EKOLOGIJA. 2008. Vol. 54. No. 2. P. 110–116
DOI: 10.2478/V10055-008-0018-9

Ecological assessment of agrotechnical measures in sandy light loam soils

Gintas Viselga[1],

Mečislovas Pauza[2]

[1] Department of Machine Building, Vilnius Gediminas Technical University, J. Basanavičiaus 28, LT-032214 Vilnius, Lithuania
E-mail: visgin@gmail.com

[2] Department of General Technology, Vilnius Pedagogical University, Studentų 39, LT-08106 Vilnius, Lithuania
E-mail: eva@vpu.lt

Potato as the most widespread agronomic culture was used for assessment of soil compaction caused by the new ecological farming technologies.

The experiment was carried out in 1998–2007 growing potatoes in a sandy light loam soil. The influence produced by different types of tractors (traction classes 6 and 14 kN) used for potato planting and the care of potato crops on soil compaction in the technological tracks and ridges was compared. The experimental technology was based on the use of a cultivator-mulcher with the horizontal rotor whose symmetrical axis is perpendicular to the direction of movement. It was compared with the traditional technology when the soil ploughed in autumn is cultivated and harrowed in spring before potato planting and later when potato haulms are stalking. The compared parameters included the influence of mulching and repeated driving of tractors on physical soil properties in the tracks: density, hardness, compaction level, fractional composition and the crumbling index.

The structure of the study soil was seriously damaged by aggregate carriers. After three drives, soil density in tracks approached the limit value suitable for plant cultivation (1.6 g/cm^3). The compaction level in the 16-cm surface soil layer increased 1.10–1.65 times. In deeper layers, its value quickly approached 1. As a result, the physical degradation and cultivation resistance of soil as well as energy input for soil cultivation increased. The environment was increasingly polluted with exhaust gases. Therefore, the ecological experimental technology of potato growing requires reducing the number of drives between the rows.

Applying the common technology, the soil crumbling index reached 78.5% using the tractor T-25, and 82.9% using the tractor MTZ-82. Applying the experimental technology, these indices were 73.0% and 78.7% respectively.

The potato plant mass grown applying the traditional technology and using the T-25 tractor (with narrower tyres) was by 30.2% larger than the plant mass grown using the MTZ-82 tractor (wider tyres). In the mulched soil with a lower compaction value, the potato plant mass was even by 46.1% larger.

Key words: soil properties, potato, technologies, forecrops, mulching, tractors, energy input

INTRODUCTION

In many European countries and in the USA, the dominant intensive technologies of the end of the last century have been recently replaced by farming technologies sustaining resources, soils and environmen – limited loosening of soil and a reduced number of tractor aggregate drives on the soil surface to avoid loamy soil compaction and to reduce its physical degradation and, concomitantly, erosion (Jankauskas, Jankauskienė, 2006).

Soil density, hardness, compaction level, fractional composition and crumbling index are the main factors describing soil compaction. Potatoes are especially sensitive to soil compaction because they grow best and yield largest crops only when the soil is loose over the entire zone of potato plant formation. Otherwise, the yield and quality of potatoes reduce: potato tubers are small and have an irregular form unconformable with the requirements. Clods of earth getting among potatoes when harvesting with combine harvesters damage tubers and reduce their storage life. The mentioned factors considerably reduce the portion of marketable products in the total potato yield. For this reason, potatoes were chosen as the best agronomic testers of soil compaction.

The timely and good quality preparation of soil for potato planting together with relevant fertilization and the least possible compaction of the zone of potato plant formation are indispensable for improving potato plant formation and growing (Klikocka, Sommer, 2003). To avoid soil compaction, first of all it is necessary to abandon their fertilization with manure because this technological operation is performed in autumn after harvesting when the soil moisture regime is far from the optimal one. However, fertilization of soils with mineral fertilizers alone reduces the content of humus and makes the soil sticky. The time of physical maturity of soil when its crumbling index is highest shortens (Spiess et al.,

1997) and the soil cannot be properly prepared for potato planting (in rainy years in particular). In some countries, modern technologies of preparation of loamy soils for potato planting and care of the crops create better conditions for formation of potato plants and harvesting with minimal losses and input. Rotor aggregates used in soil preparation for potato planting allow its more intensive mellowing and simultaneous insertion of crushed forecrops as green fertilizers (Viselga, Bareišis, 2001).

In recent years, an ever increasing attention to the forecrops used as green fertilizers has been paid (Kozlova, Viselga, 2000). They become ever more popular because the amounts of manure used for fertilization of potatoes are reducing with the reducing stock of farm animals. Manure is regarded a good fertilizer; however, its insertion into the soil in large amounts is the main source of soil pollution with heavy metals (Petraitis, 2007). For large amounts of humus and good annual yields of potatoes, 40–70 t/ha of manure must be inserted into the soil every year. In order to reduce fertilization with manure and environmental pollution, at least a certain portion of this amount could be replaced by another kind of organic fertilizer – green fertilizer (Turley et al., 2003). This portion is reported to match up to 20 t/ha of manure (Maikštėnienė, 2005). The green fertilizer not only helps to combat weeds, enriches the soil with organic matter, reduces the cohesion of clay particles in soils of heavy granulometric composition, improves their physical and geochemical properties and prevents overdrying (Clark, 1998), but also improves soil aeration and maintains the optimal moisture regime (Бабич, 1997). This facilitates tilling and the subsequent operations of soil cultivation and potato crop care.

Investigations carried out at the Lithuanian Institute of Agriculture (LIA) show that using ryegrass as a forecrop the content of humus developing in the surface soil layer (–25 cm) is only by 0.4% lower than in the case of using 80 t/ha of manure (Maikštėnienė, 2005).

The surface of potato rows in a structured soil can be daubed and sprayed with sheet-forming herbicides such as Sitrin, Zenkor, Fuzilad, etc. In this case, there is no necessity to control weeds between the rows. However, this technology is reproached with the chemical pollution of the environment. At present, attention is focused on the alternative biological agriculture (Repšienė, Mineikienė, 2006); this is relevant as not only chemicals, fertilizers and energy resources but also labour input are expensive and should be used rationally. Agricultural production should be matched with preservation and improvement of the environment, soil and genetic diversity (Čiuberkis et al., 2005). Introduction of modern sustainable technologies sets new tasks to be solved by science.

The aim of the present work was to investigate the impact of soil mulching with forecrops and use of tractors with tyres of different width on potato tuber formation in cloggy soils and on potato harvesting conditions.

CONDITIONS, EQUIPMENT AND METHODS OF EXPERIMENTAL INVESTIGATIONS

Field experiments were carried out in 1998–2007 in (IDk-p) *Harpi-Calc(ar)ic Luvisol (LVK-ha)* composed of sandy light loam (sp.) in the humus layer. In Lithuania, soils of this granulometric composition amount to about 1.1 million hectares or 17% (Eidukevičienė, Vasiliauskienė, 2001).

A triple-breasted plough was used for autumn ploughing in the control variant.

In the experimental variant, rape was grown as a forecrop. It was sown after harvesting the early potato crop in the first half of July (between the 10th and the 15th). The seed rate was 15 kg/ha. The Kemira Horti mineral fertilizer (0.7 t/ha) was used for rape fertilization. At the end of September – beginning of October, a rotor cultivator-mulcher, composed of a horizontal rotor whose symmetrical axis was perpendicular to the movement direction, was used for chopping of about 40 t/ha of rape green mass and its insertion into the surface soil layer (100 mm). The working depth was regulated with two supporting wheels. The working bits were represented by straight radial fingers mounted on the rotor. They had 100 mm long and 190 mm wide triangular pointed plates in the peripheral parts. The angle between the bits was 120°. The rotating movement at a frequency 200 min^{-1} was generated by the power takeoff shaft. The working speed of the aggregate was 0.55–0.6 m/s and the productivity was about 0.3 ha/h.

In spring when the soil moisture regime in both variants reached 14–18%, the soil was cultivated for potato planting. In the first week of May when the average daily temperature exceeded 8 °C, early potatoes ('Venta' variety) were planted using a suspended double-row potato-planter with an elevator. The width between the rows was 70 cm (Fig. 1) and the seed rate was 3 t/ha. In the control field where the traditional technology was used, mineral fertilizers were dispersed using a centrifugal duster.

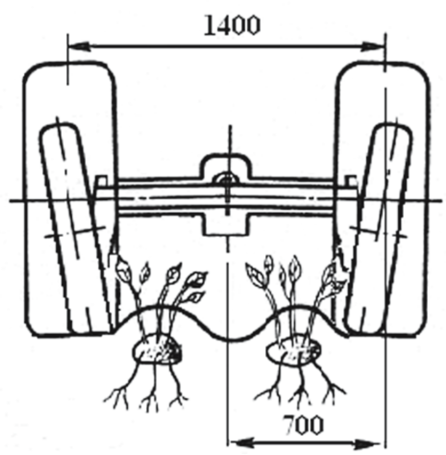

Fig. 1. Scheme of tractor carrier wheels moving between the rows

The potatoes were grown applying the traditional technology: earthed up and harrowed 2–3 times and again only earthed up 1–2 times before germination until potato haulms of the adjacent rows meet (Viselga, Bareišis, 2003). When necessary, the crops of both variants were sprayed with fungicides and insecticides. Herbicides were not applied and potatoes were weeded out manually 1–2 times depending on the abundance of weeds.

The used triple-breasted plough and rotor cultivator-mulcher were aggregated with the MTZ-82 tractor. Potatoes were planted and their crops cared for using tractors of two traction classes: 6 kN tractor T-25A and 14 kN tractor MTZ-82.

On the 10–20 September when potatoes were harvested using a double-row potato-digger with an elevator, the average soil moisture was 10–16%.

The mass of the MTZ-82 tractor is 3730 kg. During the experiment, the pressure in its tyres was about 0.15 MPa; therefore, the maximal pressure of the carriers on the soil reached 0.16 Mpa. The mass of the T-25A tractor is 2020 kg. During the experiment, the pressure in its tyres was 0.24 MPa; therefore the maximal pressure of the carriers on the soil reached 0.19 MPa.

Soil hardness in a potato row and between the rows was determined with the aid of the electronic self-recording CP 20 penetrometer (England) supplied with a standard conical point 12.5 mm in diameter. Soil resistance to point pressure was recorded in the device memory every 15 mm between the surface and a set depth. The furrow profile was also measured with a 1.5 m long board with stems for planting in the soil. On its both sides, gaps 15 mm in diameter spaced 10 mm (with a 5 mm scroll) were drilled. Its horizontal position was determined with a level. The measuring was repeated 5 times across the 100 m long experimental field.

A cylinder with sharp edges was used for taking 100 cm^3 soil samples from a formed vertical soil ridge at a depth of 6, 12, 18, 24, and 30 cm. The samples were taken for the analysis of granulometric composition, density and moisture regime. Their granulometric composition was determined by the percentage of physical clay and sand grains. Soil moisture was determined by calculating the percentage of water after drying a soil sample at 105 °C. Soil density was calculated by the ratio between the dry soil mass and the capacity of the sampling cylinder.

The fractional composition in a potato row was determined during digging using a 500 × 500 mm screen set with square meshes sized 10 × 10; 20 × 20; 30 × 30; 50 × 50 and 100 × 100 mm. The screens assembled on each other according to the increasing size of meshes were put on a wooden box of the same size, designed for collecting the fraction <10 mm. The soil dug from a potato row was poured on the screens and then manually screened. The soil fractions remaining on each screen and in the box were weighed with the German "Ohaus" electronic weighing device to the accuracy of 10 g.

The soil crumbling index was calculated by the ratio between the fraction <30 mm and the total mass per cent.

The potato plant yield was determined by digging before cutting the potato haulm and weighing the tubers of five casual plants. The tubers that had turned green were also weighed, and their portion in the marketable yield was determined.

The level of potato pollution with earth clods and the portion of mechanically damaged tubers were determined during potato harvesting using an uncoiling band mounted behind the loader in the rear of the potato-digger. After collecting tubers and earth clods larger than 30 mm from the loader, the percentage of earth clods in the tuber mass was determined.

For determining the mechanically damaged potatoes, 10 kg of tubers larger than 30 mm in diameter were sampled during digging. Ten days after digging the tubers were cut into 2 mm thick slices across the longitudinal axis. Dark patches allowed determining the damaged tubers. The damaged tubers were collected and weighed using a weighing device with an accuracy to 50 mg. After that, the portions of damaged and intact tubers were determined.

The obtained results are given as average values (except in Fig. 8) for 1998–2007 excluding a few years with meteorological conditions uncharacteristic for potato growing. The experimental data were statistically processed with "Statigraphics" computer program.

RESULTS, ANALYSIS AND DISCUSSION

For potato growing, the soil must be fertilized with organic fertilizers and earthed: manure is inserted and the soil ploughed in autumn, and the soil is earthed to the required friability using cultivators in spring. During cultivation, some of energy input is wasted on overcoming soil resistance and reduction of soil compaction in the tracks. By compaction, soil structure is spoiled, and clods form in humid and cloggy soils (Viselga, Bareišis, 2003). Soil compaction increases (in the surface layer in particular) with every new drive in the same tracks (Fig. 2).

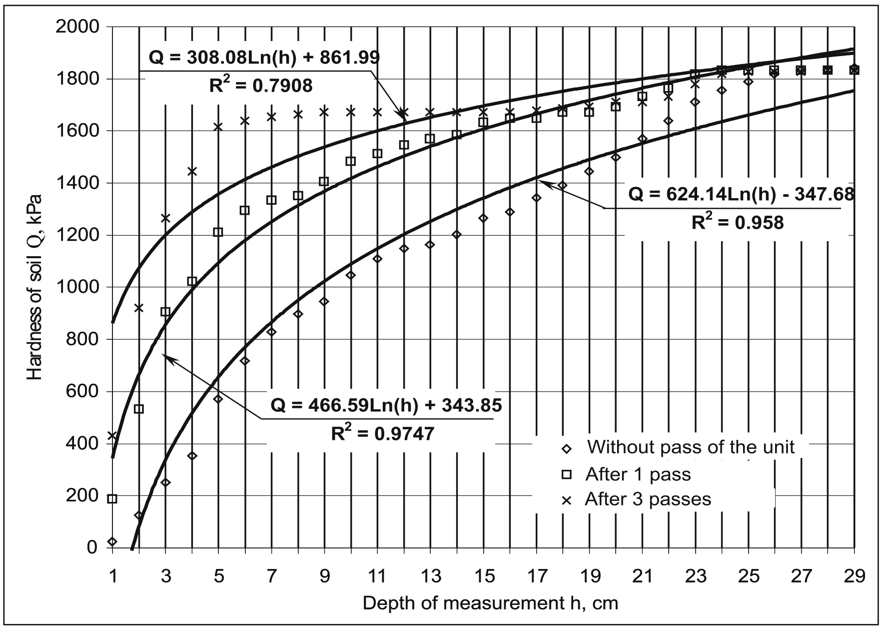

Fig. 2. Dependence of soil hardness between the rows on the number of drives with the MTZ-82 tractor supplied with earthing and harrowing aggregates

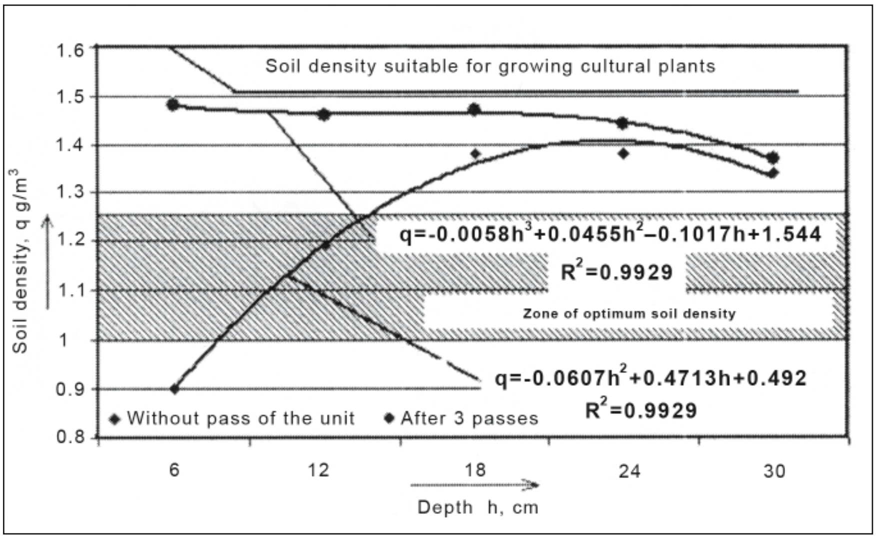

Fig. 3. Dependence of soil density between the rows on the number of drives with the tractor MTZ-82 with earthing and harrowing aggregates

The dependence of soil density in a technological track on the number of drives with the MTZ tractor is demonstrated in Fig. 3. Tractor carriers produce an adverse impact on the density of light loamy soil because even after three drives in the same track the soil density approaches the limit value suitable for plant growing (Mocek et al., 1997). Physical degradation of soil sets in, the soil resistance to the working units of aggregates increases as does also the energy input for soil cultivation. Environmental pollution with exhaust gases increases because greater amounts of fuel are used for cultivation.

The number of drives between the rows produces an impact only on the soil layer to a depth of 24–26 cm. In deeper layers, changes of hardness and density are felt but little (Figs. 2 and 3). The zone of optimal density for cultural plant growing reaches 14 cm under the row profile, provided that tractors do not drive between the rows. The conditions for formation and growing of tubers in the mentioned zone are favourable for potatoes which "prefer an overstuffed bed". Tubers in such conditions grow large and regular.

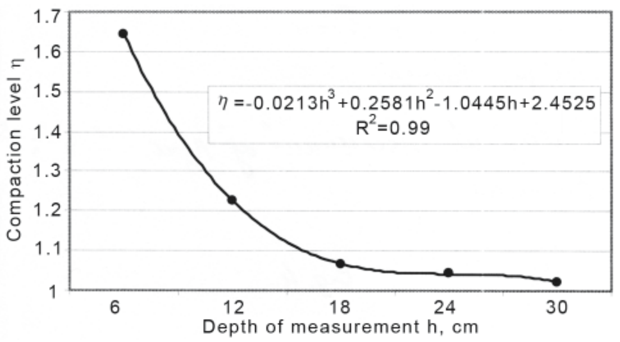

Fig. 4. Compaction level in loamy soil after three drives of the MTZ-82 tractor with earthing and harrowing aggregates between the rows

The soil compression with aggregate carrier wheels is best described by the compaction level η, i. e. the ratio between soil density after and before compaction. The compaction level in the loamy soil after three drives of the MTZ-82 tractor between the rows is shown in Fig. 4.

After three drives of the MTZ-82 tractor with aggregates between the rows, the compaction level of sandy light loamy soil increases 1.10–1.65 times to a depth of 16 cm. In deeper layers, this value rapidly approaches 1. The total and aeration porosity of soil reduces and soil moisture increases. Thus, the ecological experimental technology of potato cultivation requires the possibly least number of drives between the rows.

The impact of carrier wheels of the MTZ-82 tractor on row profile compaction is obvious (Fig. 5). The width of the left side of the profile under the tractor wheels (Fig. 1) is 354.7 cm^2, i. e. by 20.6 cm^2 smaller than the right side (375.0 cm^2). The curves of soil hardness within the furrow width are also asymmetric (Fig. 5). In the compacted side of the profile, the average hardness of the surface soil layer to a depth of 10 cm reaches 708.4 kPa and is by 192.5 kPa higher than the average hardness of the non-compacted side, reaching 515.9 kPa. At a depth of 10–20 cm, the difference of soil hardness between the compacted (1733.0 kPa) and non compacted (1148.9 kPa) sides of the profile is even greater (584.1 kPa). A strong link between the compaction level and soil hardness in deeper layers is proved by the high correlation coefficient $R^2 = 0.7958$. In the surface layer,

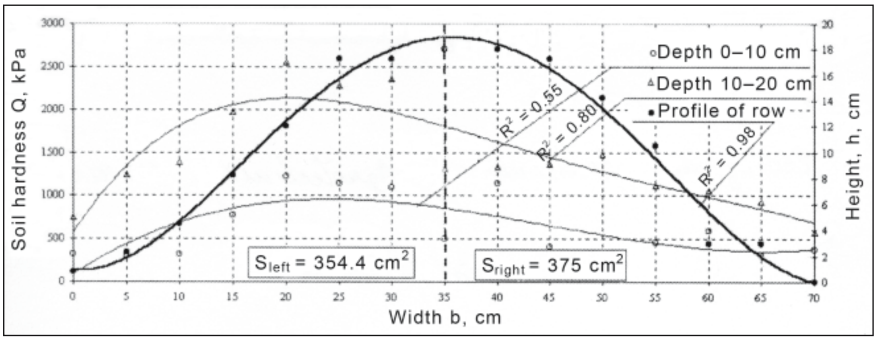

Fig. 5. Dynamics of soil hardness under the row profile in unmulched soil

the correlation coefficient is only $R^2 = 0.5543$, implying a weaker link between the compaction level and the increase of soil hardness. Presumably some other factors skew this dependence. Greater differences of moisture regime in the soil surface layer than in deeper layers can be mentioned as one of these factors. The surface layer is sensitive to meteorological conditions: even a short rainfall may be important because the surface of furrows is unevenly covered with leaves. The time of day after the rainfall is also important because the drying intensity of the row profile area is uneven at different times of day. Wind and precipitation direction, furrow orientation according to the points of the compass, etc. also can be mentioned among these factors.

The hardness of a potato row after its formation in mulched soil is shown in Fig. 6. In the centre of the profile, it is by about 300 kPa higher when the area between rows is attended by a tractor supplied with wider tyres.

Cultivation of soil for potato growing in such a way as to reduce its lumpiness is the ultimate potato growing technology in the countries with a developed potato growing (the Netherlands, Germany, Scotland, Denmark, Poland, etc.). The working bits of rotor tyres are more suitable for this purpose in cloggy soils (Viselga, Kaminski, 2006). Figure 7 shows the per cent distribution of row soil fractions during potato digging, implying that the tractor type did not produce any substantial impact. Yet soil mulching was important. It increased the content of fraction >50 mm by about 10% and reduced the fraction 30–50 mm by 4–6%. Formation of larger clods is induced by remains of mulch mass on the soil surface, which failed to disintegrate. These remains bind the soil into larger lumps which hardly crumble after drying. The per cent distribution of other soil fractions is within the limits of experimental error, therefore we may assume that their formation depends, neither on soil mulching nor on the type of tractors.

The crumbling index of soil in the traditional variant reached 78.5% using the T-25 tractor and 82.9% using the MTZ-82 tractor. In the experimental variant, the index was 73.0% and 78.7%, respectively.

The narrower tyres of the T-25 tractor used for planting and earthing potatoes (control) allowed growing a 30.2% larger mass of potato plant (Fig. 8). In the mulched soil, the plant mass was higher even by 46.1% due to the lower soil compaction value.

The more friable soil in the experimental variant exerted a positive influence on potato plant growth. The average potato plant mass was about 0.89 kg, i. e. by 0.13 kg larger than in the control variant (traditional technology) using the MTZ-82 tractor and by about 0.31 kg larger using a lighter tractor (T-25) with narrower tyres (Fig. 8).

In the experimental technology, the lower compaction of the sides of potato rows contributes to more friable soil favourable for physical soil properties and potato yields. Following the experimental potato growing technology, it is possible to increase potato yield by up to 46.1%. Soil compaction inflicts even

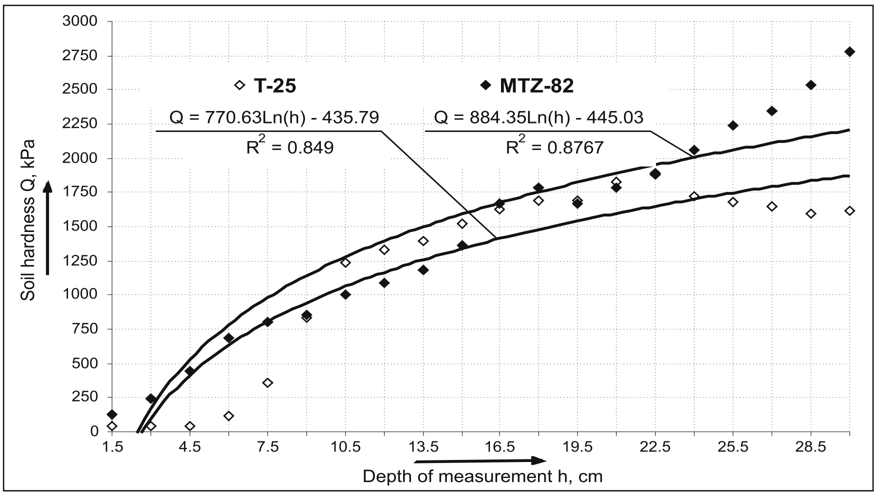

Fig. 6. Soil hardness in the centre of potato row profile after formation in mulched soil

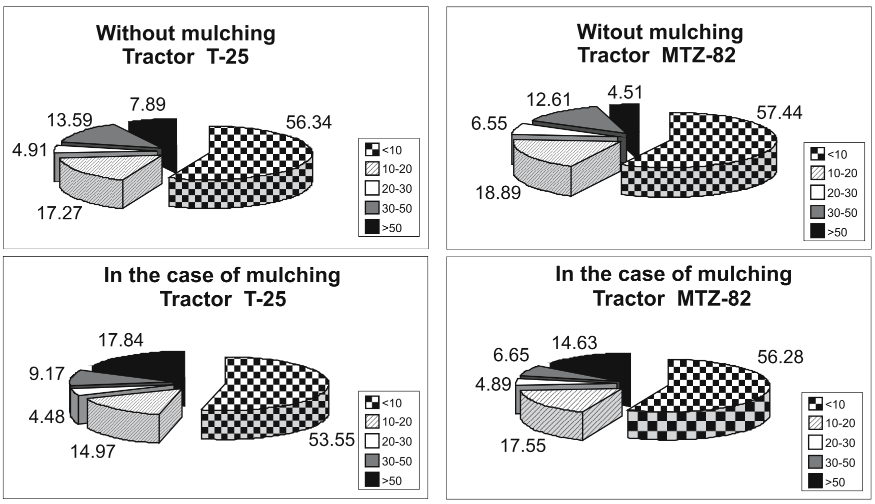

Fig. 7. Dependence of potato plant yield on the type of tractors used for mulching and potato crop care

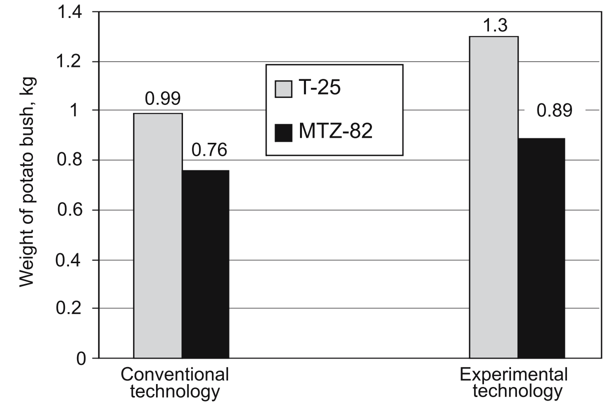

Fig. 8. The impact of different types of tractors used for mulching and potato crop care

more harm to yields of some other kinds of plants. For example, although germination of barleycorns increases, the losses of their yield may reach up to 90% when the spring is rainy and the vegetation period is dry (Kuht et al., 2006). Thus, we may assume that under the mentioned meteorological conditions application of the experimental technology may increase the potato yield even more.

During potato digging in the experimental variant, the potato row profile in the mulched soil was by about 3 cm higher than in the control variant (Fig. 9). The average area of its cross-section was 682 cm^2 if compared with the cross-section in the control variant (618 cm^2). Usually, the row profile area is asymmetric due to compaction by tractor wheels when driving in the technological tracks. The value of asymmetry in the control variant was 31.6 cm^2 due to a greater number of drives, whereas in the experimental variant it was 19.7 cm^2.

The friable soil in the experimental variant was favourable for potato harvesting. When the content of soil on the upper elevator of a potato digger was lower, the amount of damaged tubers in the experimental variant was by 10% higher than in the control variant. To reduce the damage, it was necessary to speed up the digging process. However, in this case yield pollution increased by 3–5%.

Investigation of potato turning green is related with the analysis of row profile (Fig. 9), the mass of potato plant and weed density. Growing of large plants of a productive potato variety in mulched soils, expansion of friable soil during potato growth, and water erosion on tops of potato rows contribute to exposure of tubers and their turning green. The larger the potato plant and the greater the content of the fine-grained soil fraction, the more intensive are the mentioned processes. Therefore, the amount of tubers that turned green in the experimental variant was by 10% greater than in the control variant. The thinner was the weed cover, the more intensive were the greening processes (Viselga, Bareišis, 2001). This implies that potato rows must be earthed in such a way as to form their possibly larger cross-sections, and the number of aggregate drives in the technological tracks must be reduced.

CONCLUSIONS

1. The structure of cloggy soil is seriously damaged by aggregate carriers because assoon as after three drives the density of soil in tracks approaches the limit value suitable for plant cultivation (1.6 g/cm^3). Physical degradation of soil sets in, and the soil resistance to cultivation and energy input increase. The increasing consumption of fuel results in an elevated environmental pollution with exhaust gases.

2. After three drives of the MTZ-82 tractor with aggregates in the technological tracks between potato rows planted in sandy light loam soils, the compaction level increased 1.10–1.65 times to a depth of 16 cm. The total aeration porosity of soil reduced, soil moisture increased and soil erosion intensified.

3. The area of the side of the potato row profile compacted by the MTZ-82 tractor is by 20.6 cm^2 smaller than of its other side. The asymmetry of curves of soil hardness at a depth of 0–10 cm and 10–20 cm is opposite to the asymmetry of row width.

4. The soil crumbling index in the traditional variant reached 78.5% using the T-25 tractor and 82.9% using the MTZ-82tractor. In the experimental variant, these indices were 73.0% and 78.7%.

5. Planting potatoes and attending their crops using lighter tractors with narrower tyres allowed growing a 30.2% larger

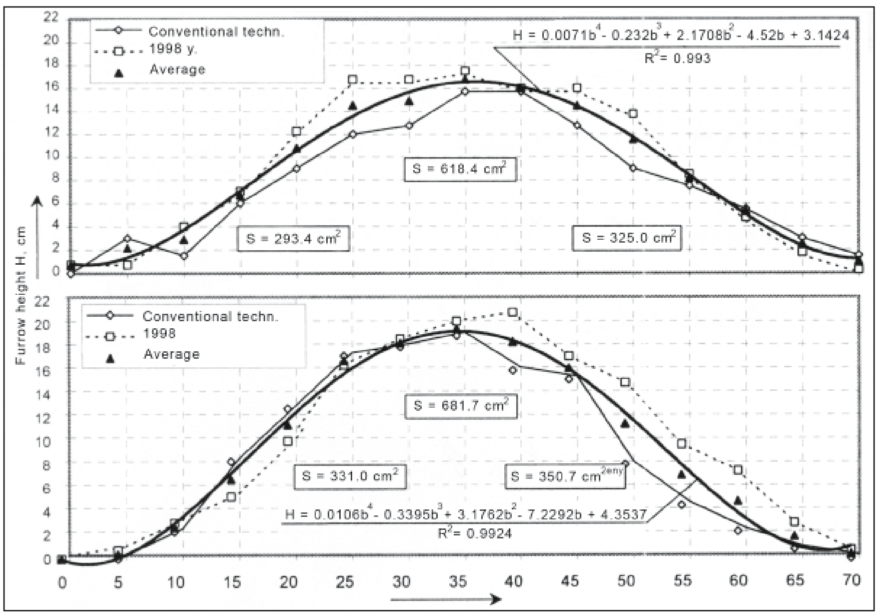

Fig. 9. Profiles of potato rows at harvesting: the point of departure is in the centre of the technological track (S – total profile area, S_{tt} and S_{nt} – areas of each half of the profile on the compacted and non-compacted sides of rows)

potato plant mass in the traditional variant and by up to 46.1% larger mass of plants in the experimental variant.

6. Soil mulching and the use of lighter tractors with narrower tyres for potato planting and the care of crops are effective technological measures which reduce soil compaction, energy input, demand for fuel and adverse environmental effects.

Received 18 October 2007
Accepted 7 March 2008

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Gintas Viselga, Mečislovas Pauza

AGROTECHNINIŲ PRIEMONIŲ SMĖLINGUOSE LENGVO PRIEMOLIO DIRVOŽEMIUOSE EKOLOGINIS ĮVERTINIMAS

Santrauka

Tyrimai atlikti 1998–2007 m. smėlingame lengvo priemolio dirvožemyje auginant bulves 'Venta'. Siekta išsiaiškinti naujos ekologinės agrotechnikos efektyvumą dirvožemio suslėgimui. Buvo palyginta 6 ir 14 kN traukos klasės traktorių įtaka dirvos suslėgimui, juos naudojant bulvių pasėlių priežiūrai. Eksperimentinės technologijos atveju naudotas rotorinis kultivatorius – mulčiuotuvas. Ši technologija lyginta su tradicine. Buvo palyginta bulvių dirvų mulčiavimo bei traktorinių agregatų daugkartinio važiavimo pasėlių tarpueiliais įtaka dirvožemio fizikinėms savybėms: tankiui, kiečiui, suslėgimo laipsniui, dirvos frakcinei sudėčiai bei jos trupėjimo rodikliui.

Tiriamo dirvožemio struktūrai traktorinių agregatų važiuoklės daro didelę žalą. Jau tris kartus pravažiavus tuo pačiu bulvių vagučių tarpueiliu, dirvos, esančios po juo, tankis priartėja prie tinkamo kultūrinių augalų auginimui tankio ribos – 1,6 g/cm^3. Dirvos sutankinimo laipsnis yra ženklus iki 16 cm gylio, kur jis padidėja iki 1,10–1,65 karto. Dėl to didėja dirvožemio fizinė degradacija, pasipriešinimas dirbimui ir energijos sąnaudos. Visa tai didina aplinkos taršą vidaus degimo variklių išmetamosiomis dujomis. Todėl, auginant bulves ekologiškai, pagal eksperimentinę technologiją, reikia kuo mažiau važinėti bulvių tarpueiliais.

Įprastinės technologijos atveju dirbant T-25 traktoriais dirvos trupėjimo rodiklis yra 78,5%, o MTZ-82 traktoriais – 82,9%, eksperimentinėse technologijose atveju – atitinkamai 73,0 ir 78,7%.

Lengvesnių traktorių siauresnės padangos tradicinėje technologijoje leido išauginti apie 30,2% didesnę kero masę. Mulčiuotoje dirvoje dėl tos priežasties kero masė padidėjo net 46,1%.

Raktažodžiai: dirvos savybės, bulvės, technologijos, tarpiniai augalai, mulčiavimas, traktoriai, energijos sąnaudos