ECONOMIC EFFICIENCY OF SELECTED CROPS CULTIVATED UNDER DIFFERENT TECHNOLOGY OF SOIL TILLAGE*

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The objective of this study was the model comparison and economic evaluation of different methods of soil tillage and crop stand establishments used. Based on yield results (winter wheat, spring barley, and white mustard cultivated in three-crop rotation) from field experiments with conventional, conservation with minimum tillage, and no-tillage methods conducted at the site Prague-Ruzyně, model economic balances were evaluated. Prices of the main products were determined based on the yield results from the period 2010–2013 and the current market prices. In the individual tillage systems, the total costs of production of evaluated crops were counted up and profitability was calculated as a ratio of profit to total costs. The highest total costs of crop cultivation were identified in cereals under conventional soil tillage, on the contrary, the lowest in cereals cultivated under conservation tillage technology. As for the growing technologies, the highest profitability was found in winter wheat, as for the tillage methods, it was in the conservation variant with minimum tillage. The economic evaluation for individual crops was based on standards of growing technologies and particular work operations.

winter wheat; spring barley; white mustard; different soil tillage intensity; production; economic balances

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INTRODUCTION

When farmers use different soil tillage technologies and methods of crop stand establishment for a long time, then they are more interested in consequences of particular cultivation measures on the soil environment. In addition to conventional technology based on ploughing, minimization methods of soil tillage without ploughing are becoming increasingly important. Topsoil is loosened into smaller depth without turning over, or conservation measures are applied where after crop seeding at least 30% of soil surface remains covered with post-harvest residues or catch-crop biomass.

Utilization of organic matter supports higher microbial activity in soil improving most of soil fertility parameters (Dzenia et al., 1999; Šimon, Javůrek, 1999; and others). Direct drilling into no-tilled soil using special sowing machines is the extreme variant of minimization technologies of crop stand establishment without ploughing.

Apart from soil properties of the given site, weed status of land, appropriate machinery in the agrocompanies, also economic efficiency of crop production is one of the key issues deciding about tillage technology used in the final stage.

Results to date from the field experiments and experience from agricultural practice demonstrate the favourable influence of minimization tillage technologies on economy of crop production through work operation decrease and subsequent decrease of direct costs, lower fuel consumption, and labour needed per production unit (Kovacev et al., 2011).

A permanent rise in fuel as well as labour prices increases the differences in costs among conventional technologies using a various rate of minimization elements (Hůla et al., 2008).

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Minimization technologies of cereal production are labour-saving which reduces the total costs of growing technologies. Also the costs of fuel and use of machines, which have a smaller number of passages, are lower. However, in minimization technologies we have to take into account higher expenditures on weed control (more expensive herbicides) which are obviously reflected in the total costs (H o r á k , 2005).

For this reason, we focused on the evaluation of long-term effect of different soil tillage technologies on the total production and economic efficiency of winter wheat, spring barley, and white mustard cultivation.

Based on yield results from the field experiments, model economic balances were evaluated for particular soil-climatic site conditions and given agronomic measures. The objective of this study was the model comparison and economic evaluation of different methods of soil tillage and crop stand establishments used.

MATERIAL AND METHODS

The data for the evaluation of economic balances of cultivated crops, i.e. winter wheat, spring barley, and white mustard in three-crop rotation, were derived from a plot field experiment established at the site Prague-Ruzyně in 1995. During the years 2010–2013 three different methods of soil tillage and crop stand establishment were applied, and subsequently total yields were evaluated and all work operations, material consumed, and concrete use of farm machines were recorded by each of the individual technologies used.

The experimental plots (plot size 24 m^2) are located in a temperate semiarid climate, 350 m a.s.l., with an annual mean air temperature of 7.9 °C, and mean annual precipitation of 477 mm. The field site has a soil of clay-loam texture (Orthic Luvisol, FAO Taxonomy). As an experiment design a split-plot method with four replications was used. The P and K fertilization was uniform (54 kg P_2O_5 per ha in superphosphate and 100 kg K_2O per ha in potassium salt yearly). For economic evaluation the annual divided doses of nitrogen in the total dosage of 100 kg for wheat, 80 kg for barley, and 30 kg (single dose) for mustard per ha were included. For calculation, the average total yields from the field experiments for four years (2010–2013) were used.

Cultivation practices evaluated

Conventional soil tillage and crop stand establishment (CT) included post-harvest stubble breaking, mouldboard ploughing to a depth of 0.20 m, usual seed-bed preparation, sowing, rolling, N-fertilization, harrowing, treatments of crops against weeds and pests, harvest and grain transport, crushing of straw by a harvester adapter.

Conservation soil tillage and crop stand establishment (MT) included shallow disking (about 10 cm deep) with crushed straw incorporating, seed-bed preparation and levelling of soil surface with vibratory or rotary harrows, sowing, N-fertilization, pesticide treatments, harvest and grain transport, crushing of straw by a harvester adapter.

Crop stand establishment by no-tillage practice (NT) included direct drilling into no-tilled soil by special drill machine, N-fertilization, pesticide treatments, harvest and grain transport, baling of straw and its transport to storage.

To ensure comparable crop stand structure in all tillage variants, all crops (including conventional tillage treatment) were sown using a John Deere 750A drill machine (John Deere International GmbH, Schaffhausen, Switzerland).

The economic evaluation for the individual crops cultivated under different soil tillage systems was based on the standards of cultivation methods and the particular work operations for monitored crops according to current regulations (www.agronormativy.cz). The same source was used to determine prices of seeds, fertilizers, and agrochemicals consumed and the average farm prices of crop products.

For cultivation technologies of individual crops and finally for the whole crop rotation, the total costs (variable + fixed of machinery) converted to 1 ha were calculated. Variable costs included material costs and mechanized operations, fixed costs comprised rent for land, taxes, depreciation and repair of buildings, machinery depreciations, interests, production and administrative overheads. According to yields achieved in the field trials in the period 2010–2013 and actual market prices, the prices of the main products were determined. Furthermore, profitability of the individual crops under different soil tillage methods was calculated as a rate of profit and/or loss to the total costs. The mentioned prices do not include VAT.

RESULTS

Production

In the particular years assessed, relatively significant differences in the yields of the main products (grains/seeds) of the crops monitored were recorded (Table 1). In winter wheat the yields varied on average from 6.65 t ha^{-1} in 2012 to 10.05 t ha^{-1} in 2013; similarly in spring barley from 6.61 t ha^{-1} in 2012 to 9.25 t ha^{-1} in 2013. The yields of mustard seed were comparable within the years.

In 2012, when grain production of cereals was the lowest in the given period, the above-average temperatures and below-average rainfalls were recorded in the periods critical for yield formation. For example, during the period from April to September the temperature at the Ruzyně site was on average 1.8 °C

Table 1. Average seed /grain yields (t ha^{-1}) of crops tested under different soil tillage methods in the selected period

Crop	Method	2010	2011	2012	2013	Average
Winter wheat	CT	9.46	9.15	6.23	9.68	8.63
	MT	10.57	10.61	6.79	10.08	9.51
	NT	9.27	9.42	6.93	10.40	9.00
	Average	9.77	9.73	6.65	10.05	9.05
Spring barley	CT	8.50	7.54	6.09	9.21	7.84
	MT	8.43	8.71	6.87	9.25	8.31
	NT	8.40	8.59	6.86	9.29	8.28
	Average	8.44	8.28	6.61	9.25	8.14
White mustard	CT	1.82	1.69	1.88	1.87	1.81
	MT	1.79	1.91	1.95	1.85	1.87
	NT	1.93	1.76	2.03	1.80	1.88
	Average	1.85	1.79	1.95	1.84	1.86
Sum of average grain yields in crop rotation	CT	19.78	18.38	14.20	20.76	18.28
	MT	20.79	21.23	15.61	21.18	19.69
	NT	19.60	19.77	15.82	21.49	19.16

Table 2. Economic evaluation of conventional soil tillage treatment (CT) in CZK ha^{-1}

Crop	Price of material consumed	Costs variable+fixed of machinery	Total without VAT	Fuel consumption (l ha^{-1})	Hum. labour need (h ha^{-1})
Winter wheat	10 549	7 861	18 410	75.40	5.42
Spring barley	11 565	7 764	19 329	75.90	5.81
White mustard	7 484	7 029	14 513	69.05	4.72
Total	29 598	22 654	52 252	220.35	15.95

Table 3. Economic evaluation of conservation (reduced) soil tillage treatment (MT) in CZK ha^{-1}

Crop	Price of material consumed	Costs variable+fixed of machinery	Total without VAT	Fuel consumption (l ha^{-1})	Hum. labour need (h ha^{-1})
Winter wheat	10 879	5 634	16 513	46.50	3.82
Spring barley	10 579	6 101	16 680	52.60	4.47
White mustard	7 704	5 948	13 652	50.35	4.17
Total	29 162	17 683	46 845	149.45	12.46

Table 4. Economic evaluation of no - tillage treatment (NT) in CZK ha^{-1}

Crop	Price of material consumed	Costs variable+fixed of machinery	Total without VAT	Fuel consumption (l ha^{-1})	Hum. labour need (h ha^{-1})
Winter wheat	11 224	6 842	18 066	55.10	5.07
Spring barley	11 604	6 779	18 383	54.60	4.97
White mustard	8 159	6 621	14 780	56.65	5.07
Total	30 987	20 242	51 229	166.35	15.11

Table 5. Grain/seed yields (t ha^{-1}), total costs of production (CZK ha^{-1}) and profitability (%) of the individual crops and entire crop rotation with respect to different soil tillage method

Crop	Technology	Average yield (t ha^{-1})	Total main product price (CZK ha^{-1})	Total costs of production (CZK ha^{-1})	Profitability (%)
Winter wheat	CT	8.63	43 582	18 410	136.7
	MT	9.51	48 026	16 513	190.8
	NT	9.00	45 450	18 066	151.6
	Average	9.05	45 686	17 663	159.7
Spring barley	CT	7.84	40 352	19 329	108.8
	MT	8.31	42 772	16 680	156.4
	NT	8.28	42 617	18 383	131.8
	Average	8.14	41 914	18 131	132.3
White mustard	CT	1.81	27 389	14 513	88.7
	MT	1.87	28 297	13 652	107.3
	NT	1.88	28 448	14 780	92.5
	Average	1.85	28 045	14 315	96.2

Notes: CT = conventional tillage; MT = minimum tillage; NT = no-tillage

above the long-term average. The total sum of rainfall was influenced by the record amount of precipitation (138 mm) in the first decade of July, however in other months the precipitation was significantly lower if compared to long-term average. Whereas in 2013, when grain yields of cereals were the highest, the course of temperature and rainfall during the vegetation period was favourable, except an excessive sum of precipitation (370% of normal) in June.

Average yields of individual crops monitored and the whole crop rotation in the period 2010–2013 under different soil tillage methods and crop stand establishment are shown in Table 1. Four-year average results show the highest yields of winter wheat by the conservation soil tillage variant with minimum soil cultivation (9.51 t ha^{-1}), the lowest wheat grain production (8.63 t ha^{-1}) by the conventional tillage treatment. The differences of grain production represent 3.8%.

As for spring barley, the highest grain production (8.31 t ha^{-1}) was recorded by the conservation variant with minimum tillage as well, in other tillage treatments, the yields were slightly lower.

The seed production of mustard was comparable in all years of the experimental series. On the plots with conservation tillage treatment, higher seed yields (1.88 t ha^{-1}) than in the other variants (1.81 and/or 1.87 t ha^{-1}) were registered. In the frame of the whole crop rotation, yields of the main product on plots with different tillage technology were considerably stable during the given period; higher production was recorded in variants of reduced tillage method (19.69 t ha^{-1}), lower one in conventional tillage treatment (18.28 t ha^{-1}), which represents a difference of 7.2% (Table 1).

Economics

A model evaluation of production of all crops and the whole crop rotation under different soil tillage management from an economic viewpoint was carried out. Based on four-year results and work operation used, variable costs were determined and then calculated (Tables 2–4).

The highest fuel consumption was found in all crops cultivated under conventional tillage method. On the other hand, the lowest fuel consumption was recorded at conservation tillage. For the entire crop rotation, it was 220.35 l ha^{-1} in conventional tillage technology and 149.46 l ha^{-1} in conservation tillage method which represents saving of about 70 l ha^{-1}. Similarly, the need of human labour was the highest under conventional crop cultivating, particularly in cereals and for the whole crop rotation as well, the lowest in conservation tillage method. This is due to the necessary use of more labour-intensive operations in conventional technology, especially by the costs of medium deep ploughing. Conservation method based on minimum tillage required more operations, especially in plant protection, than the other tillage systems evaluated. The highest total costs were found in cereals under conventional tillage method, the lowest also in cereals, but under conservation minimum tillage system. In winter wheat, the total costs were 16 513–18 410 CZK ha^{-1} (Tables 2, 3), in spring barley 16 680–19 329 CZK ha^{-1}.

For all crops in crop rotation cultivated under conventional tillage method, the total costs were 52 252 CZK ha^{-1}, in conservation (minimum) soil

tillage variant 46 845 CZK ha^{-1}, and under no-tillage treatment 51 229 CZK ha^{-1}, which represents a difference of 6 407 (10.3%) and/or 1 023 (2.0%) CZK ha^{-1} compared with conventional soil tillage treatment (Tables 2–4).

When comparing the individual crops, the highest profitability was found on average in winter wheat (159.7%), then in spring barley (132.3%), and the lowest in white mustard (96.2%) – see Table 5. As for soil tillage methods, regardless of crops, the highest profitability was attained in the conservation variant with minimum tillage and the lowest (except spring barley) in conventional tillage treatment (Table 5).

Total costs in Table 5 are calculated without VAT, straw production was not included in this evaluation, and revenue does not include any subsidies. A farmer may apply for subsidy; in the year 2012, the subsidies represented 5 387.30 CZK ha^{-1} for SAPS (Single Area Payment Scheme) and 491 CZK ha^{-1} for TOP-UP (National Additional Payments to direct aids)**.** In standards for economic evaluation (www.agronormativy.cz), a wide-range subsidy in the amount of 6 068.88 CZK ha^{-1} is cited.

DISCUSSION

The obtained yield results are obviously higher than those presented as an average in agricultural practice. For example, according to the Section of Agricultural Commodities of the Ministry of Agriculture of the Czech Republic (MZE Report 2013a, b), average grain yield results during the period 2009–2013 were 5.20 t ha^{-1} in winter wheat, 4.44 t ha^{-1} in spring barley, and 0.85 t ha^{-1} in white mustard. Also the information source www.farmprofit.cz for the cost calculation by production area gives the following results: yield of winter wheat 4.69–4.98 t ha^{-1}, yield of spring barley 4.39–4.81 t ha^{-1}. The farm Agro Žlunice, located in favourable soil and climatic conditions (sugar beet production type area), in winter wheat achieved an average grain yield of 7.10 t ha^{-1} in the period 2010–2012 (Homolka, Bubeníková, 2013). The above mentioned data are average regardless of the tillage technology used.

Kovacev et al. (2013) mentioned the great influence of weather conditions on production of spring barley and the occurrence of dry periods during the vegetation season, which could have negative effect on crop yields. The highest average yields in barley production near Staro Petrovo Selo (Croatia) oscillated around 3.20 t ha^{-1} (Kovacev et al., 2013).

Dzenia et al. (1999), Reinhard et al. (2001) and many other authors found minimum and insignificant yield difference between soil tillage methods of different intensity. Šimon, Javůrek (1999) presented the results from exact field experiments on fertile chernozem, where yields of cereals were significantly higher in conventional variant than after drilling into no-tilled soil. From this short review it is evident that the results of the study of the soil tillage impact on crop yields are different and their dissimilarity logically stems from different soil and climatic conditions of the sites.

Hůla et al. (2008) mentioned yield results of winter wheat from the field trials in the maize production type area (Hrušovany u Brna) under different soil tillage technologies. The average highest grain yield (6.62 t ha^{-1}) was achieved after the shallow tillage method, then after direct sowing of winter wheat into no-tilled soil (6.58 t ha$^{-1)}$, and finally the lowest yield (6.49 t ha^{-1}) was recorded after mouldboard ploughing. In the sugar beet production type area (Ivanovice na Hané), the highest yield (6.47 t ha^{-1}) was recorded after the shallow tillage technology as well. After ploughing and direct sowing into no-tilled soil the average yields of winter wheat were slightly lower (6.44 t ha^{-1} in both).

Similarly, the long-term yield results of spring barley from the sugar beet production area (the 15-year average) confirmed that shallow soil tillage is fully sufficient for achievement of high grain production (Hrubý et al., 2007). The average grain yield achieved under shallow ploughing (up to 0.15 m) was 6.55 t ha^{-1}, under medium deep ploughing (up to 0.22 m) it was 6.38 t ha^{-1}, and under sowing into no-tilled soil the yield was 6.43 t ha^{-1}.

It can be stated that the grain production of experimental cereals in particular evaluated variants of soil tillage in the present study is comparable with the conclusions given in literature (Hrubý et al., 2007; Hůla et al., 2008).

And now to economics. Kovacev et al. (2011) studied economic efficiency of non-conventional tillage systems in winter barley production. A comparison showed that conventional system had the highest fuel consumption (50.93 l ha^{-1}). The most economical system in crop production (33.03 l ha^{-1} with a decrease of 35.1%) was identified in RT1 variant (chisel plough, disc harrow seed-bed implement, drill).

Kavka et al. (2006) reported total technological costs according to cultivation intensity for food winter wheat 15 509–23 618 CZK ha^{-1}, for malting spring barley 15 934–22 302 CZK ha^{-1}, and for white mustard 9 668–16 030 CZK ha^{-1}. Total costs according to cultivation intensity published in standards (www.agronormativy.cz) are 19 793–29 296 CZK ha^{-1} for food winter wheat, 20 760–27 407 CZK ha^{-1} for malting spring barley, and 16 902–21 631 CZK ha^{-1} for white mustard.

According to the website www.farmprofit.cz, in 2012 the total actual costs on average of the production areas were 22 677 CZK ha^{-1} for winter wheat and 20 781 CZK ha^{-1} for spring barley. Similarly, the Research Institute of Agricultural Engineering, Prague-Ruzyně in the normatives for counselling

gave the model total costs of growing operations according to production areas for winter wheat 20 683–21 897 CZK ha^{-1}, for spring barley 18 772–19 066 CZK ha^{-1} (www.vuzt.cz). Homolka, Bubeníková (2013) mentioned the total direct costs established for a concrete example in practice for winter wheat, depending on the year, from 16 345 to 19 437 CZK ha^{-1}. However, all the above mentioned data do not distinguish the differences of the individual soil tillage methods.

Nave et al. (2013) found out that the medium-input variant is the most efficient with the best economic results for any wheat price. On the other hand, the high-input type has a lower economic performance.

As for the particular technologies of soil tillage for cereals growing, we may say that with decreasing soil tillage intensity the costs for growing technology decrease, too. But in no-tillage technology the costs may rise owing to the necessity of non-selective and more effective (more expensive as well) pesticides application and higher nitrogen doses to reach a comparable yield with conventional technology. But shallow tillage with crushed straw incorporated has proved to be cheaper.

CONCLUSION

The highest average grain production of winter wheat was achieved in the experimental variant of conservation land management (MT) with minimum tillage, the lowest one under conventional tillage method (CT). The same results were recorded in spring barley.

The highest average seed production of white mustard was recorded in the no-tillage variant (NT), in other tillage variants the yields of seeds were insignificantly lower.

The highest total costs of cultivation technology were found in cereals under CT method, the lowest ones in cereals as well, but cultivated using MT variant with minimum tillage.

Production costs of crops cultivated must be calculated case by case, because it depends on many factors – soil-climatic and other site conditions, method of stand establishment and crop harvesting, number of necessary work operations (fertilization, pest control and others), transport distances, storage method etc., all depending on the level of yield achieved by the cultivated commodities.

The highest profitability of cultivating methods was identified in winter wheat, then in spring barley, and the lowest in white mustard. Regarding the tillage methods, the highest profitability values were found in the MT variant, the lowest ones (except spring barley) under CT technology.

Regarding the choice of tillage systems, assuming the relative uniform level of yields, priority should be given to systems with lower tillage intensity level, which are cost-saving and simpler to manage due to less need of machines and human labour.

Reduced soil tillage treatment with straw and post-harvest residue incorporation (conservation soil tillage) was proved to be cheaper than the other two tillage methods.

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