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THE EFFECT OF CONSERVATION FARMING ON THE ABUNDANCE OF EARTHWORMS ON ERODED SOILS

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Abstract

The soil of the experimental site is (JIb-el) *Eutric Albeluvisol* (Abe-el) with a texture of loamy sand at footslopes and clay loam at top part of the slopes. The population density of earthworms (*Lumbricidae)* on slope soil was the lowest after winter wheat, which was the first crop in the rotation (38 earthworms m^{-2}) and the highest after the second crop - spring barley (77 earthworms m^{-2}) and after the third crop – oats (61 earthworms m^{-2}). Through the soil conservation technology – disking, straw mulch incorporation, catch crops autumn undersowing the density of earthworm population in wheat stubble increased by 53 per m^2, in oats stubble by 40 per m^2 and through trash conservation, no tillage practice, respectively, in wheat by 27 per m^2 in oats by 26 per m^2. The number of earthworms in the plough layer of eroded soil was also dependent on the relief conditions: there were significantly fewer earthworms in the lower part of slope (in 2000 by 28.9 %, in 2001 by 60.6 %, in 2002 by 73.5 %) than on the top of slope. Higher number of earthworms resulted in an increased amount of valuable soil aggregates (1-5 mm) on the top of slope, but not in the middle and lower parts of slope.

Key words: conservation tillage, trash conservation, earthworms, crop rotation, slopes.

Introduction

Modern and intensive agrotechnologies tend to have a strong influence on soil macro-organisms. There is little research on the impact of conservation farming and trash conservation on undulating landscape on soil macrofauna.

Positive impact of earthworms is well known. Today researchers are re-discovering the importance of earthworms in agriculture. As far back as 1881 Charles Darwin said: “soil was tamed well by earthworms long before the plough was invented” /Vasinauskas, 1989/. Earthworms of *A. caliginosa* species dominate in Lithuanian arable soils, they make up 41.8-88.2 % of the total earthworm’s population. Earthworms feed on organic plant residues, mineral particles, and enrich the soil with water soluble nutrients. The activity of earthworms depends first of all on feeding conditions and soil humidity /Stancevičius, Gavenauskas, 1999/. In spring earthworm population density is higher in the upper layer of soil /Gavenauskas, 1998/. The number of earthworms can be controlled by agrotechnical measures /Vasinauskas, 1989; Tripolskaja, 2002/. Crop rotation, red clover crop and direct sowing have a positive influence on earthworm population density /Lauringson et al., 1999/. Ploughless soil tillage also encourages the spreading of different earthworm species /Rasmussen, 1999/. Simplified soil tillage

creates the conditions for reproduction of earthworms /Chan, 2001/. After wheat crop harvesting earthworm population density was by 47.1-69.3 % higher when deep ploughing had been replaced by shallow ploughing or deep/shallow tillage by a heavy cultivator. Earthworm population density and biomass after barley crop harvesting was by 23.4-53.4 % and 18.3-62.7 % higher as a result of non-inversion soil tillage (deep and shallow cultivation) /Jodaugienė, 2002/. The abundance of earthworms depended on the shortening of the rotation, choice of the preceding crop, and on how long the crops can be grown in the same place /Seibutis, Magyla, 2004/. Injured earthworms are more active in straw mineralization process /Atlavinytė, 1989/. Earthworms burrow the tunnels in soil, thus improving soil structure, aeration and water permeability. More earthworms were found in loams than in sandy loams and peat soils. Earthworm populations in 1958 in lower part of slope were three times larger than the populations in upper part of slope /Atlavinytė, 1975/. Earthworms and micro-fauna feed on the decomposing straw. In an open field 400 earthworms per m^2 population density makes the mineralization faster by 14.8-41.8 %. Investigations have shown that natural conditions (soil characteristics, climate, relief) and agrotechnology (agricultural crops, soil cultivation) are the factors influencing earthworm population density /Atlavinytė, 1989/.

The aim of this research was to evaluate the impact of conservation farming methods on the earthworm population density in eroded soils of hilly relief.

Experiment design and methods

The experimental site is located on the southern-central Žemaičiai Upland. The field experiment was conducted at the Kaltinėnai Research Station of the Lithuanian Institute of Agriculture on the undulating topography during the period of 1998-2002 on the slopes with inclination 7^o (southerly aspects). The field experiment was performed on an eroded *Eutric Albeluvisol* (Abe-el) with the typical hilly-rolling relief of western Lithuania. Soil texture in the experimental plots was loamy sand at footslopes and clay loam at top part of slopes. The soil was moderately eroded on shoulder and slightly with colluvial deposits on basal slope. The experimental field had the following crop rotation: winter wheat (*Triticum aestivum* L.) in 1998-99, spring barley (*Hordeum vulgare* L.) in 2000 and oats (*Avena sativa* L.) in 2001. Winter wheat and spring barley straw yield was used as mulch in the experiment. The pre-crop (before winter wheat) was a mixture of oats+vetch+white mustard+forage peas for green manure, incorporated into the plough layer using a disker in July.

The experimental design was as follows: 1) deep ploughing (control); 2) straw ploughing-in; 3) Roundup, disking, no ploughing; 4) straw, Roundup, disking, no ploughing; 5) straw, disking, white mustard, no ploughing; 6) straw, deep loosening, white mustard, no ploughing; 7) straw, Roundup, no ploughing; 8) straw, disking, Roundup, deep ploughing. The experimental treatments were arranged randomly in four replikations lengthwise of the slope. The soil of the experimental site was close to neutral (pH_{KCl} 6.2-6.5), with high concentrations of potassium (175-239 mg kg^{-1} soil) and low concentrations of phosphorus (47-66 mg kg^{-1} soil). Humus content in the ploughed (Ap) horizon for the slope was 2.3 % at the top and 2.9 % on the basal slope. Conventional and conservation soil tillage in combination with chopped straw mulch, catch crop (white mustard, *Sinapis alba* L.) and herbicide glyphosate 360 a.i (Roundup) was used

on the slopes after harvesting of winter wheat. The experimental plots were fertilized with 90 kg P ha^{-1}, 90 kg K ha^{-1} and 70 kg N ha^{-1}.

Three to four weeks after harvesting, soil (both with and without chopped straw) was sprayed with Roundup, at a rate of 3.0 l ha^{-1}. Two to three weeks after spraying the soil was disked and deeply ploughed and straw was incorporated at the same time. Deep ploughing depth was 22-25 cm, plough PLN-3-35; deep loosening depth was 18- 25 cm, heavy cultivator-chisel KČ-5.1, disking depth was 12-15 cm, heavy disker BDT-3.

Earthworms were counted in spring on 27 04 2000, 10 04 2001, and 04 04 2002 before soil tillage, two years after the start of the experiment. Earthworms were analysed using Carter method in four replications in three spots of the testing plot representing the top, middle and lower parts of slope /Carter, 1993/. Sampling area was 0.25 m^2 with a depth of 25 cm.

Representative soil samples (0-20 cm depth) for the determination of soil structure were taken in spring before sowing of spring cereals from 3 replications, 3 spots per plot. Soil structural stability was analysed using Savinov method in order to determine dry aggregate strength by dry sieving.

The significance of differences between treatment means was determined using Fisher's LSD_{05}. Analysis of variance and correlation-regression analyses were performed using the software ANOVA and STAT /Tarakanovas, Raudonius, 2003/.

HTC was calculated using the formula of G. Selianinov:

$$HTC = \frac{\sum p}{0.1\sum t},$$ where ∑p – total rainfall mm over the period with air temperature over 10 ^{o}C; ∑ t – sum of temperatures during the same period /Bukantis, Rimkus, 1997/.

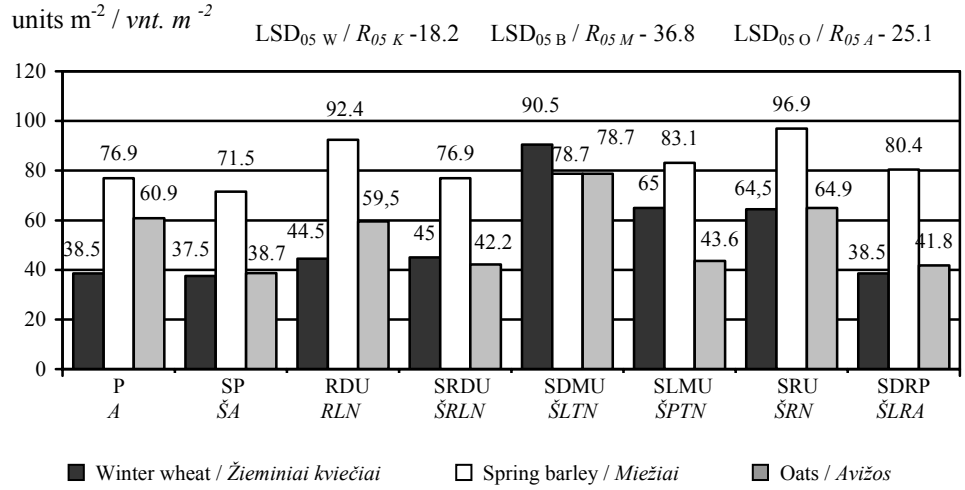
Results

The data from Kaltinėnai weather station show that during the whole experimental period the highest annual precipitation fell in 1998 (965.8 mm) and 2001 (825.9 mm). Exceptionally dry spring periods (April-May) were recorded in 2000 (HTC = 0.9) and in 2002 (HTC = 0.6). Autumn rains in 1999 and 2000 started in October, and in 2001 in September. The dry weather conditions in spring had negative effect on the germination and growing of plants on the slopes. Surplus moisture was recorded in the summer months in July in 2000 and 2001 (HTC = 2.4) and in August in 1999, very dry in August in 2002 (HTC = 0) (Table 1). The number of earthworms in spring depended not only on the structure of crop rotation and conservation agrotechnologies but also on the weather conditions. A direct correlation (r = -0.995*) was established between annual air temperature in the years of investigation (2000 = 7.5^{o}C, 2001 = 6.5^{o}C, 2002 = 7.1^{o}C) and the number of earthworms. The importance of the weather conditions for the number of earthworms has been indicated by other authors /Raškauskienė, 2003/.

Table 1. Values of hydrothermal coefficients (HTC) over crop growing periods
1 lentelė. *Augalų vegetacijos periodų hidroterminių koeficientų (HTK) reikšmės*

Month / *Mėnuo*	Hydrothermal coefficient / *Hidroterminis koeficientas*			
	1999	2000	2001	2002
May / *Gegužė*	1.3	0.9	1.2	0.6
June / *Birželis*	1.5	1.5	0.8	1.7
July / *Liepa*	1.0	2.4	2.4	1.8
August / *Rugpjūtis*	2.9	1.5	1.9	0
Average / *Vidurkis*	1.7	1.6	1.6	1.0

According to the research data obtained, the highest number of earthworms in slope soil was found in the stubble of barley grown after winter wheat in 2001. That year there was found no significant impact of the tested agrotechnical measures on the number of earthworms. In 2000 the lowest number of earthworms – 37.5-38.5 per m^2 was found in ploughed wheat stubble with and without straw. The effect of several agrotechnical conservation measures on the macrofauna (earthworms) was different in different crops (Figure).



P – Deep ploughing as the control */ A - Arimas (kontrolinis);* SP – Straw incorporated by ploughing / *ŠA - Šiaudai, arimas;* RDU – Roundup, disking, unploughed / *RLN - Raundapas, lėkščiavimas, nearta;* SRDU – Straw, Roundup, disking, unploughed / *ŠRLN - Šiaudai, raundapas, lėkščiavimas, nearta;* SDMU – Straw, disking, white mustard, unploughed / *ŠLTN - Šiaudai, lėkščiavimas, tarpiniai augalai, nearta*; SLMU – Straw, deep loosening, white mustard, unploughed / ŠPTN - *Šiaudai, gilus purenimas, tarpiniai augalai, nearta*; SRU – Straw, Roundup, unploughed / *ŠRN - Šiaudai, raundapas, nearta*; SDRP – Straw, disking, Roundup, deep ploughing / *ŠLRA - Šiaudai, lėkščiavimas, raundapas, arimas*

The influence of conservation - trash cover farming on the density of earthworms in the stubbles of cereals.
Sliekų gausumas dirvosauginės - ražieninės žemdirbystės sąlygomis
Kaltinėnai, 2000-2002

Compared to earthworm number in the soil where straw had been deep ploughed-in (control), earthworm population density through soil conservation technology (straw disked-in, catch crop, not ploughed) in wheat stubble increased by 53 per m^2, or 141 %, in oats stubble by 40 per m^2, or 103 %. Earthworm population in trash conservation technology (not ploughed, mulched with wheat straw chop and sprayed with Roundup) in wheat stubble was larger than in ploughed soil with straw incorporation by 27 per m^2, or 72 %, in oats stubble – 26 per m^2, or 67 %. Different conservation methods in treatments of barley stubble did not have any positive effects on macrofauna.

Earthworm population in deep-cultivated soil with straw incorporation and white mustard as a catch crop was significantly larger (by 27.5 per m^2) only in 2000, or in one year out of three. Intensive soil tillage (straw, shallow disking, Roundup, deep ploughing) did not have any significant impact on earthworm density.

The number of earthworms in soil depended also on the local micro-conditions: there were significantly less earthworms in the lower part of slope than on the top of slope. Clay loam and medium loam soil on the top of slope was favourable for reproduction of earthworms; the worms found were of different development stages and different weight. O. Atlavinytė has also pointed out that earthworms are more widely spread in loams /Atlavinytė, 1975/. The impact of the tested agrotechnical conservation measures on earthworm population in different parts of the slope was not the same. In autumn-ploughed soil in all experimental years earthworm population was less in the lower part of slope: in 2000 by 28.9 %, in 2001 by 60.6 %, in 2002 by 73.5 %. The differences in earthworm number were the lowest in the year favourable for earthworm reproduction.

In 2001 in the middle part of slope sprayed with Roundup and disked with/ without straw incorporation earthworm population density was much higher than in the top part of slope (46 and 29.7 %) or in the lower part of slope (59.6 and 34.1 %); this number was the largest one throughout all experimental years, because the slope had a convex shape which created more favourable conditions for the reproduction of earthworms.

Deep ploughing-in of straw did not have any significant influence on earthworm population in 2000, and significantly decreased it in 2001 (with an exception of the top part of slope) and in 2002. Deep cultivation of soil increased earthworm population density in the first experimental year. In the second and third years (except for the lower part of slope in 2001) population density decreased or remained about the same. A significantly higher earthworm population density was found in the soil which had not been ploughed, but mulched with wheat, barley or oats straw chop and sprayed with Roundup (applied on mulch).

Analysis and evaluation of the impact of earthworm populations on the soil structure was based on the amount of the most valuable soil aggregates determined each year. On the top of slope in ploughed soil with/without straw incorporation the amount of these aggregates did not change significantly and constituted approximately 35 %, in minimally cultivated soil 27-35 %, in the soil which had been intensively tilled in autumn 11 %; significant difference ($LSD_{05} = 8.73$). In the lower part of slope there were no significant differences between the tested agrotechnical conservation measures with

regard to the amount of most valuable aggregates. Significantly smaller amount of valuable aggregates, when compared to the ploughed soil, was determined in the middle of slope in the disked and not ploughed soil (Table 2).

Table 2. The content of the most valuable aggregates (1-5 mm) of soil on the different parts of slopes %

2 lentelė. *Vertingiausių struktūrinių agregatų kiekis skirtingų šlaito dalių dirvožemyje %*

Kaltinėnai, 2000-2002 averaged data / *2000-2002 m. vidutiniai duomenys*

Treatment *Variantas*	Content of soil structural aggregates 1.0-5.0 mm size *1.0-5.0 mm struktūrinių agregatų kiekis*		
	Top of slope *Šlaito viršus*	Middle of slope *Šlaito vidurys*	Bottom of slope *Šlaito apačia*
Ploughing (control) / *Arimas (kontrolinis)*	35.1	40.0	38.9
Straw, ploughing / *Šiaudai, arimas*	34.7	36.2	37.5
Roundup, disking, unploughed *Raundapas, lėkščiavimas, nearta*	26.6	35.8	36.5
Straw, Roundup, disking, unploughed *Šiaudai, raundapas, lėkščiavimas, nearta*	33.4	33.7	32.7
Straw, disking, catch crop, unploughed *Šiaudai, lėkščiavimas, tarpiniai augalai, nearta*	35.3	34.8	33.3
Straw, deep loosening, catch crop, unploughed *Šiaudai, gilus purenimas, tarpiniai augalai, nearta*	29.2	34.1	33.9
Straw, Roundup, unploughed *Šiaudai, raundapas, nearta*	32.5	31.9	34.4
Straw, disking, Roundup, ploughing *Šiaudai, lėkščiavimas, raundapas, arimas*	24.1	37.0	32.6
LSD_{05} / R_{05}	8.73	6.16	9.55

According to the results of correlation-regression analysis of the relationship between the amount of valuable soil aggregates (1.0-5.0 mm) and the number of earthworms, strong and medium strong correlations were determined only for the soil of the top part of slope in 2001 (r = 0.761*) and in 2002 (r = 0.696) and negative correlation for the soil of the lower part of slope in 2002 (r = -0.85**) (negative trends in 2001 and 2000). Thus the earthworm population activity was the cause of the increase in the amount of most valuable soil aggregates only in the soil of the top part of slope. In 2000 there was found no relationship between these two factors: r = 0.068 for the top part of slope, r = 0.063 for the lower part of slope (Table 3).

Table 3. The relationship between the amount of the most valuable 1-5 mm aggregates % (y) and the number of earthworms m^{-2} (x) in the soil of slope parts
3 lentelė. *Priklausomybė tarp vertingiausių 1-5 mm dirvožemio agregatų kiekio % (y) ir sliekų kiekio vnt. m^{-2} (x) šlaito dalių dirvožemyje*

Part of slopes *Šlaito dalys*	Equation of regression *Regresijos lygtis*	Coefficient of correlation (r) *Koreliacijos koeficientas (r)*
Top of slope, 2000 *Šlaito viršus, 2000*	y = 28.1+0.027x	0.068
Bottom of slope, 2000 *Šlaito apačia, 2000*	y = 33.571-0.013x	-0.061
Top of slopes, 2001 *Šlaito viršus, 2001*	y = 17.202+0.206x	0.761*
Middle of slope, 2001 *Šlaito vidurys, 2001*	y = 32.98+0.032x	0.074
Bottom of slope, 2001 *Šlaito apačia, 2001*	y = 37.07-0.032x	-0.152
Top of slope, 2002 *Šlaito viršus,2002*	y = 20.63+0.095x	0.696
Middle of slope, 2002 *Šlaito vidurys, 2002*	y = 40.256-0.109 x	-0.382
Bottom of slope, 2002 *Šlaito apačia, 2002*	y = 41.106-0.158x	-0.85**

* Correlation significant at 95 % probability level / *Esminiai skirtumai esant 95 % tikimybės lygiui*
** Correlation significant at 99 % probability level / *Esminiai skirtumai esant 99 % tikimybės lygiui*

The number of soil macrofauna (earthworms) in the soil of slope recorded annually was also dependent on soil moisture conditions in different parts of slopes (Table 4). In all crops of cereals in ploughed soil (control) the strongest positive relationship between moisture content and the number of earthworms in spring was established (r = 0.75, y = 6.701+0.182x).

The increase in earthworm population became noticeable not after the first year, when wheat straw had been applied, but after the second year, when straw decomposition began. At the same time an impact on soil structure was noticed.

During the experimental period an interaction of the number of earthworms and cereal yield was established. The influence of soil macrofauna (earthworms) on the yield of cereals was weak in 2000 (r = 0.315, y = 2.228+0.002x; n = 8), in 2001 (r = - 0.157, y = 2.5-0.004x; n = 8) and in 2002 (r = 0.05, y = 1.68 + 0.001x; n = 8).

***Table 4*.** Soil moisture content in different parts of slopes during earthworm assessment %

***4 lentelė*.** *Dirvožemio drėgnumas atskirų šlaito dalių dirvožemyje sliekų apskaitos metu %*

Kaltanėnai, 2000-2002

Treatment *Variantas*	Soil moisture content % / *Dirvožemio drėgnumas %*							
	2000			2001			2002	
	top *viršus*	middle *vidurys*	bottom *apačia*	top *viršus*	middle *vidurys*	bottom *apačia*	top viršus	bottom *apačia*
Ploughing (control) *Arimas (kontrolinis)*	11.64	11.81	13.13	19.28	19.32	17.10	21.54	21.31
Straw, ploughing *Šiaudai, arimas*	13.48	10.77	14.20	19.12	18.19	20.88	22.45	20.11
Roundup, disking, unploughed / *Raundapas, lėkščiavimas, nearta*	15.33	12.88	13.86	18.59	17.44	17.86	21.83	22.43
Straw, Roundup, disking, unploughed/ *Šiaudai, raundapas, lėkščiavimas, nearta*	14.31	13.20	14.71	19.09	19.50	19.65	23.29	20.54
Straw, disking, catch crop, unploughed *Šiaudai, lėkščiavimas, tarpiniai augalai, nearta*	12.23	10.93	16.30	19.31	18.97	20.43	21.96	23.72
Straw, deep loosening, catch crop, unploughed *Šiaudai, gilus purenimas, tarpiniai augalai, nearta*	10.79	11.03	13.60	20.51	19.26	19.67	23.66	24.44
Straw, Roundup, unploughed / *Šiaudai, raundapas, nearta*	14.47	12.88	16.56	22.06	18.85	19.79	22.59	24.60
Straw, disking, Roundup, ploughing / *Šiaudai, lėkščiavimas, raundapas, arimas*	13.86	13.04	19.66	18.55	19.50	18.45	22.25	23.62
LSD_{05} / R_{05}	2.9	1.9	3.9	2.8	3.2	5.8	2.5	3.6

Conclusions

1. The density of earthworm population in *Eutric Albeluvisol* (Abe-el) with a texture of loamy sand at footslopes and clay loam at top part of the slopes was the lowest after winter wheat, which was the first crop in the rotation (38 earthworms per m^2) and in the conservation farming treatments, and the highest after spring barley, the second crop (77 earthworms per m^2) and after oats the third crop (61 earthworms per m^2).

2. Soil conservation technology composed of several measures, such as shallow disking, straw incorporation and catch crop sowing in the autumn had the strongest positive impact on earthworm population density. In winter wheat stubble there were 53

earthworms per m^2 or 141.8 %, in spring barley stubble 2.3 or 2.9 %, and in oats stubble 40 or 103 % more, compared to the soil ploughed in autumn.

3. Density of earthworm population in eroded soil significantly increased when mulch-tillage had been applied: winter wheat, spring barley or chopped oat straw was left on the soil and herbicide Roundup 3 l ha^{-1} was sprayed to control weeds.

4. Earthworm population density in the plough layer of eroded soil on the slope depended not only on different soil tillage methods used in autumn, but also on micro relief conditions: there were significantly fewer earthworms in the lower part (sandy loams) of slope than on the top of slope (loams).

5. The increase in the number of earthworms resulted in an increased amount of valuable soil aggregates. Strong and medium strong relationship was determined only for the soil of the top part of slope in 2001 ($r = 0.761^*$) and in 2002 ($r = 0.696$) and negative relationship for the soil of the lower part of slope in 2002 ($r = -0.85^{**}$) (negative trends in 2001 and 2000).

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SLIEKŲ GAUSUMAS NUARDYTOSE DIRVOSE DIRVOSAUGINĖS ŽEMDIRBYSTĖS SĄLYGOMIS

I. Kinderienė

Santrauka

Lauko bandymai daryti 1998-2002 m. Lietuvos žemdirbystės instituto Kaltinėnų bandymų stoties 7° statumo šlaite, eroduotame pasotintame balkšvažemyje (JIb-el) – *Eutric Albeluvisol* (Abe-el) vidutinio sunkumo ir sunkiame priemolyje šlaito viršutinėje dalyje ir lengvame priemolyje šlaito apačioje.

Sliekų (*Lumbricidae)* kiekis šlaite mažesnis buvo kvietienoje (38 vnt. m^{-2}), didesnis miežienoje (77 vnt. m^{-2}) ir avižienoje (61 vnt. m^{-2}).

Taikant dirvosauginę technologiją – dirvos su smulkintais šiaudais lėkščiavimo ir tarpinių augalų baltųjų garstyčių įsėjimo į lėkščiuotą dirvą – sliekų skaičius kvietienoje padidėjo 53 vnt. m^{-2}, avižienoje – 40 vnt. m^{-2}, o nuo dirvos mulčiavimo šiaudais rudenį dirvos nedirbant, atitinkamai: kvietienoje – 27 vnt. m^{-2} ir avižienoje – 26 vnt. m^{-2}. Sliekų skaičiui eroduojamos dirvos armenyje įtakos turėjo reljefo sąlygos, šlaito apačioje 2000 m. jų buvo 28,9 %, 2001 m. – 60,6 %, ir 2002 m. – 73,5 % mažiau negu šlaito viršuje. Didėjant sliekų skaičiui šlaito viršaus dirvožemyje, didėjo jame vertingų agregatų (1-5 mm) kiekis. Šio padidėjimo nenustatyta šlaito vidurinės ir apatinės dalių dirvose.

Reikšminiai žodžiai: dirvosauginis dirbimas, mulčiavimas augalų liekanomis, sliekai, javų sėjomaina, šlaitas.