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Modeling of seedbed creation for spring cereals in clayey soils

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Abstract. A model field experiment to establish the optimal parameters of seedbed structure for spring cereals was conducted at the Joniškėlis Experimental Station of the Lithuanian Institute of Agriculture from 2002–2004 on clay loam *Gleyic Cambisol.*

We evaluated seedbed models for spring barley in small plots, where on the top seedbed sublayer (from 0 to 1.5 cm) the portion of desirable large-scale (>5 mm), on the middle sublayer (from 1.5 to 3.0 cm) of medium sized (2–5 mm) and on the bottom sublayer (from 3.0 to 4.5 cm) of smallest (<2 mm) soil structural aggregates made up to 40% in the 1st, 60% in the 2nd, 80% in the 3rd and 100% in the 4th model. Spring barley germination dynamics, emergence and growing intensity on clay loam soil were dependent on the structure of the seedbed and on the moisture content in the topsoil. When the topsoil moisture under the seedbed had decreased to 17.5 and 18.0% the spring barley seeds were germinating more intensively; more seed germinated in the seedbed where desirable soil structural aggregates account for 100 and 80% respectively in all seedbed sublayers, i.e. in the more fractionated seedbed, where bigger soil structural aggregates were taken to the surface, and smaller ones were concentrated deeper, closer to the seeds. When the moisture content in the topsoil was the highest (20.5%), the seedbed structure did not condition a consequent improvement in seed emergence. With increasing the seedbed fractionating, there was increasingly more moisture and higher porosity, less crust forming on the soil surface after rain, and less germination of annual weeds in the spring barley crop.

Key words: seedbed structure, clay loam, spring barley, soil physical conditions

INTRODUCTION

The seedbed, as a research object, present in the junction of atmosphere and soil surfaces is receiving increasingly more attention of scientists. Physical processes concentrated in this junction are highly dynamic and affect the growth of plants, biological activity of the soil, water filtration, runoff and other factors. Therefore, the quality parameter of the seedbed has become one of the most important characteristics of physical conditions of soil, influenced not only by tillage, but also by other agricultural practices: crop rotations, preceding crops, fertilization.

In the clayey soils it is very important to secure a good germination of spring crops, which conditions their further growth, because dry conditions in the topsoil means little water available water for plants, approaching plant-wilting moisture content. It is more difficult to form optimum conditions for the start of crop growth in the clayey soils which have poor genetic physical properties or have been degraded due to negative climatic factors or anthropogenic activities, than in sandy soil. (Hakansson et al., 2002; Velykis & Satkus, 2002; De Toro & Arvidsson; 2003; Pietola & Tanni, 2003, Alakukku, 2006).

The soil structure is the basis for seedbed quality, because it is complex, combining genetic soil properties, and it is established by many technological conditions and functional environmental processes. The quantity of soil structural aggregates, their compression and stratification in the seedbed determine humidity, air and warmth mode, seed contact with the soil, mechanical soil resistance for plant seedlings and roots (Guerif et al., 2001; Hakansson et al., 2002; Tapela & Colvin, 2002; De Toro & Arvidsson, 2003; Romaneckas & Šarauskis, 2003).

Different methods and principles are used for the evaluation of seedbed quality in various countries. With reference to most of the research findings obtained in Norway, a good seedbed for cereals prevails when the structural soil aggregates of 0.5–6.0 mm in size compound about 50% according to weight in the seedbed (Berntsen & Berre, 2002). According to Finland scientists seedbed sublayer soil aggregates have to be 1–5 mm big to warrant good seed contact with the soil in clayey soils (Pietola, Tanni, 2003). Braunack and Dexter (1989) denote that most 'compromising' are 1–2 mm big soil aggregates. According to Swedish scientists, most valuable in the seedbed are 2–5 mm soil structural aggregates. A finer, moisture-conserving seedbed with more than 50% of soil structural aggregates, smaller than 5 mm is necessary in the clay loam and clay soils. The amount of such aggregates depends on the soil texture, the influence of past cold, humidity, type of agricultural implements used and the number of soil tillage operations (Arvidsson et al., 2000; Hakansson & Lipiec, 2000; Hakansson et al., 2002; De Toro & Arvidsson, 2003). Optimal seedbed in the soils of Estonia exists when in the top layer there are 30–45% soil structural aggregates of >5 mm in size, in the middle 40–50% soil structural aggregates of 2–5 mm in size and on the bottom layer 20–40% soil structural aggregates of <2 mm in size (Nugis, 1997).

According to the theoretical seedbed model presented by Heinonen (1985), the soil that covers seeds from the top has to be stratified so that the smallest soil particles (soil structural aggregates) would be situated close to the seeds, in the bottom sublayer of the soil that covers the seeds. In the middle (in–between) of this cover sublayer medium–sized soil structural aggregates have to prevail. On the top (superficial layer) of the seedbed, the sublayer has to bring up the biggest soil structural aggregates. This seedbed structure secures the best contact with the soil, maintains relevant water and air mode, and protects the soil from crust formation and the surface from cracking.

Many experiments were conducted at the Joniškėlis Experimental Station of Lithuanian Institute of Agriculture on a clay loam soil to study various primary, pre-sowing and post-sowing soil tillage methods and evaluate their effects on the quality of seedbed. Using conventional implements on heavy soils it is not easy to create a plant-friendly, fine-structured seedbed (Maikštėnienė, 1997; Satkus, 2000; Velykis & Satkus, 2002; Velykis & Satkus, 2005). Furthermore, it is most important in clayey soils to properly complete soil tillage implements, to apply primary and pre-sowing tillage methods suitable to ensure physical quality of the soil and also to secure formation of optimal seedbed by biological and other factors: crop rotations and preceding crops, organic and mineral fertilizers of various origin and other means. In spring the seedbed structure for spring crops in heavy soils is usually finer compared with the autumn-prepared seedbed for winter crops (Lapinš et al., 2001; Germanas & Lukošiūnas, 2004; Velykis & Satkus, 2005).

It is not possible using a common field experiment method to determine theoretically the optimal structure of seedbed in a particular soil and to evaluate what implements, their combinations, working parts and their working principles allow us to make optimal (or close to these) parameters for seedbed in available soil-climatic conditions. Field experiments only allow one to determine the best soil tillage methods and to see how various implements can prepare the seedbed. Also, there is no detailed research on optimal seedbed structure according to the proportions of different soil aggregates in seedbed sublayers. To solve these questions, micro-modeling research was done by simulating various seedbed models with different amounts of soil structural aggregates in the top, middle and bottom seedbed sublayers. Our objective was to find out optimum parameters of seedbed structure for spring barley in clay loam soils.

MATERIALS AND METHODS

Site and soil. This research was conducted at the Lithuanian Institute of Agriculture's Joniškėlis Experimental Station situated on the soils of the northern part of Central Lithuania's lowland (56^{o}21′ N, 24^{o}10′ E) during the period 2002–2004. The experiments were carried out on a drained, clay loam on silty clay *Endocalcari-Endohypogleyic Cambisol*, whose parental rock is glacial lacustrine clay. Clay particles (<0.002 mm) in A_a horizon (0–30 cm) made up 27.0%, humus content 2.35%, pH 7.1.

Design of model experiment. In the modeling approach we investigated different seedbed structures for spring barley. The seedbed structure differed in soil aggregate fractionation in its sublayers. We evaluated seedbed models for spring barley as follows: on the top seedbed sublayer (from 0 to 1.5 cm) portion of desirable large-scale (>5 mm), on the middle sublayer (from 1.5 to 3.0 cm) of medium sized (2–5 mm), and on the bottom sublayer (from 3.0 to 4.5 cm) of smallest (<2 mm) soil structural aggregates made up to 40% in the 1st, 60% in the 2nd, 80% in the 3rd and 100% in the 4th model (Table 1). The field experiment was set up in small plots of 0.5x0.5 = 0.25 m^2 size with 6 replications.

When setting up the experiment, the soil was smoothed down after ploughing in autumn, and it was loosened by hand to 5 cm depth in spring. After loosening, a loose soil layer was removed in the field where small experimental plots had been arranged. The collected soil was sifted out through sieves and was separated into fractions according to the size of aggregates: 1) >5mm; 2) 2–5 mm; 3) <2 mm.

According to such parameters of soil aggregate size fractions the method for characterization of the quality of seedbed was developed and frequently used in Sweden (Kritz, 1983; Hakansson et al., 2002; Romaneckas & Šarauskis, 2003). According to the experiment design, a soil compound for every seedbed sublayer was made from various aggregate fractions of the structure for all treatments. The amount of soil compound in volume units was calculated according to the volume of the layer and various soil aggregates proportions in every seedbed sublayer.

Table 1. Seedbed models.

Seedbed sublayer cm	Seedbed models amount of soil structural aggregates %		
	<2 mm	2–5 mm	>5 mm
	1st model		
0–1.5	30	30	40
1.5–3.0	30	40	30
3.0–4.5	40	30	30
	2nd model		
0–1.5	20	20	60
1.5–3.0	20	60	20
3.0–4.5	60	20	20
	3rd model		
0–1.5	10	10	80
1.5–3.0	10	80	10
3.0–4.5	80	10	10
	4th model		
0–1.5	0	0	100
1.5–3.0	0	100	0
3.0–4.5	100	0	0

Spring barley cv. 'Ūla' was grown in the experimental plots. Ninety seeds were sown per plot according to a seed rate of 4.5 million per ha of viable seeds. The preceding crop was winter wheat. The seeds were sown by hand on the firm base of the seedbed in rows of 10.0 cm interlines and even spaces in the row between seeds. Then following the experimental design, the soil prepared beforehand was placed in separate layers, beginning from the bottom and finishing on the top. Spring barley was fertilized with $N_{60}P_{60}K_{60}$, mixing the fertilizers with the soil of seedbed bottom sublayer. Herbicides were not sprayed on spring barley.

For the evaluation of the influence of seedbed structure, dry post-sowing conditions were simulated. As a result, experimental plots were kept covered by polythene wrap during the period after sowing until the final spring barley emergence.

Measurements and assessments. The following *soil physical properties* were determined: soil moisture content (weighing method: drying them in a thermostat until constant weight at +105°C) each year, before setting up the experiment from samples taken from 0–5, 5–15 and 15–25 cm depths, and from different fractions of soil structural aggregates, also every three days from the beginning of spring barley germination until the final germination and at the end of crop growth in the 0–5 and 5–10 cm depth, soil bulk density (Kachinsky method) and total and air-filled porosity at the beginning, middle and the end of barley growth in the 0–5 and 5–10 cm depth, crust mass on soil surface (by weighing).

Crop productivity: Seed germination (number of seedlings) and height of seedlings were measured every three days from the beginning of spring barley germination until final germination. Germination intensity coefficient (C_{ge}) for estimation of seed germination intensity was calculated in the following way: $C_{ge} = (D_{S1}/l_1 + D_{S2}/l_2 + ... + D_{Sn}/l_n) / N$, where D_{S1}, D_{S2}, ... D_{Sn} – number of seedlings per 0.25 m^2, l_1, l_2, ... l_n – period of days from the date of spring barley sowing until the final seedlings calculation, N – seedling calculating stages. Growing intensity coefficient

(C_{gr}) for estimation of crop growth intensity was calculated in the following way: $C_{gr} = (D_{C1}/l_1 + D_{C2}/l_2 + ... + D_{Cn}/l_n) / N$, where D_{C1}, D_{C2}, ... D_{Cn} – seedling height mm, l_1, l_2, ... l_n – period of days from the date of spring barley sowing until the final seedling measurements, N – seedling height measurements, weed incidence (number of annual weeds and mass of weed dry matter, having spring barley in milky stage).

Meteorological conditions. To estimate the weather conditions during the growing season, hydrothermal coefficient (HTC) was calculated according to the formula of Seleninov – $HTC = P/0.1T$, where P – amount of precipitation mm through investigated period, T – sum of temperatures >10°C through adequate period. Evaluation scale: when HTC is from 0.3 to 0.5 – drought, 0.6–0.7 – dry, 0.8–1.0 – moisture is insufficient, 1.1–1.5 – optimal moisture, >1.5 – excess of moisture (Dirsė, 2001).

The spring in 2002 was early, warm and dry. Spring barley was sown in the experimental plots on 22 April. There was insufficient moisture in April (HTC – 0.79), but May was very dry (HTC – 0.35). More rain fell in June. The weather became warm and dry during July–August (Table 2). The spring of 2003 was warm, but the soil for spring sowing dried slowly and barley was sown on 25 April. There was sufficient moisture in April (HTC – 1.27). May and June were warm and had enough rainfall. In 2004 April was cold and very dry (HTC – 0.11). Barley was sown on 19 April. May was dry (HTC – 0.56) and cool. The amount of rainfall and temperatures in July were close to average.

Table 2. Hydrothermal coefficients of the growing seasons.

Year	Month				
	April	May	June	July	August
2002	0.79	0.35	1.61	0.71	0.17
2003	1.27	1.71	1.67	0.80	1.04
2004	0.11	0.56	1.12	1.36	1.04

Statistics. Significant differences of statistically analysed data are presented at 95% and 99% probability level. The data of weed count and mass measurements used for the evaluation of statistically significant differences were transformed according to the formula: $\sqrt{x+1}$.

RESULTS AND DISCUSSION

Soil physical properties. Each year the modeling seedbed experiment was set up after the upper topsoil layers had dried to the moisture content close to soil physical maturity. The clay loam soil in our experimental site reaches physical maturity at 17–18% moisture content and the plant-wilting moisture content of this soil amounts to 11.0% (Maikštėnienė, 1997). The soils dried very differently in separate experimental years. In 2002, when the seedbed layer (0–5 cm) dried to the moisture of 15.0%, in the deeper layers (5–15 and 15–25 cm) the moisture content was 17.1 and 17.8%, respectively. In 2003 while setting up the experiment the moisture content in the above–mentioned layers was higher – 15.9, 17.9 and 18.1%, respectively. The soils dried very unequally in 2004. After having dried the seedbed layer to 13.7%, the soil moisture in deeper soil was still quite high – 19.8 and 21.1%, respectively. Thus moisture reserves for the seed germination in the topsoil were different in separate years of the experiment.

In the soil sieved out into different size fractions the content of moisture differed. Each experimental year the lowest moisture content (on average 6.34%) was identified in the biggest (>5 mm) soil structural aggregates (Table 3), middle–sized (2–5 mm) soil fraction had the highest moisture content 8.14%, and the smallest (<2 mm) fraction had moderate moisture content (7.26%).

Table 3. Moisture content in the fractions of soil aggregates after sieving.

Fractions of soil aggregates	Soil moisture content %			
	year			average
	2002	2003	2004	
<2 mm	7.20	6.83	7.75	7.26
2–5 mm	7.94	8.17	8.31	8.14
>5 mm	5.94	5.89	7.18	6.34

The influence of seedbed structure on the soil moisture-changing dynamics during the spring barley germination period and end of the growing season was estimated in the 0–5 cm and 5–10 cm topsoil layers. The obtained findings suggest that in the 0–5 cm topsoil layer, in most cases the seedbed soil moisture content during the barley germination period tended to remain higher because of more fractionated seedbed, i.e. when sorted bigger soil structural aggregates were taken to the surface, middle–sized aggregates prevailed in the middle layer and smaller ones concentrated in the deeper seedbed layers, closer to the seeds. The differences in separate cases, especially in 2002, were significant (Table 4). Similar changes in the 0–5 cm depth persisted at the end of the barley growing season.

Table 4. Effect of seedbed structure on moisture content in the soil layer of 0–5 cm, 2002.

Seedbed models (portion of desirable soil aggregates %)	Soil moisture content %						
	beginning of growing season						end of growing season
	measurements (days from sowing)					average	
	I(10)	II(13)	III(16)	IV(19)	V(21)		
1st (40%)	8.86	7.93	7.83	7.74	7.90	8.05	10.81
2nd (60%)	8.47	8.93	7.63	7.53	9.00	8.31	11.39
3rd (80%)	8.99	9.35	8.71	8.28	9.11	8.89	11.73
4th (100%)	8.59	10.32	10.26	8.54	9.21	9.38	12.30
LSD_{05}	1.141	1.681	1.681	2.002	1.575	1.640	1.104

The research results suggest that the influence of the seedbed structure on the soil bulk density, and on the total and air–filled porosity changes in the 0–5 and 5–10 cm topsoil layers was not very significant (data not shown). With the increased seedbed fractionating, the total soil porosity in the 0–5 cm topsoil layers at the beginning of crop growing season in separate cases was higher (2002 and 2003), but in 2003 such changes persisted until the middle of the spring barley growing season. Seedbed structure had no significant influence on porosity changes in the 5–10 cm topsoil layer.

The crust that forms after sowing on the top of clayey soil in spring is a frequent and damaging phenomenon which aggravates germination of crops, especially small –

seeded ones. In soil with a high content of silt particles and low content of organic matter, the danger of solid and heavy crust formation is even greater (Heinonen, 1985; Satkus, 2000; Guerif et al., 2001; Hakansson et al., 2002). The effect of the seedbed structure on crust formation on soil surface in our study was assessed after final spring barley germination, when polythene wrap cover had been removed from the experimental plots. It was determined that with increasing seedbed fractionating a consistent reduction trend occurred in the soil crust that had formed after rain. But according to the results from the year 2002 of the 4th seedbed model, the weight of formed crust on the surface of the soil was 27.5% lower compared with the seedbed of the 1st model (Table 5).

Table 5. Effect of seedbed structure on soil crust.

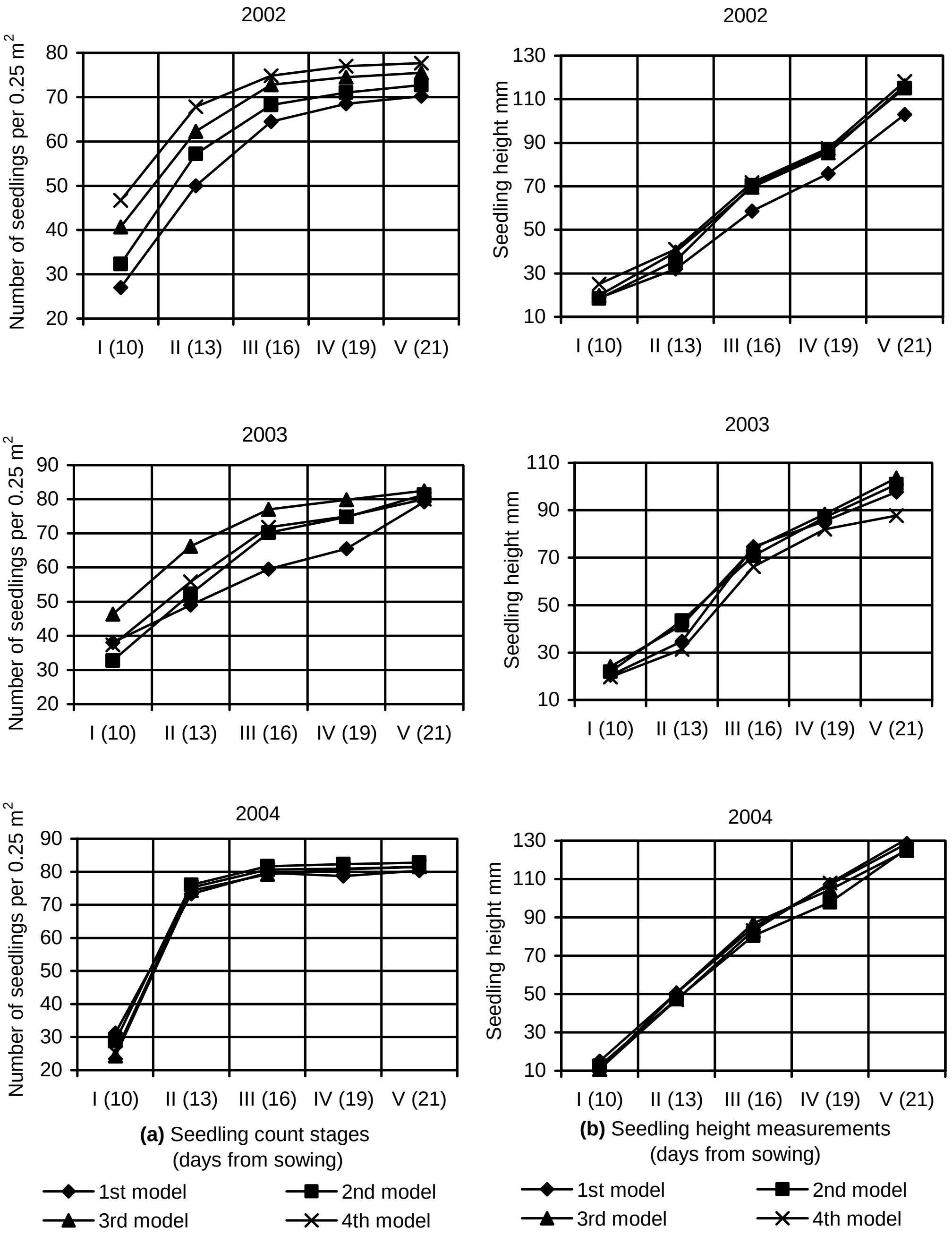
Seedbed models (portion of desirable soil aggregates %)	Year			Average	Relative values
	2002	2003	2004		
	soil crust kg per 0.25 m^2				%
1st (40%)	6.94	12.70	6.66	8.77	100
2nd (60%)	6.37	12.28	5.24	7.96	90.8
3rd (80%)	5.53	11.76	5.13	7.47	85.2
4th (100%)	5.03	11.22	5.76	7.34	83.7
LSD_{05}	1.888	2.773	2.010	2.258	–

Our previous series of field trials showed that the finer the seedbed was prepared in spring on clay loam soil, the bigger crust formed on the soil surface after rain. It decreased seed germination, seedling emergence and yield of spring–sown cereals (Satkus, 2000; Velykis & Satkus, 2002; Velykis & Satkus, 2005).

Germination dynamics and intensity of spring barley. During separate experimental years with different moisture of the topsoil at sowing, the structure of the seedbed unequally conditioned the germination of spring barley (Table 6).

In 2002 when the topsoil was the driest of all experimental years, increased seedbed fractionating (1st model→2nd model→3rd model→4th model) resulted in a consistent improvement of barley seed germination in all the five seedlings counted stages in all five seedlings (Fig. 1). In 2002 the best germination of barley was recorded in the 4th model, where 86.3% of the sown seed germinated in the fifth final stage (90 seeds per model). The germination intensity of spring barley here also varied similarly to the number of seedlings and was the highest in 4th model (Table 6). When moisture content was higher in the topsoil during the sowing time in 2003, most of the spring barley seeds germinated and their germination intensity was the highest in the 3rd model, where 91.7% of the total seed sown germinated. When the moisture content in the topsoil during the sowing time was the highest (2004), the seedbed fractionating did not condition a consequent improvement in spring barley germination. Under that year's conditions, most seed (92.0%) germinated and the highest germination intensity was recorded in the 2nd model's seedbed.

Growth dynamics and intensity of spring barley. The structure of the seedbed had a smaller influence on the height and growth intensity of the spring barley than on germination (Fig. 1, Table 6). However, similar trends remained. Having sown in the drier soil (2002) and having increased fractionating of the seedbed, spring barley seedlings were taller and grew more intensively.



(a) Seedling count stages (days from sowing)

(b) Seedling height measurements (days from sowing)

Fig. 1. Effect of seedbed structure on the germination **(a)** and growing **(b)** dynamics of spring barley.

Note. In figure (a) at seedling count stages I, II, III, IV and V LSD_{05} is as follows: 2002 – 12.50; 8.75; 6.28; 6.18 and 6.57; 2003 – 16.80; 16.93; 15.17; 13.77 and 5.79; 2004 – 11.50; 8.03; 5.62; 5.39 and 5.18. In figure (b) at seedling height measurements I, II, III, IV and V LSD05 is as follows: 2002 – 5.11; 7.15; 13.28; 9.11 and 18.89; 2003 – 8.80; 11.02; 11.16; 9.26 and 15.90; 2004 – 1.95; 15.86; 10.89; 15.41 and 23.95.

Table 6. Effect of the seedbed structure on the germination and growing intensity of spring barley.

Seedbed models (portion of desirable soil aggregates %)	Germination intensity coefficient			Growing intensity coefficient		
	year					
	2002	2003	2004	2002	2003	2004
1st (40%)	1.39	1.36	1.72	1.23	1.37	1.61
2nd (60%)	1.52	1.45	1.75	1.39	1.43	1.49
3rd (80%)	1.68	1.71	1.67	1.42	1.46	1.57
4th (100%)	1.79	1.52	1.70	1.50	1.27	1.55
LSD_{05}	0.196	0.379	0.161	0.189	0.229	0.234

When the topsoil moisture was increased (2003) during the sowing time, the tallest spring barley seedlings grew and their growing intensity was the highest in the seedbed of the 3rd model. When the moisture of the topsoil was higher, the seedbed structure (2004) had no consistent influence on the growth of barley. According to Swedish scientists, based on new experiments, sorting of coarse soil aggregates upwards and fine aggregates downwards in the seedbed should not be regarded as a goal in the case of using modern seeders, whose coulters can penetrate below the base of the seedbed (Hakansson et al., 2002). They pointed out that it seems to be relatively harmless, however probably realizable though complicated in practical seedbed preparation with traditional implements. However, they also noted that a more detailed study of the influences of various soil aggregate fractions in seedbed would be valuable. The experiments on seedbed quality in Sweden were carried out in shallow plastic boxes. In our modeling field experiment we had an effect from natural structured topsoil and subsoil layers on seedbed and crop emergence, which occurred in the field conditions.

Weed infestation. The effect of the seedbed structure on the weed infestation was evaluated according to the number and mass of dry matter of annual weeds, at the milky stage of spring barley. It was determined that with increasing seedbed fractionating, the number of annual weeds and their mass decreased (Table 7). The reason for that is poor germination of small weed seed, present in the upper layer (0–2 cm) of the seedbed, because of poor contact with the coarse soil aggregates and smaller reserves of the moisture it contains.

Table 7. Effect of the seedbed structure on annual weed infestation in spring barley
2002–2004 averaged data

Seedbed models (portion of desirable soil aggregates %)	Annual weeds				
	total annuals per m^2	among them predominating			mass of dry matter g m^{-2}
		Chenopodium album L.	*Stellaria media* (L.) Vill	*Veronica arvensis* L.	
1st (40%)	83.3	14.4	23.7	11.1	15.0
2nd (60%)	58.2*	8.7	12.2	9.1	10.3*
3rd (80%)	48.4**	4.2	11.6	4.9	9.4**
4th (100%)	46.2**	4.1*	9.8	6.4	8.3**

* – differences significant at 95 % probability level, ** – at 99 %

In contrast to our investigations, experiments conducted in the United Kingdom show an enhanced seedling emergence when weed seeds were covered by coarser soil aggregates (Cussans et al., 1996). However, in this experiment artificial watering was used and penetration of soil by light was the major controlling factor. In our study, where dry conditions were simulated after sowing and soil moisture content was the limiting factor, increasing the amount of coarse soil aggregates in the upper layers of seedbed worsened the emergence of small–seeded weeds.

CONCLUSIONS

1. The seedbed models constructed in a clay loam soil showed that spring barley germination and seedling growth dynamics and intensity were dependent on the structure of the seedbed and on the moisture content in the deeper topsoil layers. When the topsoil moisture under the seedbed was decreasing, the spring barley seeds were germinating more intensively, and more of them germinated; seedlings grew more intensively and taller when the seedbed was more fractionated, i.e. when bigger soil structural aggregates were taken to the surface, and smaller ones concentrated in the deeper seedbed layers, closer to the seeds.
2. With increased sorting of coarse soil aggregates upwards and fine aggregates downwards there was more moisture and higher porosity, or the same trends prevailed in the whole seedbed (0–5 cm) throughout the spring barley germination period, and less crust formed on the soil surface after rain.
3. Annual weeds germinated poorly in the spring barley crop with increased fractionating of the seedbed.
4. The seedbed structure ensures intensive and good germination and growth of spring barley in clay loam soil during a dry post–sowing period when on the top (0–1.5 cm) seedbed layer structural aggregates >5 mm, in the middle (1.5–3.0 cm) layer – middle–sized aggregates 2–5 mm and in the bottom (3.0–4.5 cm) layer aggregates <2 mm account for 80–100%, and in the case of moisture less than 18% in the topsoil, decreases the crop weed infestation and helps prevent soil physical degradation.

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