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Impact of Conventional and Sustainable Soil Tillage and Sowing Technologies on Physical-Mechanical Soil Properties

Egidijus Šarauskis[1], Kęstutis Romaneckas[2] and Sidona Buragienė[1]
[1] *Lithuanian University of Agriculture, Department of Agricultural Machinery*
[2] *Lithuanian University of Agriculture, Department of Soil Management*

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Application of sustainable tillage and sowing technologies are rapidly increasing all over the world stimulating an interest in new technologies and their possibilities to reduce an impact of agricultural machinery on natural processes in Lithuania. This work aims to investigate the impact of different soil tillage and sowing technologies on physical-mechanical soil properties.

Research was carried out in the periods of 2000-2002 and 2005-2007 in three Lithuanian districts with different soil properties: Kaunas, Marijampolė and Pasvalys. The interest was concentrated on the impact of conventional and sustainable soil tillage and sowing technologies on soil hardness, soil moisture and distribution of clods in the upper soil layers.

The experimental studies have established that irrespective of soil heaviness, soil hardness in non-ploughed soils is greater than that after conventional ploughing. The increasing soil hardness changes the conditions for seed insertion into soil. Research results show that under Lithuanian conditions reduction in soil tillage intensity can save a considerably higher amount of soil moisture, which enables the improvement of seed germination. Analysis of clods distribution in the upper soil layers (< 15 mm) shows that the quantity of fine (< 2 mm) clods in non-ploughed soil is lower than that in the ploughed one which reduces the crust formation on the soil surface and the possible consequences of soil erosion.

Key words: *tillage, sowing, physical-mechanical soil properties, seedbed.*

1. Introduction

Conventional soil tillage and sowing technologies that employ shellboards and agricultural machinery for intensive soil loosening are quite harmful to the environment (soil, its properties, biodiversity, water bodies, etc.). Soil tillage using any implement starts soil destruction on the cultivated slopes. Soil levellers and ploughs destroy soil surfaces most, then follow cultivators, harrows and other implements (Jankauskas & Jankauskiene 2005). Therefore, introduction of soil tillage and sowing technologies as well as application of the implements that reduce invasion into natural soil processes are of great importance in modern agriculture. Physical, chemical and biological indices are used to express how the environment sustainability is affected by soil tillage and sowing technologies without soil ploughing or tillage in comparison with conventional soil tillage and sowing technologies that involve soil ploughing, cultivation and harrowing (Feiza et al. 2006, Čiuberkis et al. 2008).

Physical indices are based on soil preservation, i.e. reduction in soil erosion, leaching of fertile soil layer, destruction of crops, ditch slopes and roads, choke up of trenches, silt up of water bodies and water pollution by soil tillage and sowing technologies. Reduction in tillage improves soil practicability which demonstrates better resistance to heavy loads, an increase in a number of soil biopores by several times, which improves a root development system in soil, increases stability of soil clods thus impeding the formation of crust on the soil surface after rain, preserving soil moisture, plants experience less stress caused by dry climatic conditions, soil compression decreases resulting in weaker consolidation of the top and deeper soil layers (Čiuberkis et al. 2008, Romaneckas et al. 2002, Rusu et al. 2009).

Regular deep ploughing has a negative influence on many soil properties, stimulates the formation of a sole arable layer (Derpsch 1999).

Scientists state that tillage in spring before sowing of non-ploughed soil with the implements that have passive working parts, which loosen the soil without upturning the moist soil, ensures a bigger amount of moisture in seedbeds, better structure and less crust formed on the soil surface (Romaneckas & Šarauskis 2003, Velykis & Satkus 2005, Hakansson et al. 2002). Research results have established that non-plough soil preparation for winter crops has equal or even better seedbed quality indices if compared with soil ploughing subject to climatic conditions of the year (Velykis & Satkus 2005).

Chemical indices of sustainable tillage focus on reduced leaching of chemical materials and emissions of various gasses accumulating in soil. Application of sustainable tillage and sowing technologies enables significant reduction in nitrate and phosphorus losses, thus conditioning better assimilation of nutrients and lower pollution of water bodies. Reduction in soil tillage, i.e. mixing of soil layers, decreases CO_2 emission from soil because deep ploughing intensifies soil air exchange and stimulates decomposition of organic matter, which causes higher CO_2 emission from soil to the environment (Holland 2004, Hirschi & Peterson 2005, Dahiya et al. 2007). Due to a smaller number of tillage and sowing technological operations and reduced drive of agricultural machinery, CO_2 exhaustion from tractors also substantially decreases. Hereby, new, cleaner, sustainable tillage and sowing technologies can make serious contribution to the reduction in a greenhouse effect in accordance to the Kioto Protocol (Basch & Tebrugge 2001).

Scientists of the Lithuanian Institute of Agriculture have established that during a 10-week period in sandy loam texture soil the mean CO_2 emission under no-tillage is 15 and 9 % lower than that under conventional tillage and reduced tillage (Feizienė & Kadžienė 2008).

Biological sustainability of the environment shows itself in the activity of live organisms in soil. Application of new sustainable tillage and sowing technologies increases even several times the number of earthworms and activity of soil organisms, which quicken mineralization of yield residues. With an increase in a number of earthworms, more canals are dug in soil which improve water filtration, seed germination and a plant root development system (Sakalauskas et al. 2007)]. Non-ploughed stubble is valuable feeding habitation for winter animals and birds. Besides, stubble provides shelter for European hare, mousy rodents and other winter mammals.

In Europe, environmentally friendly and energy saving agricultural technologies are integrated into manufacturing of agricultural production as technologies giving the most innovative, economical, energetic and environmental benefits (Holland 2004, Bertocco et al. 2008, Romaneckas et al. 2009, Vilde et al. 2003). The essence of these technologies is to limit the intensive mechanical and chemical impact on soil and vegetation, to provide the soil productivity renovation, to protect the environment, to rationally use the material, energetic and labour force resources, to meet the strict environmental regulations, to produce wholesome food, and to guarantee the economic effectiveness of agricultural produce manufacturing.

Data published by the European Federation of Sustainable Agriculture reveal that approximately 100 M ha no-tillage soils are sown using technologies of sustainable soil cultivation and sowing (as compared with 60 M ha in 2000) (Fig. 1) (Hirschi & Peterson 2005, Derpsch 2005, Basch 2009).

In the countries of Latin America only 50 % of all the crops are sown using the sustainable tillage technologies. Worldwide, approximately 47 % of this technology is practiced in South America, 39 % - in the United States and Canada, 9 % - in Australia and about 3.9 % - in the rest of the world, including Europe, Africa and Asia. Despite good and long lasting research showing positive results for no-tillage, in this part of the world this technology has had only small rates of adoption (Derpsch 2005).

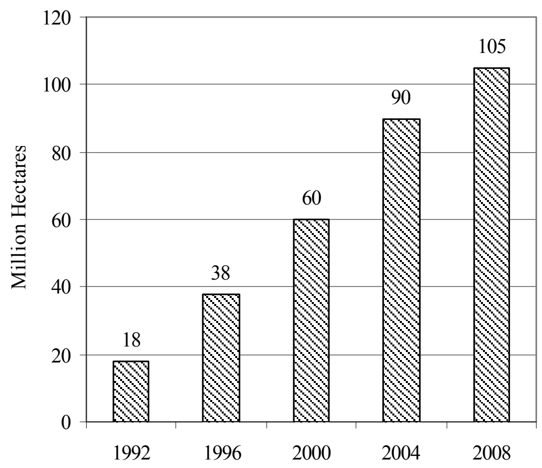

Fig. 1. No-tillage worldwide in 1992-2008

In Europe, the areas where sustainable agriculture is used are rapidly increasing. One million hectares of land (Fig. 2) are sown using the sustainable technology, according to the recent data (Linke 2006). Environmentally-friendly soil cultivation technologies and sowing into the minimally cultivated soil are still more popular. In the EC states, such as Switzerland, Great Britain, Germany, etc., from 20 to 40% of all the crops are sown into not ploughed, minimal tillage or no-tillage soil (Basch 2009, Linke 2006). In Lithuania, as in the whole Europe, new sustainable soil tillage and sowing technologies are presently introduced. But, unfortunately, there is a lack of precise official statistical data about the areas that are sown using such technologies in Lithuania.

When no-tillage technology is used during sowing, only a tractor and a precision drill are working. Before the sowing a traditional soil cultivation technology usually requires and uses tractor, stubble cleaner, plough, cultivator, harrow, rollers, and drill. To sow into no-tillage soil one tractor pass is enough. The tractor with aggregates passes the same technological track from 3 to 5 times when a traditional method of soil cultivation before sowing is used. Additionally, 4 – 5 tillage machines are used and time costs are from 3.5 to 4.5 h ha^{-1}. Moreover, a greater number of passes compacts soil layers deeper and extra cost is needed to loosen them. Technology of direct drill into no-tillage soils requires from 5 to 6 times lower time costs if compared with the traditional soil cultivation technology (Bertocco et al. 2008, Vilde et al. 2003, Šarauskis et al. 2005).

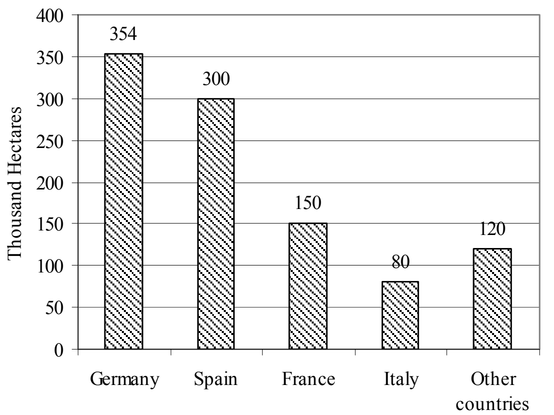

Fig. 2. Estimation of surface under direct sowing in different European Countries

New sustainable tillage technologies are useful and economically efficient in accordance with the factors relevant to the environment protection. For example, how much one could economize by saving moisture in the soil, improving air and water filtration in the soil, reducing soil erosion and drain trenches clogging with soil or yield waste, minimizing CO_2 emission into the atmosphere or reducing the leaching of chemical compounds into the water.

This study is dedicated to investigation of the impact of different soil tillage and sowing technologies on soil hardness, soil moisture and clods distribution in different soil layers.

2. Materials and Methods

Research was carried out in the period of 2000-2002 in light loam soil of the Experimental Station, Lithuanian University of Agriculture (further Kaunas), in the period of 2005-2007 - in medium heavy loam soil of Padovinys agricultural company, Marijampolė district (further Marijampolė) and in heavy loam soil of E.Palaima farm, Ūstukiai village, Pasvalys disrtict (further Pasvalys).

In Kaunas the research was carried out in two different variants of soil tillage and sowing:

- Sugar beets were sown into the soil that had been ploughed and loosened with the cultivator equipped with passive working parts;
- Sugar beets were sown into the stubble.

In Marijampolė and Pasvalys the research was also carried on in two different variants:

- Winter wheat was sown into the soil that had been ploughed and loosened with the cultivator equipped with disc working parts;
- Winter wheat was sown into non-ploughed soil that had been loosened with the cultivator equipped with disc working parts.

Sugar beets were sown with an experimental seeding machine equipped with complex ploughshares (disc + runner), produced by “KLEINE“. Winter wheat was sown with a seeding-machine of “Väderstad“ production, equipped with disc ploughshares.

In 2000-2002 soil moisture was determined by the method of weighing; the samples were taken with Nekrasov drill, soil hardness – with Reviakin hardness measurer. In 2005-2007 soil moisture and hardness were determined with “Eijkelkamp“ electronic device for soil properties analysis. Soil hardness was measured to the depth of 270 mm, soil moisture – at the soil layer of 0-50 mm.

Kritz/Hakannson (Sweden) method was used to determine seedbed soil characteristics (Romaneckas & Šarauskis 2003). This method estimated the composition of soil clods in a seedbed and determined soil moisture in different soil layers (above the seeds, at the seeds and under the seeds). Frame (400x400 mm, 100 mm height) with a tip-up rim (250 x 400 mm, 100 mm height) was used in the course of research. The frame and the rim were impacted into the soil, their horizontal level was checked. The rim was impacted above the sowing line and three soil layers (15 mm each) were removed with a trowel.

The upper soil layer removed from the rim area was poured on the kit of sieves, containing an upper sieve with round holes of 5 mm in diameter, and a lower sieve with round holes of 2 mm in diameter. Holes on both sides of the trowel and two axes passed through them in parallel enabling them to deepen the trowel at every 15 mm. Having used the vibration method to sieve out the removed soil layer, three fractions of soil clods were distinguished: soil clods of > 5 mm, of 2-5 mm and of < 2 mm size. Bulk percentage composition of soil clods in different soil layers was determined by pouring separate fractions into a volumetric flask of 2 liter capacity.

To determine soil moisture in different soil layers, three samples were taken from each soil layer and put into aluminum boxes. Samples were weighed together with aluminum boxes, and the latter were numbered. Having removed aluminum boxes covers, the samples were put into a desiccator that had been preheated up to the temperature of 105 ^{0}C. When samples were dry, the desiccator was opened, covers were put on aluminum boxes and they were cooled down to the laboratory temperature. Aluminum boxes were weighed and soil moisture was calculated.

The investigations were carried out 5 times at different soil points.

The data obtained were processed at Lithuanian University of Agriculture and evaluated using the methods of dispersion and correlation-regression analysis. Arithmetic means, their standard errors, and confidence intervals at a probability level of 0.95 were determined.

3. Results and Discussion

Soil characteristic to resist a solid agent is called soil hardness. Hardness shows cohesion among soil particles and frictional force between them and a solid body. This characteristic of soil is important in adjusting technological modes of agricultural machinery, determining soil resistance to agricultural machinery and calculating gravitational force.

Soil hardness depends on soil mineral composition, soil texture, structure, density, moisture, viscosity, coherence and other properties. These physical-mechanical soil properties are closely interrelated. Change in one of these characteristics causes alterations in the other ones. Variations in any of them have direct or indirect impact on soil hardness. Soils of heavy texture (clays, clay loams) have much stronger coherence than light soils (sands, sandy loams). The stronger soil coherence - the greater soil hardness. However, a rise in soil moisture, improvement in soil structure and increase in organic matter reduce hardness of the same texture soils.

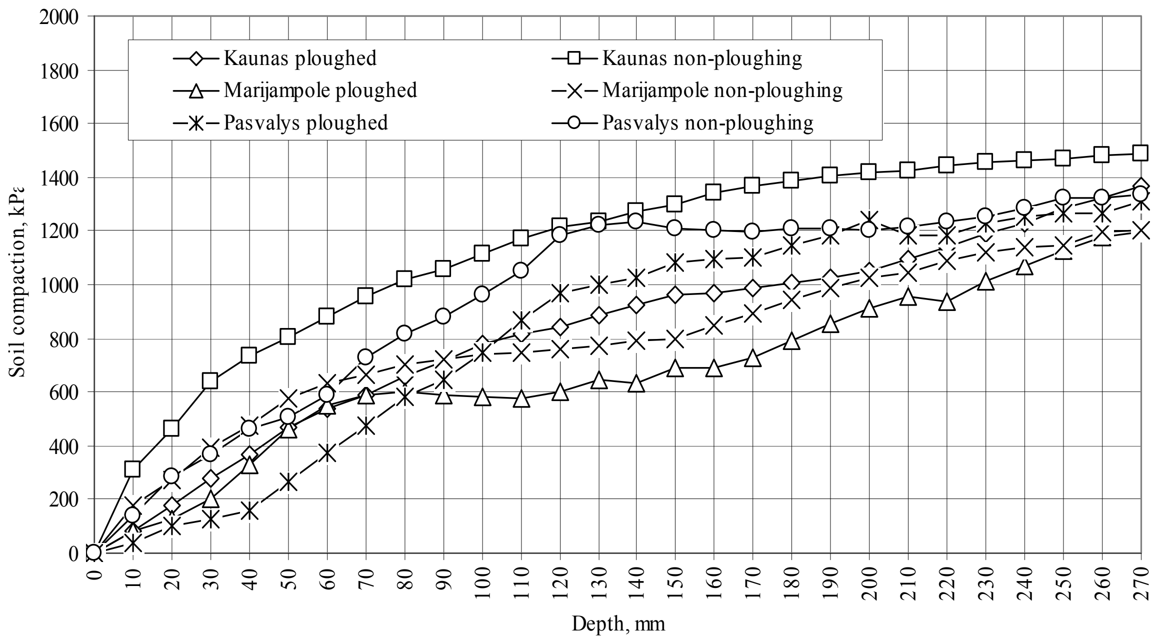

Fig. 3. The influence of soil tillage system on soil compacting in different depths of ploughed and non-ploughed soil

Tillage reduces soil hardness. The analysis has determined that irrespective of soil heaviness and the research region, ploughed soils have a significantly lower hardness than the non-ploughed ones (Fig. 3). Both the method of soil tillage and meteorological conditions influence strongly soil hardness in different regions. Maximum soil hardness has been determined in Kaunas, in the soil that has been neither ploughed nor cultivated before sowing. Hardness of differently tilled soil varies in the depth of seed insertion. Soil hardness varies less in the layers below the ploughing depth.

Soil moisture is soil water containing dissolved mineral compounds. Water is present in plant cells, it participates in photosynthesis and is indispensable to nutrient dissolution, seed swell and germination as well as to the other plant biological processes. Water influences soil physical properties.

In Kaunas soil the moisture analysis has established a significant difference between soil moisture in the upper layers of soil without tillage during sowing and that in the soil which has been ploughed and cultivated (Fig. 4).

Both in Pasvalys and in Marijampolė soil moisture was too low in all cases. However, even under these dry conditions, which are unfavourable to the plant growth, moisture retained in the upper layers of non-ploughed soils appeared to be by some per cent higher than that in the ploughed soils. A significant difference was determined in the upper 15 mm deep soil layer in Marijampolė.

Seedbed preparation for plant sowing is the work that requires responsibility and accuracy. The conditions formed in seedbeds influence seed germination, growth, yield and quality. Proper preparation of the soil structure in the course of tillage is very important. The soil structure, in which soil clods of 2-5 mm size predominate, is particularly favourable to plant growing. The soil where micro-clods (< 2 mm) make no more than 5-7 % is less resistant to the environmental factors, it dries quicker and has stronger chances for the surface crust formation after rain. This causes an increase in soil erosion and leaching of a fertile soil layer and chemical materials into the water. When the quantity of soil clods of 10 to 50 mm size exceeds 30 %, the soil contact with seeds becomes worse, seed insertion to the necessary depth is more difficult and seed germination is uneven.

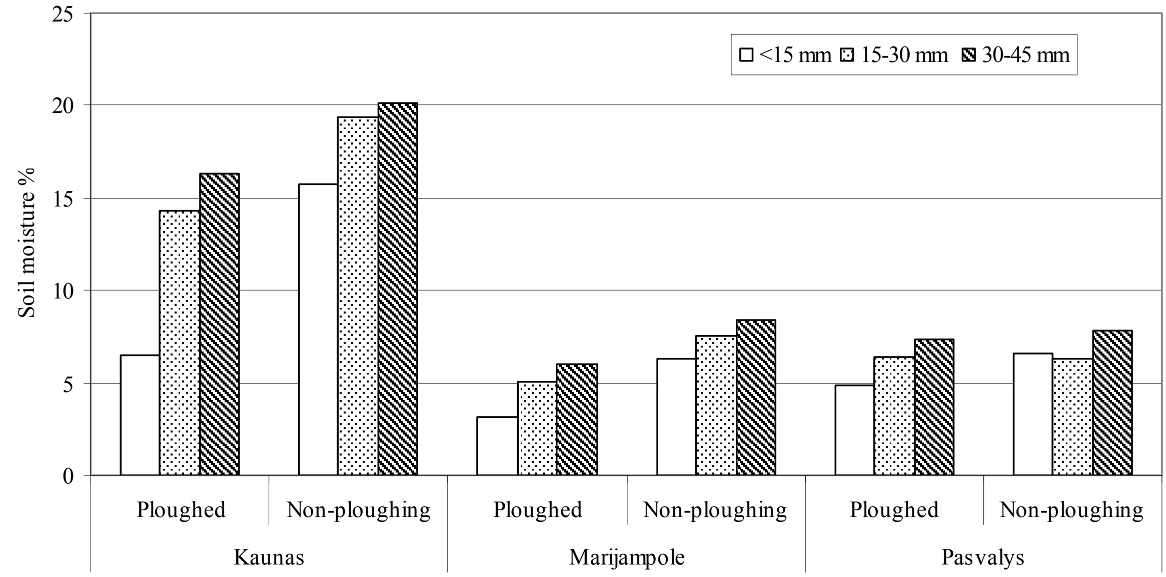

Fig. 4. The influence of soil tillage system on soil moisture in different seedbed layers of ploughed and non-ploughed soil

Table 1. The composition of soil aggregates in different seedbed layers of ploughed and non-ploughed soil

Soil tillage system	Year	Soil aggregates %								
		< 2 mm			2-5 mm			> 5 mm		
		Seedbed layers mm								
		<15	15-30	30-45	<15	15-30	30-45	<15	15-30	30-45
Kaunas										
Ploughed	2000	31.5	28.9	30.1	32.7	32.6	36.0	35.8	38.5	33.9
	2001	33.2	39.8	36.3	29.1	34.8	25.2	37.7	25.4	38.5
	2002	33.9	37.3	33.5	30.1	35.7	29.6	36.0	27.0	36.9
	Average	32.9	35.3	33.3	30.6	34.4	30.3	36.5	30.3	36.4
Non-ploughed	2000	10.2	13.9	12.0	26.7	29.2	31.5	63.1	56.9	56.5
	2001	9.4	13.2	10.7	27.9	28.6	29.1	62.7	58.2	60.3
	2002	8.2	12.5	9.6	25.3	31.7	30.0	66.5	55.8	60.4
	Average	9.3	13.2	10.8	26.6	29.8	30.2	64.1	57.0	59.1
Marijampole										
Ploughed	2005	5.6	24.4	28.1	6.4	19.9	18.9	88.0	55.7	53.0
	2006	20.3	30.0	18.2	14.6	22.5	25.4	65.1	47.5	56.4
	2007	25.4	28.2	17.2	20.4	20.8	35.1	54.2	51.0	47.7
	Average	17.1	27.5	21.2	13.8	21.1	26.5	69.1	51.4	52.4
Non-ploughed	2005	12.1	17.4	15.2	21.4	14.2	19.3	66.5	68.4	65.5
	2006	13.8	19.3	11.8	15.7	21.6	16.8	70.5	59.1	71.4
	2007	14.6	18.7	14.2	18.3	19.9	18.7	67.1	61.4	67.1
	Average	13.5	18.5	13.7	18.5	18.6	18.3	68.0	63.0	68.0
Pasvalys										
Ploughed	2005	27.5	32.1	39.8	13.5	19.4	17.3	59.0	48.5	42.9
	2006	36.6	39.2	42.5	21.5	24.8	21.7	41.9	36.0	35.8
	2007	21.7	39.5	45.2	22.4	28.6	22.4	55.9	31.9	32.4
	Average	28.6	36.9	42.5	19.1	24.3	20.5	52.3	38.8	37.0
Non-ploughed	2005	16.5	32.3	34.4	21.9	25.6	24.2	61.6	42.1	41.4
	2006	11.2	28.6	37.9	18.7	27.9	28.1	70.1	43.5	34.0
	2007	13.5	29.8	36.5	20.4	24.3	27.0	66.1	45.9	36.5
	Average	13.7	30.2	36.3	20.3	25.9	26.4	65.9	43.8	37.3

Seedbed preparation strongly depends on the physical soil properties that exist before tillage. In the course of tillage of compacted soils, the working parts of agricultural machinery meet stronger soil resistance forces. In such cases constructional parameters of machinery have a great influence on the soil tillage quality because wrong selection of these parameters may cause the formation of uneven or too compacted seedbeds.

Evaluation of soil clods distribution in different seedbed layers of ploughed and non-ploughed soils has established the lowest quantity of fine (< 2 mm) clods in the upper layer (< 15 mm) of non-ploughed soil in Kaunas (Table 1). The same layer of ploughed soil contains over 3 times bigger quantity of fine clods. This indicates an increasing danger of the soil crust formation after precipitation, increasing soil erosion and worse conditions for crop germination and growing. Experimental research determined such consequences in 2006 in Pasvalys (Fig. 5).

Fig. 5. Soil erosion in Pasvalys (2005)

Fig. 6. Seedbed in Marijampole (2005)

In 2005 soil was very dry at the time of sowing in Marijampolė. Soil preparation for sowing was very complicated (Fig. 6). Proper seedbed preparation was impossible even by the pre-sowing soil cultivation with disc working parts. This was particularly visible in ploughed soil, as the upper soil layer contained just 5.6 % of fine clods, and 6.4 % - of the bigger (2-5 mm) ones. There, bigger than 5 mm soil clods predominated (88 %). When sowing into this kind of soil, seeds are lacking a good base, they are inserted among bigger clods, and a proper contact between soil and seed is not ensured. Lack of moisture makes the seeds swell and germination more difficult.

Non-ploughed soil retains more soil moisture, therefore, distribution of soil clods is more equal and the seedbed requirements are better met.

In 2006-2007 in Marijampolė soil moisture was slightly higher, which improved seedbed preparation in both ploughed and non-ploughed soil. Similar experimental data were obtained in Pasvalys.

4. Conclusions

Intensive soil tillage methods influence physical-mechanical properties of the upper soil layer in Lithuania.

Research into soil hardness has determined that irrespective of soil heaviness reduction in soil tillage intensity increases soil hardness in comparison with that in conventionally ploughed soils. The absolutely non-tilled soil has the highest soil heaviness value.

Research into soil moisture in different tillage soils have determined that under Lithuanian conditions the increasing soil tillage intensity raises moisture release from the upper soil layer to the environment. Thus, the conditions for seed germination and growth become worse.

In non-ploughed soils the quantity of fine (< 2 mm) soil clods in the upper (< 15 mm) soil layer in all cases is lower than that in soils of intensive tillage.

The quantity of medium big (2-5 mm) soil clods in the upper soil layer has a slight dependence on the soil tillage method. Non-ploughed and no-tillage soils have been estimated to have the biggest quantity of big (> 5 mm) soil clods in the upper seedbed layer.

Reduced intensity of soil tillage results in a decreasing influence of soil tillage technological processes on soil erosion. The weakest soil erosion is observed in non-ploughed and non-tilled soils. Estimation of plant growing conditions, their productivity and influence on soil erosion shows that the best results are obtained in non-ploughed soils, which have been loosened by a cultivator with disc working parts.

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Dr. Egidijus Šarauskis - Assoc. Prof. at Lithuanian University of Agriculture, Department of Agricultural Machinery.
Main research areas: sustainable soil tillage and sowing machinery, minimization of the negative influence of soil tillage technologies on the environment, soil properties, economical and energetic aspects of technological processes of the operation of sustainable tillage machinery.
Adress: Studentų str. 15A, Akademija, Kaunas district, LT-53361, Lithuania
Tel. +370 37 752377
E-mail Egidijus.sarauskis@lzuu.lt

Dr. Kęstutis Romaneckas - Assoc. Prof. at Lithuanian University of Agriculture, Department of Soil Management.
Main research areas: soil tillage and sowing optimization, the influence of minimal pre-sowing soil tillage methods on agro-physical soil properties.
Adress: Studentų str. 11, Akademija, Kaunas district, LT-53361, Lithuania
Tel. +370 37 752211
E-mail Kestas.romaneckas@lzuu.lt

MSc. Sidona Buragienė – PhD student at Lithuanian University of Agriculture, Department of Agricultural Machinery.
Main research areas: sustainable soil tillage and sowing machinery, minimization of the negative influence of soil tillage technologies on the soil properties.
Adress: Studentų str. 15A, Akademija, Kaunas district, LT-53361, Lithuania
Tel. +370 37 752357
E-mail sidonab@meganet.lt

Tradicinių ir tausojančių žemės dirbimo ir sėjos technologijų poveikio fizikinėms-mechaninėms dirvos savybėms tyrimai

Egidijus Šarauskis[1], Kęstutis Romaneckas[2], Sidona Buragienė[1]
[1] *Lietuvos žemės ūkio universitetas, Žemės ūkio mašinų katedra*
[2] *Lietuvos žemės ūkio universitetas, Žemdirbystės katedra*

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Sparčiai didėjantis dirvą tausojančių žemės dirbimo ir sėjos technologijų taikymas pasaulyje, Lietuvoje taip pat didina susidomėjimą naujomis technologijomis, jų galimybėmis mažinti žemės ūkio mašinų poveikį natūraliems gamtos procesams. Tyrimų tikslas yra ištirti skirtingų žemės dirbimo ir sėjos technologijų poveikį fizikinėms-mechaninėms dirvos savybėms.

Tyrimai vykdyti 2000-2002 ir 2005-2007 metais trijose skirtingas dirvos savybes turinčiuose Lietuvos rajonuose: Kaune, Marijampolėje ir Pasvalyje. Tirta tradicinių ir tausojančių žemės dirbimo ir sėjos technologijų įtaka dirvos kiečiui, dirvos drėgniui ir dirvos grumstelių pasiskirstymui viršutiniuose dirvos sluoksniuose.

Eksperimentiniais tyrimais buvo nustatyta, kad neartose dirvose dirvos kietis, nepriklausomai nuo dirvos sunkumo, gautas didesnis negu tradiciniu būdu artose dirvose. Didėjantis dirvos kietis keičia sėklų įterpimo sąlygas dirvoje. Tyrimais nustatyta, kad mažinant dirvos dirbimo intensyvumą Lietuvos sąlygomis galima išsaugoti ženkliai daugiau dirvos drėgmės, kas leidžia pagerinti sąlygas sėklų dygimui. Dirvos grumstelių pasiskirstymo viršutiniuose dirvos sluoksniuose (< 15 mm) tyrimai parodė, kad smulkių (< 2 mm) grumstelių kiekis neartose dirvose buvo mažesnis negu artose, todėl mažėja plutos dirvos paviršiuje susidarymo galimybės ir galimos dirvos erozijos pasekmės.