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Results of fifteen-year monitoring of winter oilseed rape (*Brassica napus L.*) production in selected farm businesses of the Czech Republic from the viewpoint of technological and economic parameters

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Abstract. The paper presents field trials focused on technological and economic comparison of conventional tillage (CT) and reduced tillage (RT) technologies of soil cultivation and drilling of winter oilseed rape (*Brassica napus L.*). During fifteen production years starting in 2001/02, trials were set up in 520 fields of around 40 farm businesses located in all of the districts of the Czech Republic. With respect to average seed yields, no significant differences were proved with respect to tillage systems, to the application of organic fertilizers and to the fertilization during sowing. Irregular distribution of trial fields into the individual production areas influenced the outcomes thou. Concerning winter rape seed yields, costs per production unit, and earnings per hectare, the most suitable production area proved still to be the potatoes one, but particularly over the recent period also beet production area. The corn production area produced, despite some exceptions, worst results. Over the fifteen-year time, the average oilseed rape yield of all 520 monitored fields was 3.72 t ha^{-1}. Reduced tillage attained average yield of 3.73 t ha^{-1}, i.e. matched almost exactly the one of 3.70 t ha^{-1} attained by conventional tillage. Unit production costs realized by conventional tillage surpassed by 4.1% those gained by reduced tillage. Related earnings per hectare were on the other hand lower by 17.0%. With respect to fuel and labour consumption, reduced tillage brought significant savings reaching in average 20.2%, respectively 24.0%. In terms of yields, reduced tillage with deeper soil loosening proved repeatedly favourable results.

Key words: Brassica napus L., tillage system, ploughing, costs, fuel consumption, labour consumption.

INTRODUCTION

Over the recent decades, various soil tillage systems have emerged alternative to conventional tillage (CT) comprising ploughing. These systems, i.e. reduced tillage (RT) or conservation tillage, generally do not invert soil and leave significant portion of crop residue on the soil surface (at least 30% to be entitled to naming 'conservation tillage'). Reduced tillage is primarily used as a means to conserve soil moisture, to reduce production costs and to protect soils from erosion and compaction (Holland, 2004). Soil erosion is, also in Europe, a major environmental problem. According to Verheijen et al. (2009), soil erosion rates for tilled, arable land in Europe are, on average, 3 to 40 times greater than the upper limit of tolerable soil erosion. For conditions prevalent in Europe, this limit is, as equal to soil formation, ca. 1.4 t ha^{-1} yr^{-1}. In the intensive agricultural systems generally used in Europe, the effects of erosion on crop yields mainly occur due to the reduction of the amount of water the soil can store and make available to plants. As long as soil depth is sufficient, yield losses may be minor, as the nutrient losses due to erosion can be compensated for by the raised doses of fertilizers (Bakker et al., 2004, 2007). According to many authors (Holland, 2004; Lahmar, 2010; Wauters et al., 2010), the implementation of conservation agriculture and conservation tillage is clearly lagging in Europe in comparison to other continents. According to the results of the study on a soil loss done by Kisić et al. (2016), RT and tillage across the slope are recommended as tillage which preserves soil. The results of Novák et al. (2016) confirmed the importance of soil conservation technologies in reduction of risk of land degradation by water erosion. Another research (Kroulík et al., 2009) focused on compaction and field traffic intensity suggested that 145.6% of covered area can be run-over repeatedly for conventional tillage, 44.8% for minimum tillage and 18.4% only for direct seeding.

There has been considerable research on the effects of conservation tillage on crop yield in many areas in Europe over the last three decades. Often, detailed reports were published both on the economic and environmental effects of conservation agriculture (e.g. Lopez & Arrue, 1997; Tebrügge & During, 1999; Hocking et al., 2003; Kisić et al., 2010; Răus et al., 2016). However, the suggestions from different studies often seem contradictory and are therefore difficult to interpret (e.g. Cantero-Martinez et al., 2003; Lopez & Arrue, 1997). This is to be expected: both the agro-environmental conditions as well as the form of reduced tillage applied vary seriously between individual studies. The recent study of Madarász et al. (2016) however suggested that over the ten trial years, tillage type was a more important factor in the question of yields than the highly variable climate of the studied years. During the first three years of technological changeover to RT, a decrease of 8.7% was measured, respective to CT. However, the next seven years brought a 12.7% increase of RT yields of all the crops grown.

According to the analysis of 563 observations carried out by van den Putte et al. (2010), no significant yield effect of soil tillage practices was observed for potatoes, sugar beet, spring cereals and fodder maize. A significant yield reduction occurred under conservation agriculture only for grain maize and winter cereals.

Soil tillage systems must be adapted to plant requirements in accordance with crop rotation and to the pedoclimatic conditions of the area (Răus et al., 2016). In the conditions of the Czech Republic and also at large, the most suitable conditions for tillage intensity and depth reduction are in drier conditions of maize and beet production regions on medium-textured soils with higher natural fertility (Procházková & Dovrtěl, 2000; Horák et al., 2007). According to Šařec et al. (2010), RT brings the highest advantage on heavier soils in drier and warmer climatic regions. There, soil environment frequently even impede quality stand establishment using conventional soil cultivation technology including ploughing. In such case, RT is practically the only way of stand establishment. According to Hůla et al. (2008), replacing ploughing with a shallow soil loosening followed by sowing using no-till drills is a suitable alternative. Bednář et al. (2013) suggested an increase in between-the rows spacing (to 37.5 cm), and a decrease in sowings and the number of plants per m^2 (35 and fewer) both of which have a positive influence on the decrease of competition among individual oilseed rape plants.

Moreover, deeper soil loosening was proposed in order to ensure the disruption of compacted layers, and to ensure the balance of water regimen in soil profile.

A comparison of the different components of the total costs revealed that reduced-tillage required herbicide costs and larger machinery, but these costs were largely offset by reduced operating costs (Sanchez-Giron et al., 2004; 2007). In various other studies, it was concluded that slightly lower crop yields can be offset by the reduced fuel inputs and labour consumption (Gemtos et al., 1998; Bonciarelli & Archetti, 2000; Tebrügge, 2000). The advantage should be given to systems with lower level of tillage intensity, not only to reduce costs but also because of the possibility of simpler production organization due to less machine and labour requirement (Grubor et al., 2015). However, this may be dependent on particular situation and farm-specific properties such as cropping system, farm size etc. (Sanchez-Giron et al., 2007).

The purpose of this study was to evaluate conventional tillage (CT) and reduced tillage (RT) systems of winter oilseed rape production mainly in terms of yields, costs, labour and fuel consumption in the farming conditions of the Czech Republic. The evaluation was carried out by means of long-term operational monitoring of around 40 agricultural businesses that started in 2001. The monitoring followed field trials established by the authors in Opařany in 1998 (Šařec et al., 2002).

MATERIALS AND METHODS

Since the production year 2001/02, operational monitoring and measurements were carried out in the Czech Republic where around 40 agricultural businesses growing winter oilseed rape participated in. The businesses were selected in order to represent various production areas, i.e. pedoclimatic conditions, and different production technologies. According to the production system used, observations were sorted into one of the two key groups, i.e. conventional tillage (CT) and reduced tillage (RT) group. Other sorting criteria, besides production year, were:

- production area: forage, potato, cereal, beet, maize;
- winter oilseed rape variety: conventional, hybrid, mixed (both types of varieties used in a field);
- application of organic fertilizers (manure, slurry, compost, sugar cane boiling residues etc.);
- application of fertilizers at sowing.

Each production year, at least one field was examined in a particular business. If a business employed different tillage systems simultaneously, more fields representing those systems were observed. Especially the following values were monitored or measured:

- characteristics of individual fields: size, system of soil tillage and stand establishment, previous crop, manner of crop residue management, year of previous application of farmyard manure;
- characteristics of soil: bulk density (Kopecky's cylinders of a volume of 100 cm^3), gravimetric moisture, cone index (registered penetrometer PEN 70 developed at the CULS Prague);

- characteristics of crop stand: the number of plants per m^2, the weight of roots, hybrid / conventional variety, yield;
- data on conducted filed operations: machinery used, fuel and labour consumption, material applied and its rate, costs and other supplementary information.

The measurements concerning relevant soil and stand characteristics were completed by the authors in early spring each year. After the completion of terrain experiments, evaluation of monitored data followed each year. The authors processed relevant production records of plant cultivation specialists and work records of machinery operators at each agricultural business. Machinery costs were calculated in a common way and consisted of ownership (depreciation, financing costs, insurance and taxes, housing) and operation costs (repair and maintenance costs, fuel and oil costs, labour costs). With every business, the amount of expenses spent, i.e. machinery and material costs, was evaluated compared to the achieved seed yield, respectively revenues. Earnings from one hectare were calculated as total costs deducted from revenues, i.e. average annual farm price one ton of oilseeds multiplied by seed yield. Costs related to agricultural land were not included. The results were assessed using the sorting criteria mentioned above, and allowed thus to draw conclusions with a subsequent proposal for a suitable technology of effective winter oilseed rape production in particular conditions.

RESULTS AND DISCUSSION

During fifteen production years starting in 2001/02, trials were established in 531 fields located in all of the regions of the Czech Republic, but 11 fields were due to drought over the period of oilseed rape sowing or due to adverse winter climatic conditions sowed with another crop in spring. Reduced tillage (RT) system of oilseed rape production was employed in 290 cases, conventional tillage (CT) in 230 cases only. This imbalance developed over the monitored period, when some of the farm businesses swapped their system from CT to RT.

Fig. 1 documents the overall weather conditions in the Czech Republic over the period of the experiment along with the long-term norms. During some of the production years, weather development was more favourable at highlands in terms of rape growth and yields, during others on the contrary in lower placed regions. In some years, e.g. 2008 and 2009, crop stands may have been also damaged by hail storms. Concerning oilseed rape stand establishment, substantial difficulties due to droughts in autumn occurred particularly in the year 2015, and to some extent also in 2003 and 2008. Major dry frost came during winter of 2002/03, and some of the stands had to be ploughed down in spring. Generally, winters have become milder lately, and consequently springs have been often coming earlier. An extreme weather occurred principally during the year 2015, when spring and summer were exceptionally both hot and dry. It did not reduce rape yields substantially in 2015, but lowered the level of ground water to such extent that it influenced the yields of the year 2016 (Fig. 3). Since RT generally manage better soil moisture in drier conditions, it reached higher rape yields mostly in the latter mentioned year.

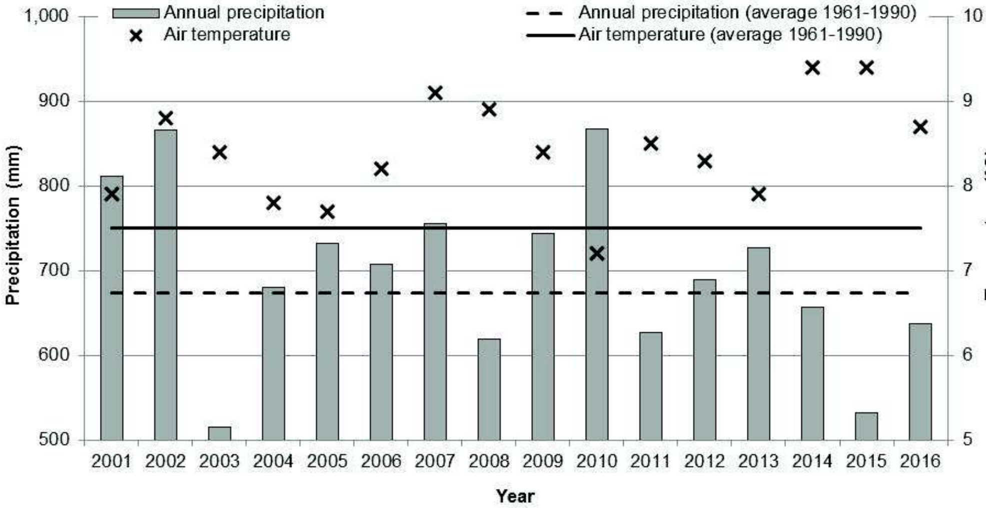

Figure 1. Graph of annual precipitation and mean temperatures in the Czech Republic in the years 2001–2016 and the long-term norms.

Oilseed rape production system characteristics

RT prevailed on heavy-textured soils in arid regions, i.e. in maize production area and in most of the beet production area. CT was used predominantly by farms with lighter soils and higher annual precipitation rates that could be found in potato and marginally beet production area. Choice of the tillage system was influenced also by the equipment that a particular agricultural business owned.

The most frequent tillage operations within RT consisted of two soil cultivations, followed in some cases by a seedbed preparation. Within CT, the common tillage procedures consisted of a stubble cultivation followed by ploughing, and a seedbed preparation done once or twice.

Disc cultivators prevailed within CT, whereas within RT, where two stubble cultivations were usual, tine cultivators were common, particularly for the second cultivation. Under RT, deeper (20 cm and more) soil loosening became more frequent in the course of time (Fig. 2).

Prior to oilseed rape sowing, manure was applied mainly in forage and potato production areas (30%, resp. 36%, of the cases), where the production of manure was adequate and potatoes production decreasing. Therefore, manure could be applied prior to oilseed rape. On the other hand in cereal, beet and maize production areas, where manure was applied primarily prior to sugar beet or corn maize, the application prior to oilseed rape displayed lower frequencies (only 16%, 10%, resp. 6% of the cases).

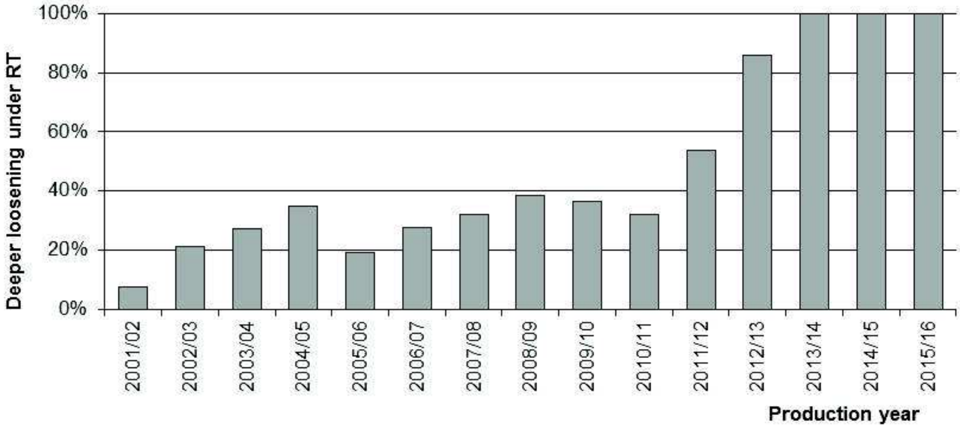

Figure 2. Graph of development of relative frequency of deeper (20 cm and more) soil cultivation employed under reduced tillage (RT) over the monitored period.

Yield results

Over the monitored period of fifteen production years, the average oilseed rape yield from all 520 fields was 3.72 t ha^{-1}. Table 1 shows average seed yields according to several sorting criteria. Average yield attained by CT matched almost exactly the one attained by RT.

Table 1. Average oilseed rape yields and frequencies of cases according to the tillage system and other sorting criteria over the whole monitored period of fifteen years

	Tillage system				Aggregate	
	RT Yield (t ha^{-1})	Frequency	CT Yield (t ha^{-1})	Frequency		
Production area						
Forage	3.45	32	3.62	12	3.49	44
Potato	4.18	16	3.81	67	3.88	83
Cereal	3.56	91	3.50	47	3.54	138
Beet	3.91	135	3.74	104	3.84	239
Maize	3.33	16	-	-	3.33	16
Variety						
Conventional	3.66	119	3.61	86	3.64	205
Hybrid	3.81	169	3.76	136	3.79	305
Mixed	2.33	2	3.58	8	3.33	10
Fertilizers at sowing						
No	3.72	174	3.69	225	3.70	399
Yes	3.76	116	4.07	5	3.77	121
Organic fertilizers						
No	3.70	213	3.69	129	3.70	342
Yes	3.83	77	3.71	101	3.76	178
Aggregate						
	3.73	290	3.70	230	3.72	520

Over the first five years of the monitoring, CT yields generally surpassed RT yields (Fig. 3). But gradually, this trend turned over and RT reached higher yields. One of the reasons might be that farmers got used to the specific requirements and opportunities of RT system and may have improved it over time, e.g. by employing the deeper soil loosening (Fig. 2). Another reason might be that favourable effect of RT was gradual and needed time to evolve.

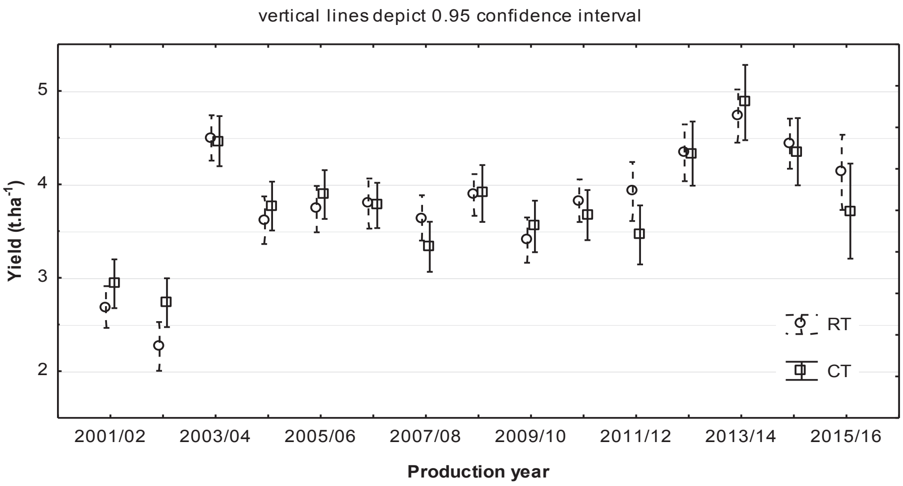

Figure 3. Graph of development of average oilseed yields attained by reduced tillage (RT) and conventional (CT) systems over the monitored period.

Concerning regionalization, potato production area demonstrated the highest average yield, followed by beet production area, while maize production area, where only RT was used, proved inferior results. In all of the production areas except the forage one, average seed yields attained by RT surpassed those produced using CT.

The average yield of more expensive hybrid varieties surpassed by 4.1% the one given by conventional varieties. With fertilizer application during rape sowing, which was mainly the case of RT, the average yield exceeded the yield produced when no fertilizers were applied while sowing by 1.9%. If organic fertilizers were applied, the average yield attained by merely 1.8% higher value. Relatively small frequencies and uneven distribution of cases into individual categories may have influenced the results. For example, in maize production area, RT was the only tillage system employed. Therefore, results of CT were not harmed due to unsuitability of maize production area in terms of winter oilseed rape growing.

Statistical analysis of seed yields showed no significant differences with regard to the tillage system used, to fertilizer application at sowing, and to organic fertilizer application. Oilseed rape variety type (*t*-Test, $n = 508$ – mixed varieties excluded, $p = 0.04583$), and production area (Table 2) were the two sorting criteria where significant differences were demonstrated between the average rape yields. Average yield attained in the cereal production area differed significantly compared to the beet and potato production areas (Table 2).

Table 2. Results of *Turkey HSD* test (homogenous groups) of oilseed rape yields according to production area over the whole monitored period of fifteen years

Production area	Average yield (t.ha^{-1})	1	2
Maize	3.328	****	****
Forage	3.493	****	****
Cereal	3.540		****
Beet	3.837	****	
Potato	3.880	****	

The trials thus correspond only partly with what Madarász et al. (2016) proved, i.e. by 12.6& significantly higher rape yield of conservation compared to ploughing technology over ten-year period. One reason might be the monitoring and operational character of the trials, another one the differences in local climatic and other conditions. The latter reason may be reduced by the following example.

In three cases in the production year 2014/15 and in two cases in 2015/16, an agricultural business employed CT and RT with deeper soil loosening in the same field (Table 3). Pedoclimatic conditions, material and machinery (except some tillage or drilling implements) used did not differ. Table 2 shows repeated by up to 0.5 t ha^{-1} higher yields gained by RT with deeper loosening. This outcome complies with the suggestions of Bednář et al. (2013).

Table 3. Seed yields of three agricultural businesses employing simultaneously different tillage systems in the years 2014/15 and 2015/16 (RT always with deeper soil loosening)

Farm/ Area	Tillage system	Stand establishment operations	Yield (t ha^{-1}) 2014/15	2015/16	Total
	CT	stubble cultivation; ploughing; seedbed preparation; sowing	4.30	4.20	4.25
	RT	stubble cultivation; deeper loosening (Simba); sowing	4.80	4.60	4.70
	CT	stubble cultivation; ploughing; sowing with seedbed preparation (Lemken – power harrow)	4.30	3.60	3.95
		stubble cultivation; deeper loosening (Horsch); sowing (Horsch)	4.50	3.90	4.20
		stubble cultivation; sowing with deeper loosening (Simba)	4.70	4.30	4.50
	CT	stubble cultivation; ploughing; seedbed preparation; sowing	4.10	—	4.10
		stubble cultivation; deeper loosening;sowing	4.37	—	4.37
		stubble cultivation; deeper loosening with fertilizer application to 0.25 m (150 kg PK per ha); sowing	4.60	—	4.60

According to *Dependent (Paired) t*-Test, the difference between yields of RT and CT, i.e. in average 0.41 t ha^{-1}, resp. 10.1% (Fig. 4), was statistically significant ($p = 0.00016$).

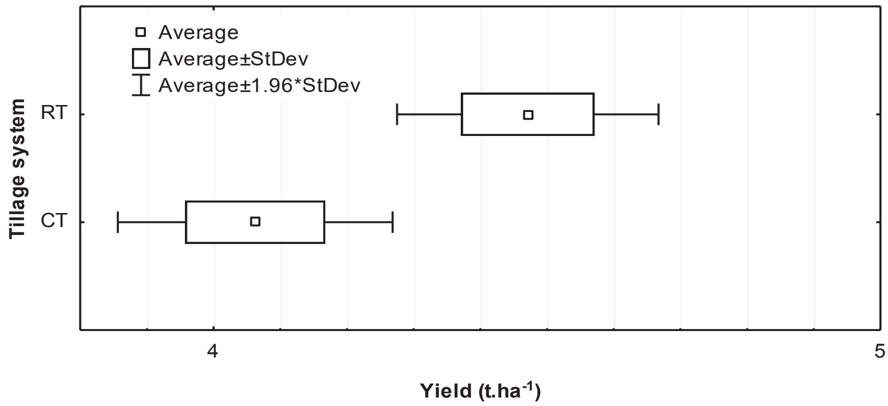

Figure 4. Graph of difference between yields provided by CT and RT with deeper soil loosening at three agricultural business that employed both systems simultaneously in the same field in 2014/15 and 2015/16 (*Dependent (Paired) t*-Test, n = 8, $p = 0.00016$).

Technological and economic indicators

The following technological and economic indicators were monitored or calculated (Table 4): length of vegetative period, fuel consumption, labour consumption, machinery, material and total costs, unit costs per ton of production and earnings per hectare.

Table 4. Average duration of vegetative period, fuel and labour consumption, averages of individual cost components, average costs per ton of oilseed rape production, and earnings per hectare according to the tillage technology and other criteria over the whole monitored period

	Veget. period (days)	Consumption Fuel (l ha^{-1})	Labour (hrs ha^{-1})	Average costs Machinery (CZK ha^{-1})	Material (CZK ha^{-1})	Total (CZK ha^{-1})	Unit. (CZK t^{-1})	Earnings (CZK ha^{-1})
Tillage system								
RT	345	71.75	3.70	6,126.67	12,655.11	18,913.16	5,384.13	12,825.55
CT	343	89.92	4.87	6,922.86	12,794.58	19,880.92	5,616.29	10,959.83
Production area								
Forage	359	90.21	5.40	6,419.52	12,513.23	19,214.57	5,686.99	8,370.13
Potato	350	88.72	4.97	6,949.16	12,570.60	19,699.28	5,200.77	13,788.03
Cereal	348	75.95	3.88	6,213.71	11,441.60	17,737.92	5,333.94	12,328.05
Beet	338	77.70	3.97	6,508.64	13,469.70	20,129.80	5,567.97	12,113.09
Maize	334	68.99	3.63	6,043.58	13,787.19	19,880.77	6,526.41	8,198.60
Variety								
Conv.	345	77.04	3.98	6,300.66	11,687.68	18,131.26	5,342.56	12,011.22
Hybrid	344	81.36	4.37	6,605.73	13,416.39	20,167.04	5,574.63	12,219.73
Mixed	332	87.89	4.57	6,261.10	12,476.24	18,957.34	5,765.54	5,085.19
Fertilizers at sowing								
No	343	82.98	4.45	6,664.56	12,757.95	19,568.13	5,554.00	12,006.75
Yes	348	69.25	3.47	5,866.39	12,581.09	18,592.94	5,265.28	11,979.14
Organic fertilizers								
No	343	70.13	3.58	6,068.47	11,889.06	18,147.88	5,207.44	12,811.79
Yes	347	98.33	5.44	7,267.28	14,307.18	21,634.01	6,023.59	10,441.22
Aggregate								
	344	79.78	4.22	6,478.83	12,716.80	19,341.21	5,486.81	12,000.33

With respect to the tillage system, the average fuel consumption of RT was by 20.2% lower than the one of CT, and the labour consumption lower again by 24.0%. The difference may have been stressed by an uneven distribution of application of organic fertilizer between the groups. If those were used, the fuel consumption would rise in average by 28.2%. As well the total costs were lower with RT, namely by 4.9%. In detail, machinery costs were lower with RT by 11.5%, material costs by mere 1.1%. Together with the slightly higher rape yield, costs per ton of seed produced using RT were by 232 CZK t^{-1}, i.e. by 4.1%, lower than those generated by CT. Related earnings per hectare reached by RT were therefore higher by 17.0%. Mainly thanks to its highest average rape yield, the potato production area demonstrated the lowest unit costs per ton of production and highest earnings per one hectare. Evaluation of the results according to the other criteria, such as organic fertilizer application etc., is only informative due to uneven distribution of cases in individual categories.

The fuel and labour consumption as well as the value of costs were increased by organic fertilizer application. Taking into account similar average yields, the unit cost per ton of seed production exceeded by 15.7% the average of the cases where no organic fertilizers were applied. Other benefits, such as an increase in soil carbon, of organic fertilizer than the immediate influence on yield must be taken into account, but they are difficult to quantify. Average length of vegetative period did not vary much except for production areas. It was slightly longer in production areas located at higher altitudes.

With respect to the costs per unit of production (Fig. 5), the best results were reached in potato production area with RT followed by CT there, and in cereal production area with both CT and RT. Beet production area with RT showed also very good results, particularly in recent years.

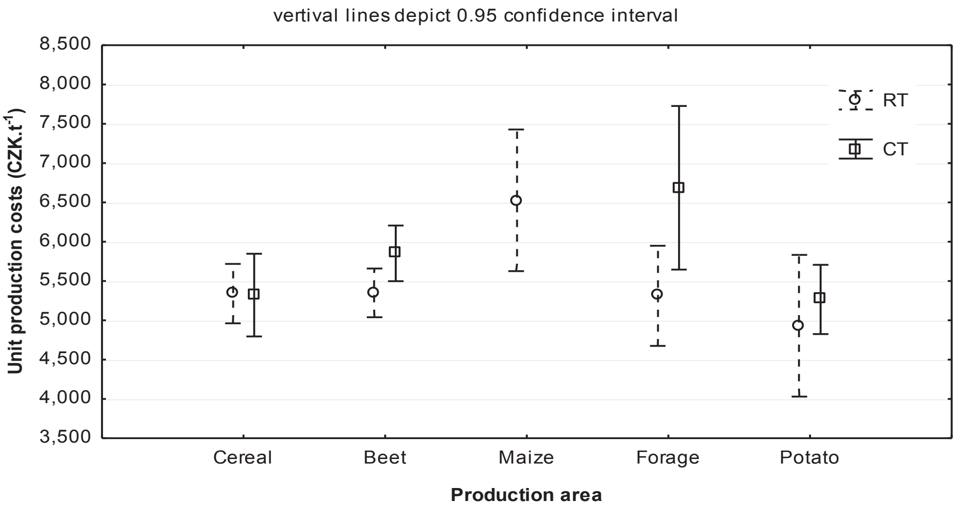

Figure 5. Graph of costs per one ton of produced rapeseed with respect to the production area and soil tillage system over the whole monitored period of fifteen years.

From the viewpoint of tillage system, fertilizer application at sowing and organic fertilizer application, the following variables proved statistically significant differences: fuel and labour consumptions, machinery costs and total costs (*t*-Test, $n = 520$, $\alpha = 0.05$). Earnings per hectare differed significantly regarding tillage system and organic fertiliser application. Material and unit costs differed significantly only with respect to organic fertilizer application. The conclusion of Sanchez-Giron et al. (2004; 2007) on higher herbicide costs of reduced-tillage was thus not confirmed, in opposite to the conclusion on lower machinery costs. Decrease in fuel and labour consumption (Gemtos et al., 1998; Bonciarelli & Archetti, 2000; Tebrügge, 2000; Grubor et al., 2015) was validated entirely.

CONCLUSIONS

The average fuel consumption of RT was by 20.2% lower than that of the CT, the overall labour consumption again lower by 24.0%. The total costs were lower by 4.9% as well. On the other hand, yields reached by RT were slightly higher, i.e. by 0.9%, and therefore the resulting unit costs lower by 4.1%. The potatoes production area proved to be the most favourable in terms of oilseed rape yields. Beet production area demonstrated also good results, namely over the recent years. In all of the production areas except the forage one, average seed yields reached by RT surpassed those produced using CT. Concerning earnings per hectare, RT results proved superior even in all of the production areas.

From the viewpoint of oilseed yields, of economics as well as of labour and fuel consumption, RT proved to be more than an adequate alternative to CT, particularly when employed on purpose and systematically. Lately, RT with deeper soil loosening has spread more and more, namely in order to ensure the disruption of compacted layers, and proved favourable results.

The operational monitoring and measurement conclusions were limited by an uneven distribution of cases into individual categories that prevented to adhere to the ceteris paribus rule of standard filed trials. On the other hand, the monitoring and measurements brought benefits of broader statistical survey that mirrored real conditions of the Czech agriculture. Since large collection of data was gathered, further on, the research will focus on analysis of particular details, e.g. of depth of soil tillage, specific material cost components etc.

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