PRODUCTION, ECONOMIC AND ENERGETIC ASPECTS OF CONTINUOUS TEN-YEAR USE OF CONSERVATION SOIL TILLAGE*

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The results, during 2002–2004, of a long-term field experiment with winter wheat, spring barley, and pea growing in crop rotations were evaluated from production, economy, and energetic standpoints. In this experiment, three soil tillage methods were used before drilling: 1) Conventional tillage (CT), 2) Minimum tillage (MT), 3) No tillage (NT). Provided that the basic conditions at a site are ensured, then by use of conservation soil tillage technologies, it is possible to achieve comparable (or higher) production, than with conventional tillage. Minimum soil tillage, with possible incorporation of straw and post harvest residues, was shown to be the cheapest method, compared with the other two assessed soil tillage treatments. Catch crop use with MT technology turns out to be the most expensive of the observed methods; and in the case of comparable yields, the cost effectiveness is lowest. The no-till technology was anticipated to be the cheapest, but the costs often increased due to the necessity to use more expensive pesticides. The highest demand for total input of supplementary power was calculated for winter wheat with the CT technology; the lowest for pea with CT, as well. The best utilization of supplementary energy inputs calculated was for winter wheat.

winter wheat; spring barley; pea; different soil tillage; production; economic and energetic balances

INTRODUCTION

In the Czech Republic, about 1.6 million ha of cereals are grown, and on more then the half of this area is winter wheat (Czech Statistical Office, 2007). Farming practices and stand establishment methods of field crops, especially cereals, have passed through a series of changes during the last decade. The growing system for cereals allows utilizing minimization and soil conservation technologies for stand establishment very well (Šimon, Javůrek, 1999; Cannell, Hawes, 1994 etc.). An increasing interest in utilization of soil conservation technologies for cropping, both around the world and in our own country confirm that their importance in the system of soil management is justified. According to expert estimates the area totals, where soil protection technologies of crop stand establishment and various kinds of minimization methods of soil tillage including direct drilling into non-tilled soil are used, is at least 800 thousand ha (Ministry of Agriculture CR, 2005). In farming practice, there is interest in simple minimization i.e. a decrease of the depth and intensity of tillage during the establishment of field crops. Subsequently, the methods of conservation soil tillage with the use of organic matter from post harvest residues of precrops or from catch crops are applied is increasing.

Minimization technologies of soil tillage are especially favourable methods for regions with an arid and warm climate. On lighter soils, with sufficient organic matter content for the achievement of higher water retention abilities, it is possible to reach yields significantly higher when compared to classic ploughing technology (Javůrek et al., 2005). However, conservation tillage methods also open-up methods for better soil management of heavier soils, where the state of the soil environment in autumn often does not allow one to establish a quality stand of winter crops by conventional tillage methods (Hůla, Procházková et al., 2002). In those cases with a lack of precipitation during the vegetation period, it is possible to prevent serious production failures of field crops by the use of conservation tillage methods. This is especially true with mulch use, as was confirmed in the 2003 spring crops with a large rainfall deficit in most of regions of the Czech Republic (Javůrek, Vach, 2004).

Both experimental results and experience from farming show the favourable influence of minimization technologies on the economy of plant production resulting from reductions of the number of operations, and consequently lower direct costs, as well as fuel and working time consumption per production unit. On the other hand, excessive costly farm equipment machines for soil preparation and drilling can influence the farm economy unfavourably, due to their insufficient utilization throughout the year (Sens, 1990). The savings with minimization technologies, compared to the conventional ones decrease in the following sequence: service prices, total costs, and then variable costs. Further, published savings markedly reached beyond 1000 CZK per ha (Hůla, 2001). The change of technologies can influence further the level of direct costs, especially the costs of seeds, fertilizers, and pesticides. Costs of seeds in filed experiments are usually

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the same for both conventional and conservation technologies, but in practice, it is usual to assume a slightly higher cost, due to higher sowing rates in the case of later sowing. In some cases, the impacts, in the absence of weed ploughing is compensated by herbicide application. These costs further decrease savings achieved; sometimes they can even exceed them. H ů l a (2001) presents an evaluation of costs for the machinery operations most frequently used, and on this basis, it is possible to compare the minimization and conservation technologies chosen for individual crops or crop groups.

Besides improvements of the economic parameters of crop production, protection technologies have a favourable effect on soil fertility, so there is a greater supply of organic matter into the soil, than usual. This causes a more intensive development of the soil microorganisms and some parameters of the soil quality are enhanced as a result of their higher activity (K l a d i v k o, 2001; M i k a n o v á et al., 2006). Some physical soil properties are improved, as well (J a v ů r e k et al., 2006).

Energy assessment is one of the most significant objective measures of agricultural production; either taken as partial sections or as a whole. The energy balance is not subject to various accidental fluctuations, and enables one to impartially compare both the various production types and the considerably different methods of production activity. The purpose of energy assessment is to reveal the existing reserves, and to optimize energy inputs into the production process to achieve the highest possible production effect with the lowest specific energy consumption.

Energy balances in agriculture can be assessed in various methods. Items assessed are the energy balances of particular energy inputs, and energy balances of individual plants [detailed calculations for wheat or barley, e.g. P i m e n t e l (1976), and energy balances in the framework of complex crop rotation H r u š k a, J a n í č e k (1982), K r e j č í ř (1984) and S t r a š i l, Š i m o n (1991) etc].

From the scientific point of view, the most valuable works are those that study the energy balance problems as a whole, i.e. the problems are solved globally, either of agriculture's individual parts, e.g. crop and livestock production; or as complex agriculture with regards to the energy inputs of other industries. Among such a comprehensive view on energy balances, can be included the examples of B e n d a et al. (1968), Č i s l á k (1983), H a n et al. (1985), P o s p í š i l, V i l č e k (2000).

In an effort to add further data and information to that mentioned above, we assessed the production, economy and energetic consumption of short crop rotation, using the results of a three-year cycle (2002–2004) from a ten-year field experiment established at the Prague-Ruzyně site.

MATERIAL AND METHODS

Since 1995, field experiments have been conducted on an experimental site at Prague-Ruzyně (altitude 350 m, average annual air temperature 7.9 °C, sum of annual precipitation 477 mm). The experiment was run as a rotation of three crops: winter wheat, spring barley and pea. A split-plot design with four replications was used. From 2000, the experimental design and tillage methods used were as follows:

1. Conventional tillage (CT): mouldboard ploughing to a depth of 0.20 m, current seed-bed preparation and sowing.
2. Minimum tillage (MT):
   a) For winter wheat: chopping of pea straw and incorporating it into the soil by disc tiller, sowing with a John Deere 750 drill machine.
   b) For spring crops (barley, pea): after pre-crop harvest shallow tillage, seed-bed preparation, catch crop sowing, and in spring direct drilling into non-tilled

Table 1. Energetic balances of different tillage technologies of choice crops (GJ.ha^{-1}.year^{-1})

Crop	Soil tillage	Energetic outputs			Total energy input	Energetic coefficient	
		Energy of main product	Energy of secondary product	Total energy output		Main product	Total production
Winter wheat	CT	117.74	84.28	202.02	19.66	5.99	10.28
	MT	117.20	82.31	199.51	17.60	6.66	11.34
	NT	117.74	81.60	199.34	17.99	6.54	11.08
Spring barley	CT	92.10	59.90	152.00	17.43	5.28	8.72
	MT	93.92	63.09	157.01	17,03	5.51	9.22
	NT	94.10	59.37	153.47	15.93	5.91	9.63
Pea	CT	56.66	38.63	95.29	10.05	5.64	9.48
	MT	55.94	37.73	93.67	12.25	4.57	7.65
	NT	50.38	32.88	83.26	10.29	4.90	8.09
Average	CT	88.83	60.94	149.77	15.71	5.65	9.53
	MT	89.02	61.04	150.06	15.49	5.75	9.69
	NT	87.41	57.96	145.36	14.74	5.93	9.86

Notes: CT = conventional tillage, MT = minimum tillage, NT = no tillage soil, covered by frost-killed biomass of the catch crop (mustard).

3. No-tillage (NT): straw taken away before sowing application of non-selective herbicide (glyphosat), direct sowing into non-tilled soil with a John Deere 750A drill machine.

Nitrogen fertilization was as follows: for winter wheat at 100 kg per ha, spring barley at 80 kg per ha, and pea at 40 kg per ha. The P and K fertilizers were applied before drilling of the catch crops, in all variants, at a universal dose of 54 kg P_2O_5 and 100 kg K_2O per ha. Standard herbicides were applied, depending on the intensity of weed infestation at each site.

Production levels were evaluated by yields of the main and secondary products; determination based on a 24 m^2 test area at the harvest of the individual tillage variants. For the significance of the differences between the individual tillage technologies, average data from the selected three years were statistically processed using Unistat 5.0 software.

The economic assessments, variable and total costs of individual operations in conventional, minimum, and no tillage technologies were calculated according to Kavka et al. (2003). Market prices of the main product and total production for individual crops in individual technologies were calculated using the average market prices of these products during the period 2002–2004 (Czech Statistical Office 2002, 2003, 2004). From the data obtained, the cost effectiveness was worked-out by comparisons of profit (loss) and total costs.

From the viewpoint of energy balance, the three crops grown under three different soil tillage technologies (CT, MT, NT) were compared. Results of these assessments are found in Table 1. Energetic inputs including different methods of soil tillage, seeds, fertilizers, pesticides and all operations, from sowing to harvest, were calculated according to standardized fuel consumption and the kWh used in practice (Preininger, 1987), and further according to the amounts of chemicals and seeds consumed in a given technology. The calculation comprises both the direct and indirect components of supplementary energy. Energy outputs are determined from actual measures of the energetic contents of the main and secondary products of the given crops, determined as dry matter combustion heat (Strašil, 1998). As the criterion for the determination of energetic balances, the energetic coefficient (energy produced and total energy inputs rate) was used.

RESULTS AND DISCUSSION

Production

The yield results, which have been averaged from 2002–2004, are shown in Fig. 1. For winter wheat, there are no significant differences among individual soil tillage methods (Table 2). For spring barley, the yields in both conservation tillage treatments are significantly higher than in conventional ones. From the pea results, a negative reaction of pea on direct drilling is evident. Yield in this variant is significantly lower than in the conventional tillage treatment and in the minimum tillage variant, as well. The lowest significant differences, at the 95% level, are in Table 2.

According to the American results (Cannell, Hawes, 1994), plough-less technologies guaranteed higher yields of field crops than the classic soil tillage plough methods. According to results from Canada (Arshad, 1999), reduced soil tillage is preferred because of

Table 2. The influence of different soil tillage on grain yield (LSD 0.05)

Crop	Conventional tillage	Minimum tillage	No tillage	LSD
Winter wheat	6.45	6.42	6.40	0.114
Spring barley	5.05	5.15	5.16	0.084
Pea	3.16	3.12	2.81	0.047

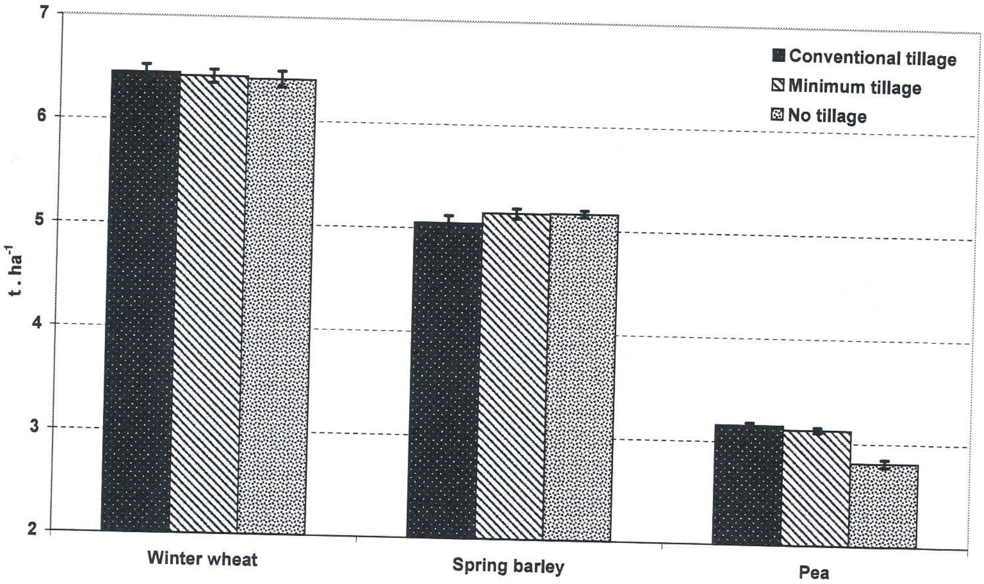

Fig. 1. The impact of different method of stand establishment on grain yields

Table 3. Economic evaluation of different ways of cropping

Crop	Technology	Average yield		Variable costs (€.ha^{-1})	Total costs (€.ha^{-1})	Main product price (€.ha^{-1})	Total production price (€.ha^{-1})	Cost effectiveness (%)
		Grain (t.ha^{-1})	Straw (t.ha^{-1})					
Winter wheat	CT	6.45	4.71	499	744	733	836	12.4
	MT	6.42	4.60	450	639	730	831	29.9
	NT	6.45	4.56	490	701	733	833	18.8
Spring barley	CT	5.05	3.38	451	683	691	767	12.3
	MT	5.15	3.56	491	736	704	785	6.7
	NT	5.16	3.35	441	669	706	782	16.8
Pea	CT	3.16	2.15	372	558	453	510	–8.6
	MT	3.12	2.10	430	644	447	503	–21.9
	NT	2.81	1.83	374	561	403	452	–19.6

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

better yield results, while direct drilling into non-tilled soil is practised, only exceptionally, because the failure of yields in experiments or in farming. Reinhard et al. (2001) and similarly Dzenia et al. (1999) present the results from Switzerland and Poland, where they found minimum and statistically insignificant yield differences among soil tillage methods of different intensities.

Šimon and Javůrek (1999) presented the results from exact field experiments on fertile chernozems, where the yields of cereals were significantly higher in conventional variants than after drilling into non-tilled soil.

From this short review, it is evident that the results of study of soil tillage impacts on crop yields vary, and their dissimilarities proceed logically from different soil and climatic conditions of sites from which they are drawn. This has been confirmed by results of the chosen three-year series that includes three different years, from the point of view of weather changes: precipitation during the vegetation period 2002 was above normal; 2003 subnormal and dry; 2004 normal. In 2002, yields of cereals were significantly higher in conventional variants. In 2003, with considerable soil moisture deficit yields were higher in conservation variants; and in 2004, with a normal course of precipitation the yield results, between both treatments, were insignificant.

Further, the results confirmed the availability of soil tillage, conservation technologies being utilized on medium-heavy soils with higher natural soil fertility. This is especially so for cereals, in drier conditions, where a soil and water protection effect (especially with the use of mulch from catch-crops and application of post-harvest residue) would be of use. The optimal recommended alternative would be utilization of the available conservation technology of soil tillage, based on its verification in the actual soil and climatic conditions.

Economics

In experimental crop rotation in the chosen interval, direct and total costs were compared for the growing technologies of three crops, with different intensities and depth of tillage, and with various organic matter utilizations (CT, MT, NT), that are used in farming practice. Based on the

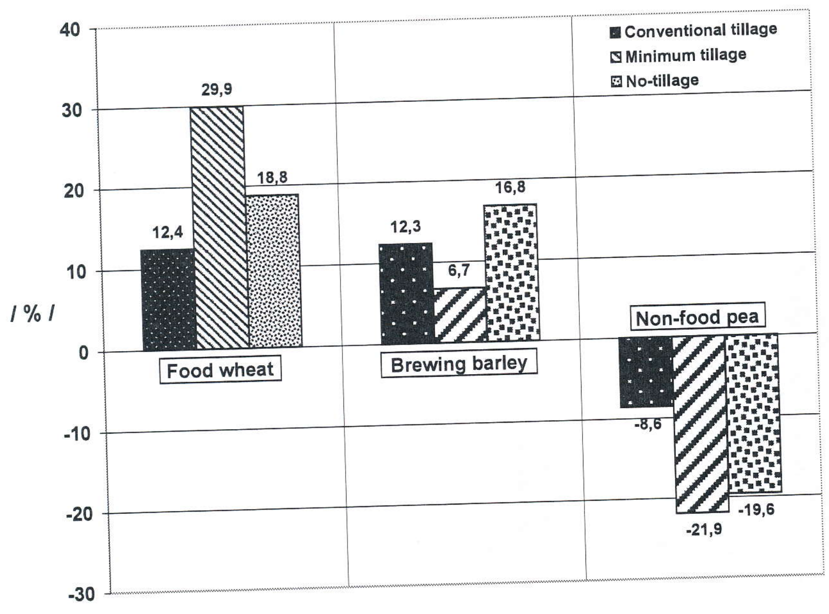

Fig. 2. Cost effectiveness of experimental crops grown under technologies of different tillage intensity

yields attained in the field experiments and the CR market prices of the assessed crops for individual years, the market price of the main product and total biomass production were calculated. For comparison of profit (loss) and total costs, the cost effectiveness was calculated. These results are shown in Table 3 and in Fig. 2.

The greatest cost effectiveness, on average, of the three methods of soil tillage were achieved with food variety of winter wheat, in spite of the fact that total costs were relatively high and being sold for a relatively high price. Regarding particular ways of stand establishment, the highest effectiveness cost was calculated for MT technology (29.9%), in NT it was about 11% lower, and in CT 17.5% lower (comparing with MT).

The cost effectiveness of brewing barley, grown under the same cost level for a given technology as wheat, was calculated to be about 50% lower than in food wheat. The lower price of total production was as a consequence of a significantly lower grain yield; this decrease in spite that the market price was slightly higher than in wheat.

As for specific tillage treatments, the highest cost effectiveness was achieved in NT (17%), then in conventional tillage, and finally in MT the cost effectiveness was lowest. This was caused by establishment of a catch crop stand, which increased the total costs of MT technology, in spite of the price of total production being higher.

The pea growing technology showed negative values of cost effectiveness based on the grain yields achieved. It is not possible to sell for such a price; the price of total production being higher than the total costs. Looking at these negative values, the highest cost effectiveness was reached in the CT variant (–8.6%); the lowest in MT technology (–21.9%). Similar to the MT technology of barley growing, the cost increases were caused by inclusion of a catch crop in the pea growing technology.

In agricultural practice, the economic parameters mentioned above range slightly in their values because the average yields (winter wheat 4.82 $t.ha^{-1}$, spring barley 3.85 $t.ha^{-1}$, and pea 2.50 $t.ha^{-1}$) do not achieve the yield levels of exacting field experiments. This means that the price of total production per ha is lower. It was assumed that total costs per area unit for individual tillage technologies and crops were also on average lower. Consequently, it indicates that the average level of cost effectiveness for food wheat and brewing barley grown in the Czech Republic show positive values, in most of cases.

Under actual market prices and cost levels pea growing technologies are economically inefficient. Nevertheless, in the Czech Republic about 3000 ha of pea are grown for its excellent pre-crop attributes, especially for cereals and as a crop with soil improving properties.

Generally, regarding the particular soil tillage technologies for cereal growing, it is possible to say that with decreasing soil tillage intensity, the costs for growing technology also decrease. But in no-till technology the costs can go up, owing to the necessity of non-selective and more effective (more expensive) applications of herbicides (Malhi et al., 1988), as well as higher nitrogen doses (depending on natural soil fertility), in order to reach yields comparable to conventional technology. Use of catch crops in minimum tillage technologies for spring crops increases costs. Furthermore, in the case of similar yields the profitability is considerably lower, than in conventional means of soil tillage. If technology with chopped straw incorporation would be used for spring crops (as in winter wheat), then profitability should increase significantly because shallow tillage with chopped straw incorporated proves to be cheaper (see Table 3: winter wheat). However, organic matter supplied into the soil from catch crops is of greater quality, comparing to chopped straw; and catch crops fulfil yet other functions, for instance nitrogen fixation, long term soil coverage, etc. Catch crop use for conservation tillage technologies does indeed decrease economic profit, but it also influences physical and biological soil properties favourably and contributes to increased soil fertility.

Brunotte et al. (1996) came up with similar results for the costs of establishment of a sugar beet stand by conventional means, when they compared sowing in mulch from frost-killed catch crop with sowing in mulch from wheat straw.

Energetics

The highest total demand for supplementary power inputs was found to be in the conventional tillage technology – CT (15.71 $GJ.ha^{-1}.year^{-1}$); next in the minimum tillage – MT (15.49 $GJ.ha^{-1}.year^{-1}$); and finally with the no-tillage – NT (14.74 $GJ.ha^{-1}.year^{-1}$) – see Table 1. For example, Krejčíř (1984) stated that the minimum soil cultivation needs less energy consumption, when compared with the traditional approach. The reason is primarily the lower energy inputs of fuels, dependent on the crop rotation type from 84% to 94%, compared with traditional cultivation.

The greatest additional energy input was needed by wheat with CT (19.66 $GJ.ha^{-1}.year^{-1}$). The least additional energy inputs were found for peas with CT (10.05 $GJ.ha^{-1}.year^{-1}$) – see Table 1. These figures are lower than some other authors reported. For example, Preininger (1987) in his model presents energy input balances for winter wheat of 25.26 $GJ.ha^{-1}$. Pospíšil and Vilček (2000) present the total inputs of additional energy: for winter wheat ranging from 22.95 to 28.09 $GJ.ha^{-1}$; for peas 14.73 to 19.14 $GJ.ha^{-1}$; depending on the soil-ecological sub-region. This is closer to that specified in our balance results. The total value difference will mainly be affected by the additional partial fertilization inputs of industrial fertilizers (nitrogen in particular), which represent 25–50% of total inputs for grain crops, depending on the different farming techniques (Preininger, 1987; Strašil, Šimon, 1991). The amounts of fertilizers used in our experiments are presented in the material and methods section.

The best of the energy rates produced and total energy inputs (i.e. the best utilization of supplementary energy inputs) for the main product, reflecting total one was calculated for winter wheat with MT technology. On the contrary, the worst coefficient was found with pea growing with MT. The high values for total energy inputs for barley and pea in the MT variant, compared with other inputs, were caused by the catch crop used. Positioning of catch crops in crop rotation before spring crops in MT technology does not lead to a significant increase of the main and total production (energy output) in both barley and pea; compared with other soil tillage technologies.

CONCLUSIONS

- Minimization nor conservation soil tillage are a priori reason for production decrease. Provided, that the basic agronomical conditions at a site are ensured, it is possible to achieve comparable or higher production, than with conventional tillage.
- Good production levels of crops under conservation tillage technologies are possible to achieve on medium heavy soils, in drier regions on soils of higher natural fertility.
- Minimum soil tillage, with the possible incorporation of straw and post harvest residues, have been shown to be the cheapest method when compared with the other two soil tillage treatments tested. The use of this technology can increase the profitability of crop growing, if yield levels stay comparable or higher.
- In the cases of catch crop use, minimum tillage technology was the most expensive from the tested tillage methods and at comparable production levels, the cost effectiveness is the lowest.
- In the no-till technology there is an assumption of it being the cheapest soil tillage method, but the costs often increase as a result of the necessity to use more effective and expensive pesticides; higher doses of nitrogen and, thus, profitability is often reduced by lower production.
- In the tested soil tillage technologies, regardless of the crops there, calculated energy demands were calculated as follows: CT (15.71 $GJ.ha^{-1}.year^{-1}$); in minimum tillage – MT (15.49 $GJ.ha^{-1}.year^{-1}$); and finally with the no-tillage – NT (14.74 $GJ.ha^{-1}.year^{-1}$).
- The highest input demand of total supplementary power was calculated for winter wheat under the CT technology; the lowest inputs were for pea with CT.
- The best utilization of supplementary energy inputs was calculated for winter wheat with the MT technology.

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Produkce, ekonomika a energetické aspekty víceletého využívání půdoochranných technologií.

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V příspěvku jsou publikovány výsledky dlouhodobých polyfaktoriálních polních pokusů na stanovišti v Praze-Ruzyni za období 2002–2004. Pokus je koncipován jako tříhonný osevní postup s pšenicí ozimou, ječmenem jarním a hrachem. Je použit split-plot design se čtyřmi opakováními, plocha sklizňové parcely je 24 m^2. Pokus zahrnuje tři odlišné způsoby zpracování půdy. Konvenční zpracování (CT), kde je pro všechny plodiny použita orba do hloubky 0,2 m, běžná předseťová příprava a setí. Minimální zpracování (MT), kde pro pšenici ozimou je aplikováno mělké zapravení drcené slámy diskovým kypřičem, setí strojem John Deere 750A; pro jarní plodiny (ječmen, hrách): po sklizni předplodiny mělké zpracování a předseťová příprava, setí hořčice bílé jako meziplodiny, na jaře přímé setí ječmene nebo hrachu do nezpracované půdy, pokryté mulčem z biomasy vymrzlé meziplodiny. Bez zpracování (NT) zahrnující úklid slámy, před setím aplikaci neselektivního herbicidu (glyphosat), přímé setí do nezpracované půdy strojem John Deere 750A. V jednotlivých variantách založení porostu byla hodnocena výše produkce hlavního a vedlejšího produktu, byly zjištěny náklady na jednotlivé pracovní operace a tržní ceny celkové produkce a z těchto údajů byla vypočtena rentabilita vynaložených nákladů. Rovněž byly propočítány parametry energetické náročnosti a stanoven energetický koeficient pro hlavní produkt i pro celkovou produkci.

Za sledované období a za daných stanovištních podmínek nezpůsobila změna technologie zpracování půdy statisticky významné rozdíly ve výnosu ozimé pšenice. V CT a NT variantách jsou výnosy zcela shodné, výnos v MT je neprůkazně nižší. U jarního ječmene jsou výnosy v MT a NT variantách vyšší než v CT na hladině významnosti 95 %. Mezi oběma půdoochrannými variantami není statisticky významný rozdíl. U hrachu není významný rozdíl mezi CT a MT variantou. NT varianta je významně nižší než ostatní varianty.

V porovnání s ostatními dvěma testovanými technologiemi se jako nejlevnější ukazuje být minimální zpracování půdy s případným zapravením drcené slámy a posklizňových zbytků. Při zajištění určité úrovně výnosu a při realizaci na trhu za příznivou cenu může být touto technologií dosaženo vysoké rentability pěstování dané plodiny. V případě využití meziplodin se stává MT technologie nejdražší z testovaných způsobů zpracování a při srovnatelné produkci má nejnižší rentabilitu vynaložených nákladů. Důvodem je zvýšení celkových nákladů o náklady na založení porostu meziplodiny. NT má předpoklady pro nejlevnější technologii, avšak náklady často narůstají vlivem nutnosti použití účinnějších a dražších pesticidů i vyšších dávek N. Rentabilita této technologie je často redukována nižší produkcí. Z hlediska zpracování půdy byly v průměru hodnocených plodin nejnáročnější na celkové dodatkové vstupy energie v sestupném pořadí: CT (15,71 $GJ.ha^{-1}.rok^{-1}$); MT (15,49 $GJ.ha^{-1}.rok^{-1}$); NT (14,74 $GJ.ha^{-1}.rok^{-1}$). Na celkové dodatkové energetické vstupy byla ze sledovaných plodin nejnáročnější ozimá pšenice při CT, nejnižší dodatkové energetické vstupy byly zjištěny u hrachu při CT. Nejefektivnější využití použitých dodatkových energetických vstupů při započtení hlavního produktu, resp. celkového produktu bylo zjištěno u ozimé pšenice při využití technologie MT.

pšenice ozimá; ječmen jarní; hrách; odlišné zpracování půdy; produkce; ekonomika; energetické bilance

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