THE ENERGY EFFECTIVENESS OF CROPS IN CROP ROTATION UNDER DIFFERENT SOIL TILLAGE SYSTEMS

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The paper identifies and compares the energy balance of winter wheat, spring barley and white mustard – all grown in crop rotation under different tillage conditions. The field trial included the conventional tillage (CT) method, minimum tillage (MT) and a system with no tillage (NT). The energy inputs included both the direct and indirect energy component. Energy outputs are evaluated as gross calorific value (gross heating value of phytomass dry matter) of the primary product and the total harvested production. The energy effectiveness (energy output: energy input) was selected for evaluation. The greatest energy effectiveness for the primary product was established as 6.35 for barley, 6.04 for wheat and 3.68 for mustard; in the case of total production, it was 9.82 for barley, 10.08

for wheat and 9.72 for mustard. When comparing the different tillage conditions, the greatest energy effectiveness was calculated for the evaluated crops under the MT operation and represented the primary product of wheat at 6.49, barley at 6.69 and mustard at 3.92. The smallest energy effectiveness for the primary product was found in wheat 5.77 and barley 6.10 under the CT option; it was 3.55 for mustard under the option of NT. Throughout the entire cropping pattern, the greatest energy effectiveness was established under the minimum tillage option – 5.70 for the primary product and 10.47 for the total production. On the other hand, the smallest values were calculated under CT – 5.22 for the primary product and 9.71 for total production.

Key words: energy balance, winter wheat, spring barley, white mustard, soil tillage systems, yields

Given the rise of energy prices, it is natural that there is an effort to limit large energy deposits into production by introducing rational practices, not only in other industries but in agriculture as well. For this reason, it is not possible to judge the effectiveness of crop production solely by the volume and quality of achieved yields, but it is also necessary to take into account the amount of additional energy that was expended to generate the yields. Energy flows and energy-saving possibilities can be evaluated by energy balances. The aim of energy evaluation is to reveal existing reserves (e.g. when growing crops) and to optimise energy deposits from the view of achieving the highest possible

production effect at low specific energy consumption (Čislák 1983).

Changes in agricultural systems are coming now. There is a lot of questions linked with new agricultural systems, which is necessary to study separately, and also in its interactions with the determination of impact on production. Experimental evaluation of energetic optimisation of regulation elements in different crop production systems and its analyse enables to suggest new energy-saving crop management practices (Pospíšil & Vilček 2000).

Aside from economic evaluation, energy evaluation is one of the significant objective measures of

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production usefulness as a whole. Energy balances are based on the constant useful value of the product, are not subject to various random fluctuations and allow the objective comparison of even largely differing production activities (Stražil & Homolka 2005).

Energy inputs and outputs are important factors affecting the energy efficiency and environmental impact of crop production. The magnitude of these factors, and consequently the energy efficiency of an agrarian system, varies considerably depending on farm location (weather, soil type), crop rotations, the use of fertilisers, etc. (Rathke *et al.* 2007; Moreno *et al.* 2011; Ferreira *et al.* 2014).

Energy balances generally compare energy inputs with energy outputs. Energy inputs are comprised of all energies used and consumed in the production process with a certain conversion efficiency into the final product. In terms of additional energy, the energy demands in agricultural production can be evaluated in two ways, namely, in terms of direct energy consumption or according to the total energy consumption, that is, direct and indirect energy.

In addition to direct energy consumption in the form of fuel, electricity, heating and human labour, agriculture also uses an indirect form of energy. It is the energy that is consumed in the production of agricultural equipment (agricultural machinery, tractors, etc.), products from the chemical industry (mineral fertilisers, pesticides, growth regulators, etc.) and agricultural construction, including the production of building materials. The evaluation of direct energy points to agricultural effectiveness. The other method of evaluation gives an overview of the level and share of other sectors of the national economy in the agricultural industry (Preininger 1987).

Energy outputs from crop production are made up of energy contained in the produced biomass, from which a part belongs to the useable production (primary, secondary) and another part that is not harvested, unused or transformed, either returning in the form of accumulated energy in the soil or is released into the environment in the form of irreversible energy losses that generally increase the entropy of the external environment.

The amount of produced biomass depends both on biological traits of the grown crop and on the

optimisation of conditions during vegetation, which are created or influenced by a technological process – that is, with the use of energy deposits. From this perspective, it is vital which crops are grown in the given area.

Energy outputs from crop production can be measured in different ways. The most widely used and most universal method of establishing the energy content of organic matter – and thus, crop production – is establishing the gross calorific value of a unit of dry product production, measured in calorimeters. This is also the most widely used method in international literature when evaluating energy balances.

In this paper, the partial and total energy inputs calculated according to a model and energy balances of a short crop rotation and individual crops (winter wheat, spring barley, white mustard), grown under different tillage conditions, are evaluated.

MATERIAL AND METHODS

In terms of energy balances, three crops were used for comparison, grown under different tillage systems. Field trials in Prague-Ruzyně (soil type is brown soil, soil texture clay-loam soil, altitude 350 m above sea level, average annual air temperature 7.9°C, total annual precipitation 477 mm) were composed of a three-crop rotation pattern, where winter wheat, spring barley and white mustard were rotated. For all crops, conventional tillage (CT) included stubble breaking, medium ploughing (to a depth of 0.2 m), seedbed preparation, seeding, fertilising with nitrogen (N), necessary chemical treatments, harvest, grain transport and straw shredding by a harvester adapter.

Minimum tillage (MT) represented shallow tillage with disk harrows, seedbed preparation by levelling the ground with vibration or rotary harrows, seeding, fertilising with N, chemical treatment, harvest, grain transport and straw shredding by a harvester adapter.

The no-tillage system (NT) included seeding via the John Deere 750 sowing machinery directly into no-tilled soil, fertilising with N, chemical treatment, harvest, grain transport and straw shredding by a harvester adapter.

Fertilisation was uniform and represented an annual application of 54 kg/ha P_2O_5 of superphosphates and 100 kg/ha K_2O of potassium salts to all crops under all tillage conditions. For the energy evaluation, annual divided doses of nitrogen in the total amount of 100 kg/ha for wheat, 80 kg/ha for barley and a one-time dose of 30 kg/ha for white mustard were also used in the calculations.

Energy inputs were calculated according to normalised consumptions of diesel (kWh), human labour used in practice (Preininger 1987) as well as chemicals, fertilisers, and seed used in the field trials. The value of energy inputs supplied in pesticides was used as per Stout (1992). Converting coefficients of energy units and energy equivalents for the calculation of energy inputs are given in Table 1. The calculations included both direct (human labour, fossil fuels, other sources of energy) and indirect components of additional energy (energy in machinery, chemical products, organic fertilisers, seeds).

Yield parameters were evaluated from field trials as an average for the years 2010–2013. Energy outputs were established according to measurements of energy content of the primary and secondary product of the monitored crops, established as dry matter combustion heat (Stražil 1998). An energy coefficient was used as a criterion for the establishment of energy balances (the ratio of produced energy to the total energy inputs).

RESULTS AND DISCUSSION

Weather conditions were monitored in all years and its impact on yields of primary and secondary products of evaluated crops was assessed in different soil tillage systems. Measured temperature and precipitation data per months are mentioned in Figures 1 and 2. Yields of crops counted in dry biomass for all evaluated years in different crop management practices are in Table 2.

T a b l e 1

Conversion coefficients of energy units, energy equivalents for the calculation of energy inputs (Preininger 1987) and outputs (Stražil 1998)

Name	Unit	Energy value [GJ]	Name	Unit	Energy value [GJ]
Machinery and equipment					
Trucks	1 t	146.00	Wheat seed	1 t	11.77
Tractors	1 t	134.00	Barley seed	1 t	10.35
Self-propelled machinery	1 t	119.00	Mustard seed	1 t	35.00
Stationary crop production lines	1 t	92.00	Pesticides	1 t	110.0
Complex trailer machinery	1 t	88.00	P_2O_5	1 t	17.70
Simple trailer machinery	1 t	63.00	K_2O	1 t	9.60
Electricity	1 MWh	3.60	N	1 t	82.50
Diesel	1,000 l	35.28	Herbicides*	1 t	239.00
Petrol	1,000 l	32.29	Insecticides*	1 t	184.00
Light fuel oil	1,000 l	42.30	Fungicides*	1 t	92.00
Human labour	1,000 hrs.	25.65	—	—	—
Seed					
Winter wheat**	1 t	18.255	Straw of wheat**	1 t	17.894
Spring barley**	1 t	18.237	Straw of barley**	1 t	17.721
White mustard**	1 t	25.125	Straw of white mustard**	1 t	17.750

* According to Stout (1992)

** Heating value of dry biomass after subtraction of ash (Stražil 1998)

The highest grain yields of cereals were obtained in 2013, the lowest in 2012. In 2013, the amount of precipitation for period IV–IX in Prague-Ruzyně was higher (+205 mm; 163%; Figure 2). The highest difference in the amount of precipitation was in June (+87.5 mm; 373%) in comparison with long-term average. According to the classification of World Meteorological Organization in 2013, March was cold, July very warm and August warm. Other months were normal (Figure 1). Relatively suitable weather was in 2013, when yield components were formatted, in comparison with 2012 (Table 2).

Weather in 2012 in vegetation period (IV–IX) was relatively warm and wet, but with uneven distribution of precipitation. The yield level was limited by available water. Very low temperatures in the first decade of April (−5.0°C) played negative role. Grain yields of winter wheat reached an average of all variants soil tillage 4.21 t/ha (Table 2), which is only 65.9% of yield level in 2013. Similarly, grain yield of spring barley was 4.28 t/ha in 2012 but 6.00 t/ha in 2013.

Weather fluctuation had less negative effect on the yield of white mustard than cereals (Table 2).

From the monitored crops, the largest energy outputs converted to gross calorific value in the primary product were from winter wheat 105.03 GJ/ha per year (at a grain yield of 5.75 t/ha), followed by spring barley 96.41 GJ/ha per year (at a grain yield of 5.29 t/ha) and the least was white mustard 33.08 GJ/ha per year (at a grain yield of 1.32 t/ha) – see Table 3. The same order was also attained for the conversion to gross calorific value of the total biomass product, where the value for wheat was 175.35 GJ/ha, barley 149.11 GJ/ha and white mustard 87.27 GJ/ha.

If we compare particular tillage methods and their effect on production, then the greatest energy production, over the average of evaluated years, in the primary product was reached in wheat under the MT (107.16 GJ/ha), the smallest under the CT (103.14 GJ/ha). The situation was similar in the case of barley, where the greatest energy produced in the primary product was reached an average under the MT (96.84 GJ/ha) and the lowest under the CT (96.11 GJ/ha). White mustard had the highest energy production under the NT 33.41 GJ/ha) and the lowest under the CT (32.66 GJ/ha; Table 3). When comparing the differences of gross calorific value

T a b l e 2

Grain and straw yields [t/ha] of monitored crops in dry biomass in different soil tillage systems (2010–2013)

Crop/yield/crop technology	Grain yield [t/ha]					Straw yield [t/ha]				
	2010	2011	2012	2013	Average	2010	2011	2012	2013	Average
Winter wheat										
CT	6.28	6.00	4.03	6.34	5.65	4.45	4.26	2.88	4.41	4.00
MT	6.52	6.54	4.19	6.22	5.87	4.35	4.32	2.80	4.18	3.91
NT	5.91	6.00	4.42	6.62	5.74	3.99	4.05	3.00	4.47	3.88
Average	6.24	6.18	4.21	6.39	5.75	4.26	4.21	2.89	4.35	3.93
Spring barley										
CT	5.71	5.07	4.10	6.19	5.27	3.11	2.76	2.24	3.36	2.87
MT	5.42	5.55	4.38	5.89	5.31	3.10	3.17	2.51	3.34	3.03
NT	5.35	5.47	4.37	5.92	5.28	3.06	3.12	2.50	3.39	3.02
Average	5.49	5.36	4.28	6.00	5.29	3.09	3.02	2.42	3.36	2.97
White mustard										
CT	1.30	1.22	1.34	1.34	1.30	2.89	2.71	2.97	2.98	2.89
MT	1.27	1.32	1.38	1.31	1.32	2.92	3.04	3.17	3.01	3.04
NT	1.36	1.25	1.43	1.27	1.33	3.30	3.05	3.46	3.10	3.23
Average	1.31	1.26	1.38	1.31	1.32	3.04	2.93	3.20	3.03	3.05

CT – conventional tillage; MT – minimum tillage; NT – no-tillage

production, the values were balanced and statistically insignificant. The same is true when comparing the energy volume of the total product (seed + straw).

Over the course of the entire crop rotation, the greatest energy production was achieved in both the primary and total product under the MT (79.05 GJ/ha, 138.26 GJ/ha); the lowest was under the CT

Figure 1. Comparison of average month air temperatures in Prague-Ruzyně in 2010–2013 with long-term average

Figure 2. Comparison of sum of precipitation per month in Prague-Ruzyně in 2010–2013 with long-term average

(77.3 GJ/ha, 135.22 GJ/ha). Even here, the compared differences in values in the production of gross calorific value under the given tillage were inconclusive.

For comparisons according to Preininger (1987), the largest energy outputs (total gross calorific value production = primary + secondary product) are represented by the sugar beet 214.31 GJ/ha, less by alfalfa 107.08 GJ/ha, wheat 104.40 GJ/ha and potatoes 88.62 GJ/ha.

Direct, indirect and total model energy inputs for individual crops as well as the entire crop rotation were calculated for various tillage variants.

Tables 4 and 5 show the direct, indirect and total energy inputs of individual partial work tasks for individual crops and different tillage variants. Regardless of the tillage, it was found over the average of years that the highest energy inputs were in the case of wheat 17.43 GJ/ha, lower in the case of barley 15.21 GJ/ha and the lowest in the case of white mustard 8.99 GJ/ha (Table 3). For comparison with other crops, Stražil (2003), for example, stated the

total energy inputs for hemp as 18.29 GJ/ha, millet as 17.21 GJ/ha and reed canary grass as 7.87 GJ/ha. Furthermore, the total energy inputs are stated for, for example, winter wheat with a value of 23.2 GJ/ha, sugar beet 39.2 GJ/ha, grain maize 37.8 GJ/ha, potatoes 34.9 GJ/ha and spring barley 21.9 GJ/ha (Preininger 1987; Stražil & Šimon 1988).

When comparing differing tillage options with respect to the evaluated crops, the least demanding tillage option on total energy input was the MT variant; the total energy inputs were similar in the CT and NT options (Table 3). If we consider the entire crop rotation and total inputs under the MT option as 100% (13.15 GJ/ha), then the total inputs were 8.4% higher (14.25 GJ/ha) in the CT option and 8.1% higher (14.22 GJ/ha) in the NT variant.

Stražil and Homolka (2005) stated that individual partial inputs vary according to the crop and used farming technology. The average of total supplied inputs (30.19 GJ/ha), on an average, is represented as live labour 9.4%, fossil fuels 22.3%, machinery 12.8%, chemicals 46.1% and seed 9.9%.

T a b l e 3

Average values of grain and straw yield [t/ha] of evaluated crops under various tillage variants over the period 2010–2013 and the produced amount of energy converted to dry matter [GJ/ha]

Crop	Dry grain yield [t/ha]	Dry straw yield [t/ha]	Grain energy value [GJ/ha]	Straw energy value [GJ/ha]	Total energy value [GJ/ha]
Winter wheat					
CT	5.65	4.00	103.14	71.58	174.72
MT	5.87	3.91	107.16	69.97	177.13
NT	5.74	3.88	104.78	69.43	174.21
Average	5.75	3.93	105.03	70.33	175.35
Spring barley					
CT	5.27	2.87	96.11	50.86	146.97
MT	5.31	3.03	96.84	53.70	150.54
NT	5.28	3.02	96.29	53.52	149.81
Average	5.29	2.97	96.41	52.69	149.11
White mustard					
CT	1.30	2.89	32.66	51.30	83.96
MT	1.32	3.04	33.16	53.96	87.12
NT	1.33	3.23	33.41	57.33	90.74
Average	1.32	3.05	33.08	54.20	87.27

CT – conventional tillage; MT – minimum tillage; NT – no tillage

Similarly, if we take the total energy inputs as 100%, then the energy share of human labour inputted into the process, according to individual variants, fluctuated between 0.7 and 1.5%, into the energy share of fuel between 10.4% and 26.4%, in seed between 2.2 and 14.2%, in machinery between 11.3% and 20.5% and into the energy share of chemicals between 50.0 and 61.4% (Table 5). On an

T a b l e 4

Energy production inputs for the evaluated crops and differing tillage systems [GJ/ha]

Crop	Tillage	Indirect energy inputs [GJ/ha]				Direct energy inputs [GJ/ha]			Total inputs [GJ/ha]
		Equipment	Chemicals	Seed	Sum	Fuel	Human labour	Sum	
Wheat	CT	2.133	10.502	2.354	14.990	2.741	0.164	2.905	17.895
	MT	1.875	10.102	2.354	14.679	1.721	0.123	1.844	16.523
	NT	2.309	11.100	2.354	15.763	1.962	0.137	2.099	17.862
	Average	2.106	10.568	2.354	15.144	2.141	0.141	2.283	17.427
Barley	CT	2.133	8.852	1.863	12.848	2.471	0.164	2.905	15.753
	MT	1.918	8.852	1.863	12.633	1.721	0.123	1.844	14.478
	NT	2.309	9.450	1.863	13.287	1.962	0.137	2.099	15.386
	Average	2.120	9.051	1.863	12.923	2.051	0.141	2.283	15.206
Mustard	CT	1.801	4.554	0.210	6.564	2.409	0.139	2.548	9.112
	MT	1.710	4.661	0.210	6.581	1.750	0.124	1.874	8.455
	NT	2.021	5.151	0.210	7.383	1.909	0.130	2.038	9.421
	Average	1.842	4.789	0.210	6.840	2.023	0.131	2.153	8.994

CT – conventional tillage; MT – minimum tillage; NT – no tillage

T a b l e 5

Energy production inputs for individual crops and differing tillage systems (percentage of total inputs)

Crop	Tillage	Indirect energy inputs [%]				Direct energy inputs [%]		
		Equipment	Chemicals	Seed	Sum	Fuel	Human labour	Sum
Wheat	CT	11.9	58.7	13.2	83.8	15.3	0.9	16.2
	MT	11.3	61.1	14.2	88.8	10.4	0.7	11.2
	NT	12.9	62.1	13.2	88.3	11.0	0.8	11.7
	Average	12.1	60.6	13.5	86.9	12.3	0.8	13.1
Barley	CT	13.5	56.2	11.8	81.6	15.7	1.0	18.4
	MT	13.2	61.1	12.9	87.3	11.9	0.8	12.7
	NT	15.0	61.4	12.1	86.4	12.7	0.9	13.6
	Average	13.9	59.5	12.3	85.0	13.5	0.9	15.0
Mustard	CT	19.8	50.0	2.3	72.0	26.4	1.5	28.0
	MT	20.2	55.1	2.5	77.8	20.7	1.5	22.2
	NT	21.4	54.7	2.2	78.3	20.3	1.4	21.7
	Average	20.5	53.2	2.3	76.1	22.5	1.5	23.9

CT – conventional tillage; MT – minimum tillage; NT – no tillage

average, when considering all crops and tillage options, total additional energy inputs were made up of 17.3% of direct energy inputs and 82.7% of indirect energy inputs.

When comparing different tillage options, individual partial energy inputs change. In the classical tillage method, all investigated crops have an apparently higher percentage rate of energy inputs in fuel, human labour and chemicals; cereals show a lower energy input share linked to machinery (energy in equipment) as opposed to other tillage technologies (Table 5). The lowest percentage rate of energy inputs in fuel, human labour and machinery was recorded under the MT in the case of cereals as opposed to the other tillage methods. If we take, for example, the amount of fuel needed for the growing and harvesting of wheat under CT as 100% (77.7 l/ha), then the savings under the MT technology were 33.3% (25.9 l/ha) and under NT were 28.4% (22.1 l/ha).

After evaluating the usage of differing tillage technologies, Pospíšil (1986) also proved a reduction in diesel under MT winter crops in the range from 10 to 18 l/ha and during seeding into untreated soil in the range from 13 to 19 l/ha as opposed to traditional technology. Energy savings are also possible when special technology is applied. Kňákal and

Suškevič (1985) stated that when a multi-tiller is applied, 10.76 l/ha of diesel is consumed and when conventional technology (ploughing) is applied, the value is 21.20 l/ha. Hančárová (1989) recommended ploughing with reversible ploughs, which facilitate savings in diesel consumption of 10% as opposed to traditional ploughs. Also, substituting ploughing with chisel or disc cultivators facilitates energy savings of 30–40%.

From amongst the partial energy inputs in individual work tasks, tillage and harvest have a higher consumption of direct energy. On the other hand, fertilising with mineral fertilisers, which burdens the values of additional energy and crop treatment the most, has a low representation of direct energy. This is due to the fact that fertilisers and pesticides, which enter agriculture through indirect inputs of other sectors of the national economy, are highly demanding energy inputs during their production.

The specified total energy inputs for wheat or barley are lower than what is stated in other publications. This is due to the fact that lower levels of mineral fertilisers were used, which otherwise greatly burden energy inputs. A high proportion of additional energy in chemicals is given by the high energy demands on the production of mineral nitro-

T a b l e 6

Model energy balances of crops under different tillage variants

Crop	Tillage	Energy content of primary product [GJ/ha]	Energy content of secondary product [GJ/ha]	Total energy production (output) [GJ/ha]	Total energy inputs [GJ/ha]	Energy effectiveness	
						Primary product	Total product
Wheat	CT	103.14	71.58	174.72	17.89	5.77	9.77
	MT	107.16	69.97	177.13	16.52	6.49	10.72
	NT	104.78	69.43	174.21	17.86	5.87	9.75
	Average	105.03	70.33	175.35	17.42	6.04	10.08
Barley	CT	96.11	50.86	146.97	15.75	6.10	9.33
	MT	96.84	53.70	150.54	14.48	6.69	10.40
	NT	96.29	53.52	149.81	15.39	6.26	9.73
	Average	96.41	52.69	149.11	15.21	6.35	9.82
Mustard	CT	32.66	51.30	83.96	9.11	3.59	9.22
	MT	33.16	53.96	87.12	8.46	3.92	10.30
	NT	33.41	57.33	90.74	9.42	3.55	9.63
	Average	33.08	54.20	87.27	9.00	3.68	9.72

CT – conventional tillage; MT – minimum tillage; NT – no tillage

gen (on an average 82.5 GJ/t – for comparison, the energy needed to produce phosphate fertilisers is on an average 17.75 GJ/t and 9.6 GJ/t for potash fertilisers).

For the evaluation of energy balances, we selected energy effectiveness that states how much energy one crop creates per unit of energy input. The largest energy effectiveness for the primary product over the averaged years and evaluated tillage options was found in barley (6.35), wheat (6.04) and mustard (3.68) (Table 6). In the event of figuring in the secondary product to the primary, the total production of energy increases and the values of energy effectiveness of the monitored crops will be even more favourable. Energy effectiveness for total production was 9.82 in barley, 10.08 in wheat and 9.72 in mustard. Increased energy effectiveness for total production is given by the higher yields of wheat and mustard straw in comparison with barley as well as low energy inputs and relatively high yields of the evaluated crops.

When comparing different tillage methods, the greatest energy effectiveness for all crops, in both the primary and total product, was found to be under the MT (Table 6). Its value represented 6.49 (10.72)

for wheat, 6.69 (10.40) for barley, and 3.92 (5.77) for mustard. The smallest energy effectiveness was found for the primary product of wheat (5.77) and barley (6.10) under the CT option and mustard under the NT option (3.55). The results show that energy effectiveness of the evaluated crops' total product was similar.

If we consider the entire crop rotation, then the greatest energy effectiveness was found under the MT – for the primary (5.70) as well as total (10.47) product (Table 7). On the other hand, the smallest were the values of energy effectiveness found under the CT (5.22 for the primary product, 9.71 for the total product).

About every tillage technology, it can be generally said that as tillage intensity decreases, total energy inputs also decrease, linked to crop management practice. However, total energy inputs can increase under the NT option (in our case, even in the conventional variant), thanks to the necessity to apply more effective, more energy-demanding pesticides as well as higher doses of nitrogen in order to achieve a comparable yield to other technologies. The size of total inputs then subsequently affects energy effectiveness as well.

T a b l e 7

Model energy balance of crop rotation under different tillage variants

Crop rotation	Crop	Energy content of primary product [GJ/ha]	Energy content of secondary product [GJ/ha]	Total energy production (output) [GJ/ha]	Total energy inputs [GJ/ha]	Energy effectiveness of primary product	Energy effectiveness of total product
CT	Wheat	103.14	71.58	174.72	17.89	5.77	9.77
	Barley	96.11	50.86	146.97	15.75	6.10	9.33
	Mustard	32.66	51.3	83.96	9.11	3.59	9.22
	Average	77.30	57.91	135.22	14.25	5.15	9.44
MT	Wheat	107.16	69.97	177.13	16.52	6.49	10.72
	Barley	96.84	53.7	150.54	14.48	6.69	10.40
	Mustard	33.16	53.96	87.12	8.46	3.92	10.30
	Average	79.05	59.21	138.26	13.15	5.70	10.47
NT	Wheat	104.78	69.43	174.21	17.86	5.87	9.75
	Barley	96.29	53.52	149.81	15.39	6.26	9.73
	Mustard	33.41	57.33	90.74	9.42	3.55	9.63
	Average	78.16	60.09	138.25	14.22	5.22	9.71

CT – conventional tillage; MT – minimum tillage; NT – no tillage

For comparison, for example, Pospíšil and Vilček (2000) stated the energy effectiveness of the primary (total) product of winter wheat as 2.12 (4.59) and spring barley as 2.71 (4.77). Čislák (1983) too stated the energy effectiveness of primary arable crops, which are given for the primary or total product for winter wheat as 3.89 (7.00), for spring barley as 5.39 (9.16), for sugar beet as 4.69 (7.04) and for corn grain as 4.77 (7.78). For conditions in Great Britain, Wilson (1980) stated the energy coefficient for the primary product of wheat as 3.11, barley as 3.36 and potatoes as 1.33. Most of these crops are grown in CT. Koga (2008) stated energy coefficient 6.72 for winter wheat grown under CT system for conditions of Hokkaido island in Japan.

The stated values calculated by each author are different. This state is given not only by agro-climatic differences but also by the use of energy equivalents of inputs and outputs when calculating balances. This implies that the boundaries, especially whilst setting indirect energy inputs, can be very broad. Therefore, we must follow certain procedures so that we can reach comparable results when calculating energy balances. That is why methods for the process of calculating direct and indirect energy inputs and outputs were developed (e.g. Preininger 1987; Pospíšil & Vilček 2000), which should be followed. The following is presented: energy equivalents of energy units, energy volume of crop production, direct energy consumption norms of work tasks and groups of technological tasks, energy equivalents of indirect energy inputs and a model balance of energy inputs and energy production in selected crops.

CONCLUSIONS

When comparing different tillage methods, the minimum tillage technology was the least demanding variant on the total inputs of the evaluated crops. In the case of crops, this technology showed, as opposed to other tillage methods, the lowest percentage of rate of energy inputs: fuel, human labour and machines.

The largest production of energy in the primary product was shown by winter wheat and spring barley under the MT, the smallest under the CT tech-

nology variant. White mustard showed the largest energy product under the NT and the lowest energy production under the CT.

From the monitored plants, the greatest energy outputs converted to gross calorific value in the primary product over the averaged years 2010–2013 were winter wheat 105.03 GJ/ha per year, followed by spring barley 96.41 GJ/ha and white mustard 33.08 GJ/ha. Regardless of the tillage method, the highest energy inputs over the average of the monitored time period were revealed in winter wheat 17.43 GJ/ha and in spring barley 15.21 GJ/ha and the lowest in white mustard 8.99 GJ/ha.

The greatest energy effectiveness for particular crops in crop rotation was found out in MT variant. For the primary product, its value was 6.49 in wheat, 6.69 in barley and 3.92 in mustard. The lowest values of energy effectiveness for grain of wheat and barley were found in the CT system.

In conclusion, it can be stated that through a comprehensive study of energy inputs and their individual components, it is possible to find savings and come to a more effective use of direct and indirect forms of energy, which enter into the system of growing crops.

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