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# An Assessment of Lime Filter Drainage Systems

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## 1. Introduction

Fine-textured clayey soils are of high fertility but often have a low hydraulic conductivity (Forsburg, 2003; Tuli et al., 2005). The infiltration of water into these soils is too slow therefore frequent surface ponding occurs. It follows that clay soils are usually poorly drained and difficult to manage when wet. Agricultural activities and mechanisation are extremely restricted without adequate drainage (Ritzema, 1994). Besides, clay soils often have a seasonal variation in hydraulic conductivity because of swelling and shrinking (Tuller & Or, 2003). Due to the swelling of clay, rainfall is unable to percolate deeper into drains. It either accumulates in depressions or discharges as surface runoff. Therefore the effectiveness of subsurface drainage of clay soils much depends on the permeability of trench backfill. Based on the assumption that 2.5% of the soil volume in a newly tile-drained clay soil is made up of backfill (0.5 m wide pipe trench and 20 m drain spacing), it is obvious that the backfilling method has a great impact on drainage efficiency of such soil (Ulén, 2007). Traditional subsurface drainage in such soils does not always ensure excess water removal within the normative period; therefore, adding of the amendments to the trench backfill increasing water infiltration rate is practiced frequently. The permeability of these soils can be greatly improved by filling the trenches with coarse material. In Western Europe gravel was used for drainage trench backfill (Ritzema, 1994; Smedema et al., 2004). However, in some countries this is too expensive because of the limit of natural resources of gravel.

Many researchers reported that lime additives contribute substantially to the change in the physical properties of clay soils (Puustinen, 2001; Rajasekaran & Narasimha, 2002; Halme et al., 2003; Mubeen, 2005; Cox et al., 2005). They referred that due to a certain rate of added lime the soil bulk density may be reduced by 25%, porosity increased by 30%, filtration coefficient increased 100-300 times, the amount of aggregates (0.25-10 mm) increased 3 times and the swelling practically disappear. As a result, soil mixed with lime is less susceptible to compaction, because calcium and magnesium carbonates may form hydro-silicates inducing soil resistance to the pressure. In addition, lime modifies the characteristics of clay particles so that they flocculate resulting in easier movement of all major ingredients in plant development i. e. higher amount of mobile phosphorus, potassium, nitrogen, sulphur, calcium and magnesium, and lower amount of mobile aluminium. Therefore, liming leads not only to an improved water regime but also to the changes in water quality.

Calcium carbonate ( $\text{CaCO}_3$ ), gypsum ( $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$ ), dolomitic limestone ( $\text{CaMg}(\text{CO}_3)_2$ ), quicklime ( $\text{CaO}$ ) or other calcium-containing materials may be used as liming material.

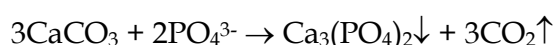
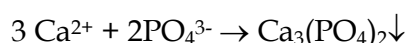
Lime is usually applied by spreading it on the soil surface. However, lime will not react well unless it is incorporated into the soil (Doss et al., 1979). Stable structure of clay soils may ensure properly prepared soil-lime mixture. Therefore it is crucial to mix thoroughly the soil with liming material before the arrangement of lime filters and the filling of the drainage trenches. To obtain excellent soil structure, the optimal proportion of lime should be determined. Unfortunately, there is insufficient research about the methods for calculation lime rates required to improve infiltration features of clay soils.

Nowadays usage of the drained land must be substantiated not only economically, but have also corresponded to the ecological requirements. Drainage impact on water quality is evaluated contradictorily. It stimulates the natural process of organic matter mineralization and expedites the transport of chemical substances from the soil zone to surface waters (Zucker & Brown, 1998; Busman & Sands, 2002). Therefore the new tasks and functions of land reclamation activities should be focused on the reduction of their negative action on the environment, which consists of the intensive emission of biogenic substances by drainage water (Skaggs et al., 1994; Heiskanen et al., 2004).

As in the clay soil the largest part of runoff discharges through more permeable drainage trenches, backfilled trench above drain tiles can be considered as a pathway for preferential transport of biogenic substances (Dekker et al., 2001; Cho et al., 2005). Preferential flow has always been conceived to have a detrimental impact on water quality because it moves solutes beyond the soil zone where both biotic and abiotic chemical reactions are usually at their highest potentials (Ryan 1998; Ekholm et al., 1999; Van den Eertwegh, 2006). In fine-textured soils preferential flow is generally considered more significant in contrast to coarse-textured soils, therefore for these soils additional measures should be considered to reduce leaching of pollutants (Van der Salm et al., 2007).

Various technologies are currently being developed to reduce concentrations of biogenic substances in tile effluent (Foy & Dils, 1998). Ionic composition of water changes with the introduction of calcium-containing materials to the soil. Increased soil pH influences the concentration of many dissolved ions in the soil solution. Literature sources affirmed that soil treated with lime amendments noticeably prevent the migration of phosphorus (Rhoton & Bigham, 2005), however, limited data is available on the alternation of the concentrations of other basic ions.

A method developed for clayey soils in Finland involves incorporating burnt lime (CaO) with the backfill material in drains (Weppling & Palko, 1994). Soils treated with lime contain high amount of soluble and exchangeable  $\text{Ca}^{2+}$  ions, and frequently also calcium carbonate  $\text{CaCO}_3$ . Phosphate is reported to react with both ionic and the carbonate form of Ca to form insoluble compounds (Tan, 2010). The reactions can be illustrated as follows:



Therefore the lime filter drainage acts as a mini chemical treatment plant and may be treated as one of water pollution control methods in agriculture (Rhoton & Bigham, 2005). The result is a stable and porous backfill that efficiently binds the phosphorus in percolating water (Curtin & Syers, 2001; Murphy & Stevens, 2010). The adsorbed phosphates are held

tightly and are generally resistant to leaching (Bergström et al., 2007). Phosphate binding capacity increases from sand to clay because of the adsorption of phosphorus to soil particles (Djodjic et al., 2004).

In 1995-1999, lime filter drainage (LFD) was installed on almost 1000 hectares of land in Finland as means to combat drainage-induced adverse environmental impacts of acid sulphate soils (Bärlund et al., 2005; Aström et al., 2007). The average lifetime for the LFD has been shown to exceed 10 years without any loss in treatment effect. In Sweden, the method has only been tested at one experimental site (Ulén, 2003) and the long-term effects have not been monitored.

The territory of Lithuania lies in the zone of excessive humidity; therefore, 88% of farmlands are artificially drained. The problem of agricultural non-point pollution is typical for Lithuania because the surplus of nutrients is leached from the soil profile to the drainage water. According to the data of the Agency of the Environment Protection, in 2005 concentrations of biogenic compounds exceeded the maximum admissible concentrations (MAC) in 64% of the investigated rivers. It was estimated that agriculture contributes from 42.2 to 71.1% of the total phosphorus load depending on the percentage of arable land (Šileika, 2010). However, there are large regional differences and great variations in the amounts of P lost from agricultural land as a result of differences in soils, soil hydrology and land use patterns (Valsami-Jones, 2004; Withers & Haygarth, 2007). Curtailment of pollution extension is a very urgent question in the clayey soils with low water permeability that makes up 45.3% of soil cover in Lithuania. Therefore, the field studies, the aim of which was to investigate the efficiency of lime filter drainage under the different climate conditions and to evaluate the impact of lime admixture in trench backfill on drainage water quality in clay soils were conducted.

## 2. Study objects and investigation methods

The greater part of fine-textured clay soils are located in the Middle Lithuanian Plain. Two sites at different districts were arranged for field experiments in order to assess the efficiency of lime filter drainage in such soils.

*Pasvalys site.* The site was arranged in 1986. It has been in operation for a ten-year period. The *Endocalcari-Epihypogleyic Cambisols* with soil texture of silty clay loam (according to FAO classification) are prevailing here. Soil acidity in the topsoil layer (0.0-0.2 m) ranges from pH 5.9 to pH 6.6. Deeper soil horizons were near neutrality ( $6.6 < \text{pH} < 7.2$ ). The experimental set-up consisted of 200 x 40 m levelled plots surrounded by a 0.4-m high dike and resembled to an artificial land surface depression (Fig. 1). The site was drained with single tile drains, spacing at 4 m, trench width of 0.5 m, 33 cm long tile drains with an inner diameter of 75 mm were laid at the depth of 1.0 m.

Steady-state infiltration method using a ring infiltrometer was applied to determine saturated hydraulic conductivity (K-values) of the soil. The ring ( $H = 0.25$  m,  $d = 0.4$  m) driven into the soil at the depth of 0.1 m was supplied with a constant head of water at 0.1 m from a mariotte bottle. K-values of the topsoil layer vary within a wide range (0.65–2.75 m/d). The statistical mean value at  $p < 0.05$  equalled to  $1.70 \pm 1.05$  m/d whereas the mean value of the subsoil layer (at the depth of 0.30 m) was only  $0.04 \pm 0.03$  m/d.

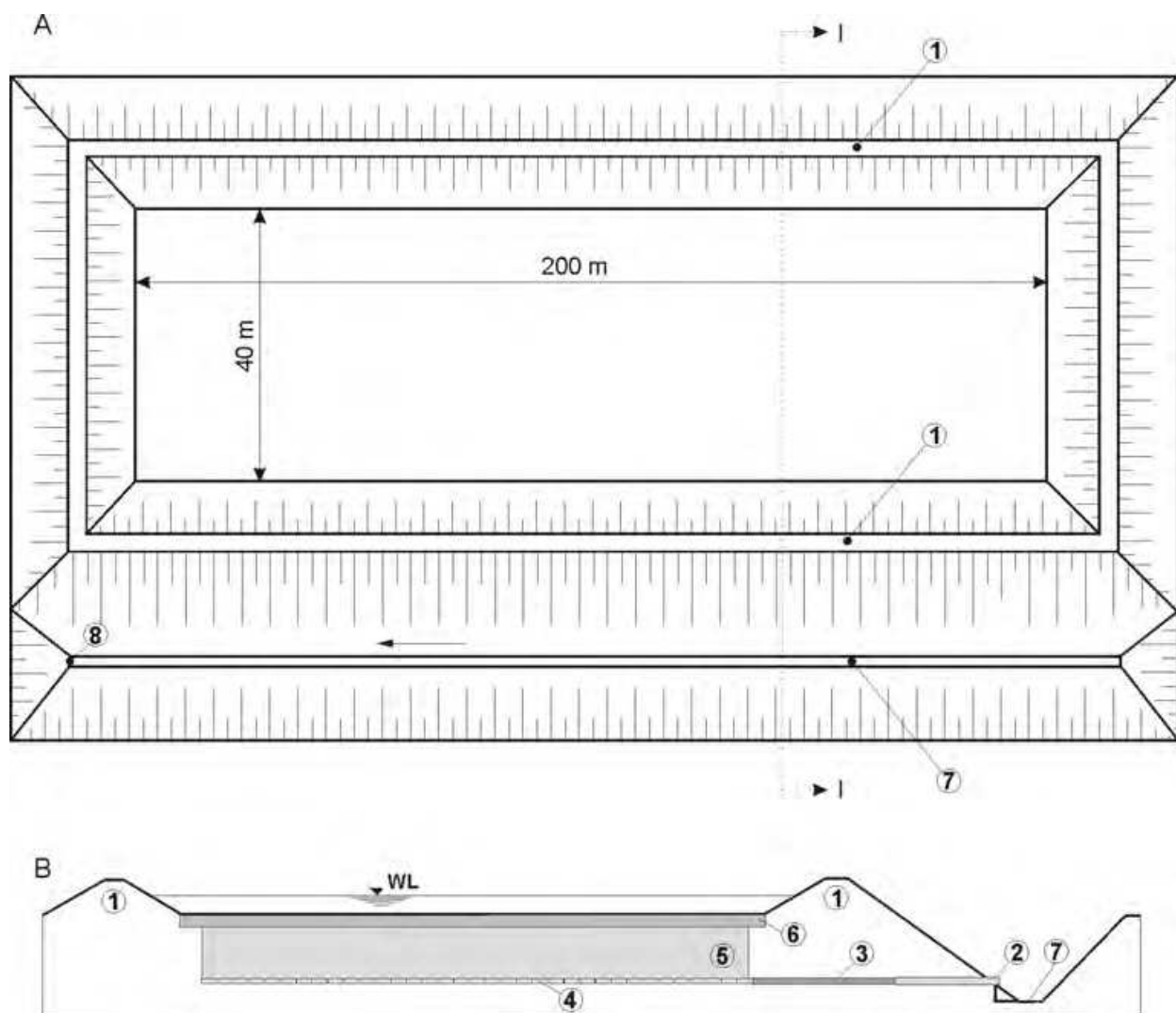


Fig. 1. Plan (A) and cross section (B) of the Pasvalys model site: 1 – dykes ( $h = 0.4$  m), 2 – drainage outlet, 3 – non-perforated plastic pipe ( $l = 10$  m;  $d = 100$  mm), 4 – tile drains ( $d = 75$  mm), 5 – trenches with different backfill, 6 – topsoil layer, 7 – open main drain, 8 – open water inlet to the pipe collector.

For the investigation of the efficiency of the surface water drainage in heavy soils, drains with the higher permeability of trench backfill (when using both mineral and organic materials) were arranged. Alongside the lime filter, backfills with sand/gravel mixture ( $K_f = 11.2$  m/d), breakstone ( $\varnothing 10\text{--}30$  mm), turf (decomposition rate 10%), chopped straw (5 kg/m), wood chips ( $0.036$  m<sup>3</sup>/m) were arranged in the site.

Shale ashes containing 16.8% CaO from Estonia were used as liming material. It is the rest product the burning of shale (in power stations) and contains a mixture of calcium, magnesium, potassium and other trace elements. Neutralising value of shale ashes ranges from 65 to 90% CaCO<sub>3</sub>. Four different amounts of shale ashes (0.15, 0.30, 0.40 and 0.80% of active CaO for soil mass) were mixed with the clay soil using the transporter of a multi-scoop excavator and backfilled to the drainage trenches. Control treatment was backfilled with the disturbed native soil from the trench. All treatments were installed in three replications.



During the investigations water from an adjacent stream was pumped into the experimental site. The site was flooded 16 times during the season from April to November considering soil water content.

Three sets of soil samples with 30 replications at the mid-point between the drains were taken at a depth of 0.25-0.30 m every time before the site was flooded. Soil moisture content was determined in the laboratory by the gravimetric method (the moisture content to be expressed as a percentage of the sample's dry weight). Drain discharges were measured three times a day, keeping the water level at 0.2 m above the soil surface.

The lime filter drainage effectiveness when trench backfill was mixed with different amounts of lime was assessed by comparing drainage coefficients as calculated from the following equation (Ritzema, 1994):

$$q = \frac{Q}{L B}, \tag{1}$$

where q – drainage coefficient, m/d, Q – pipe discharge, m<sup>3</sup>/d, L – drain spacing, m, B – length of line, m.

*Kalnujai site.* Another experimental site with a total area of 14.6 ha was arranged in the Jūra river catchment of the South-Western Lithuania (Fig. 2).

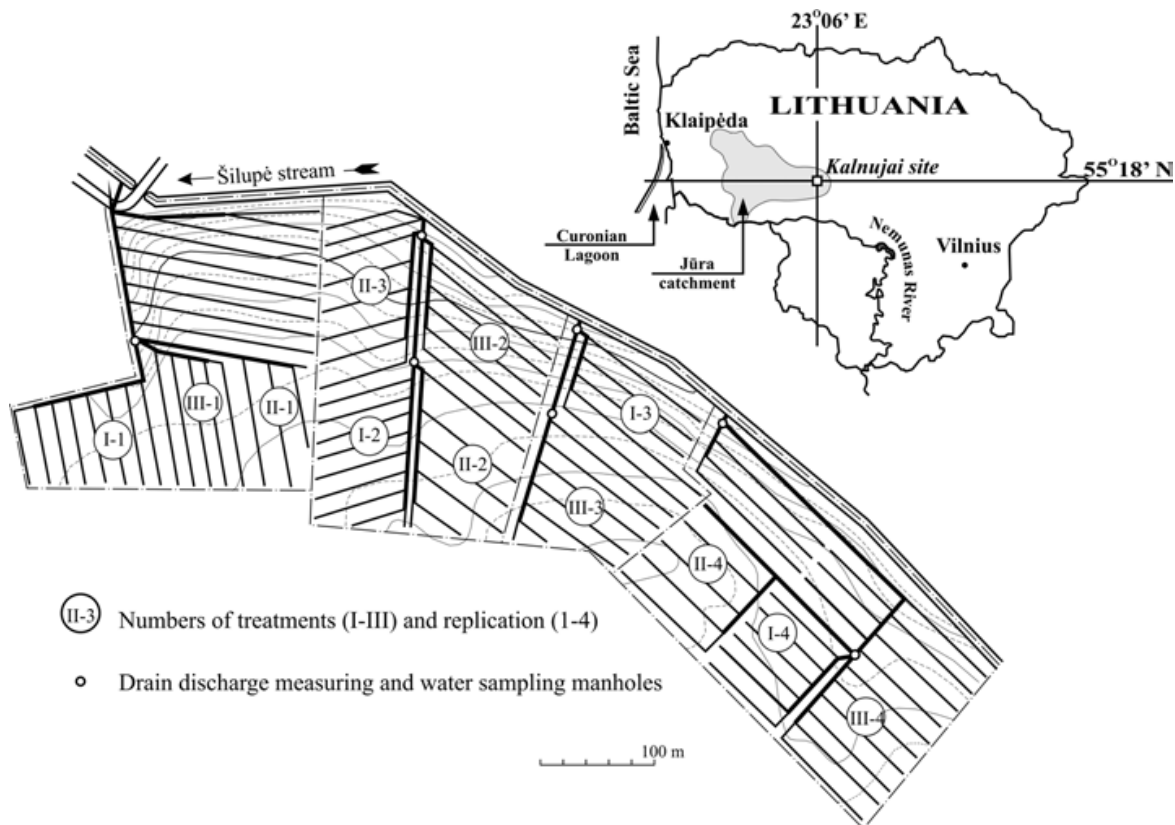


Fig. 2. Geographical location and experimental layout of Kalnujai site.

Drainage water from the main collectors discharges into the modified (deepened and straightened) reach of the Šilupė stream. This stream (length – 4.4 km, basin area – 4.0 km<sup>2</sup>)

according to the Lithuanian river classification, is attributed to small rivers that constitute 75.5% of the total length of all rivers (Gailiusis et al., 2001). Small and medium rivers that usually are drainage water recipients are very important from the ecological point of view because concentrations of biogenic substances there are often higher than in the large rivers.

Experimental drainage systems with lime backfill were installed in 1989 (Fig. 3). The site was drained by composite subsurface drainage systems. Tile drainpipes (length of 33 cm, laterals Ø50 mm, collectors Ø75 mm) have been installed at the depth of 1.1 m, width of drainage trench – 0.5 m. Three drainage treatments have been installed with four replications of each:

1. drainage trench backfill mixed with lime (0.6% CaO), drain spacing  $L = 16$  m;
2. the same,  $L = 24$  m;
3. (control) – drainage trench backfilled with native clay loam soil,  $L = 16$  m.



Fig. 3. Installation of lime filter drainage in Kalnūjai site

*Calculations of the optimal lime rate.* Laboratory experiments with different clay soil samples were carried out before the lime filter drainage installation in order to determine the optimal rates of lime additives to be mixed with clay soil of a trench backfill. Equation (2) was obtained from the results of laboratory analyses (Blažys et al., 1993):

$$a = 0.13 + 0.011 N, \quad (2)$$

where  $a$  – optimal lime rate considering active CaO and MgO, %;  $N$  – amount of physical clay particles contained in soil, %.

This equation should be applied when the soil contains from 20 to 80% of physical clay particles ( $<0.01$  mm). This particular composition was named as physical clay according to soil textural classification by Kačinskij, which was used in the former Soviet Union.

Laboratory findings showed, that water permeability of clay soils is increasing when lime rate is increased to a certain limit that depends on the amount of physical clay particles obtained in the soil. Lime activity should not be less than 70-85% for dry mass as this is the best material to improve the texture of clay soils. The optimal amount of lime that needs to be mixed with clay soil in order to enhance its best hydraulic conductivity may be calculated from the following equation:

$$A = \gamma b h a n^{-1}, \quad (3)$$

where  $A$  – amount of lime for one linear meter of the trench, kg;  $\gamma$  – soil bulk density, g/cm<sup>3</sup>;  $b$  – width of drainage trench, m;  $h$  – depth of drainage trench, m;  $n$  – neutralizing value of lime according to the total amount of CaO and MgO, %;  $a$  – optimal amount of lime required to improve soil permeability, %.

Silty clay soil samples (sum of <0.01 mm physical clay particles made up 73.8%) were mixed with lime additives (0.6% of active lime for soil mass). After 28 days a microphoto was taken and then enlarged 400 times (Fig. 4). The photo clearly shows 15-20% higher soil porosity (black color) than that of the soil where no lime was added. Based on the laboratory results the amount of lime for one linear meter of the trench backfill was calculated out of the soil characteristic and drainage parameters in Kalnujai site ( $\gamma = 1.58$  g/cm<sup>3</sup>,  $b = 0.5$  m,  $h = 1.1$  m,  $N = 43.0\%$ ,  $n = 21.5\%$ ). Estimated amount of shale ashes was 24 kg/m.

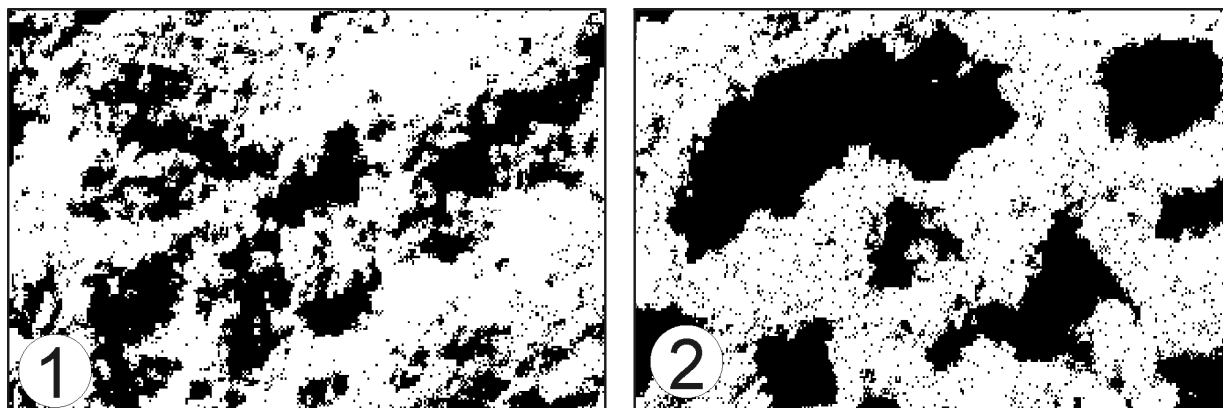


Fig. 4. Microphoto of clay soils (enlarged 400 times): 1 – silty clay; 2 – the same clay mixed with 0.6% CaO

*Soil and climate data.* The Jūra catchment drains middle part of Žemaičiai Upland, the surface of which is covered with humus rich but poor in labile phosphorus clay loams (80% of the basin area). Almost half (47%) of average annual precipitation amount turns to runoff. Such conditions stimulate soil outwash and inflow of adsorbed phosphorus. High concentrations of suspended matter in the Jūra and its tributaries show the phosphorus loads to be formed there by soil erosion. It must be noted, that Lithuanian soils have low phosphorus retention potential (the definition is based on global soil climate map and global soil map).

*Orthi-Haplic Luvisols (LVh-or)* and *Hapli-Epihypogleyic Luvisols (LVg-p-w-ha)* with soaking features prevail in the site. The soils of sandy clay loam/clay loam are maintained at about pH 6.9-7.5. The layer below 40 cm consisted from over 60 to 34% of clay. At the beginning of the investigations the average bulk density determined in the soil profile to the depth of 1.0 m was  $1.65 \pm 0.02$  g/cm<sup>3</sup>, particle density –  $2.67 \pm 0.01$  g/cm<sup>3</sup>, porosity –  $38.05 \pm 0.43\%$ , phosphorus content in the plough-layer (0-23 cm) ranges from very low to medium (27-144 mg/kg), potassium content varied from 84 to 124 mg/kg.

Perennial grasses for hay were grown in the period of four years (1999-2002). In autumn of 2002, the plot was tilled and since 2003 it has been used under crop cultivation. Principal crops are cereals.



The data of Meteorological Station located 5 km from the experimental site was used to characterize meteorological conditions. The mean air temperature of the study period was 7.1°C and exceeded the seasonal norm (5.9°C) by about +1.2°C. In the warmest years – 2000, 2002 and 2008 – it was by about +2°C higher than the norm (higher temperatures were more frequent in winter-spring months – December–April and July) (Fig. 5).

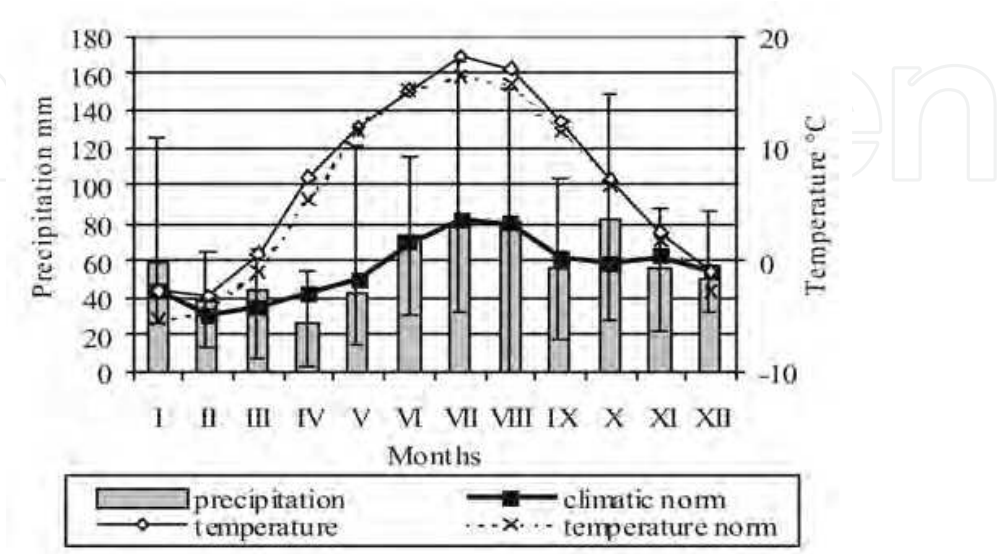


Fig. 5. The means of monthly precipitation and air temperature, 1999–2009 (error bars show data range)

The territory experienced 71% of annual precipitation during the warm season (April – October). Comparison with seasonal norm of annual precipitation the years of 2001 and 2007 attributes to humid ones (precipitation likelihood 14 and 2%). In the dry year (2005) precipitation likelihood was 93%. The remaining period may be considered as moderate: annual precipitation was close to long-term average for this region (665 mm). Significantly uneven rainfall distribution was observed in April and May (variation coefficient  $V = 68\text{--}73\%$ ). In some years precipitation in January, May and October made 2.5–3 of monthly norm, while the average of April made only 60%. Drainage occurred during the entire year of 2001 and 2007, in 2005 dormant period of the drainage lasted even for ten months.

*Data collection and analysis.* To evaluate the efficiency of lime filter drainage, drain discharge and watertable depth were measured once a day in the main drainage season (from January to May). Drain discharges were measured by volumetric way in the tile outlets, while the depth of the watertable was measured in observation wells installed at the mid-point between the parallel laterals in each treatment. Hydraulic conductivity of drainage trench backfill, topsoil layer and soil between the drains were measured by the same ring infiltration method as in the Pasvalys site.

Monitoring on water quality in the site has been ongoing since 1999. Water samples were analysed for pH, calcium ( $\text{Ca}^{2+}$ ), magnesium ( $\text{Mg}^{2+}$ ), potassium ( $\text{K}^{+}$ ), sodium ( $\text{Na}^{+}$ ), chloride ( $\text{Cl}^{-}$ ), sulphate ( $\text{SO}_4^{2-}$ ), bicarbonate ( $\text{HCO}_3^{-}$ ) phosphate ( $\text{PO}_4^{3-}$ ), nitrate ( $\text{NO}_3^{-}$ ) and ammonia ( $\text{NH}_4^{+}$ ) ions also for total phosphorus (TP) and total nitrogen (TN). Periodicity of sampling was once a month. Water samples from the Šilupė stream were taken simultaneously. The methods used to determine chemical parameters are summarized in Table 1.

Parameter	Method	References
pH	Electrometry	ISO 10523-1:1994
Calcium	EDTA Titrimetry	LAND 68:2002
Magnesium	EDTA Titrimetry	LAND 73:2005
Potassium	Flame Photometry	LST ISO 9964-3:1998
Sodium	Flame Photometry	LST ISO 9964-3:1998
Chloride	Mohr’s method	LAND 63-2004
Sulphate	Gravimetric	ISO 9280
Bicarbonate	Potentiometric	LST EN ISO 9963-2:1999
Phosphate	Spectrophotometry	LAND 58:2003
Nitrate	Spectrophotometry	LST EN ISO 13395:2000
Ammonia	Spectrophotometry	LAND 38:2000

Table 1. Analytical methods for determining chemical composition of drainage water.

The comparison of ion concentration means during the investigation period was made, i.e. a hypothesis was checked if mixing lime into drainage trench backfill had impact on the basic ions concentrations in drainage water. In parallel, water quality differences of the control drainage treatment and stream water were compared.

The reliability of the results was determined by processing them with mathematical statistical methods, using MS Excel 2000 Data Analysis Tool Pack. Differences of drainage treatments were tested at the significance level  $p < 0.05$  and  $p < 0.01$ . The temporal changes in concentrations of basic ions were evaluated choosing the most reliable trendlines for the data sets. Correlation between phosphorus concentrations in the drainage treatments and meteorological indices (precipitation and temperature) was established. The annual load of phosphorus and nitrogen was calculated on the basis of the linear interpolation method recommended by the Helsinki Commission (Guidelines..., 1994).

3. Results

3.1 The effect of lime admixture to trench backfill on the functioning of tile drainage in clay soils

The drainage treatments efficiency was assessed by comparing drainage coefficients in the Pasvalys site. The data obtained shows that the drainage coefficient (q) from the control trench backfill reduces by 13 times on the average when the soil moisture content increases from 23.0 to 27.0% (Fig. 6). When the drainage trench is mixed with shale ashes, lime reduces clay swelling and ensures stabilized clay soil structure. This results in more stable drainage coefficients. When trench backfill is mixed with 0.15 and 0.30% CaO, q decrease by 4.2 and 3.3 times respectively; when 0.40 and 0.80% CaO is applied, – only 2.6 times.

In case when the soil moisture content is less (23.0%), the average drainage coefficients from trench backfill mixed with 0.40% CaO are 0.58 m/d, i. e. 11 times higher than in the control treatment (0.05 m/d). With higher soil moisture content (27.0%) q is even 55 times higher in treatment with 0.40% CaO (0.22 m/d) than in the control treatment (0.004 m/d). This is a rather favourable index for drainage functioning at critical moments.

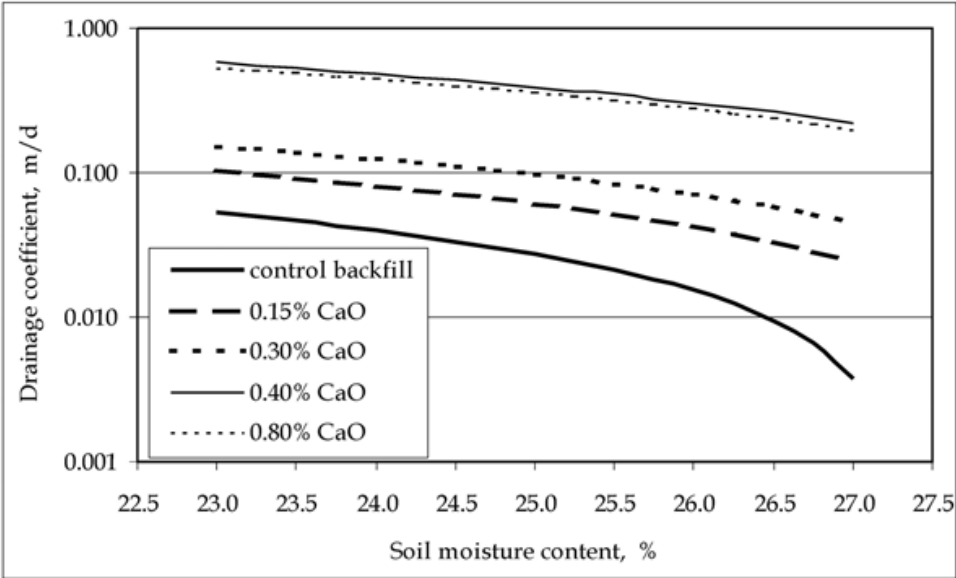


Fig. 6. Trendlines of drainage coefficients in the Pasvalys site.

In case when soil moisture content is higher (27.0%) drainage coefficients from trench backfill mixed with 0.80% CaO are 0.20 m/d, i.e. 50 times higher than in the treatment without lime (0.004 m/d). When trench backfill contained half as much lime (0.40% CaO), q is by 55 times higher. This shows that a certain limit was achieved above which the increased amount of lime additives does not result in the increased permeability of the trench backfill. It could be explained by the large amount of ballast elements contained in shale ashes that frequently make up 85% of the whole material. The ballast elements fill in a certain part of soil pores, and so decrease water permeability of the trench backfill.

The following logarithmic relationship between soil moisture content and drainage coefficients of different drainage trench backfill was determined when analyzing the data over a ten-year period (1987-1997):

$$q = A - B \ln w, \tag{4}$$

where q – drainage coefficient, m/d; A and B – coefficients of regression equation (Table 2), w – soil moisture content at a 25-30 cm deep soil layer, %.

The equation (4) is valid when the soil moisture content is changing within the range of 23 to 27%. Observations have shown that the changing moisture content of clay soils enhances the changes in water permeability of the trench backfill: with the increase in soil moisture content the drainage coefficients decrease ( $r = 0.67 - 0.96$ ). A strong reverse relationship was determined between the soil moisture content and drainage coefficients from the control drains and in treatments with 0.40 and 0.80% CaO; a moderate relationship was determined when the drains were backfilled with fewer amounts of lime (0.15 and 0.30% CaO) (Šaulys, 1999).

No	Type of backfill	Coefficients of regression equation		Drainage coefficient, m/d		Correlation coefficient
		A	B	max	min	
1	Control backfill	1.02	0.31	0.05	0.005	0.96
2	0.15% CaO	1.62	0.48	0.10	0.012	0.77
3	0.30% CaO	2.22	0.66	0.17	0.019	0.67
4	0.40% CaO	7.53	2.22	0.69	0.252	0.82
5	0.80% CaO	7.18	2.12	0.59	0.171	0.81

Table 2. Coefficients of regression equation (4), and comparable values of drainage coefficient ( $p < 0.01$ ).

Analysing the permeability of other drainage backfills it was defined that the permeability of all of them was higher than of the control one. It was substantiated on the calculated discharges per unit length. The data show that with the higher moisture content (27%) in clay soils, discharges from the drains with wood chips backfill are 5 times higher than from the drains with control backfill, with chopped straw backfill – 10, with sand and gravel mixture – 14, with turf backfill – 18, with breakstone backfill – 24 times higher (Fig. 7). The drainage works even more effectively when backfill was mixed with lime (0.40% of active CaO) – 45 times better than drains with control backfill (drainage discharge 0.045 l/s·m).

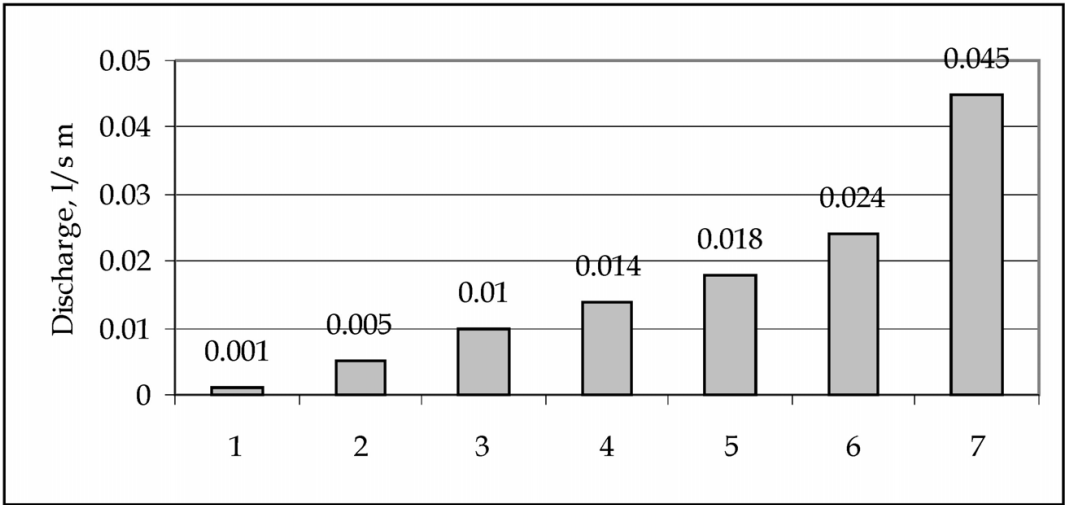


Fig. 7. Comparison of different backfills efficiency in the reference of drainage water discharges per unit length (soil moisture content  $W=27\%$ ): 1 – control (native clay soil) , 2 – wood chips , 3 – chopped straw , 4 – sand/gravel mixture; 5 – turf; 6 – breakstone; 7 – the backfill mixed with lime (0.40 % of active CaO).

The obvious advantage of lime filter drainage over other backfills shows the unquestionable efficiency of this measure when draining the surface water excess in heavy clay soils. Since this conclusion was based on the experiments carried out in the model site it was important to investigate efficiency of lime filter drainage under natural field conditions. Further investigations were carried out in the Kalnujai site.

Under the meteorological conditions of Lithuania, drainage outflow commonly lasts till the beginning of May. In autumn it starts again in November. During the months from January to April there are usually several peaks of drainage outflow, the time and duration of which depend on the fluctuations of air temperature and precipitation.

Three peaks of drainage discharge were observed in Kalnuijai site. The first peak was observed in the first ten-day period of January when the soil surface was frozen. Average drainage discharges were 3.0 mm/d (control), treatments with lime - 3.2-3.3 mm/d. The differences between the control drainage and LFD were 6.6-10%. The highest drainage discharge measured in the system of control drainage during the snow melt period at the outset of February reached 6.7 mm/d and was 1.3 times higher than the design drainage coefficient (5.2 mm/d). At the same time drainage discharge in LFD was lower, reaching 6.2 mm/d in treatment I, and 5.0 mm/d in treatment II. The third slightly lower discharge peak occurred on the middle of March. During this peak drainage discharge in the control system and in LFD I with the same spacing ( $L=16\text{ m}$ ) were equal (4.2 mm/d). In LFD II with spacing  $L=24\text{ m}$ , drainage discharge was 3.8 mm/d, i.e. decreased by 11%. As the data shows, it is difficult to evaluate the advantage of drainage variants because of great impact of meteorological conditions on drainage work.

The differences between the control and lime filter drainage are more noticeable according to watertable depth between the drains (Fig. 8).

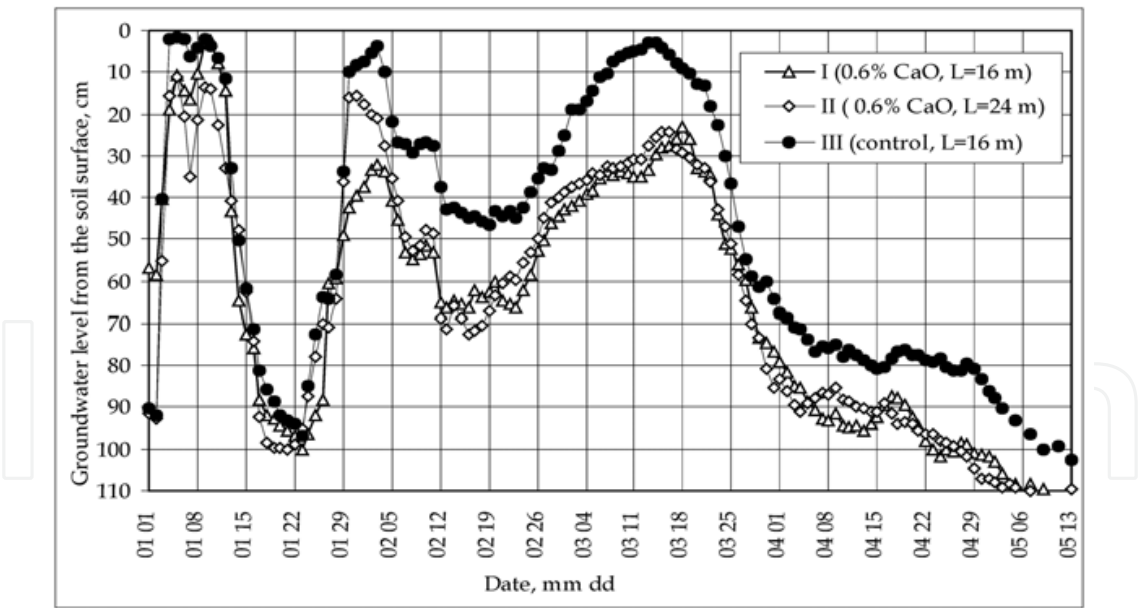


Fig. 8. Dynamic of groundwater level in different drainage treatments (Kalnuijai site, 2000) (Šaulys & Bastienė, 2003).

During the main drainage season (from January to April) average depth of the watertable in the control drainage system was 0.16 m (35%) higher than in LFD. Increased drain spacing from 16 to 24 m has no negative impact as the depth of the watertable in LFD varied from 0.003 to 0.025 m and was statistically insignificant (Table 3).



Treatments	Months				Average (I-IV)
	I	II	III	IV	
I (0.6% CaO, L=16 m)	0.55	0.54	0.42	0.93	0.61
II (0.6% CaO, L=24 m)	0.57	0.52	0.41	0.93	0.61
III (control, L=16 m)	0.49	0.33	0.22	0.77	0.45

Table 3. Average watertable depth between the drains (m) in 2000.

The relationship between drainage coefficients and watertable depth in between the drains (Fig. 9) may be expressed by the exponential regression ( $r = 0.85 - 0.91$ ):

$$q = m e^{-nh}, \tag{5}$$

where  $q$  – drainage coefficient,  $m/d$ ;  $m$  and  $n$  – coefficients of regression equation;  $h$  – depth of the watertable in between the drains,  $m$ .

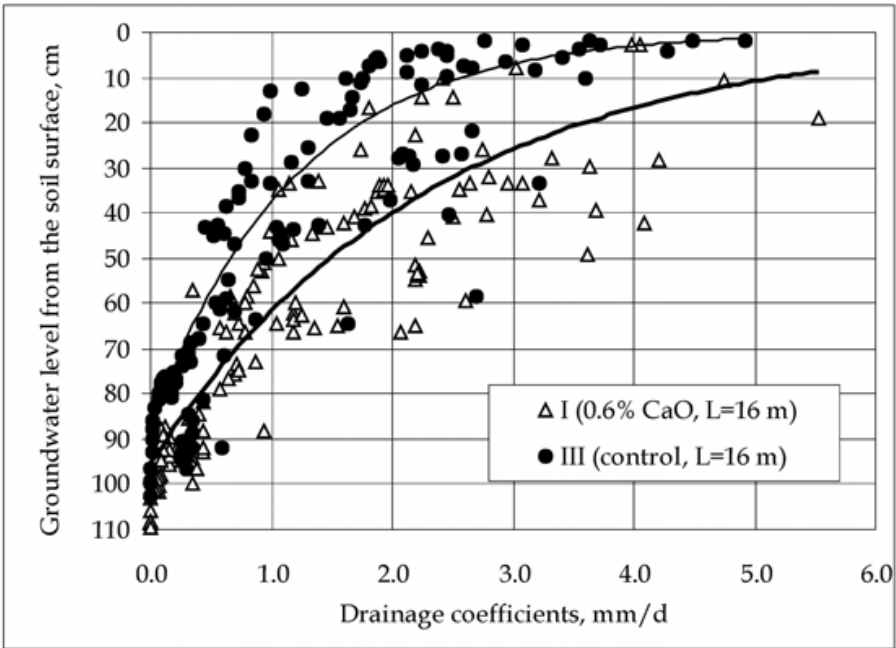


Fig. 9. Relationship between drainage discharge and watertable depth in between the drains (Šaulys & Bastienė, 2003)

The statistical analysis shows there are significant differences between the mean values of watertable depths in the control drainage system and those of the treatments with lime mixed into the trench backfill (Table 4).

In the period 2000-2002 the watertable depth in LFD I was on average  $0.25\pm0.04$  m deeper than in the control drainage system while in LFD II it was  $0.21\pm0.03$  m deeper. It was also observed that during the wet period (in 2002) the differences between watertable depth in LFD and the control drainage were more distinct ( $0.33\pm0.05$  m and  $0.24\pm0.04$  m respectively) than during the dry period (in 2000) ( $0.20\pm0.02$  m and  $0.18\pm0.02$  m respectively).

Drainage treatments	Number of measurements	Groundwater level differences, m			Standard deviation	Variation coefficient
	<i>n</i>	Max	Min	Mean	SD, m	V, %
2000 (precipitation 112% of seasonal norm)						
I (L=16 m)	60	0.31	0.08	0.20±0.02	0.06	28.6
II (L=24 m)	60	0.29	0.06	0.18±0.02	0.05	30.7
2001 (precipitation 116% of seasonal norm)						
I (L=16 m)	41	0.40	0.07	0.23±0.04	0.08	38.1
II (L=24 m)	41	0.36	0.02	0.23±0.04	0.09	39.4
2002 (precipitation 143% of seasonal norm)						
I (L=16 m)	56	0.62	0.10	0.33±0.05	0.14	43.9
II (L=24 m)	56	0.44	0.08	0.24±0.04	0.11	44.4
2000-2002						
I (L=16 m)	157	0.62	0.07	0.25±0.04	0.10	38.7
II (L=24 m)	157	0.44	0.02	0.21±0.03	0.07	32.5

Note: Mean value ± confidence interval

Table 4. Statistical estimation of differences in the reference of watertable depth in lime filter drainage and control drainage ( $p<0.05$ )

The data obtained at the Kalnujai site were similar to the study results gained by Gurklys (1998), who has determined that watertable between the drains was 20-30% lower when lime was added into the drainage trench backfill (this difference is most obvious when watertable are at their highest level).

According to measurements watertable depth at 0.10 m below the soil surface in the control drainage system lasted for 11 days; at the depths of 0.20 and 0.30 m it remained for 20.5 and 24 days. In drainage treatments with lime it rose only to 0.30 m from the soil surface and remained here for 5.5 and 6 days respectively. The increased drain spacing did not result in less drainage functioning.

Clay soils often have relatively high permeable top layer, which is determined by the agriculture activity. Under extreme conditions topsoil layer saturates by surface water and depression curve does not form. In this case, inflow to the drains can be roughly estimated according to the Donat-Slichter formula (Bereslavskii, 2008):

$$q=1,48\,k_a\,h_a,$$

(6)

where  $q$  – water inflow from the 1 m width strip formed between the drains,  $m^3/s$ ;  $k_a$  – hydraulic conductivity of top layer,  $m/s$ ;  $h_a$  – thickness of the top layer,  $m$ .

In cases of perched watertable (when clay soils are swollen) surplus of water interflows the pervious top layer, which has connection with trench backfill more permeable than the original soil. This flow mode will only be evident if the backfill is of high hydraulic conductivity:

$$q=k_t\cdot b_t,$$

(7)

where  $k_t$  – hydraulic conductivity of the drainage backfill,  $m/s$ ;  $b_t$  – width of the trench,  $m$ .

In order to ensure satisfactory functioning of drainage in clay soils, the inflow through drainage trench backfill should be more than the inflow through the topsoil layer. Between the permeability of topsoil layer and trench backfill the following dependency should be:

$$k_t \cdot b_t \geq 1,48 \, k_a h_a. \tag{8}$$

The width of drainage trenches dug by multi-scoop excavator –  $b_t = 50$  cm, thickness of the topsoil layer in clay soils  $h_a = 15\text{-}20$  cm. Based on the equation (8) we receive that:

$$k_t \geq 0,45 \div 0,60 \, k_a. \tag{9}$$

The tests of infiltration allowed to compare the hydraulic conductivity of the control and lime filter drainage backfill with hydraulic conductivity of undisturbed clay soil at the same depth between the drains (Fig. 10).

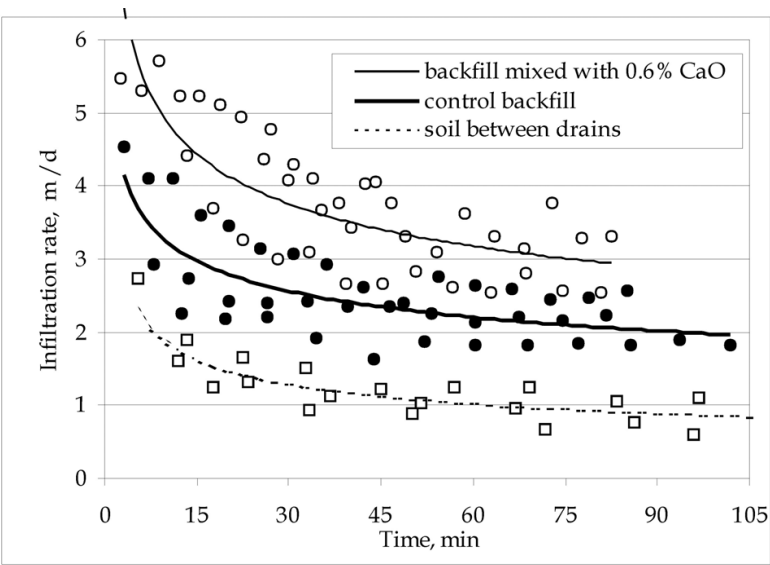


Fig. 10. Variation of water infiltration rate in the Kalnujai site: (o)–trench backfill mixed with lime, (•)–control backfill, (□)–soil between the drains.

The mean value of water infiltration rate in the trench backfill with lime at  $p < 0.05$  after the steady flow was established amounted to  $3.2 \pm 0.25$  m/d and was 1.5 times higher than in control backfill –  $2.2 \pm 0.14$  m/d. The water infiltration rate between the drains reached only  $0.83 \pm 0.09$  m/d, i.e. 2.6 times lower than in the control backfill and 3.8 times lower than in the backfill with lime. The power trendlines show the changes of infiltration rate ( $r = 0.65\text{-}0.82$ ).

Lime admixture into the trench backfill in clay soils ensures lower watertables and improved water regime of the body of soil between the trenches because heavy clay soils often have relatively high permeable top layer, which is determined by the agriculture activity. In cases of perched watertable surplus of water interflows the pervious top layer, which has connection with trench backfill more permeable than the original soil. This flow mechanism will only work if the backfill is of high hydraulic conductivity.

### 3.2 The effect of lime filter drainage on chemical composition of drainage water

Chemical analysis showed that lime admixture determined changes of ions composition of drainage water (Table 5). Lime admixture has hardly any influence on drainage water pH

Treatment	Parameter	pH	Ca <sup>2+</sup>	*Mg <sup>2+</sup>	K <sup>+</sup>	*Na <sup>+</sup>	Cl <sup>-</sup>	SO <sub>4</sub> <sup>2-</sup>	*HCO <sub>3</sub> <sup>-</sup>	PO <sub>4</sub> <sup>3-</sup>	NO <sub>3</sub> <sup>-</sup>	NH <sub>4</sub> <sup>+</sup>
I (0.6% CaO L=16 m)	Mean	7.4	97.6	38.0	0.95	16.7	16.4	31.2	445.6	0.039	15.5	0.09
	Max	8.0	130.0	52.0	2.1	25.0	32.0	60.0	560.0	0.092	58.0	0.88
	Min	6.9	52.0	19.0	0.5	6.0	6.9	14.0	223.0	0.009	0.5	0.001
	Conf. <sub>0.05</sub>	0.06	4.0	2.2	0.08	1.3	1.5	2.5	20.2	0.005	3.8	0.04
	CV	3.4	17.1	21.6	33.1	26.8	37.9	32.8	16.0	51.2	130.2	174.2
II (0.6% CaO L=24 m)	n	64	67	48	67	48	67	65	48	67	66	66
	Mean	7.4	96.4	38.8	0.94	16.8	16.5	31.8	450.7	0.037	16.0	0.08
	Max	8.2	127.0	52.0	3.1	29.0	33.0	64.0	595.0	0.098	62.8	0.79
	Min	6.9	50.0	16.0	0.5	5.0	6.0	13.0	209.0	0.003	0.1	0.001
	Conf. <sub>0.05</sub>	0.06	4.2	2.5	0.10	1.4	1.4	2.8	23.1	0.005	4.1	0.03
III (control)	CV	3.5	18.2	22.7	46.2	30.0	35.6	35.9	17.9	54.9	105.3	177.4
	n	63	66	47	66	47	66	64	47	66	65	66
	Mean	7.4	99.9	39.2	1.62	17.0	21.5	40.5	440.8	0.114	17.8	0.08
	Max	7.9	135.0	52.0	3.8	23.0	47.0	93.0	560.0	0.193	61.1	0.93
	Min	6.9	53.0	23.0	0.7	9.0	10.0	15.0	240.0	0.031	0.5	0.001
Stream	Conf. <sub>0.05</sub>	0.07	4.3	1.9	0.13	0.9	1.7	3.4	19.1	0.007	4.3	0.04
	CV	3.7	18.2	17.2	33.2	19.7	33.4	34.7	15.5	27.2	101.4	179.1
	n	65	68	49	68	49	68	66	49	68	67	68
	Mean	7.9	91.6	21.4	6.42	9.7	19.0	62.0	271.8	0.060	25.5	0.11
	Max	8.4	136.0	39.0	19.0	24.0	35.0	120.0	398.0	0.150	66.4	1.0
	Min	7.4	50.0	10.0	2.0	4.0	8.0	21.0	205.0	0.003	1.8	0.001
	Conf. <sub>0.05</sub>	0.04	3.2	1.1	0.66	0.7	0.9	3.9	9.2	0.006	2.8	0.04
	CV	2.8	17.1	21.6	50.8	29.4	23.1	30.7	14.6	52.8	53.3	160.4
	n	90	93	72	93	72	93	91	72	93	93	93

Notes: \*observation period of Mg, Na and HCO<sub>3</sub> concentrations – 1999-2004; Conf.<sub>0.05</sub> – confidence interval of calculated mean at 0.05 significance level; CV – variation coefficient in percent; n – number of average concentrations calculated from four replications of water samples.

Table 5. Statistical estimation of basic ions concentrations (mg/l) in the Kalnujai site in 1999-2007.

because the mean values of the pH for the different treatments are almost the same (pH 7.4±0.06). They have relatively small standard deviations and variation coefficients (3.4-3.7%), pH values of stream water range from 7.4 to 8.4.

Calcium and magnesium cations prevail in drainage water. They make 64 and 25% of the total cation amount respectively. In treatments with lime (I and II), the mean Ca<sup>2+</sup> concentrations were 97.6±4.0 and 96.4±4.2 mg/l, in the control treatment they were 2-3% higher (99.9±4.3 mg/l). Statistically the differences of these concentrations were insignificant (Table 6). The mean Ca<sup>2+</sup> concentration in the stream water was only 5-8% lower compared with the drainage water outflow. However, the estimation of mean differences by t-test showed that it was significant (*p*<0.01). During the entire period of observations Ca<sup>2+</sup> concentrations did not exceed maximum admissible concentrations (MAC) in surface water (180 mg/l).

Treat- ments	Chemical parameters										
	pH	Ca <sup>2+</sup>	*Mg <sup>2+</sup>	K <sup>+</sup>	*Na <sup>+</sup>	Cl <sup>-</sup>	SO <sub>4</sub> <sup>2-</sup>	*HCO <sub>3</sub> <sup>-</sup>	PO <sub>4</sub> <sup>3-</sup>	NO <sub>3</sub> <sup>-</sup>	NH <sub>4</sub> <sup>+</sup>
I-III	-	-	-	++	-	++	++	-	++	-	-
III-str	++	++	++	++	++	+	++	++	++	++	-

Notes: - difference statistically insignificant at *p* < 0.05; + difference statistically significant at *p* < 0.05; ++ difference statistically significant at *p* < 0.01.

Table 6. Testing of statistical differences between the means of basic ions concentrations in drainage treatments and the Šilupė stream

Average concentrations of Mg<sup>2+</sup> in drainage water were 2.5 times lower than the average concentrations of Ca<sup>2+</sup>. They vary between 16 and 52 mg/l (the mean of I-III treatments – 38.6±2.2 mg/l). At certain moments due to biochemical processes taking place in the soil (especially in summer) the maximum values of Mg<sup>2+</sup> concentrations were 30% higher than the MAC (40 mg/l) in surface water. In the stream water average Mg<sup>2+</sup> concentration was 21.4±1.1 mg/l.

Migration of K<sup>+</sup> depends on the hydrogeological environment of soil (especially on pH). As the pH increases, increased soil cation exchange capacity (CEC) occurs, as well as reduced leaching of basic cations, particularly K<sup>+</sup>. The research made in the Kalnūjai site showed that K<sup>+</sup> ions were more stable in the neutral environment. Therefore, it was observed that lime filter drainage water had the average potassium concentrations 1.7 times lower compared with the control treatments and 6.8 times lower compared with the Šilupė stream water (0.95±0.08, 1.62±0.13 and 6.42±0.66 mg/l respectively). The test on the differences between the mean values of the potassium ions concentrations in the different treatments would lead to the conclusion that they are indeed statistically significant at *p* < 0.01.

Analysis show that lime did not have any effect on Na<sup>+</sup> concentrations in drainage water: treatments I-II – 16.7±1.3 mg/l, III – 17.0±0.9 mg/l. Sodium ions concentrations were nearly two times lower in the stream water compared with drainage water (mean value 9.7±0.7 mg/l).

There were significant differences between the mean values of the concentrations of Cl<sup>-</sup> and SO<sub>4</sub><sup>2-</sup> anions in drainage water of LFD and in control treatment where they were thereabout



23% higher. Sulphate concentration in the stream water varied from 21 to 120 mg/l (mean value  $62 \pm 3.9$  mg/l). It is noteworthy, that during warm season sulphate concentration in the stream water was higher than it is allowed in open water bodies (MAC=100 mg/l), however, it was not influenced by drainage water but by biochemical processes in the nature.

$\text{HCO}_3^-$  anions prevail in the Kalnuij site water. Their concentrations vary from 209 to 595 mg/l in drainage water and from 205 to 398 mg/l in the stream water. Concentration differences between the drainage treatments are insignificant; values are closely grouped around the mean (CV = 15–18%).

The highest average concentrations of  $\text{PO}_4^{3-}$  were determined in the drainage outflow of the control treatment (0.114 mg/l). Summing-up all study period the mean value of phosphate ions was 1.9 times higher than the average concentrations in the Šilupė stream water (0.06 mg/l). In the outflow of lime filter drainage  $\text{PO}_4^{3-}$  concentrations were 66% lower than in the control drainage water. The statistical analysis determined those differences to be significant at  $p < 0.01$ . So, it can be concluded that LFD may reduce phosphate ions concentrations considerably.  $\text{PO}_4^{3-}$  in Šilupė stream ranged between 0.003 and 0.150 mg/l and do not exceed Lithuanian surface water quality standards.

Water containing nitrate concentrations above 10 mg/l is considered to be of relatively poor quality, whereas 55–60% higher  $\text{NO}_3^-$  concentrations were determined in LFD treatments I-II ( $15.5 \pm 3.8$  –  $15.9 \pm 4.1$  mg/l). The average concentrations of  $\text{NO}_3^-$  in control drainage water were 15% higher compared to the treatments with lime. Nitrate levels in the Šilupė stream were about 2.5 times higher and exceeded the guideline concentration for nitrate in surface water.

In the water of small rivers ammonium made up about 5–10% of the total amount of nitrogen, therefore, the concentrations of this ion were much less: in the Šilupė stream –  $0.11 \pm 0.04$  mg/l, in drainage treatments –  $0.08 \pm 0.03$  –  $0.09 \pm 0.04$  mg/l. They did not exceed MAC approved in Lithuania (1 mg/l).

The following regularities were established by analysing the variation tendencies of the basic ions concentrations in the experimental drainage water and the Šilupė stream water during the studies. The fluctuations of  $\text{Ca}^{2+}$  ions concentrations were expressed by an Order 2 polynomial trendlines with one valley in the autumn of 2002 ( $r = 0.69$ – $0.76$ ) (Fig. 11). The same type regression was detected when analysing the fluctuations of  $\text{Mg}^{2+}$  and  $\text{Cl}^-$  concentrations; however, the trendlines reliability is of less significance ( $r_{\text{Mg}} = 0.55$ – $0.60$ ,  $r_{\text{Cl}} = 0.62$ – $0.73$ ).

As the soil solution in the site was near neutrality (pH=6.8)  $\text{K}^+$  concentrations in LFD water were stably lower compared with the control drainage during the entire observation period. Despite the seasonal variation (CV=33–51%), trends of concentrations of  $\text{K}^+$  ions generally remained steady throughout the ten-year period both in water of drainage treatments and the Šilupė stream (Fig. 12).

The similar slightly decreasing linear trends of  $\text{Na}^+$ ,  $\text{SO}_4^{2-}$  and  $\text{HCO}_3^-$  ions concentrations ( $r_{\text{Na}} = 0.31$ – $0.42$ ,  $r_{\text{SO}_4} = 0.59$ – $0.65$ ,  $r_{\text{HCO}_3} = 0.32$ – $0.40$ ) in drainage water were detected. At the end of monitoring the mean values of sulphate concentrations decreased by 50% in LFD and by 53% in control treatment in comparison with those observed at the onset of investigations

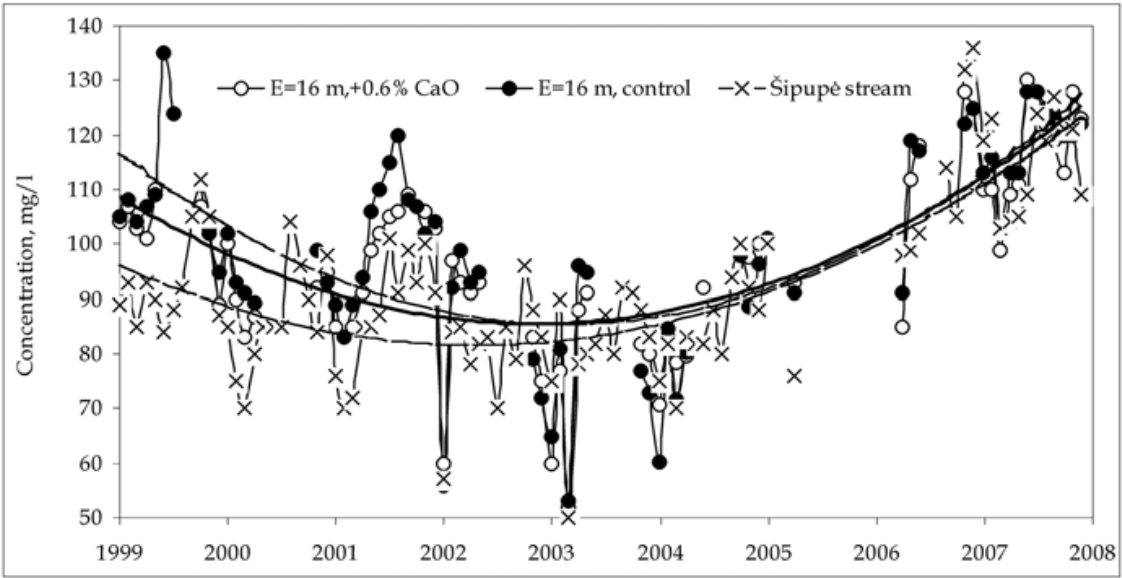


Fig. 11. Variation of calcium cations concentration in drainage treatments and stream water.

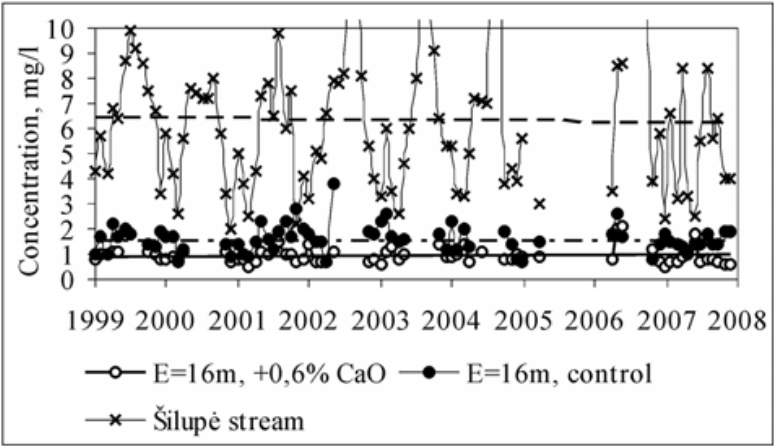


Fig. 12. Variation of potassium cations concentration in the Kalnujai site.

(Fig. 13). Accordingly, the mean values of sodium concentrations decreased by 25% (LFD) and by 21% (III) while bicarbonates concentrations – by 20% on the average. At the same time there was no decreasing/increasing trend in these concentrations in the stream water. They were near the natural background levels for most Lithuanian rivers.

The distribution of  $\text{PO}_4^{3-}$  concentrations in the stream water and lime filter drainage water showed slightly downward trends ( $r_{\text{str}}=0.32$ ,  $r_{\text{I}}=0.27$ ). Considerable fluctuations in phosphate concentrations in the control drainage water were detected, therefore, the reliability of chosen linear trendline is very low ( $r_{\text{III}}=0.05$ ) (Fig. 14).

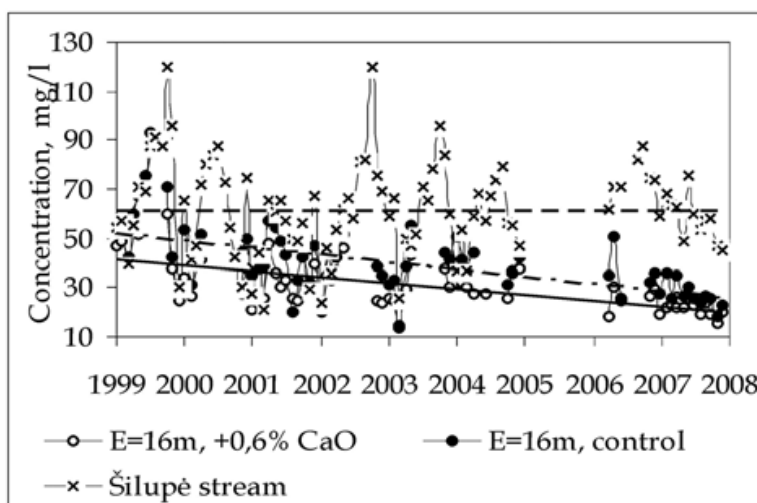


Fig. 13. Dynamics of sulphate anions concentration and temporal trends.

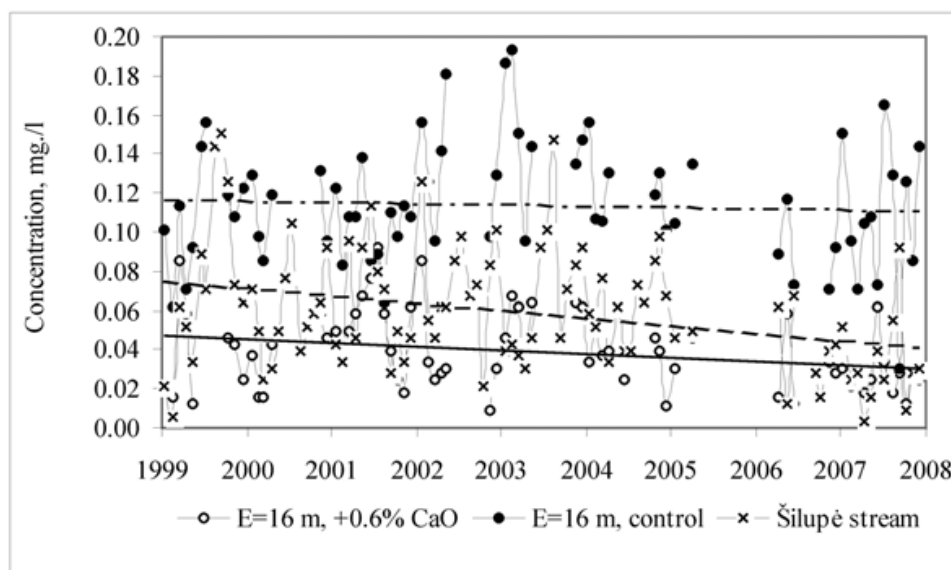


Fig. 14. Temporal changes in phosphate ions concentrations for the period 1999-2008.

The distribution of annual average phosphorus concentration in Šilupė stream water within the period of 1999-2008 shows a slightly decreasing trend of TP ( $r = 0.49$ ) and  $\text{PO}_4\text{-P}$  ( $r = 0.84$ ). These results confirm the tendencies established earlier and correspond to general character of downward trends found in the Lithuanian rivers within agricultural areas (Povilaitis, 2004; 2006).

Two periods can be discerned when analysing the dynamics of  $\text{NO}_3^-$  concentration in subject to land management. First period lasted from the beginning of the investigations until the end of 2002 when the site was used for grassland. The second period spanned since crop

cultivation (2003–2007). During the first streak mean values of  $\text{NO}_3^-$  in drainage treatments I–III were 0.77, 0.64 and 1.02 mg/l respectively. Conspicuous moderate downward trend ( $r=0.66\text{--}0.74$ ) in all treatments was determined in the time series. The situation changed after the grassland had been tilled in the autumn of 2002. The concentrations of  $\text{NO}_3^-$  began progressively increase every year. Trends of nitrates of the second streak can be expressed by strong linear regression ( $r=0.83\text{--}0.88$ ). It must be noted that  $\text{NO}_3^-$  concentrations in Šilupė stream water started rising thereabout the year later than in drainage water (from the autumn of 2003).

$\text{NH}_4^+$  level both in the Šilupė stream and drainage water changed widely from the beginning of the investigations until the middle of 2001. Later, fluctuations of ammonium concentrations assumed a moderate character.

3.3 Fluctuation of biogenic substances concentration and loads with drainage outflow

The highest average concentrations of TP and  $\text{PO}_4\text{--P}$  were determined in the drainage outflow of the control treatment (Table 7). They reached  $0.044\pm0.006$  and  $0.032\pm0.004$  mg/l, respectively. Summing-up of all study period the mean value of  $\text{PO}_4\text{--P}$  was 1.8 times higher than its average concentrations in the Šilupė stream water ( $0.018\pm0.003$  mg/l) and 3.2 times higher than its average concentrations in the outflow of LFD treatments ( $0.010\pm0.001$  mg/l). Extreme annual values of  $\text{PO}_4\text{--P}$  (0.049 mg/l) were quantified in the dry year of 2003, when the lowest annual drainage runoff was observed (33 mm).

Indices	I	II	III	Stream	I	II	III	Stream
	TP				$\text{PO}_4\text{--P}$			
Mean	0.021	0.021	0.044	0.039	0.010	0.010	0.032	0.018
Max	0.035	0.034	0.060	0.062	0.013	0.015	0.046	0.027
Min	0.012	0.012	0.028	0.026	0.008	0.007	0.022	0.012
SD	0.007	0.007	0.009	0.012	0.001	0.002	0.006	0.005
V %	33	33	20	31	13	22	19	26
Conf <sub>95</sub>	0.004	0.004	0.006	0.007	0.001	0.001	0.004	0.003

SD – standard deviation, V % - variation coefficient, Conf<sub>95</sub> – 95% confidence interval for a mean

Table 7. The mean concentrations of phosphorus (mg/l) in drain discharge and stream water in 1999–2009.

TP concentration in the Šilupė steam varied between 0.026 and 0.062 mg/l (the mean value  $0.039\pm0.007$  mg/l).  $\text{PO}_4\text{--P}$  concentration in receiving stream increased from the lowest values in spring (0.012 mg/l) to 0.027 mg/l in August (the mean value  $0.018\pm0.003$  mg/l). According to the rates approved in Lithuania, surface water quality is considered to be good than  $\text{TP} < 0.1$  mg/l and  $\text{PO}_4\text{--P} < 0.065$  mg/l. Consequently, the water of the Šilupė stream can be considered as uncontaminated with phosphorus because the concentrations do not exceed Lithuanian surface water quality standards. However, critical levels of phosphorus in water, above which eutrophication is likely to be triggered, are approximately 0.03 mg/l of dissolved phosphorus and 0.1 mg/l of total phosphorus. According to the UN ECE classification, surface water is considered fairly eutrophic at 0.025 mg P/l consequently the risk of eutrophication in the Šilupė stream still exists. Whereas phosphorus concentrations in the Šilupė stream besides the Kalnujai site were 1.5 times higher than those found in the

effluent of LFD, it must be concluded that this drainage practice may reduce surface water pollution with phosphorus compounds.

In Fig. 15 the dynamics of nitrogen concentrations in the Kalnūjai site is represented. Despite the seasonal changes, the average concentrations of  $\text{NO}_3\text{-N}$  in the Šilupė stream ( $5.43 \pm 0.72$  mg/l) generally remained steady during 1999-2003.  $\text{NO}_3\text{-N}$  concentrations in the stream water started rising from the autumn of 2003 (approximately the year later than in drainage water). The average  $\text{NO}_3\text{-N}$  concentrations of  $9.83 \pm 1.92$  mg/l were determined in 2004-2005.

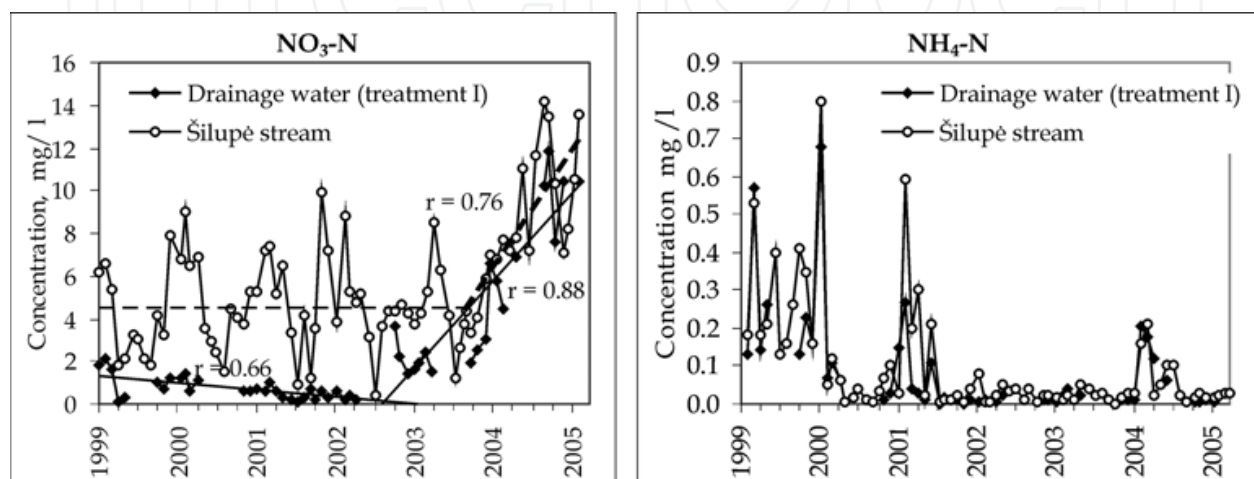


Fig. 15. Dynamics of nitrogen concentrations in the Kalnūjai site (dash and line show linear trends of  $\text{NO}_3\text{-N}$  in stream water:  $r = 0.003$  and  $r = 0.76$ , solid line – in drainage water:  $r = 0.66$  and  $r = 0.88$ ).

In Lithuanian rivers with natural background level pollution the average concentrations of 0.29 mg/l  $\text{NO}_3\text{-N}$  and 0.13 mg/l  $\text{NH}_4\text{-N}$  were established (Povilaitis, 2006). The concentrations of  $\text{NO}_3\text{-N}$  below 0.3 mg/l are considered to be natural or background levels for most European rivers (Nixon, 2004). It is obvious that in comparison with rivers of natural background level pollution nitrate nitrogen levels in the Šilupė stream are about 20-30 times higher and exceed the guideline concentration for  $\text{NO}_3\text{-N}$  (2.3 mg/l) given for the surface water. The concentrations of  $\text{NO}_3\text{-N}$  above 7.5 mg/l are considered to be related with relatively poor quality, though twice-higher concentrations (15.20 mg/l) were determined in 2005.

The annual loads of biogenic substances with drainage outflow in the Kalnūjai site are given in Table 8. The greatest annual mean of TP losses ( $0.06 \pm 0.017$  kg/ha) was calculated in the control treatment. In LFD the mean leached amounts of TP ( $0.029\text{-}0.031$  kg/ha) are 1.9-2.0 times less than in the control treatment; while  $\text{PO}_4\text{-P}$  amounts ( $0.015\text{-}0.016$  kg/ha) are even 2.7-3.0 times less ( $0.045 \pm 0.011$  kg/ha) (the differences are statistically significant at  $p < 0.05$ ). The same differences in terms of total phosphorus loads are statistically significant too. The comparison of phosphorus loads in the drainage treatments with drain spacing  $L=16$  m and  $L=24$  m revealed no significant difference. Hence the lime as amendment of the fine-textured soils positively affects the quality of drainage water and reduces the transport of phosphorus into open water bodies.



Year	PO <sub>4</sub> -P			TP			NO <sub>3</sub> -N		
	I	II	III	I	II	III	I	II	III
1999	0.016	0.014	0.042	0.030	0.029	0.062	1.784	1.585	1.951
2000	0.018	0.018	0.058	0.042	0.040	0.085	2.058	1.449	1.856
2001	0.021	0.026	0.048	0.042	0.047	0.074	5.660	3.690	7.510
2002	0.021	0.017	0.062	0.037	0.033	0.078	0.696	0.491	0.791
2003	0.008	0.008	0.016	0.015	0.012	0.022	13.490	12.320	10.900
2004	0.011	0.018	0.050	0.023	0.034	0.062	8.804	11.590	9.513
2005	0.011	0.012	0.036	0.017	0.021	0.038	9.133	6.652	9.822
Total	0.104	0.114	0.313	0.205	0.216	0.420	41.624	37.777	42.343
Annual mean*	0.015 ±0.004	0.016 ±0.004	0.045 ±0.011	0.029 ±0.008	0.031 ±0.009	0.060 ±0.017	5.946 ±3.5	5.397 ±3.6	6.049 ±3.2

Table 8. Annual load of biogenic substances (kg/ha) by drainage outflow in the Kalnujai site in 1999-2005 (*p*<0.05).

The negative charge on the clay particles retains ammonium ions (NH<sub>4</sub><sup>+</sup>) and protects them from leaching. Nitrate ions (NO<sub>3</sub><sup>-</sup>) are negatively charged and are not retained by the clay particles; therefore, subsurface drainage increased the amount of nitrates that can potentially leach from the soil to the drainage water. The calculations showed that in the control drainage treatment NO<sub>3</sub>-N load amounted to 6.049±3.2 kg/ha per year on the average. In LFD when drain spacing L=16 m the load of nitrate nitrogen amounted to 5.946±3.5 kg/ha per year, when drain spacing L=24 m, NO<sub>3</sub>-N load was 9% less (5.397±3.6 kg/ha) on the average. During the seven-year investigations the nitrate nitrogen load was 1.7% and 10.8% less from the lime filter drainage systems than that from the control drainage, but these differences could not be treated as statistically significant. Furthermore, it must be noted that nitrates load in particular years differed much more (variation of data 72-91%) than phosphorus, the load variation of which was only 35-38%. At the same treatment the ratio between marginal values of nitrate load varied from 13.8 to 25.1 during the investigation period. The largest nitrate nitrogen input to the stream water observed in 2003 is likely to be related to intensified agricultural activities (tillage of grassland and crop cultivation, application of mineral fertilizers). Other references also proved that the magnitude of nitrogen loss depended on the soil management (Zucker & Brown, 1998; Povilaitis, 2006). However, the results obtained in the Kalnujai site revealed that the drainage trench backfill permeability improved with lime additives did not increase nitrate leaching to drainage water.

3.4 Seasonal variability of phosphorus concentrations in lime filter drainage outflow

Research shows that the differences in between conventional drainage and LFD have a seasonal variation in respect of phosphorus concentrations in drain discharge (Fig. 16). The lowest concentration of TP was determined in September, whereas the highest one - in January. The values of TP concentrations from the plot with LFD shows more variability depending on seasonal peculiarities (*V* = 33%) versus phosphate phosphorus (*V* = 13-22%). Dils & Heathwaite (1999) appeal to field experiments in mixed agricultural catchment in the UK and state that phosphorus concentrations in drain discharge are low (<100 µg TP/1) and stable during base-flow periods (<0.5 l/min), and generally lower than the ones in the

receiving stream. In contrast, temporary (hours) elevated P peaks are measured in drain-flow during high discharge periods ( $>10 \text{ l/min}$ ). Large sediment-associated particulate P losses are measured during the first major drain-flow event of the autumn.

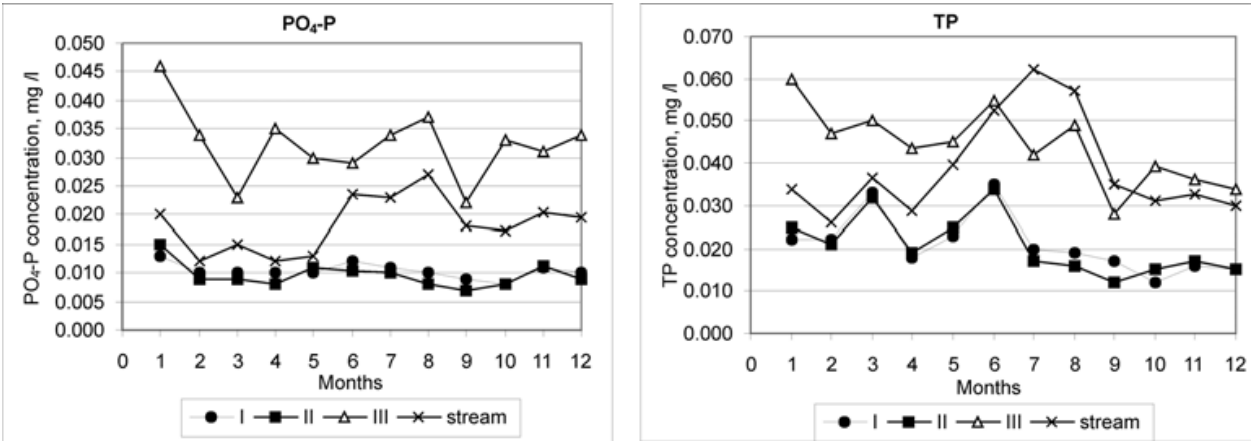


Fig. 16. Seasonal variability of mean phosphorus concentrations in drain discharge and stream water during 1999–2009 (I-II – lime filter drainage, III- control drainage)

Results of studies carried out in the Kalnujai site indicate otherwise. The highest  $\text{PO}_4\text{-P}$  concentrations in control drainage outflow are fixed during the entire year with extreme values in January. In the Šilupė stream increased  $\text{PO}_4\text{-P}$  concentrations are observed in summer, decreased ones – in spring. However, in all months the  $\text{PO}_4\text{-P}$  content in receiving stream is lower than that in the control drainage outflow but exceeds that in the outflow from LFD. This confirms that in cultivated areas drainage has a significant impact on  $\text{PO}_4\text{-P}$  content in surface water and such means as LFD in clay soils can reduce this negative impact.

The salient inflow of TP in receiving stream was observed in warm season from April to July later concentrations gradually decrease. The highest phosphorus concentrations (0.052–0.062 mg/l) are observed in summer time (June–August) when runoff is low and intensive release of dissolved phosphorus from the sediments takes place. From July to October is the period when TP content in the stream is higher than that in the drainage outflow. A. Povilaitis (2004) states that trends in the change of phosphorus concentrations in Lithuanian rivers are strongly affected by fluctuations of runoff and phosphorus content in streambed sediment. Taking into account the fact that high quantities of phosphorus can be transported with suspended sediments, the significantly increased loads of suspended matter during the heavy rains in summer can result in the increased particulate phosphorus content.

The changes in predominating phosphorus forms in the Šilupė stream depend on the season of the year. The portions of phosphate phosphorus amounts make from 33% to 63% of total phosphorus amount there. The largest ones were detected in winter months. Thus, the water outflowing from the conventional drainage systems can influence water quality in the recipient stream in cold season only but this influence may vary.

Comparison of lime filter drainage (I and II) and control drainage (III) outflow gives ambiguous results, which show that significant differences develop only in certain months (Table 9).

Treat-ments	Months											
	1	2	3	4	5	6	7	8	9	10	11	12
TP												
I-II	-	-	-	-	-	-	-	-	-	-	-	-
I-III	++	+	+	+	+	-	-	-	-	-	++	++
II-III	++	+	+	+	+	-	-	-	-	-	+	++
I-st	+	-	-	-	-	-	++	+	+	++	+	++
II-st	-	-	-	-	-	-	++	++	++	+	+	++
III-st	+	-	-	-	-	-	-	-	-	-	-	-
PO <sub>4</sub> -P												
I-II	-	-	-	-	-	-	-	-	-	-	-	-
I-III	++	+	++	++	++	-	-	-	-	-	++	++
II-III	+	+	++	++	++	-	-	-	-	-	++	++
I-st	-	-	-	-	-	-	-	-	-	-	++	-
II-st	-	-	-	-	-	-	+	-	+	-	++	+
III-st	+	+	-	+	+	-	-	-	-	-	-	-

Table 9. Statistical estimation of phosphorus concentrations in drainage outflow and in the Šilupė stream in the period of 1999–2009 (+ significant difference at  $p<0.05$ ; ++ significant difference at  $p<0.01$ ; - no differences)

Hence, the effectiveness of LFD depends on the meteorological conditions of the season. It has been established that in cold season (November–January) TP concentrations decrease by 56–63% in the outflow of LFD (significant differences at  $p<0.01$ ), differences are less significant in February – May period ( $p<0.05$ ), and no significant differences have been established for the June – October period due to high variation of data. Similar variability detected for PO<sub>4</sub>-P concentrations. According to the data of wet year, phosphate phosphorus content in LFD treatments is significantly lower than that in conventional drainage ( $p<0.01$ ) in all months, with exception of June – October period, when drainage outflow usually stops.

Comparison of TP concentrations in LFD outflow and in the stream shows that significant differences become distinct in the beginning of July, after the discharge has decreased, and persist until January – in this period TP concentration in the stream increases 2.0–3.6 times. Significant differences between PO<sub>4</sub>-P concentrations in the stream and in drainage outflow are estimated in November ( $p<0.01$ ), and those at the significance level  $p<0.05$  – in July, September and December. In the comparison of LFD no significant differences between phosphorus concentrations have been established.

Differences between phosphorus concentrations in stream water and control drainage outflow are observed in some months only. In January – February TP concentration in drainage outflow is 1.8 times higher than that in the stream, but statistically significant differences are estimated only in January. PO<sub>4</sub>-P concentration in drainage outflow significantly increases (2.3–2.9 times) in January – May, with exception of March. In any other time of year the PO<sub>4</sub>-P content in drainage outflow was 1.2–1.5 times higher, than that in the stream water, but statistically differences are insignificant.

In the period of observations phosphorus concentrations in LFD outflow do not pertain neither to precipitation amount nor to fluctuations of air temperature (Fig. 17, Fig. 18). This brings to the statement that the effectiveness of lime does not depend on meteorological conditions.

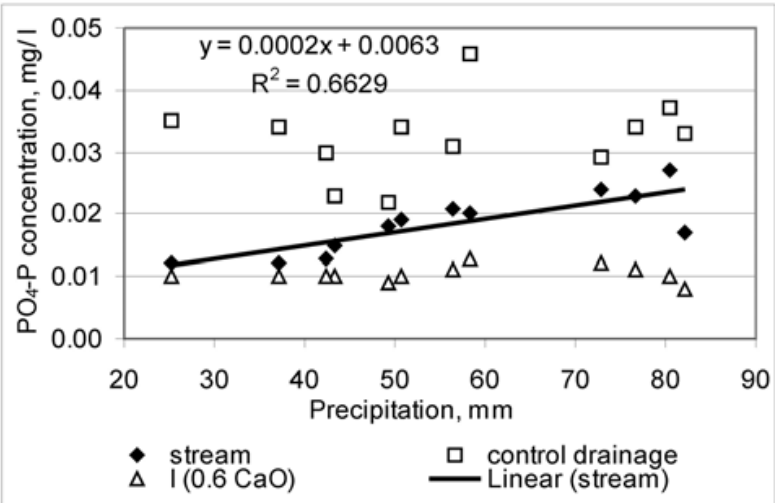


Fig. 17. Correlation between monthly precipitation (x) and mean PO<sub>4</sub>-P concentration in drain discharge and stream water (y)

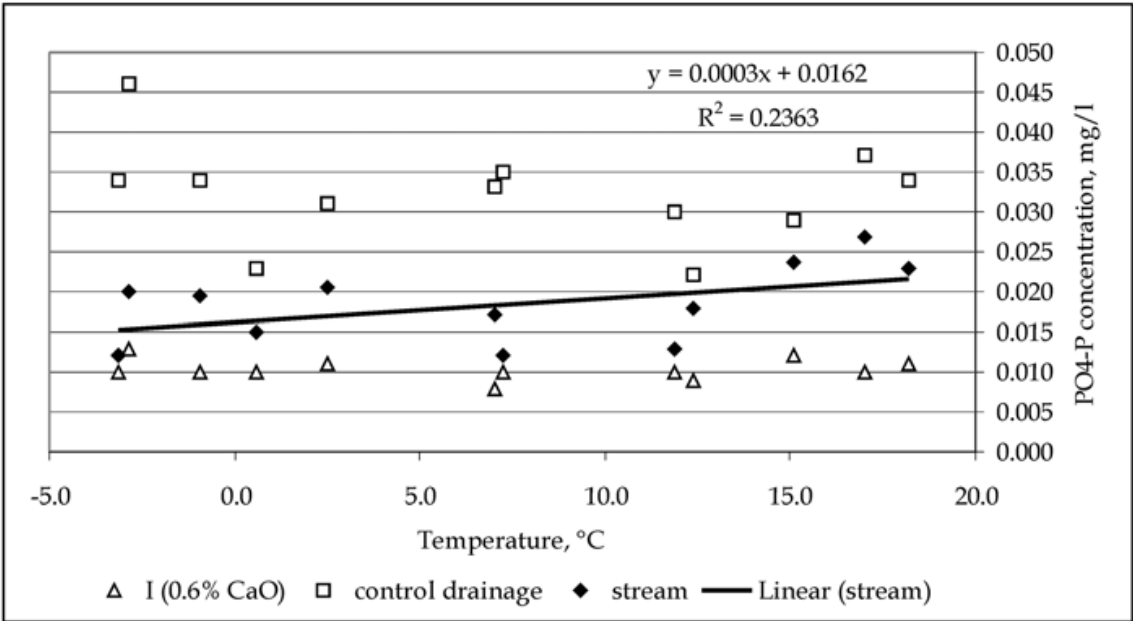


Fig. 18. Correlation between average monthly temperature (x) and mean PO<sub>4</sub>-P concentration in drain discharge and stream water (y)

Correlation between phosphorus concentrations in the control drainage outflow and the amount of precipitation and temperature are very weak. At the same time strong correlation between TP concentration in surface water and monthly precipitation ( $r = 0.82$ ), and medium correlation ( $r = 0.49$ ) between the PO<sub>4</sub>-P concentration and the temperature was estimated (Table 10).

	I	II	III	Stream	Precipitation mm	Temperature °C
TP						
I	1					
II	<b>0.827</b>	1				
III	0.480	0.571	1			
Stream	0.364	0.130	0.211	1		
Precipitation mm	0.058	0.049	0.190	<b>0.817</b>	1	
Temperature °C	-0.113	-0.328	-0.236	0.486	0.503	1
PO <sub>4</sub> -P						
I	1					
II	0.935	1				
III	0.655	0.759	1			
Stream	0.301	0.134	0.257	1		
Precipitation mm	-0.084	-0.124	0.112	0.689	1	
Temperature °C	0.071	-0.106	-0.099	0.805	0.503	1

Table 10. Pirson’s correlation coefficients between phosphorus concentration and climate indices.

4. Conclusions

Subsurface lime filter drainage systems installed in clay soils differ from conventional drainage due to their more efficient hydrological functioning. Lime added to the trench backfill ensures significantly higher surface water infiltration rate, lower watertable depth in between the drains and more stable drainage coefficients at critical moments.

Lime filter drainage positively affects the quality of drainage water. This mean may reduce potassium, chloride, sulphate and phosphate concentrations in drainage water considerably.

In the outflow of lime filter drainage the total phosphorus concentrations were 50% lower while phosphate phosphorus concentrations were 64.4% lower than those in the control drainage water. Therefore with certainty must be concluded that lime admixture in trench backfill may reduce phosphorus transport into open water bodies.

However, seasonal variability is characteristic of the efficiency of lime filter drainage under the climatic conditions of Lithuania. It has been estimated that in cold season (November–January) TP concentrations are 2.3–2.7 times lower in outflow of lime filter drainage (significant differences at  $p=0.01$ ), in February – May the differences are less significant (1.5–2.0 times,  $p=0.05$ ), and no significant differences have been estimated for the June – October period. PO<sub>4</sub>-P concentration in lime filter drainage treatments is significantly lower than that in conventional drainage ( $p=0.01$ ), with exception of June – October period, when drainage outflow usually stops.



The results obtained in experimental sites in Lithuania show that lime filter drainage is long lasting improvement of clay soils because persistent significant differences were observed in drainage treatments that are in operation since the year of 1989. Therefore this drainage practice can be treated as an effective measure preventing non-point pollution of surface waters in agricultural areas where clay soils prevailing.

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