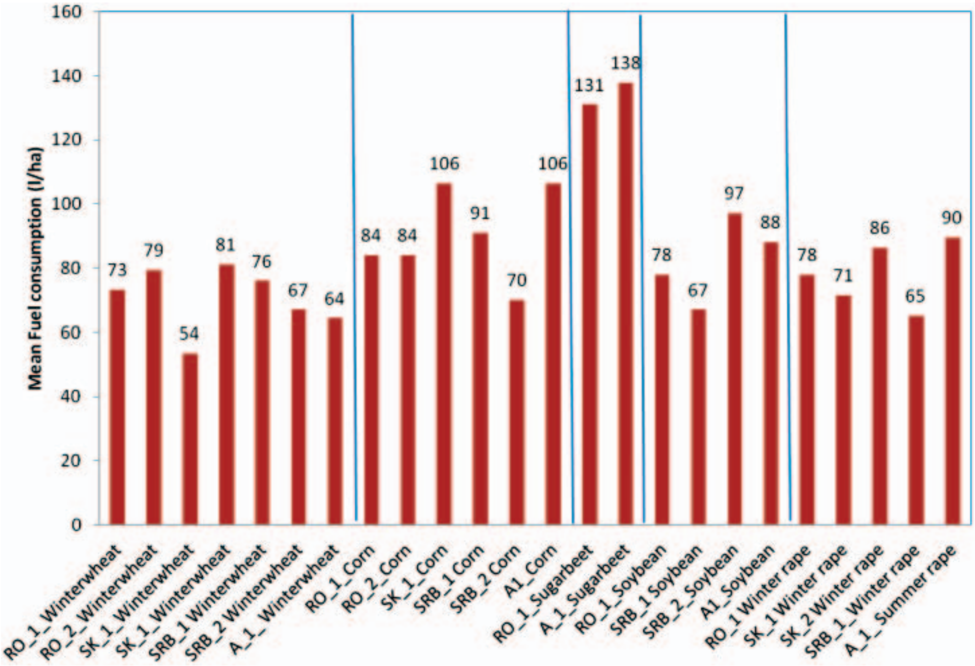

Figure 1. Mean fuel consumption (l/ha) for different crops

Table 3. Steps of agricultural processing with fuel consumption (l/ha) and labour consumption (h/ha) in the winter cropping system (177.13 ha) at the large scale farm in the Slovak Republic

No.	Operation	Month/ halfmonth	Operation share, %	Unit fuel consumption, l/ha	Total fuel consumption, l per area	Unit labour consumption, h/ha	Unit labour consumption, h per area
1	1st stubble loosening	7/2	0.80	5.8	821.88	0,42	59,52
2	Manure loading	7/2	0.20	0.3	10.63	0,4	14,17
3	Manure transport	7/2	0.20	1.1	38.97	3	106,28
4	Manure incorporation into the soil	7/2	0.20	21	743.95	0,67	23,74
5	Ploughing (20-22 cm, middle depth)	9/1	0.00	17.5	0.00	0,78	0,00
6	2nd stubble loosening	9/2	0.80	5.5	779.37	0,32	45,35
7	Deep subsoiling	9/2	0.05	18	159.42	1,5	13,28
8	Fertilizer loading	10/1	0.25	0.3	13.28	0,2	8,86
9	Fertilizer transport	10/1	0.25	0.5	22.14	0,1	4,43
10	Fertilizer spreading (rate 0,2 t/ha) without transport	10/1	0.25	2.3	101.85	0,25	11,07
11	Seed loading, Bigbags	10/1	1.00	1	177.13	0,4	70,85
12	Seed transport on the field	10/1	1.00	0.2	35.43	0,14	24,80
13	Seed hopper filling	10/1	1.00	0.1	17.71	0,4	70,85
14	Seeding by combined machine	10/1	1.00	10	1771.30	0,4	70,85
15	Fertilizer loading	3/2	1.00	0.2	35.43	0,2	35,43
16	Fertilizer transport	3/2	1.00	0.2	35.43	0,2	35,43
17	Fertilizer spreading (rate 0,2 t/ha) without transport	3/2	1.00	2.4	425.11	0,25	44,28
18	Fertilizer transport, Nitrohum	4/1	0.65	0.3	34.54	0,17	19,57
19	Water transport for spraying	4/1	0.65	0.4	46.05	0,12	13,82
20	Spraying (rate over 400 l/ha)	4/1	0.65	2.5	287.84	0,36	41,45
21	Water transport for spraying	5/2	1.00	0.3	53.14	0,12	21,26
22	Spraying (rate 200-400 l/ha)	5/2	1.00	2.6	460.54	0,26	46,05
23	Wheat harvest with straw chopping	7/2	0.35	12.8	793.54	0,65	40,30
24	Wheat harvest without straw chopping	7/2	0.65	11	1266.48	0,65	74,84
25	Grain transport by truck	7/2	1.00	0.7	123.99	0,8	141,70
26	Works with wheeled front loader	7/2	1.00	0.15	26.57	0,23	40,74
27	Straw baling	7/2	0.65	6	690.81	0,52	59,87
28	Straw bales loading	7/2	0.65	0.3	34.54	0,42	48,36
29	Straw bales tractor transport	7/2	0.65	0.9	103.62	0,1	11,51
30	Straw bales unloading and stacking	7/2	0.65	3.2	368.43	0,4	46,05
31	Total for winter wheat cropping system				9479.112		1244.69
32	Total for winter wheat				53.51 l/ha		7.02 h/ha
33	Energy consumption for fuel				2370.5 MJ/ha		

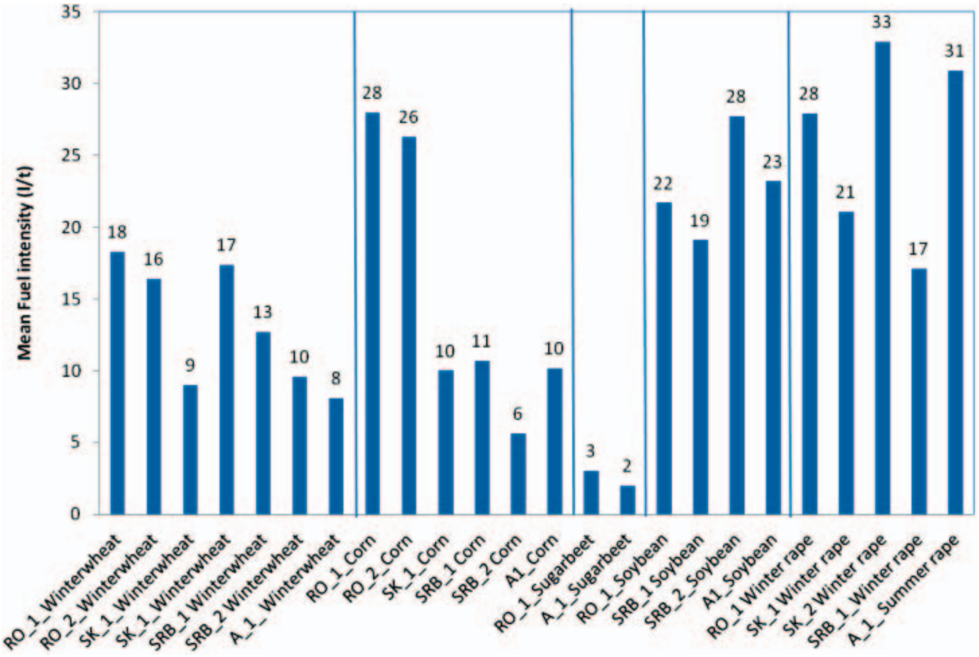

Figure 2. Mean fuel intensity (l/t) for different crops

Table 4. Crop specific data for wheat production on seven arable farms

	Romania		Slovak Republic		Serbia		Austria
Location	RO 1 Transylvanian Plateau A	RO 2 Transylvanian Plateau B	SK 1 Kolinany	SK 2 Risnovce	SRB1 Sremska Mitrovica	SRB 2 Novi Sad	A1 Ansfelden
Arable land on the farm (ha)	400	600	1112	1266	115	450	368
Winterwheat area (ha)	20	76	177	155	38	120	185
Mean Fuel consumption (l/ha)	73.2	79.4	53.5	81.1	76.0	67.0	64,4
N-fertilizer (kg N/ha)	30	37.5	145	145	160	207	164
Herbicide (kg/ha)	2	1.15	1.20	0.4	0.35	2.50	3.20
Fungicide (kg/ha)	-	-	1.10	1.0	0.50	-	3.82
Insecticide (kg/ha)	-	-	0.1	0.1			
Seed (kg/ha)	230	230	223	200	200	240	190
Organic manure (t/ha)	15	20	-	-	-	-	-
Mean yield (kg/ha)	4.000	4.850	5.920	4.657	6.000	7.000	8.000

Table 5. Parameters for energy analysis in wheat production on seven arable farms

	Romania		Slovak Republic		Serbia		Austria
Location	RO 1 Transylvanian Plateau A	RO 2 Transylvanian Plateau B	SK 1 Kolinany	SK 2 Risnovce	SRB1 Sremska Mitrovica	SRB 2 Novi Sad	A1 Ansfelden/ Linz
Arable land (ha)	400	600	1112	1266	115	450	368
Winterwheat (ha)	20	76	177	155	38	120	185
Yield (kg/ha)	4.000	4.850	5.920	4.657	6.000	7.000	8.000
Energy ratio	5.05	5.58	6.51	5.09	4.91	4.82	7.08
Energy intensity (MJ/kg)	3.19	2.89	2.81	3,59	2.62	3.17	2.27
Fuel intensity (l/t)	18.3	16.4	9.0	17.4	12.70	9.60	8.06
Net energy gain (GJ/ha)	51.67	64.10	91.69	68.49	74.54	84.56	110.64
Energy productivity (kg/MJ)	0.31	0,34	0.36	0.28	0.32	0.31	0.44
Energy efficiency index (%)	80.2	82.1	84.6	80.4	79.6	79.3	85.9

(%) show that wheat cropping stores more energy via the photosynthesis as energy (fuel, pesticide, fertilizer, machinery) is need for field management.

Energy saving visions

Soil tillage in conventional tillage systems, which use mouldboard ploughs, is one of the most energy-consuming processes (Stout 1990, Kalk 1981). Alternative soil tillage systems without plough (non soil turning systems, e.g. conservation tillage) should be applied, if there are no specific requirements regarding soil conditions, climate and crop. In comparison to conventional tillage systems with a plough for primary tillage, the fuel consumption can be significantly reduced with non soil turning systems (Mileusnić et al. 2010, Moitzi et al. 2009).

Besides, the fuel consumption of soil tillage operations varies widely and can be reduced through proper matching of the tractor size and operating parameters to the tillage implement (McLaughlin et al. 2008).The "gear up, throttle down" operating strategy is a suggested method to reduce fuel consumption (Grisso and Pitman, 2001). The idea is to operate tractors in a higher gear when pulling lighter loads, thus achieving lower engine speed and fuel consumption while maintaining the same ground speed. Moreover slippage, which is a measure of the traction efficiency, affects field performance and fuel consumption (Moitzi et al. 2006; Jenane et al. 1996).

Mineral nitrogen fertilizers are very energy consuming in production (Table 2). Besides the substitution with organic fertilizers (slurry, stable manure) from animal husbandry, the improvement of mineral fertilizer broadcasting with variable rate technology (VRT) could also reduce the indirect energy input. The other possibility for nitrogen fertilizers' broadcasting could be real time adjustment of needed amount by utilization of Normalized Difference Vegetation Index (NDVI) technology, i.e. on-line color measuring and appropriate change of nitrogen distribution. This could be further improved by utilization of overlay support, additional use of yield and soil characteristics maps.

Especially for large scale arable farms with heterogeneous soil conditions, variable rate technology in fertilizer application reduces the nitrogen fertilizer amount per Hectare (Ehlert et al. 2004).

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