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The effect of conservation primary and zero tillage on soil bulk density, water content, sugar beet growth and weed infestation

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Abstract. The effect of different conservation primary soil tillage on sugar beet was investigated at the Experimental Station of the Lithuanian University of Agriculture in a silty loam Luvisol during the period of 2001 – 2006. The aim of the trial was to establish the influence of reduced soil tillage intensity on some soil physical properties, sugar beet yield and quality, and weed infestation. Treatments of the trial: 1. conventional (22–25 cm) ploughing with a mouldboard plough (CP); 2. shallow (12–15 cm) ploughing with a mouldboard plough (SP); 3.deep (25–30 cm) cultivation with a chisel cultivator (DC); 4. shallow (10–12 cm) loosening with a disc harrow (SL); 5. zero tillage (ZT).

Reduction of primary soil tillage intensity increased the amount of moisture and level of soil bulk density in the soil upper layer (0-10 cm). According to the average data of 2001-2006, the highest amounts of moisture and soil bulk density were observed in no tilled soil (ZT) before pre-sowing soil tillage (25.8% and 1.40 Mg m^{-3}) and after sowing until sugar beet germination (23.6% and 1.40 Mg m^{-3}). Soil tillage intensity had no significant influence on soil moisture content and bulk density in a deeper (10-20 cm) layer.

Sugar beet seed germination in shallow loosened soil (SL) was higher in comparison with control treatment (CP) fourfold per 6 years; this influence was significant in two experimental years. Average data showed that germination of directly sowed seeds was less by 37% in comparison with conventional ploughing (CP). Reducing of soil tillage intensity to zero tillage had no significant influence on sugar beet yield, ramification and sucrose content of root-crop.

The reduction of soil tillage intensity and refusal to use full-scale herbicides had negative, but not significant influence on weed infestation in the sugar beet crop, except in the no-tillage pattern. The data of the beginning of the second rotation showed a significantly higher number of annual (32%) and all (29%) weeds in no-tilled (ZT) soil in comparison with conventional ploughing (CP). Generally, the number of weed species increased from 22 to 26. The number of *Chenopodium album* increased from 11.3 to 22.1, *Poa annua* – from 5.6 to 14.2, *Taraxacum officinalis* – from 0.66 to 6.1 plants per m^2. *Elytrigia repens* became a widespread weed.

Key words: primary and zero tillage, sugar beet, soil properties, yield, quality, weeds.

INTRODUCTION

Reduced tillage, often called conservation, is increasingly used for sugar beet crops in some areas. The extreme form of this soil tillage is direct sowing. More often mouldboard ploughing is replaced by discs or chisel ploughing. The mulch of crop residues on the soil surface may reduce evaporation; rainfall may lead to surface hardening. Shallow tillage normally results in a higher bulk density in the deeper parts of the topsoil layer, which may reduce yield and/or increase ramification of sugar beet roots. Direct sowing has occasionally resulted in a crop yield of sugar beet similar to that after conventional tillage but usually the crop yield has been considerably poorer (Draycott, 2006).

The conservation primary soil tillage in autumn is possible in structural soils (Stancevicius et al., 1990; Arlauskas, 1993; Velykis et al., 1996). Additionally, comparison of conventional and conservation soil tillage methods shows that they have significant effect on soil bulk density, structure and total porosity (Auskalnis, 2005). According to the results of many investigations, soil hydraulic conductivity, bulk density and compaction increased and porosity decreased because of the applicaton of a zero tillage system (Munkholm et al., 2001; Strudley et al., 2008). By other results, the minimalisation of soil tillage had no significant influence on variation of these indices (Aura, 1993; Ferreras et al., 2000). In most cases, extensively tilled soils contain more moisture in springtime than in the case of intensive primary tillage (Cannel & Hawes, 1994; Lafond et al., 2006; Tsuji et al., 2006; Strudley et al., 2008). Mostly, conservation soil tillage improves physical properties, although this was observed only after 4-5 years of such soil tillage system application (Håkansson, 1993). According to the results of other investigations, this influence showed even later (Cannel & Hawes, 1994). However, the soil texture and content of organic matter has a stronger influence on soil physical properties than on soil tillage systems (Arvidsson, 1998; Strudley at al., 2008).

According to the results of the trials, reduction of soil tillage intensity had no significant influence on the yield of many crops (Ekeberg, 1993; Håkansson et al., 1998; Hao et al., 2001.). The zero tillage system mostly showed the decrease of crop yield but sometimes converse influence (Riley et al., 1998; Riley, 2005) was observed.

Reduced tillage may lead to increased weed infestation, especially of perennials (Munkholm et al., 1998; Draycott, 2006). In some trials the increase of weed number had a negative influence on crop yield (Børresen, 1993). However, converse results (Campbell et al., 1998) were also obtained.

Reduced primary soil tillage systems have not been investigated enough in Lithuania. Direct seeding of sugar beet still is not investigated in Lithuania at all; therefore the main goal of this work was to ascertain the influence of soil tillage intensity on productivity and quality of a sugar beet root crop. The hypothesis states that conservation and zero tillage do not have significant influence on soil bulk density, sugar beet seed germination, yield and quality of roots in comparison with conventional soil tillage (deep ploughing). However, the crop weediness may have a tendency to increase.

MATERIALS AND METHODS

The trial was conducted on a silty loam (*Hipogleyic Luvisol (Calcaric)*) (WRB, 2006) at the Experimental Station of the Lithuanian University of Agriculture during 2001 – 2006. The soil was slightly alkaline or neutral; it was rich in phosphorus (280 mg kg^{-1}) and medium rich in potassium (129 mg kg^{-1}), organic carbon content – 2.1%.

The trial was established according to the following scheme: 1. conventional (22–25 cm) ploughing with a mouldboard plough (CP) (control treatment); 2. shallow (12–15 cm) ploughing with a mouldboard plough (SP); 3. deep (25–30 cm) cultivation with a chisel cultivator (DC); 4. shallow (10–12 cm) loosening with a disc harrow (SL); 5. zero tillage (ZT). There were four trial replications. The block design was randomised. The initial size of the trial plots was 117 m^2, estimated plot size was 84 m^2. Crop rotation: spring rape - winter wheat - sugar beet - spring barley, i.e. the fore crop for sugar beet was winter wheat.

Straw was loosened in all plots of the trial except plots for zero tillage after harvesting of winter wheat. In late October plots were tilled according the scheme of the trial. Plots of zero tillage were spread with full-scale herbicides *glyphosates* 4 l ha^{-1} before wintering. Full-scale herbicides were not applied in the trial before 2002; after 2002 they were used in no tilled plots only. Primary tilled plots were tilled by compound cultivator in 3-4 cm depth before sugar beet sowing. The spaces between rows of sugar beet were 45 cm. Seeds were sown by a pneumatic drill with wedge-type coulters. The distance between seeds was 11.5-14.5 cm. The sugar beet crop was fertilized with N_{60} P_{80} K_{160} before sowing and N_{68} – additionally before the 1st of July. The crop was spread with selective herbicides Pyramin Turbo (4.5 l ha^{-1}) and Betanal Expert (1.2 l ha^{-1}) during sugar beet vegetation in each year of treatment.

The soil bulk density and gravimetric water content (mass wetness) (Hillel, 1982) were determined at the same time before spring soil cultivation and after soil tillage and sowing until sugar beet germination every 10 days by the cylindrical and weighing methods (Dospechov et al., 1977). Cylinder size is 200 cm^3. Sampling depth – 0-10 and 10-20 cm. Soil samples were taken in 4 places per each plot of treatment.

The sugar beet seed germination was observed by counting seedlings in 8 random rows per plot (25.2 m^2).

The sugar beet root yield and quality were determined in the samples taken from the area of 9 m^2 per each plot of treatment. Sidelong roots were eliminated from the root-crop and it was cut to technological length (1 cm diameter). Root-crops were washed. The yield results of clean roots were presented in the article. The ramification of sugar beet roots was estimated by counting ramified roots in each sample and recalculated into percent. Analysis of the sugar beet root sucrose content was conducted in the laboratory of the Kėdainiai sugar factory ('Danisco Sugar Kėdainiai') by the method of cold digestion.

Weed density in the crop was tested no later than 3 weeks before harvesting and was determined by quantitative method (Dospechov et al., 1977). Weed samples were taken from every trial field in 10 places by a frame 30 x 20 cm (the area was 600 cm^2). The same frames were used for counting seedlings and adult plants of perennial and annual weeds. Weed composition, according to the biological weed classification (Monstvilaite, 1986), was established in the samples. The results of crop weediness were recalculated into square metres. Latin names of weeds were presented according to Jankeviciene (1998).

The weather conditions during sugar beet vegetations are presented in Table 1.

Table 1. Average air temperatures and rainfall during sugar beet vegetation Kaunas Meteorological Station, 2001-2006

Month	April	May	June	July	August	September	October
1	2	3	4	5	6	7	8
			2001				
Temperature ^{0}C	8.1	13.0	14.4	20.9	17.9	12.2	9.1
Rainfall mm	32.2	58.4	45.7	144.5	55.0	75.3	77.3
			2002				
Temperature ^{0}C	8.2	15.7	16.8	20.6	20.4	12.8	4.9
Rainfall mm	28.1	30.4	93.1	53.5	13.8	42.3	167.0
			2003				
Temperature ^{0}C	5.4	13.6	15.4	20.1	17.1	12.7	4.7
Rainfall mm	32.3	45.1	57.1	118.2	53.4	27.9	89.5
			2004				
Temperature ^{0}C	7.4	11.0	14.2	16.6	17.9	12.7	8.3
Rainfall mm	15.1	38.3	62.9	78.5	98.0	35.3	80.7
			2005				
Temperature ^{0}C	7.5	12.1	15.0	19.0	16.7	14.2	8.0
Rainfall mm	37.4	76.9	78.1	45.4	136.2	46.5	10.8
1	2	3	4	5	6	7	8
			2006				
Temperature ^{0}C	6.5	12.5	16.5	20.9	17.8	14.6	9.7
Rainfall mm	29.3	74.5	18.0	70.7	165.6	89.8	47.7
			Average 1974-2006				
Temperature ^{0}C	6.2	12.6	15.5	17.0	16.7	11.9	6.9
Rainfall mm	36.4	42.9	63.0	84.6	65.7	38.7	56.4

The trial data were analysed by ANOVA. The treatment effects were tested by the least significant differences LSD_{05}, P and F tests. Each year data were analysed separately. The data of our six-year trial were analysed under the statistical method of several year experiment data evaluation (Gomez & Gomez, 1984) which is based on the Fisher F-test dispersion analysis. Evaluating year and treatment interaction was established. On this basis average data of the six-year experiment were presented just as tendencies. The trial data were also evaluated using correlation and regression analysis by "SigmaPlot 8.0" software (SPSS Science 2000).

RESULTS AND DISCUSSION

Soil physical properties.

Different soil tillage intensity had significant influence on soil moisture content before pre-sowing soil tillage in the topsoil layer (0–10 cm), especially in 2005 and 2006 (Table 2). The surface layer (0–10 cm) of ploughed soils dried the most rapidly after sowing during seed germination in each year of our investigations (Table 2). According to the average data of 6 years, we observed significantly higher soil moisture content (23.6%) in no tilled soil because of the winter wheat straw cover (mulch). Higher soil moisture content (20–23%) is most favourable for germination of sugar beet seeds (Kolomiec, 1990). However, in our experiment soil moisture had no positive significant influence on seed germination in not tilled soil because of the problems with sowing machinery, which was not well adapted for sowing seeds into no tilled soils. Vullioud & Charles (2000) mentioned the same problem (Draycott, 2006). Soil tillage intensity had no significant influence on soil moisture content in the deeper (10-20 cm) layer (Table 2).

After the sowing operation the soil bulk density in the surface layer decreased because of pre-sowing soil cultivation. Not tilled soil remained as dense as the tilled one; however, its bulk density was nearly the same as before sowing (Table 3). According to the average data of 2001-2006, we defined the highest amount of moisture (25.8%) in not tilled soil (ZT). However, this influence was not so clear in the deeper (10–20 cm) soil layer (Table 2). Plant residues on or near the soil surface after ploughless tillage led to lower evapotranspiration and higher content of soil water in the upper (0-10 cm) soil layer (Rasmussen, 1999). Meteorological conditions during winter had a stronger influence on the level of soil bulk density in springtime before pre-sowing soil tillage than soil tillage intensity (Table 3). Mostly, the highest soil bulk density before pre-sowing soil tillage was observed after shallow loosening and zero tillage. The influence of ploughless soil tillage on soil bulk density in the upper layer (0-10 cm) was higher than in the deeper layer (10-20 cm). Comia et al. (1994) observed converse results. According to the average data, in the surface layer (0–10 cm) soil bulk density before pre-sowing soil tillage varied from 1.28 (DC) to 1.40 Mg m^{-3} (ZT). Before pre-sowing soil tillage in the deeper soil layer (10–20 cm) we defined the variation from 1.35 (ploughed soils) to 1.45 (zero tillage) Mg m^{-3} only (Table 3). Weather conditions exerted more influence on soil bulk density after sowing until sugar beet germination than soil tillage intensity. According to average data of 6 years, there were not significant differences in soil bulk density in the deeper layers. By the average data, soil bulk density after sowing till sugar beet germination varied from 1.38 to 1.46 Mg m^{-3} (Table 3).

Table 2. Soil moisture content % before pre-sowing soil tillage and after sowing until sugar beet germination, 2001-2006

Treatment	Sampling depth/ Years						
	2001	2002	2003	2004	2005	2006	Average
	before pre-sowing soil tillage						
	0–10 cm						
Conventional ploughing (CP)	23.8	16.9	23.8	-	26.4	18.8	21.9
Shallow ploughing (SP)	22.2	20.7	21.1	-	27.0	22.2	22.6*
Deep cultivation (DC)	26.4*	19.3	25.9	-	30.6	25.8*	25.6*
Shallow loosening (SL)	23.1	23.3	23.5	-	26.7	25.2*	24.4*
Zero tillage (ZT)	23.6	23.4	23.7	-	32.4	25.9*	25.8*
LSD_{05}	*2.24*	*7.37*	*3.59*	-	*6.22*	*4.80*	*5.18*
F-act. interaction of treatment and yearly meteorological conditions							*10.99***

	10–20 cm						
Conventional ploughing (CP)	24.0	21.0	25.5	-	28.2	22.0	24.1
Shallow ploughing (SP)	24.0	23.0	23.8	-	27.7	23.4	24.4
Deep cultivation (DC)	24.2	21.9	25.2	-	28.3	24.2	24.8
Shallow loosening (SL)	26.3	21.6	22.4*	-	25.6*	22.7	23.7
Zero tillage (ZT)	23.4	22.6	24.1	-	25.3*	23.6	23.8
LSD_{05}	*5.71*	*4.08*	*2.68*	-	*2.52*	*2.54*	*3.72*
F-act. interaction of treatment and yearly meteorological conditions							*12.93***
	after sowing till sugar beet germination						
	0–10 cm						
Conventional ploughing (CP)	21.0	19.4	21.9	17.3	19.8	18.2	19.6
Shallow ploughing (SP)	21.2	18.8	19.1	18.6	20.0	19.1	19.5
Deep cultivation (DC)	24.5*	20.3	22.3	19.1	21.8	22.1*	21.7
Shallow loosening (SL)	21.8	22.2	21.7	17.4	22.8*	22.3*	21.4
Zero tillage (ZT)	23.0	22.8	27.7*	20.1	23.1*	24.8*	23.6*
LSD_{05}	*2.16*	*3.62*	*2.83*	*3.92*	*2.24*	*2.54*	*2.96*
F-act. interaction of treatment and year meteorological conditions							*6.12***
	10-20 cm						
Conventional ploughing (CP)	22.2	22.7	22.9	20.1	22.7	20.2	21.8
Shallow ploughing (SP)	20.8	21.3	20.2*	22.0*	22.9	22.6	21.6
Deep cultivation (DC)	23.5	22.5	23.4	21.4	21.3	22.6	22.4
Shallow loosening (SL)	21.7	20.7*	21.0	19.9	21.3	20.7	20.9
Zero tillage (ZT)	21.8	22.5	22.5	20.5	20.8*	22.1	21.7
LSD_{05}	*1.54*	*1.83*	*2.04*	*1.87*	*1.41*	*2.48*	*1.89*
F-act. interaction of treatment and year meteorological conditions							*1.18*

Note: * and **– significant differences in comparison with control treatment (CP) at $P < 0.05$ and $P < 0.01$

Table 3. Soil bulk density Mg m^{-3} before pre-sowing soil tillage and after sowing until sugar beet germination, 2001-2006

Treatment	Sampling depth/ Years						
	2001	2002	2003	2004	2005	2006	Average
	before pre-sowing soil tillage						
	0–10 cm						
Conventional ploughing (CP)	1.42	1.27	1.33	-	1.35	1.27	1.33
Shallow ploughing (SP)	1.37	1.38	1.30	-	1.32	1.21	1.32
Deep cultivation (DC)	1.36	1.31	1.33	-	1.32	1.08*	1.28
Shallow loosening (SL)	1.40	1.34	1.38	-	1.42	1.19	1.35
Zero tillage (ZT)	1.42	1.45*	1.36	-	1.38	1.37	1.40
LSD_{05}	*0.090*	*0.163*	*0.130*	-	*0.120*	*0.103*	*0.122*
F-act. interaction of treatment and yearly meteorological conditions							*7.81***
	10-20 cm						
Conventional ploughing (CP)	1.42	1.37	1.32	-	1.33	1.31	1.35
Shallow ploughing (SP)	1.45	1.41	1.24	-	1.38	1.28	1.35
Deep cultivation (DC)	1.46	1.38	1.41	-	1.42	1.30	1.39
Shallow loosening (SL)	1.34*	1.41	1.41	-	1.44*	1.38	1.40
Zero tillage (ZT)	1.44	1.51	1.41	-	1.47*	1.40*	1.45

LSD_{05}	*0.075*	*0.145*	*0.124*	-	*0.103*	*0.078*	*0.108*
F-act. interaction of treatment and yearly meteorological conditions							*2.88*
	after sowing till sugar beet germination						
	0–10 cm						
Conventional ploughing (CP)	1.47	1.22	1.47	1.18	1.32	1.02	1.28
Shallow ploughing (SP)	1.45	1.20	1.37*	1.22	1.32	1.04	1.27
Deep cultivation (DC)	1.37	1.22	1.42	1.21	1.39	1.06	1.28
Shallow loosening (SL)	1.42	1.24	1.42	1.28	1.30	1.00	1.28
Zero tillage (ZT)	1.47	1.46*	1.38	1.26	1.49*	1.35*	1.40*
LSD_{05}	*0.131*	*0.138*	*0.093*	*0.106*	*0.138*	*0.079*	*0.116*
F-act. interaction of treatment and yearly meteorological conditions							*17.05***
	10-20 cm						
Conventional ploughing (CP)	1.52	1.32	1.45	1.34	1.41	1.22	1.38
Shallow ploughing (SP)	1.46	1.41	1.47	1.32	1.40	1.31	1.40
Deep cultivation (DC)	1.46	1.39	1.47	1.36	1.48	1.32	1.41
Shallow loosening (SL)	1.42*	1.44*	1.40	1.34	1.43	1.48*	1.42
Zero tillage (ZT)	1.44*	1.46*	1.43	1.44	1.54*	1.43*	1.46
LSD_{05}	*0.077*	*0.124*	*0.124*	*0.130*	*0.117*	*0.110*	*0.107*
F-act. interaction of treatment and yearly meteorological conditions							*3.51**

Note: * and **– significant differences in comparison with control treatment (CP) at $P < 0.05$ and $P < 0.01$

Sugar beet seed germination, yield and quality of roots

According to the average data of 2001–2006, sugar beet seed germination in tilled soils was nearly similar despite the different soil moisture conditions during the period of germination (Table 4).

Germination of sugar beet seeds directly sown into stubble was poor because a thick layer of straw on the soil surface blocked incorporation of seeds during sowing, and some of the seeds remained on the surface. The poor germination of seeds had a negative influence on crop formation. In other investigations, sugar beet seed germination, yield and quality of roots were similar in comparison with conventional tillage (deep ploughing) when an experimental direct drill with combined disc-shoe coulters was used (Romaneckas & Šarauskis, 2004).

Table 4. Sugar beet seed germination %, 2001-2006

Treatment / Years	2001	2002	2003	2004	2005	2006	Average
Conventional ploughing (CP)	18.7	37.0	39.8	75.5	81.4	73.4	54.3
Shallow ploughing (SP)	20.4	40.7	40.6	70.9	81.6	78.2	55.4
Deep cultivation (DC)	22.8	38.7	41.4	71.6	81.0	82.4*	56.3
Shallow loosening (SL)	29.0*	41.3	47.4	69.4	81.2	80.6*	58.1
Zero tillage (ZT)	22.8	39.2	30.0	16.1*	44.3*	52.0*	34.1*
LSD_{05}	*5.82*	*7.77*	*9.91*	*6.76*	*5.35*	*6.86*	*7.23*
F-act. interaction of treatment and yearly meteorological conditions							*20.9***

Note: * and **– significant differences in comparison with control treatment (CP) at $P < 0.05$ and $P < 0.01$

However, the influence of soil tillage intensity on seed germination was not so clear in each year of investigation. In 2001–2002 the germination of sugar beet seeds in not tilled soil was better than in ploughed soil. In 2006 the significantly best results of germination were observed in the deep cultivated (DC) and shallow loosened (SL) soils. The results of 2006 showed that sugar beet seed germination in tilled soils strongly depended r = 0.7033** P = 0.0024 on soil moisture content in the surface layer before pre-sowing soil tillage. Increasing soil moisture content by one per cent in the surface layer before pre-sowing soil tillage regularly increased the sugar beet seed field germination by 1,44 per cent according to the regression equation $y_{2006} = 45.5702 + 1.43739\ x$.

Generally, in shallow loosened soil (SL) sugar beet seed germination was higher in comparison with the control treatment (CP) in four cases per 6 years and this influence was significant in two experimental years. According to the average data of 2001–2006, the sugar beet that had been sown into not ploughed soils produced a similar yield of roots. Commonly, productivity of root crops varied from 41.9 (ZT) to 44.8 (SL) t ha^{-1} (Table 5). No significant differences were determined among the treatments.

Table 5. Sugar beet yield of roots t ha^{-1}, 2001-2006

Treatment / Years	2001	2002	2003	2004	2005	2006	Average
Conventional ploughing (CP)	41.9	42.3	46.0	55.3	54.0	26.5	44.3
Shallow ploughing (SP)	44.0	42.1	47.3	49.1	53.7	27.0	43.9
Deep cultivation (DC)	39.6	46.9	51.7	48.9	43.9	27.0	43.0
Shallow loosening (SL)	48.7	43.6	49.1	49.9	43.7*	34.0	44.8
Zero tillage (ZT)	46.4	41.3	41.6	40.1*	43.7*	38.4*	41.9
LSD_{05}	*18.80*	*9.54*	*8.85*	*13.79*	*10.11*	*9.68*	*12.31*
F-act. interaction of treatment and yearly meteorological conditions							*9.99***

Note: * and **– significant differences in comparison with control treatment (CP) at $P < 0.05$ and $P < 0.01$

However, in 2004 and 2005 (twice per 6 years only) reduction of soil tillage intensity had significant negative influence on the root yield (Table 5) in the treatment of not tilled soil because of 50–80 % lower field germination of seeds and poor crop density (Table 6). Lowered plant density and soil structure degradation due to reduced tillage down to zero tillage may independently decrease the sugar beet yield (Koch et al., 2008). Direct drilling is inappropriate for root crops, but strip tillage for sugar beet may become practicable (Cannel, 1985). Despite that, in 2006 we observed the converse effect. The highest yield of roots was harvested in not tilled (zero tillage treatment) soil (Table 5) because of optimal crop density (Table 6).

Table 6. Crop density before harvesting, thousand plants ha^{-1}, 2001-2006

Treatment / Years	2001	2002	2003	2004	2005	2006	Average
Conventional ploughing (CP)	35.9	66.5	60.0	127.5	103.2	103.3	82.7
Shallow ploughing (SP)	37.1	66.7	61.3	107.4	104.4	100.0	79.6
Deep cultivation (DC)	41.0	68.2	62.4	112.7	111.9	98.9	82.5
Shallow loosening (SL)	52.3*	74.2	71.6	118.5	104.4	96.7	86.3
Zero tillage (ZT)	52.1*	71.4	45.3	53.4*	70.1*	93.3	64.3
LSD_{05}	*12.52*	*18.04*	*14.90*	*35.30*	*22.83*	*16.31*	*21.36*
F-act. interaction of treatment and yearly meteorological conditions							*17.98***

Note: * and **– significant differences in comparison with control treatment (CP) at $P < 0.05$ and $P < 0.01$

Results of our investigations suggest growing sugar beet in shallow loosened soil (SL) because we observed higher yields of root crop in comparison with control (CP) in 4 cases per 6 years. According to Koch et al. (2008), soil mulching up to 0.1-0.15 m depth showed nearly similar results of sugar beet yields in comparison with deep ploughing. On the other hand, Rydberg (1992) analysed converse results in Sweden. Conclusively, the success of reduced tillage and direct drilling depends on the crop species as well as on soil type and climatic conditions (Rasmussen, 1999).

According to the average data of 2001-2006, reduction of soil tillage intensity had a negative but not significant effect on sugar beet root ramification (Table 7). Fewer ramified roots were observed in ploughed soils – from 13.05 to 14.58%. The highest amount of ramified roots (24.2%) was defined in not tilled soil. In 2001–2003 these trends were not observed but in 2004–2006 root ramification was significantly higher in not tilled soil than in deep ploughed soil. In not tilled plots the highest ramification of roots was observed in 2005 because of the uneven distribution of rainfall during the sugar beet growing season.

Table 7. Fanging of sugar beet roots %, 2001-2006

Treatment / Years	2001	2002	2003	2004	2005	2006	Average
Conventional ploughing (CP)	23.3	11.6	12.4	5.9	18.5	6.6	13.0
Shallow ploughing (SP)	27.5*	12.8	13.8	7.9	15.9	9.6	14.6
Deep cultivation (DC)	24.7	15.8	14.5	7.0	40.3	11.8	19.0
Shallow loosening (SL)	21.7	13.7	10.9	9.3	57.0*	10.2	20.5
Zero tillage (ZT)	23.5	14.4	14.8	16.1*	54.5*	21.6*	24.2
LSD_{05}	*3.44*	*4.94*	*6.77*	*7.19*	*29.97*	*7.35*	*13.45*
F-act. interaction of treatment and yearly meteorological conditions							*8.96***

Note: * and **– significant differences in comparison with control treatment (CP) at $P < 0.05$ and $P < 0.01$

Neither soil tillage intensity nor crop density had significant effect on sucrose content in the roots (Table 8). This suggests that crop density reduction from 86.3 to 64.3 thousand plants ha^{-1} (Table 6) had no significant effect on sugar beet root sucrose content (Table 8) in this trial. The saccharinity of roots mostly depended on meteorological conditions during the vegetation period each year.

Table 8. Sucrose content in sugar beet roots %, 2001-2006

Treatment / Years	2001	2002	2003	2004	2005	2006	Average
Conventional ploughing (CP)	15.61	17.55	17.50	16.58	17.18	14.26	16.45
Shallow ploughing (SP)	15.33	17.98	17.07	16.98	16.91	14.59	16.48
Deep cultivation (DC)	15.78	17.38	17.73	16.97	17.51	14.68	16.68
Shallow loosening (SL)	15.55	19.32*	17.13	17.03	17.20	14.87	16.85
Zero tillage (ZT)	15.92	17.68	16.97	16.24	17.73	15.64*	16.70
LSD_{05}	*0.862*	*1.142*	*2.140*	*0.542*	*1.417*	*0.775*	*1.260*
F-act. interaction of treatment and yearly meteorological conditions							*32.62***

Note: * and **– significant differences in comparison with control treatment (CP) at $P<0.05$ and $P<0.01$

Weed infestation in sugar beet crop

At the beginning of the first rotation (2002) the following species of annual weeds dominated: *Chenopodium album, Poa annua, Sinapis arvensis, Polygonum lapathifolium, Stellaria media.* Perennial weeds were in recessive position, of which *Cirsium arvense, Plantago major, Taraxacum officinalis* were most widespread (Table 9).

Table 9. Weed density m^{-2} in the crop of sugar beet, 2002 & 2006

Weeds	Soil tillage methods				
	conventional ploughing (CP)	shallow ploughing (SP)	deep cultivating (DC)	shallow loosening (SL)	zero tillage (ZT)
1	2	3	4	5	6
2002 (beginning of first rotation)					
Chenopodium album L.	4.2	7.9	14.6	15.8	14.2
Veronica persicaria L.	0.0	0.4	0.4	0.0	0.0
Roripa palustris Bess.	0.0	0.0	0.0	0.0	0.4
Poa annua L.	0.8	0.0	1.7	5.0	20.5
Sinapis arvensis L.	9.6	15.8	6.2	7.2	0.4
Polygonum lapathifolium L.	5.0	2.6	1.7	1.3	5.0
Stellaria media (L.) Vill.	2.2	0.0	2.5	0.8	8.3
Galium aparine L.	0.0	0.0	0.8	0.0	0.0
Capsella bursa pastoris (L.) Medik.	0.0	0.0	0.0	0.8	0.0
Tripleurospermum inodorum (L.) Sch. Bip.	0.0	0.4	0.0	0.0	0.0
Echinochloa crus galli (L.) P. Beauv.	0.0	0.0	0.0	0.0	0.8
Galeopsis tetrahit L.	0.4	0.0	0.0	0.0	0.0
Fallopia convolvulus (L.) A. Löve	0.8	1.7	2.9	1.8	0.4
Euphorbia helioscopia L.	1.3	1.8	1.3	0.8	0.4
Lamium purpureum L.	0.0	0.0	2.5	0.0	0.4
Myosurus minimus L.	0.0	0.0	0.4	0.4	12.6
Polygonum aviculare L.	0.0	0.0	0.0	0.4	0.0
Taraxacum officinalis L.	0.4	0.4	1.3	0.4	0.8
Equisetum arvense L.	0.0	0.0	0.8	0.0	0.0
Cirsium arvense L.	1.2	0.8	0.0	4.6	0.0
Sonchus arvensis L.	0.4	0.4	0.0	0.0	0.0
Plantago major L.	0.0	0.8	1.2	0.4	2.5
Annual	24.2	30.5	35.0	34.2	63.4
±SE			*±13.69*		
LSD_{05}			*42.19*		
Perennial	2.1	2.5	3.3	5.5	3.3
±SE			*±1.78*		
LSD_{05}			*5.48*		
All weeds	26.3	33.0	38.3	39.7	66.7
±SE			*±14.45*		
LSD_{05}			*44.52*		

2006 (beginning of the second rotation)					
Chenopodium album L.	15.9	21.3	31.6	27.1	14.6
Veronica persicaria L.	2.5	1.7	0.4	2.1	2.1
Myosotis arvensis (L.) Hill.	0.0	0.0	0.0	0.4	0.0
Poa annua L.	0.8	12.0	10.0	8.3	40.0
Sinapis arvensis L.	7.1	7.9	7.9	5.8	0.8
Polygonum lapathifolium L.	2.1	0.4	1.3	0.8	0.4
Stellaria media (L.) Vill.	1.7	0.4	2.9	2.5	4.2
Galium aparine L.	0.8	0.4	2.2	1.2	2.5
Capsella bursa pastoris (L.) Medik.	0.8	0.8	0.8	0.8	0.8
Tripleurospermum inodorum (L.) Sch. Bip.	2.1	0.4	0.8	5.8	0.0
Echinochloa crus galli (L.) P. Beauv.	2.5	2.9	4.3	3.7	3.7
Galeopsis tetrahit L.	0.0	0.0	0.0	0.4	0.0
Fallopia convolvulus (L.) A. Löve	0.0	0.0	2.9	2.1	1.7
Euphorbia helioscopia L.	1.7	0.8	0.8	0.0	1.3
Crepis tectoris L.	0.0	0.0	0.0	0.0	0.8
Apera spica venti (L.) Beauw.	0.0	0.0	0.4	0.8	0.4
Myosurus minimus L.	0.0	0.0	0.4	0.4	0.0
Conyza canadensis (L.)	0.4	0.0	0.0	0.0	0.0
Polygonum aviculare L.	0.0	0.0	0.0	0.0	0.4
Viola arvensis Murray	0.8	0.0	0.0	0.0	0.0
Taraxacum officinalis L.	5.0	4.1	5.5	7.5	8.3
Elytrigia repens (L.) Nevski	0.4	9.6	0.8	5.8	4.6
Cirsium arvense L.	3.3	1.2	0.4	0.0	0.8
Sonchus arvensis L.	2.1	0.0	1.8	0.8	3.8
Plantago major L.	1.7	2.0	0.8	3.3	2.1
Tussilago farfara L.	0.0	0.4	0.4	0.0	1.6
Annual	39.3	49.2	67.2	62.9	73.4*
±SE			*±10.25*		
LSD_{05}			*31.60*		
Perennial	12.4	17.5	9.2	16.7	21.2
±SE			*±5.25*		
LSD_{05}			*16.19*		
All weeds	51.7	66.7	76.4	79.6	94.6*
±SE			*±12.03*		
LSD_{05}			*37.06*		

Note: ± SE – standard error, * – significant differences in comparison with control treatment (CP) at $P < 0.05$.

In 2002 we observed the highest number of all weeds in not tilled soils (66.7 weeds m^{-2}). However, the number of perennial weeds was similar in all trial plots. At the beginning of the second rotation (2006) the number of weed species increased from 22 to 26. The number of *Chenopodium album* increased from 11.3 to 22.1, *Poa annua* – from 5.6 to 14.2, *Taraxacum officinalis* – from 0.66 to 6.1 plants per m^2. *Elytrigia repens* became a widespread weed in 2006 when in 2002 it was not observed (Table 9).

According to the data of many scientists the decrease in soil tillage intensity increased the number of weeds, especially perennial, in the crops (Stancevicius et al., 1990; Campbell at al., 1998). According to the statistical analysis of results, soil tillage intensity had no significant influence on weed density at the beginning of the first rotation (2002). The number of annual weeds varied from 24.2 to 63.4 and of perennial – from 2.1 to 5.5, that of all weeds – from 26.3 to 66.7 plants m^{-2} (Table 9). Generally in the experiment the number of all weeds increased during the 4-year crop rotation. The data of 2006 showed significant increase the number of annual and all weeds in not tilled soil only in comparison with conventional ploughing (CP). So, reducing the soil tillage intensity and refusal to use full-scale herbicides had negative, but not significant influence on weed infestation in sugar beet crop, except in the not tilled pattern.

CONCLUSIONS

Reduction of primary soil tillage intensity increased the amount of moisture in the soil upper layer (0-10 cm). According to the average data of 2001-2006, the highest amount of moisture was observed in not tilled soil (ZT) before pre-sowing soil tillage (25.8%) and after sowing until sugar beet germination (23.6%). Soil tillage intensity had no significant influence on soil moisture content in the deeper (10-20 cm) layer. Moisture content significantly depended on meteorological conditions each year.

Conservation primary soil tillage intensity significantly influenced soil bulk density increase in the upper soil layer (0-10 cm). Generally, the highest soil bulk density before pre-sowing soil tillage was observed after shallow loosening (1.35 Mg m^{-3}) and zero tillage (1.40 Mg m^{-3}), and in zero tilled soil (1.40 Mg m^{-3}) after sowing until sugar beet germination. Meteorological conditions had stronger influence on the level of soil bulk density in the deeper layer (10-20 cm) than soil tillage patterns.

Sugar beet seed germination in shallow loosened soil (SL) was higher in comparison with control (CP) fourfold per 6 years; the influence was significant in two experimental years. On average, germination of directly sowed seeds was less by 37% in comparison with conventional ploughing (CP).

According to the average data of 2001–2006, reducing soil tillage intensity up to zero tillage had no significant influence on the sugar beet yield of the root-crop. The yield depended more on meteorological conditions during vegetation. However, results of our investigations suggest growing sugar beet in shallow loosened soil (SL) because the yield of the root-crop was 1.3-8.5 t ha^{-1} higher in 4 cases per 6 years in comparison with control (CP).

The intensity of primary soil tillage had no significant influence on ramification and sucrose content of the root-crop.

The reduction of soil tillage intensity and refusal to use full-scale herbicides had negative, but not significant influence on weed infestation in sugar beet crop, except in the not tilled pattern. The data of the beginning of the second rotation showed a significantly higher number of annual (32%) and all (29%) weeds in not tilled (ZT) soil in comparison with conventional ploughing (CP). Generally, the number of weed species increased from 22 to 26. The number of *Chenopodium album* increased from 11.3 to 22.1, *Poa annua* – from 5.6 to 14.2, *Taraxacum officinalis* – from 0.66 to 6.1

plants per m^2. During the 4-year crop rotation *Elytrigia repens* became a widespread weed.

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