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Sustainable tillage: results from long-term field experiments on *Cambisol*

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Abstract

The goal of this paper is to present the newly obtained data on the changes in soil physical and chemical properties, weed incidence and crop yielding capacity from the long-term tillage experiments, lasting for more than 10 successive years, carried out in the middle lowland of Lithuania on an *Endocalcari-Epihypogleyic Cambisol* (*CMg-p-w-can*), at the Institute of Agriculture, Lithuanian Research Centre for Agriculture and Forestry. It was revealed that conventional tillage (CT) produced the best soil physical properties (the lowest bulk density, cone penetration resistance, and the highest air permeability). Significantly worse soil physical properties were registered after no-tillage (NT) application, while under global warming conditions the application of the NT system may be the right measure to preserve soil moisture at the early stage of crop development. NT caused higher soil total N, available P_2O_5 and K_2O stratification in the soil during crop rotation period compared to reduced tillage (RT) and CT. Effectiveness of moderate rate of NPK fertilisers on loam decreased in this order according to tillage intensity: CT → RT → NT, while on sandy loam the effectiveness of moderate rate of NPK fertilisers tended to increase in the same tillage order. Application of high rate of fertilisers on loam was ineffective in CT and RT systems, but in NT system this measure increased metabolizable energy (ME) by 16% compared to moderately fertilised treatments. Efficacy of high rate of fertilisers on sandy loam was not significant in all tillage systems investigated compared to moderately fertilised treatments. The heavier weeds population, the more favourable conditions for herbicide action were created. Therefore a combination of NT and glyphosate application on sandy loam was less effective than mechanical weed control in CT and RT. In CT treatment the changes in weed incidence were irregular in a 4-course crop rotation in the experiment set up in 1956. Application of both RT systems tended to decrease weed mass during the experimental period. NT application produced significantly lesser amount of ME during an 8-course crop rotation, compared to CT and RT on both loam and sandy loam.

Key words: physical properties, NPK stratification, soil CO_2 exchange rate, metabolizable energy, rotation.

Introduction

Soil is a dynamic resource that supports plants. It has biological, chemical, and physical properties which respond in different ways depending on how the soil is managed. A wide range of physical and chemical soil properties are used trying to evaluate suitability of a particular soil management system. It is recognized internationally, that favourable soil characteristics should be accomplished by utilizing management practices that optimize the processes found in native soils under local soil and climatic conditions (Latey et al., 2003).

Lithuania's mineral soils could be marked out as having two inherent features: shallow humic horizon and low nutrient content. To solve these problems a series of field experiments on soil tillage issues, including ploughing depth, were carried out during 1924–1950 at the Institute of Agriculture. The findings of these investigations were summarised by P. Vasinauskas. It was pointed out that when a soil having a shallow plough (humic) horizon was ploughed somewhat deeper, then the deeper ploughing was an affective measure for soil fertility improvement, and as a rule, the deep ploughing favoured yield increase of different agricultural crops. In addition, the basic conclusion has been drawn stating that weed-free fields, especially those where potatoes and beets had been grown could not to be ploughed in the autumn, but shallow cultivated in spring before barley sowing (Vasinauskas, 1950).

We would like to highlight a very important fact in Lithuania's history of agriculture that this statement published by P. Vasinauskas in early 1950's is to be considered as the very first scientific idea about the feasibility of reduced tillage application in Lithuania.

The very first field experiment designed to study ploughing depth in a 9-course crop rotation was established in 1956 at the Lithuanian Institute of Agriculture (Petraitis, Zimkuvienė, 1999). This outstanding long-term experiment is still running. The results of this experiment in mid-1980s revealed that crop yielding was not in all cases higher under deep ploughing. It was suggested to alter ploughing depth in a crop rotation (Arlauskas, 1987). It was also recommended that not ploughed soil before crop sowing could be cultivated to 10–12 cm depth, or rotary tilled down to 12–14 cm depth (Šimanskaitė, 1996).

Improvement of soil quality under intensive land use and fast economic development is a major challenge for sustainable resource use in the developing world. Propagation of sustainable soil management technologies implementation in practical farming becomes very important world wide (Andrews et al., 2004). An insufficient use of the results of long-term field experiments is not responsible and it means harm to research capacities. Long-term experiments are very expensive, but under the conditions of comprehensive and coordinated evaluation they still represent the most cost-effective research method. With the knowledge obtained on the basis of long-term field experiments farmers could double the yields in the last decades, improve the quality of the products and the environmental protection and secure the sufficient human nutrition. In the concluding scientific and practical experience the following points were emphasized: contribute to the maintenance of the European long-term field trials, as they are essential for agricultural and environmental research; support the efforts aiming at more extensive and cooperative use of the long-term field trials, which are a basis of the research on sustainable land use; help to use the scientific knowledge originating in the long-term field trials to increase food production by means of maintenance of the soil quality and protection of natural resources; contribute to keeping the long-term field trials available and functioning effectively as a scientific heritage for future generations (Tebrügge, Düring, 1999; Körschens, 2006).

Climate change is becoming also one of the main factors directly or indirectly affecting the productivity of agricultural crops. Reality of climate changes requires a careful revision of traditional soil and plant management technologies (Feiza et al., 2004). Noways, sustainable soil management technologies implementation in practical farming is important, but, in turn, land and soil management encourages observing essential changes which demonstrate a soil.

The goal of this paper is to present newly obtained data on soil physical and chemical properties changes, weediness, crop yielding capacity from long-term (lasting longer than 10 successive years till now) tillage experiments carried out in the middle lowland of Lithuania on *Endocalcari-Epihypogleyic Cambisol*, at the Institute of Agriculture, Lithuanian Research Centre for Agriculture and Forestry (former Lithuanian Institute of Agriculture).

Materials and methods

The results presented in this paper were obtained from three long-term field experiments located at the Institute of Agriculture (55º24′ N and 23º52′ E). One of them was set up in 1956 on a sandy loam *Endocalcari-Endohypogleyic Cambisol* (experiment I). In 2004, the long-term experiment was reconstructed according to the following design: 1) stubble cultivation to 10–12 cm depth, mouldboard ploughing to 22–23 cm depth, tillage by a precision seedbed cultivator before sowing, sowing by a disc-coulter drill (CT); 2) stubble cultivation to 10–12 cm depth, tillage by a precision seedbed cultivator before sowing, sowing by a disc-coulter drill (RT-I); 3) stubble cultivation to 10–12 cm depth, sowing by a disc sowing unit DS-3 (RT-II); 4) no tillage, sowing by a disc sowing unit DS-3 (NT-I); 5) no tillage, direct sowing by a sowing unit with a rotary cultivator (NT-II). The base of experiment reconstruction has remained the same (tillage depth) as it was set up in 1956. New modern tillage equipment was introduced. Direct drilling was introduced instead of long-term treatment – shallow ploughing according to the need. Crop sequence in the experiment was as follows: field pea-winter wheat-spring wheat and spring barley. Each year, 3 weeks after harvesting of previous crop, non-selective herbicide (a.i. glyphosate at a dose of 1.44 l ha^{-1}) was sprayed in treatments 2–5 to control weeds and volunteer plants. Basic soil properties at the filed experiment reconstruction in 2004 are described in Table 1.

Table 1. Soil characteristics before last rotation of experiment I in 2004

Tillage system	Arable layer cm	Available P_2O_5 mg kg^{-1}	Available K_2O mg kg^{-1}	pH_{KCl}	Humus %	Organic C %	Total N %
	Indices						
CT	32	218	202	6.9	2.64	1.54	0.156
RT-I	30	218	192	7.0	2.91	1.69	0.175
RT-II		208	184	6.8	2.99	1.74	0.177
NT-I		218	193	6.8	2.96	1.71	0.170
NT-II		228	195	6.8	2.75	1.59	0.159

Other long-term field experiments were established in 1999 on an *Endocalcari-Epihypogleyic Cambisol*. Soil texture is loam (experiment II) and sandy loam (experiment III). Field experiments consisted of 4 replicates of a randomized split-plot design. Each replicate included 3 tillage systems: conventional tillage (CT) – deep ploughing (23–25 cm) + spring tine cultivation (4–5 cm), reduced tillage (RT) – shallow ploughing (14–16 cm) + spring tine cultivation (4–5 cm), no tillage (NT) – direct drilling. Each tillage treatment consisted of 3 fertilisation levels: 1) not fertilised, 2) moderate rates – NPK fertilisers according to soil properties and expected yield and 3) high rates – the rates of NPK fertilisers higher by 30% than in treatment 2.

Crop rotation was as follows: winter wheat-sugar beet-spring wheat-spring barley-peas-winter wheat-oil-seed rape, spring wheat and spring barley. Each year, 3 weeks after harvesting of previous crop, non-selective herbicide (a.i. glyphosate at a dose of 1.44 l ha^{-1}) was sprayed in tillage treatment NT to control weeds and volunteer plants. Basic soil properties at the filed experiments establishment are presented in Tables 2 and 3.

Table 2. Soil texture of field experiments II and III

Soil layer cm	Soil particles %					
	Experiment II – loam			Experiment III – sandy loam		
	sand (2.0–0.05 mm)	silt (0.05–0.002 mm)	clay (<0.002 mm)	sand (2.0–0.05 mm)	silt (0.05–0.002 mm)	clay (<0.002 mm)
0–20	51.76	28.96	19.28	53.71	32.58	13.71
20–40	47.53	40.87	11.60	53.66	33.91	12.43

Table 3. Soil characteristics of field experiments II and III at establishment in 1999

Soil of field experiments	Indices ± standard error (S_x)					
	Arable layer cm	Available P_2O_5 mg kg^{-1}	Available K_2O mg kg^{-1}	Total N %	Humus %	pH_{KCl}
Loam	34	320 ± 7.6	261 ± 1.9	0.123 ± 0.0012	2.10 ± 0.023	6.8 ± 0.02
Sandy loam	30	107 ± 2.7	157 ± 2.2	0.108 ± 0.0010	1.60 ± 0.010	6.2 ± 0.06

Soil texture was determined according to Sheldric and Wang (1993). Soil bulk density (BD) was determined according to Kachinsky method. Cone penetration resistance (PR) was determined by hand-held penetrometer “Eijkelkamp”. The penetration measurements were taken in increments of 5.0 cm, from the soil surface down to 20 cm depth, with a penetration velocity of about 1 m min^{-1}. PR was determined at one position, i.e. in the untrafficked interrow. Soil air permeability (AP) was determined according to Anderson method. Soil texture was determined by pipette method. Available P_2O_5 ir K_2O mg kg^{-1} were determined by ammonium lactate (A-L) extraction method (Egner et al., 1960) nitrogen was determined by Kjeldahl method, pH – electropotentiometric method, soil water content – by frequency domain reflectometry method with HH2-WET sensor and net CO_2 exchange rate – by closed chamber method with SRS-1000 analyser. Closed (non-steady state) chambers are widely used for quantifying carbon dioxide (CO_2) fluxes between soils or low-stature canopies and the atmosphere. It is well recognised that covering a soil or vegetation by a closed chamber inherently disturbs the natural CO_2 fluxes by altering the concentration gradients between soil, vegetation and the overlying air. The closed chamber method is often applied to quantify the net CO_2 exchange between the atmosphere and low-stature canopies typical for agricultural crop stands (Dugas et al., 1997; Wagner et al., 1997; Maljanen et al., 2001; Steduto et al., 2002; Kutzbach et al., 2007).

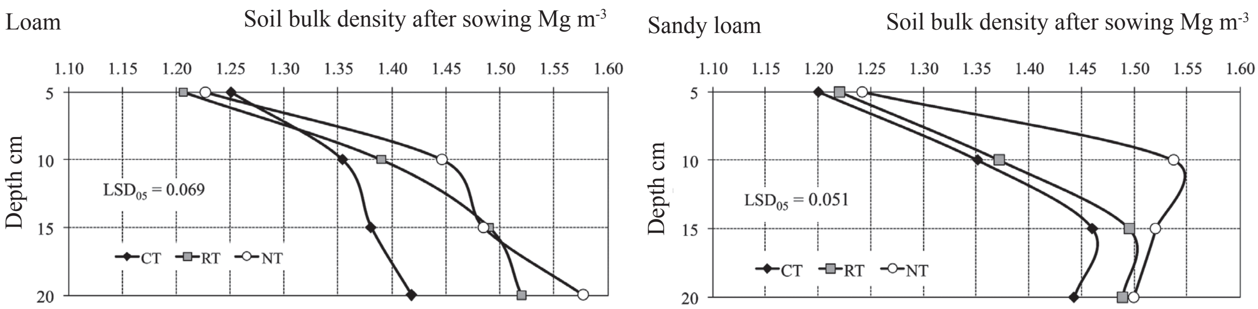
Metabolizable energy (ME) was calculated according to formula: ME = Σ (xa), where x – dry matter yield of crop t ha^{-1}, a – ME coefficient (for winter and spring wheat 13.87 MgJ kg^{-1}, sugar beet 13.69 MgJ kg^{-1}, spring barley 12.84 MgJ kg^{-1}, oil seed rape 18.20 MgJ kg^{-1}, peas 13.87 MgJ kg^{-1}) (Aleksynas, 1990).

For statistical data analyses Fisher's protected LSD test was applied.

Results and discussion

Bulk density (BD). According to investigations of A. Tindžiulis, the optimal value of BD for plant growing on loamy soils is about 1.1–1.2 Mg m^{-3} (Tindžiulis, 1979). Our investigations revealed that BD was very much influenced by the tillage system in the 10th year of investigations and rather well followed the intensity of soil tillage (Fig. 1). BD at the top 0–5 cm soil layer was close to the optimal in all tillage treatments, while in the 5–10, 10–15 and 15–20 cm soil layer the highest BD was determined under NT system application in the both experiments II and III. BD at 10 cm soil depth was significantly higher under NT system in sandy loam than in loam. This index at 10 cm soil depth in sandy loam reached up to 1.54 Mg m^{-3}, while on loam it was 1.44 Mg m^{-3}. On sandy loam BD in the 10–20 cm soil layer did not differ significantly in the CT and RT systems. The deeper soil layer the higher BD was registered irrespective of the tillage system applied. Our findings are in general line with the data obtained by other Lithuanian scientists (Šimanskaitė, 1996; Trečiokas, Raudonius, 1999; Stancevičius et al., 2003).

Penetration resistance (PR). PR is a very valuable indicator to describe and evaluate soil physical state. PR is influenced by other soil properties: the size of soil aggregates, soil moisture content and bulk density. As a common rule, the lower soil moisture content the higher bulk density; the larger amount of small-size soil aggregates results in a higher PR. Very often, reduced tillage tends to increase PR compared to conventional tillage (Da Veiga et al., 2007).

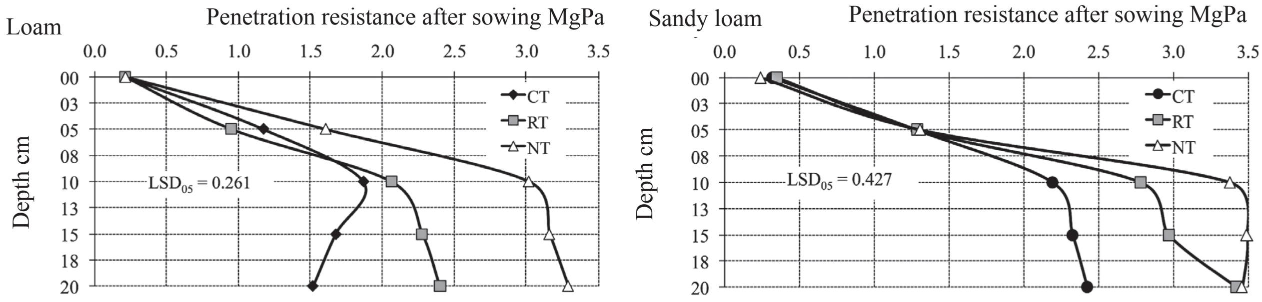


Note. CT – conventional tillage, RT – reduced tillage, NT – no tillage, direct drilling.

Figure 1. Soil bulk density on loam and sandy loam (experiments II and III respectively) after crop sowing in 2009

PR in the 0–2.5 cm soil layer did not differ significantly after crop sowing in all tillage treatments and on both loam and sandy loam. PR in the 5 cm soil depth did not differ significantly after crop sowing on loam under CT and RT systems, while in the NT system it was higher by 37–68% as compared to the CT and RT (Fig. 2).

On sandy loam, PR in the 5 cm soil depth was the same in all tillage treatments. PR under RT in the 10–20 cm soil layer on both loam and sandy loam was higher by 28–36% and under NT by 41–58% higher than under CT. Soil agrophysical parameters are interrelated. By changing one of them the rest properties also change. It should be noted that correlation-regression analysis of our experimental data showed an inverse strong relationship (r = −0.86, $P \leq 0.01$) between PR and soil moisture content at 0–20 cm soil depth on both loam and sandy loam during all crops vegetation period by applying any of the tillage systems investigated (Kadžienė et al., 2007; Feiziene et al., 2008). A moderately strong correlation was determined between BD and PR (r = 0.66, $P \leq 0.05$). Detailed investigations in field experiments II and III and exponential regression revealed that if bulk density did not exceed 1.41 Mg m^{-3} and penetration resistance did not exceed 1 MPa, the soil physical conditions still remained suitable for crop growing (Feiza et al., 2008).

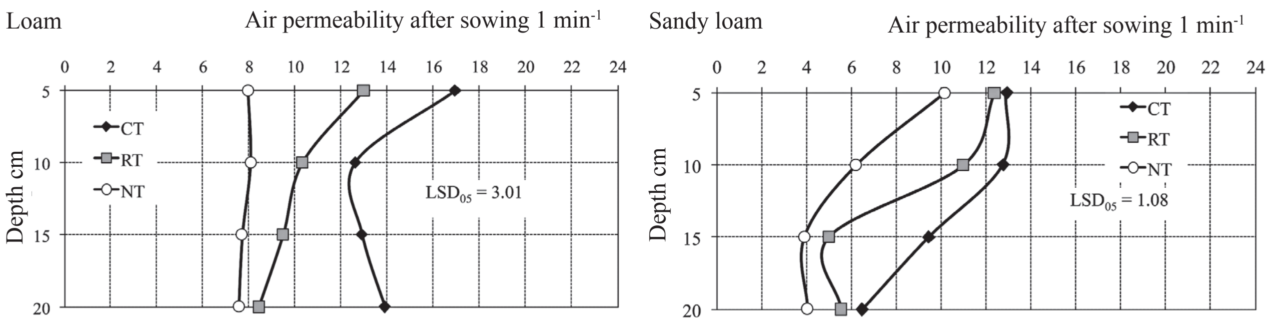


Note. CT – conventional tillage, RT – reduced tillage, NT – no tillage, direct drilling.

Figure 2. Soil penetration resistance on loam and sandy loam (experiments II and III respectively) after crop sowing in 2009

Air-permeability (AP). The best AP after crop sowing was registered under CT system application (Fig. 3).

On loam, in the 0–5 cm soil layer, the AP under RT was by 23% lower and under NT by 53% lower as compared to AP in the CT system. On sandy loam, the AP under RT was by 4% lower and under NT by 21% lower as compared to AP in the CT system. AP differences in deeper layers in both experiments remained significant like those at 0–5 cm. However, it should be noted that AP differences in 15–20 cm layer on both loam and sandy loam after RT and NT application were lesser than in 0–10 cm layer. Conversely, AP differences in 15–20 cm layer after RT and CT application were higher than in 0–10 cm layer.

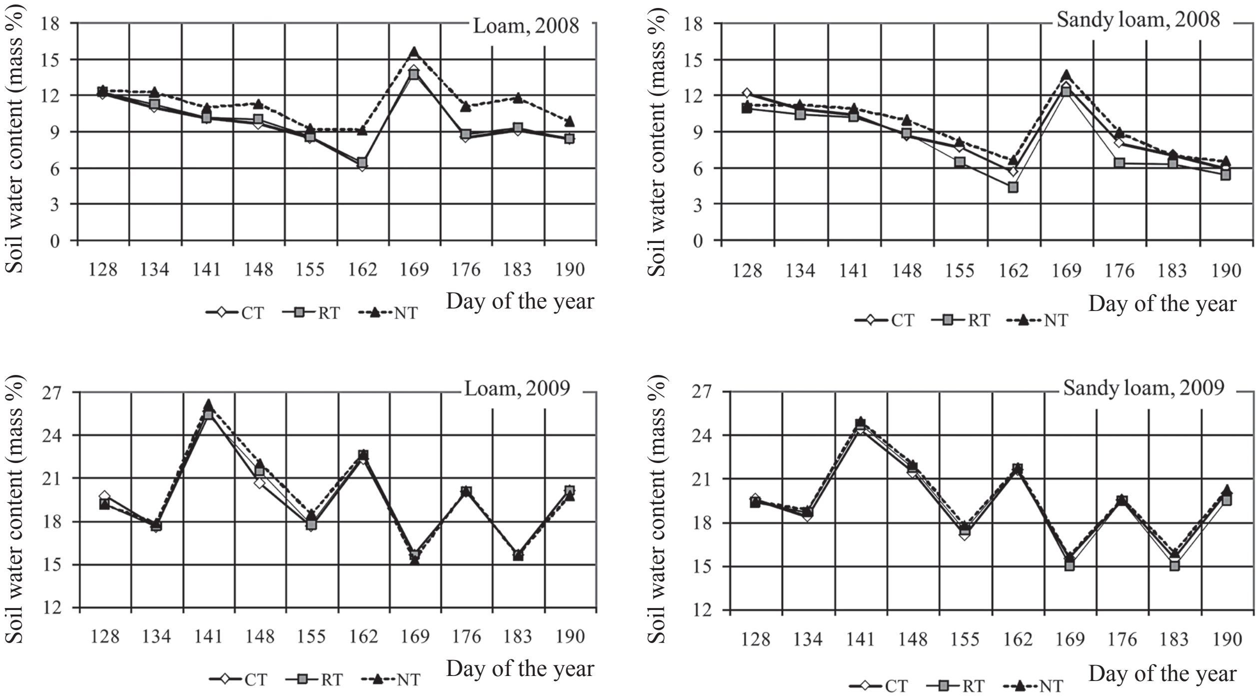


Note. CT – conventional tillage, RT – reduced tillage, NT – no tillage, direct drilling.

Figure 3. Soil air-permeability on loam and sandy loam (experiments II and III respectively) after crop sowing in 2009

Soil water content (SWC) depended on year meteorological conditions and tillage traits. SWC at 0–10 cm depth, on the loam was higher on average by 1.9 fold and on the sandy loam by 2.2 fold in 2009 than in 2008 (Fig. 4). It was higher in NT than in RT and CT on a day of the dry 2008 year (DOY) 134, 141, 148, 155, 162, 169, 176, 183 and 190.

Soil water storage in 2008 on the loam was greater on average by 15.04 g kg^{-1} than on the sandy loam. Application of NT on both loam and sandy loam increased soil SWC on average by 13.50 g kg^{-1} and 10.38 g kg^{-1} compared to RT and CT respectively, however it was observed that SWC on the loam in NT treatment was higher by 14.60–15.92 g kg^{-1} than in RT and CT, while on the sandy loam this distinction amounted only to 4.83–12.40 g kg^{-1}. In wet 2009, soil SWC averaged between soil textures and was higher in NT than in RT and CT on DOY 134, 141, 148, 155, 162, 169, 183 and 190. Water storage on the loam was greater on average by 2.19 g kg^{-1} than on the sandy loam. Application of NT on both loamy soil and sandy loam increased SWC on average by 2.43 g kg^{-1} and 2.46 g kg^{-1} compared to RT and CT respectively, meanwhile SWC on the loam in NT treatment was higher by 1.54–1.97 g kg^{-1} than in RT and CT (difference was not significant), while on the sandy loam this distinction amounted only 2.95–3.32 g kg^{-1}.



Note. CT – conventional tillage, RT – reduced tillage, NT – no tillage, direct drilling.

Figure 4. Soil water content changes on loam and sandy loam (experiments II and III respectively) in 2008 and 2009

Our results evidenced that under global warming conditions the application of the NT system may be the right measure to preserve soil moisture at the early stage of crop development.

NPK ratio. Change of ratio "*nutrient 0–10 cm depth / nutrient 10–20 cm depth*" demonstrates different character of total N, available P_2O_5 and K_2O stratification in soil arable layer during crop rotation period under different tillage systems (Table 4).

On sandy loam, the change in ratio "*N 0–10 cm depth / N 10–20 cm depth*" under CT and RT systems application was negative and amounted to 4.4–5.1% and 3.1–11.7%, respectively. This means that the total N reduction from top soil layer occurred due to crop N removal or due to greater leaching processes taking place as compared to that of NT system. Under NT the change in ratio "*N 0–10 cm depth / N 10–20 cm depth*" over crop rotation period was positive and amounted to 2.5–16.0%. On loam soil, the change in this ratio under CT and RT system application was not significant, while under NT it reached 9.7–12.2%. It means that conditionally higher amount of total N occurred on the top 0–10 cm soil layer compared to 10–20 cm soil layer.

Phosphorus (P_2O_5) stratification was irregular and not significant on loam under CT and RT systems application. Phosphorus was distributed evenly within 0–10 and 10–20 cm soil layer. Under NT the change in ratio "*P_2O_5 0–10 cm depth / P_2O_5 10–20 cm depth*" over crop rotation period was negative (on average 6.7%). This also means that more phosphorus was removed from the top soil layer compared to 10–20 cm. On sandy loam, phosphorus stratification under conventional tillage was irregular, while under RT it increased by 5.2–15.3% and under NT – by 31.7–64.7%. This phosphorus increase in top soil layer shows increasing concentration of this nutrient within 0–10 cm soil depth.

Potassium (K_2O) stratification was also negligible on loam under CT and RT systems application. Potassium was distributed evenly within 0–10 and 10–20 cm soil layer. Under NT the change in ratio "*K_2O 0–10 cm depth / K_2O 10–20 cm depth*" over crop rotation period was positive (40.8–60.7%). On sandy loam potassium stratification under CT was irregular, while under RT it increased by 11.4–12.7% and under NT – by 64.7–127.6%. Similar to phosphorus, the increase of potassium in top soil layer was also documented.

Table 4. Nutrient ratio on loam and sandy loam (experiments II and III respectively) in arable layer during crop rotation under different tillage-fertilisation systems application

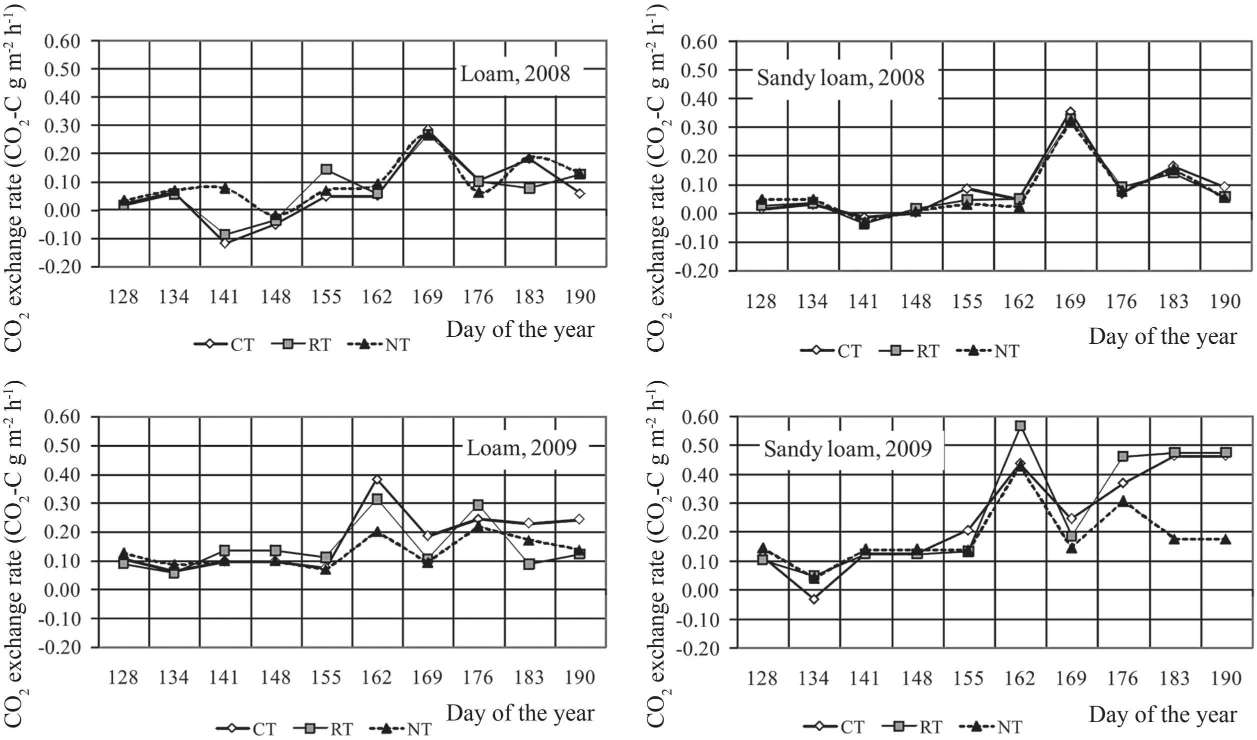
Time of nutrient ratio estimation	Tillage								
	Conventional (CT)			Reduced (RT)			No tillage (NT)		
	NPK rates								
	Not fertilised	Moderate rates	High rates	Not fertilised	Moderate rates	High rates	Not fertilised	Moderate rates	High rates
Loam									
Total N (%)									
At the beginning of crop rotation	1.00	1.02	1.02	0.99	1.00	0.97	0.96	1.00	1.01
At the end of crop rotation	0.99	0.98	0.99	1.01	0.98	0.99	1.07	1.12	1.11
Change %	−1.4	−4.3	−2.4	2.0	−2.1	1.9	11.8	12.2	9.7
Available P_2O_5 (A-L mg kg^{-1})									
At the beginning of crop rotation	0.99	0.97	0.94	0.97	1.01	0.89	1.12	0.96	1.08
At the end of crop rotation	1.06	1.01	0.91	0.94	0.95	1.01	1.03	1.00	0.90
Change %	6.6	4.0	−2.5	−2.5	−5.3	13.5	−8.0	4.3	−16.5
Available K_2O (A-L mg kg^{-1})									
At the beginning of crop rotation	0.91	0.92	0.99	0.92	0.98	0.91	0.96	0.98	0.97
At the end of crop rotation	0.99	0.95	1.17	1.00	1.05	0.95	1.36	1.56	1.56
Change %	8.1	2.9	18.6	8.6	6.8	4.1	40.8	60.2	60.7
Sandy loam									
Total N (%)									
At the beginning of crop rotation	0.97	0.98	0.95	1.07	0.99	1.00	0.99	1.05	1.08
At the end of crop rotation	0.92	0.99	0.91	0.95	0.91	0.97	1.15	1.10	1.11
Change %	−5.1	0.6	−4.4	−11.7	−8.4	−3.1	16.0	5.0	2.5
Available P_2O_5 (A-L mg kg^{-1})									
At the beginning of crop rotation	0.87	1.16	1.04	0.91	1.03	0.98	0.97	0.93	1.00
At the end of crop rotation	1.03	1.02	0.95	1.00	1.08	1.13	1.28	1.50	1.66
Change %	17.9	−12.4	−9.2	9.9	5.2	15.3	31.7	62.4	64.7
Available K_2O (A-L mg kg^{-1})									
At the beginning of crop rotation	0.89	1.16	0.89	0.81	0.86	0.92	0.86	0.73	0.85
At the end of crop rotation	1.07	0.99	1.02	0.90	0.96	1.04	1.55	1.67	1.40
Change %	19.3	−15.0	14.1	11.4	11.7	12.7	80.5	127.6	64.7

Soil CO_2 net exchange rate (NCER). Because of contrasting meteorological conditions, the experimental data significantly differed between 2008 and 2009 years (Fig. 5). Mean soil CO_2 exchange rate (NCER) on both soils with different texture in humid 2009 was higher by 0.115 g CO_2-C m^{-2} h^{-1} than in dry 2008 (LSD_{01} = 0.037) and mean NCER during a two-year experiment period on loamy soil was lesser by 0.043 g CO_2-C m^{-2} h^{-1} compared to sandy loam (LSD_{05} = 0.027).

On the loam, difference of mean NCER between 2008 and 2009 years amounted to 0.072 g CO_2-C m^{-2} h^{-1}; certainly this index was higher under humid conditions in 2009. Whereas, on the sandy loam identical difference of this measurement value was greater than on the loam and amounted 0.158 g CO_2-C m^{-2} h^{-1}.

Soil NCER varied between different year meteorological conditions, soil texture classes and among tillage practices. It was observed that average soil CO_2 flux, on the loam was higher on average by 1.9 fold and on the sandy loam by 3.1 fold in 2009 than in 2008 (LSD_{01} = 0.16). In dry 2008 the NCER, averaged across soil texture and tillage practices, increased from 0.025 g CO_2-C m^{-2} h^{-1} (on DOY 128) to 0.303 g CO_2-C m^{-2} h^{-1} (on DOY 169), after which it declined. In humid and cloudy 2009 it ranged from 0.118 g CO_2-C m^{-2} h^{-1} (on DOY 128) to 0.387 g CO_2-C m^{-2} h^{-1} (on DOY 162), after which it also decreased.

In 2008, the NCER was higher on the loam than on the sandy loam on DOY 128, 134, 155, 162, 176 and 190, while average values of the measurements per year on loam and on sandy loam did not statistically differ. Soil NCER averaged between soil textures and was highest in NT treatment (0.084 g CO_2-C m^{-2} h^{-1}) (LSD_{01} = 0.005). However, CO_2 flux on the loam in NT treatment was higher by 0.024–0.033 g CO_2-C m^{-2} h^{-1} than in RT and CT, while on the sandy loam this distinction was reverse, i.e. CO_2 flux in NT treatment was lesser by 0.011 g CO_2-C m^{-2} h^{-1} than in CT, but not significantly differed from RT (LSD_{01} = 0.009).



Note. CT – conventional tillage, RT – reduced tillage, NT – no tillage, direct drilling.

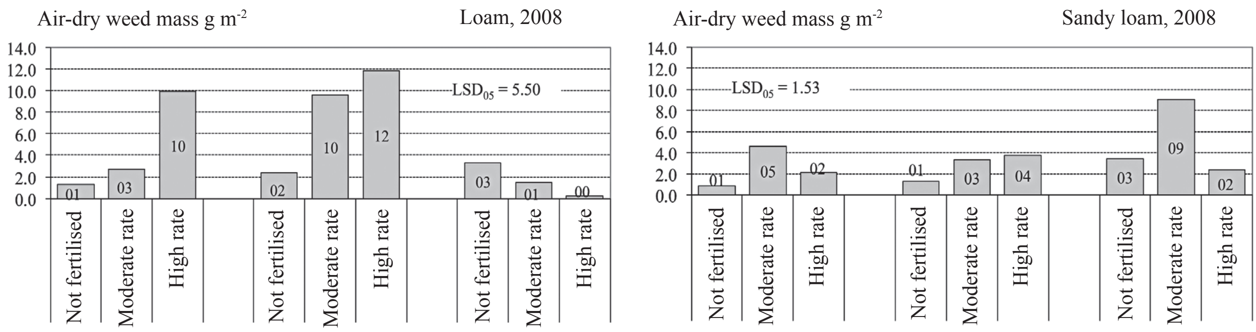
Figure 5. Soil CO_2 net exchange rate on loam and sandy loam (experiments II and III respectively) in 2008 and 2009

In 2009, NCER was higher on the loam than on the sandy loam only on DOY 134. Soil NCER averaged between soil textures and contrary to expectations was highest in CT treatment (0.212 g CO_2-C m^{-2} h^{-1}) (LSD_{01} = 0.019). CO_2 flux on the loam in NT treatment was lesser by 0.043 g CO_2-C m^{-2} h^{-1} than in CT, but not significant differed from RT; whereas on the sandy loam CO_2 flux in NT treatment was lesser by 0.069–0.087 g CO_2-C m^{-2} h^{-1} than in RT and CT (LSD_{05} = 0.024).

Weediness. A disadvantage of RT and NT is difficulty in controlling weeds. Weed control strategies, such as crop rotation and herbicide application may be the only practical way to eliminate weeds from the field. Density of weed populations may increase under RT and NT because weed seeds tend to accumulate in the topsoil layer under conditions that favour germination by some species (Cardina et al., 1991; Buhler, 1995; Spandl et al., 1999; Nakamoto et al., 2006).

Because chemical weed control had been carried out every year, the air-dry mass of weeds in both tillage-fertilisation experiments was low (Fig. 6). As a result, weed infestation was not a problem in RT and NT systems. On loam, average mass of weeds in CT was 4.6, in RT 7.9 and in NT 1.7 g m^{-2}. On sandy loam, average mass of weeds in CT was 2.6, in RT 2.8 and in NT 5.0 g m^{-2}. It is important that each year, 3 weeks after harvesting of previous crop, non-selective herbicide (a.i. glyphosate at a dose of 1.44 l ha^{-1}) was sprayed in NT to control weeds and volunteer plants. It is likely that better soil properties on loam caused stronger weed development than on sandy loam. The heavier weed population, the greater its leaf area, the more even distribution of unwanted plants was registered, the more favourable conditions for herbicide action were created. Therefore a combination of NT and glyphosate application on sandy loam was less effective than mechanical weed control in CT and RT.

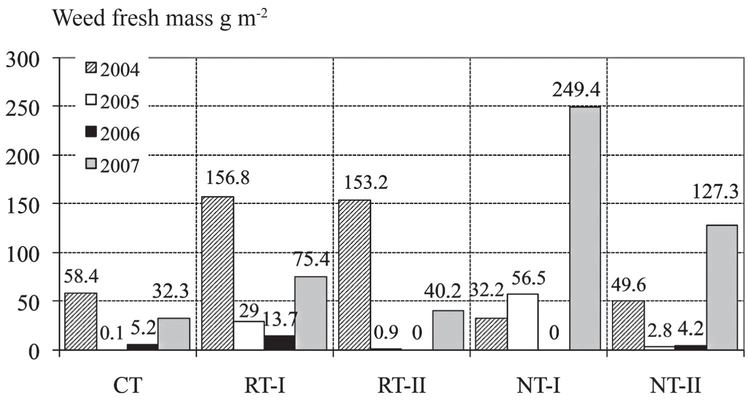
No statistically significant differences were registered on weed infestation between fertilisation rates on loam soil. While on sandy loam soil, the moderate rates of fertilisers increased air-dry mass of weeds, but after application of high rates of fertilisers the air-dry mass of weeds reduced. The reason of this could be that the better nutrition caused better crop competitive ability on weeds.



Note. CT – conventional tillage, RT – reduced tillage, NT – no tillage, direct drilling.

Figure 6. Air-dry mass of weeds on loam and sandy loam (experiments II and III respectively) at the end of an 8-course crop rotation)

Each year in reconstructed experiment, non-selective herbicide (a.i. glyphosate at a dose of 1.44 l ha^{-1}) was sprayed in treatments RT-I, RT-II, NT-I and NT-II three weeks after harvesting of previous crop, to control weeds and volunteer plants. Weed fresh mass in CT treatment varied in different years from 0.1 to 58.4 g m^{-2} during a 4-course crop rotation period (Fig. 7).

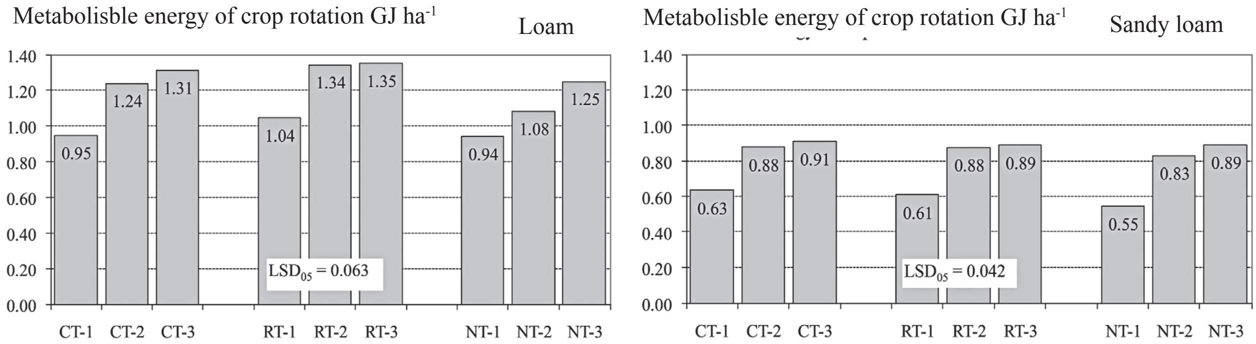


Note. CT – conventional tillage, RT-I – reduced tillage I, RT-II – reduced tillage II, NT-I – no tillage I, NT-II – no tillage II.

Figure 7. Weed fresh mass changes during a 4-course crop rotation (experiment I)

In CT treatment, the changes in weed incidence were irregular. Application of RT-I and RT-II systems tended to decrease mass of weeds during investigation period. Opposite results were obtained in NT-I and NT-II systems. Significantly highest fresh mass of weeds (127.3–249.4 g m^{-2}) was registered in the last year of crop rotation.

Productivity of crop rotation. Different tillage, fertilisation and soil conditions produced different crop yields in both tillage-fertilisation experiments (Fig. 8). The sum of metabolizable energy (ME) on loam was higher by 50% than on sandy loam during 8-course crop rotation. On loam, highest ME was accumulated in RT system (1.25 GJ ha^{-1}), while NT application produced the lowest amount (1.09 GJ ha^{-1}) of ME. Use of CT was in the middle position between RT and NT (LSD_{01} = 0.032). Application of moderate rate of NPK fertilisers in CT and RT systems increased ME by 29–31%, compared to not fertilised treatments. While in the NT system this increase was only 15%. Effectiveness of moderate rate of NPK fertilisers significantly decreased in this order according to tillage intensity: CT → RT → NT. Application of high rate of fertilisers was not effective in RT system, but in NT system this measure increased ME by 16% and in CT system by 6% compared to moderately fertilised treatments (LSD_{01} = 0.032).

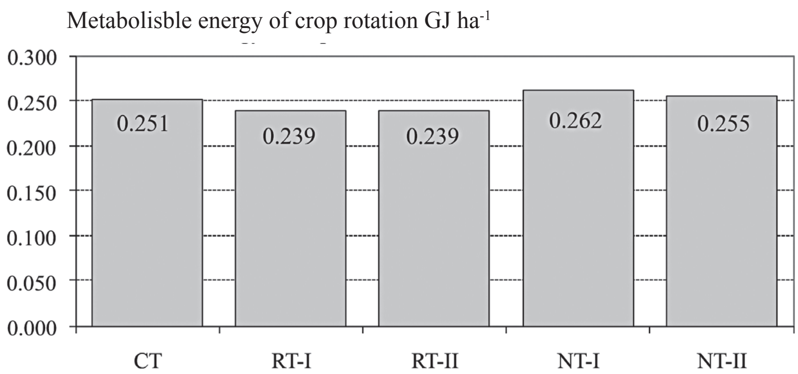


Note. CT – conventional tillage, RT – reduced tillage, NT – no tillage, direct drilling; 1 – not fertilised, 2 – moderate rate, 3 – high rate.

Figure 8. Metabolizable energy accumulated during an 8-course crop rotation on loam and sandy loam (experiments II and III respectively)

On sandy loam, the highest ME was accumulated in CT system (0.81 GJ ha^{-1}), while NT application produced the lowest amount (0.76 GJ ha^{-1}) of ME. Use of RT was in the middle position between CT and NT (LSD_{01} = 0.028). Effectiveness of moderate rate of NPK fertilisers increased in this order according to tillage intensity: CT → RT → NT. The less soil mechanical disturbance was produced by tillage system, the higher efficacy of moderate rate was registered. Efficacy of high rate of fertilisers was not significant in all tillage systems investigated compared to moderately fertilised treatments (LSD_{01} = 0.028).

ME accumulated during the last 4-course crop rotation from long-term field experiment established in 1956 revealed that there were no significant differences among tillage systems (Fig. 9). These data are in line with the previous results of this experiment. The reason of this could be that soil rich in nutrients and organic matter did not clearly respond to tillage depth.



Note. CT – conventional tillage, RT-I – reduced tillage I, RT-II – reduced tillage II, NT-I – no tillage I, NT-II – no tillage II.

Figure 9. Metabolizable energy accumulated during last 4-course crop rotation (experiment I)

Conclusions

1. CT produced the best soil physical properties (the lowest bulk density, cone penetration resistance, and the highest air permeability). Significantly worse soil physical properties were registered after NT, while under global warming conditions the application of the NT system may be the right measure to preserve soil moisture at the early stage of crop development.

2. NT caused higher soil total N, available P_2O_5 and K_2O stratification in soil during crop rotation period compared to RT and CT.

3. During an 8-course crop rotation, on loam the highest ME was accumulated in RT system, NT application produced the lowest amount of ME. The use of CT was in the middle position between RT and NT. On sandy loam, the highest ME was accumulated in CT system, NT application produced the lowest amount of ME. The use of RT was in the middle position between CT and NT. Effectiveness of moderate rate of NPK fertilisers on loam decreased in this order according to tillage intensity: CT → RT → NT, while on sandy loam the effectiveness of moderate rate of NPK fertilisers tended to increase in the same tillage order. Application of high rate of fertilisers on loam was not effective in CT and RT systems, but in NT system this measure increased ME by 16% compared to moderately fertilised treatments. Efficacy of high rate of fertilisers on sandy loam was not significant in all tillage systems investigated compared to moderately fertilised treatments.

4. The heavier weed population, the more favourable conditions for herbicide action were created. As a result, a combination of NT and glyphosate application on sandy loam was less effective than mechanical weed control in CT and RT.

5. In CT treatment, the changes in weed incidence were irregular in a 4-course crop rotation in the experiment set up in 1956. Application of both RT systems tended to decrease mass of weeds during the experimental period. Opposite results were obtained in both NT systems.

6. NT application produced significantly less metabolizable energy during an 8-course crop rotation, compared to CT and RT on both loam and sandy loam.

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Tausojamasis žemės dirbimas: ilgamečių lauko bandymų rudžemyje rezultatai

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Santrauka

Straipsnyje pateikiami nauji dirvožemio fizikinių bei agrocheminių savybių, pasėlio piktžolėtumo pokyčių ir augalų derlingumo tyrimų duomenys, gauti Lietuvos agrarinių ir miškų mokslų centro Žemdirbystės institute vykdant ilgamečius, ilgesnius nei 10 metų, žemės dirbimo tyrimų lauko bandymus, kurie įrengti Vidurio Lietuvoje, Dotnuvoje, giliau karbonatingame sekliai glėjiškame rudžemyje (RDg8-k2), *Endocalcari-Epihypogleyic Cambisol* (*CMg-p-w-can*). Geriausios dirvožemio fizikinės savybės (mažiausias tankis, kietumas ir didžiausias oro laidumas) nustatytos žemę dirbant tradiciniu būdu (CT). Iš esmės prastesnės dirvožemio fizikinės savybės buvo nedirbtai dirvai taikant augalų tiesioginę sėją (NT), tačiau galimo klimato atšilimo sąlygomis ši žemdirbystės sistema padeda tausoti drėgmės kiekį viršutiniame dirvos sluoksnyje po sėjos ir ankstyvuoju augalų augimo tarpsniu. NT lėmė didesnę suminio N, judriųjų P_2O_5 ir K_2O stratifikaciją dirvožemio sluoksniuose per sėjomainos rotaciją, palyginti su CT ir supaprastinto (RT) žemės dirbimo sistemų taikymu. Mineralinių NPK trąšų vidutinių normų efektyvumas priemolio dirvožemyje mažėjo žemės dirbimo intensyvumui mažėjant taip: CT → RT → NT, o jų efektyvumas smėlingo priemolio dirvožemyje didėjo žemės dirbimo intensyvumui mažėjant tokia pat seka. Tręšimas didesniu kiekiu mineralinių NPK trąšų priemolio dirvožemyje buvo neefektyvus taikant CT bei RT žemės dirbimo sistemas, tačiau taikant NT toks tręšimas pagrindinėje produkcijoje sukauptos apykaitinės energijos (AE) kiekį padidino 16 %, palyginti su AE kiekiu produkcijoje, patręšus pagal vidutines trąšų normas. Smėlingo priemolio dirvožemyje tręšimas didesniu kiekiu mineralinių NPK trąšų buvo neefektyvus taikant visas tirtas žemės dirbimo sistemas, palyginti su tręšimu pagal vidutines trąšų normas. Kuo didesnis buvo dirvų piktžolėtumas, tuo efektyviau piktžolės naikintos naudojant herbicidus. Plataus veikimo spektro (glifosato grupės) herbicido naudojimas kartu taikant NT smėlingo priemolio dirvožemyje buvo mažiau efektyvus nei taikant CT bei RT žemės dirbimo sistemas. Piktžolėtumo pokytis taikant CT nebuvo nuoseklus per 4 sėjomainos narių rotacijos laikotarpį rekonstruotame ilgamečiame bandyme. RT taikymas turėjo tendenciją mažinti piktžolių žalią masę. Taikant NT buvo sukauptas iš esmės mažesnis AE kiekis per 8 narių sėjomainos rotaciją, palyginti su CT ir RT taikymu vidutinio sunkumo priemolio ir smėlingo lengvo priemolio dirvožemiuose.

Reikšminiai žodžiai: fizikinės savybės, NPK stratifikacija, dirvožemio CO_2 apykaitos intensyvumas, apykaitos energija, sėjomaina.