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THE IMPACT OF AGRICULTURE DRAINAGE RECONSTRUCTION ON GROUND WATER RECESSION CLOSE TO THE SUBGRADE

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Abstract. Good drainage is the most important design consideration for a road, both to miniaturize road maintenance costs and maximize the time the road is operational. The lack of good drainage lead to the structural damages and costly repairs. Many of roads are built in intensively drained agricultural land. The effective way to drain subgrades is reconstruction of existing agricultural drainage. The impact of cross-subsurface drainage system on water level fluctuation was measured using Plane geofiltration mathematical model, one of 3D geofiltration modelling programs. The hydraulic permeability characteristics were determined in field of Pikeliai, close to local road in Kėdainiai district, Lithuania. This object is composed of clay and loamy soils. Subsurface cross drains trenches spacing of 20 m, 30 m and 40 m were simulated. The hydraulic permeability of cross drain trenches and lateral trenches modelled was from 0.006 m/a day to 6 m/a day. The simulation of cross drains trenches showed that the most effective distance between them are 20 m. The highest water depression occurs when the permeability of cross drain trenches and lateral trenches is ~ 6 m/day, at the distance of 20 m. The water recession is 20 cm lower compared to the drainage systems without cross drains trenches. By installing cross drains trenches every 30 m, water recession is 10 cm lower when the trench permeability is about 6 m/day. When increasing the distance between the cross drains up to 40 m their influence disappears.

Keywords: road subsurface drainage, hydraulic permeability, additional cross drains, impact on water table depression, ground water table.

1. Introduction

The drainage system in road construction depends on factors such as: sensitivity of groundwater, importance of road, area (rural or populated), and intensity of traffic, density of streams, rivers and lakes. In Lithuania about 80% of farmland is drained. This reclaimed land is dominated by clay and loam soils, which have low permeability. Many roads are built in these areas over the drainage systems. The existing drainage systems drain not only agricultural land, but also the subgrades.

The main purpose of sub-surface drains is to control the level of groundwater, which permeate through the road pavement layers in both cut and fill situations. The value of proper drainage design and maintenance of roads cannot be over-emphasized. The drainage system includes the roadway: the shoulders, ditches, subsurface drainage, culverts, the curbs, gutters and storm sewer systems. These elements work together as a system to prevent water from infiltrating the road surface, remove it from the driving lanes to the side ditches, subsurface drainage and gutter, and carry it away from the roadway (Donald 2000, Saara, Saarenketo 2006). To intercept direct excess water away before it gets into the roadway the use materials and techniques is needed, which allow excess moisture in the roadway to drain away.

Big problem of road pavement destruction is frost action. Heaving occurs when there are: freezing temperatures; free water available to create ice lenses; frost–susceptible soils present. All three must be present to have frost heaving. Since the control of weather today is impossible, it is important to eliminate the source of free water and one of them is subsurface drainage (Apakharel *et al.* 2011; Doanh *et al.* 2013; de Grandpre *et al.* 2012; Kalantari, Folkeson 2013; Salour, Erlingasson 2013; Vasiliev, Sidenko 1990).

The impact of drainage on lowering of ground water level has been known for a long time. It was stated that if

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drains are laid as close to each other as possible, intensity of ground water recession increases significantly as well. For example, water table regimes in a poorly drained, but agriculturally important clay soil (Dalhousie) of eastern Ontario were investigated (Culley, Coote 1984). Over 18 months, water table gradients in a field without pipe drains did not appear to be affected by an open outlet channel beyond a distance of about 65 m. Water table remained near the surface until mid-May after which they receded until early fall when recharge began. By late fall water table in the undrained field were again at the surface. Pipe drains, installed at a 17 m spacing, dramatically altered water table regime. Water tables rose to within 0.6 m of the soil surface only occasionally, and the mean drawdown rate due to the drains was about 0.15 m/day. Water tables were observed to rise rapidly during storms and overland flow in the Dalhousie landscape occurred after the water table had risen to the soil surface (Culley, Coote 1984). Pavement drainage is most beneficial when excessive moisture can be rapidly removed from the structure. Ideally within 2 h and preferably within 24 h; however, the benefits derived from a subsurface drainage system will vary depending on pavement type, annual rainfall, sub-grade conditions, geometric design, and design of the overall pavement system (Apakharel *et al.* 2011; Finn *et al.* 2004; Heilweil, Watt 2011; Kuang *et al.* 2011; Rokade *et al.* 2012; Sedergen 1981). It only proves that if one strives for drainage efficiency, spacing between them must be shortened. Estimating the current situation in Lithuania, where new drainage system construction is not taking place, it becomes relevant to modify (reconstruct) the already existing drainage systems in order to improve their functioning. As one of the ways, is the equipment of additional cross drains.

The depth of the water table is often used as a criterion factor because it can be related to drain depth and spacing. The drainage of roads differs from drainage of agricultural lands, flood control or the drainage of urban areas. Good road drainage design should consider the removal of runoff water, the maintenance of sensitive environments, public health, natural water resources and the cost effectiveness of future maintenance activities. The aim of such drainage systems is indeed fast flow velocities. On the other hand, it also differs from erosion control, which rather aims at retaining and conserving the water than letting it runoff at all. For agricultural purposes, land drainage would be better served with a definition relating to a modest degree of water table or water–level control, than with a definition relating to the removal of water (Griffiths *et al.* 2000; Jackson, Boutle 2008; Rocwell 2002).

Heavy clay soils often have low hydraulic permeability that they require very narrow drain spacing (Ritzema *et al.* 1994). As their permeability is dependent on the soil-water content and macro pores, it happens that their infiltration rate is too low for the water to enter the drain, therefore that frequent surface water pond will occur. In such cases, design of special drainage systems to prevent water logging is used.

Research of different groups of scientists shows that the drainage of heavy soil is efficient while employing shallow sparse drainage, the main purpose of which is to drain surface water (Singh *et al.* 2007). However, other scientists note that the potential of surface soil layer can stay wet or swampy. Therefore, research conducted by another group of scientists shows that it is most efficient to drain heavy, fertile soils with help of deep systematic compacted subsurface drains. Thus, the permeability of upper layer cultivated is increased, where downgrading of groundwater level takes place much faster because of the soil ripening process and due to increase differences in pressure heads (Cooke *et al.* 2001; Culley, Coote 1984; Rocwell 2002; Strock *et al.* 2010; Zheng *et al.* 2013). It shows that the scientists' opinion on drainage of heavy soils is not unanimous.

Drain intensity (depth and drain spacing) determines whether a drainage network is capable of reducing the depth of water table between the drain lines to an elevation most beneficial to plant growth within 24 h to 48 h after rain. For instance, in Minnesota it was found that shallow drain pipe installation and drainage systems designed for lower drainage intensity resulted in less drainage water compared to deeper drains or greater drainage intensity (Mendez *et al.* 2004; Sands *et al.* 2008).

To remove excess water from soil as fast as possible is necessary to enhance optimal water level for road subgrade. The existing subsurface drain system can be improved by filling the trench with coarse material or adding material like lime (Heilweil, Watt 2011; Kuang *et al.* 2011). One of the instruments to improve the efficiency of existing drainage systems could be installation of subsurface cross-drains.

The design and functioning of subsurface drainage systems depend largely on the saturated hydraulic permeability of soil. All drain spacing equations make use of this parameter. To design or evaluate a drainage project, it is necessary to determine the hydraulic permeability value as accurately as possible (Mendez *et al.* 2004). However, the hydraulic permeability of heavy soils because of swelling and shrinking is subject to variation in space and time, what means that it is a problem to adequately assess a representative value. Nowadays, no optimum surveying technique exists. Much depends on the skill of the surveyor. Nevertheless, large number of field measurements are required to account all variability. These measurements are not only costly but also time-consuming and relatively cumbersome. The designer must have some confidence in the design value of filtration coefficient before he/she have confidence in the subsurface drainage design. In nowadays, the most effective way to calculate the filtration value is based on water-table measurements, where lateral drains are already installed in the field (Moustafa 2000).

Given that the field models are expensive, usually empirical (mathematical) geofiltration models are used. The Surendra Kumar Mishra tested 14 physically based, semi-empirical and empirical infiltration models. The physically based models performed better on the soils tested in the laboratory than those tested in the field (Dan *et al.* 2012; He *et al.* 2002; Mishra *et al.* 2003; Ranieri *et al.* 2012).

The aim of investigations was to research the influence of cross-section drainage to subgrade on the improvement of hydraulic permeability of subsurface drainage systems in Lithuanian clayey soils. Therefore, the hypothesis was that the one of the instruments to decrease ground water level close the subgrade would be installation of cross tile drains between the existing laterals. In Lithuania, such drainage systems have not been equipped and tested yet.

2. Methods and materials

2.1. Description of geofiltration model boundary conditions

Geofiltration model was used to determine the influence of cross drains trenches to ground water level recession on normal drainage. Achievement of goals requires:

– to design the model of cross drains trenches;
– to describe geofiltration model boundary conditions;
– to perform model calibration and validation.

The effect of Plane geofiltration mathematical model (PLAFI) is based on partial derivatives of unsteady geofiltration differential equation (Fig. 1).

Mathematical modelling of groundwater recession was carried out applying the 3D PLAFI model, which uses the finite difference method. The area between the two laterals was covered with a rectangular grid, with every node point having an elementary cell assigned to it. According to the finite difference procedure, a water level balance equation was obtained for every cell. The calculation procedure

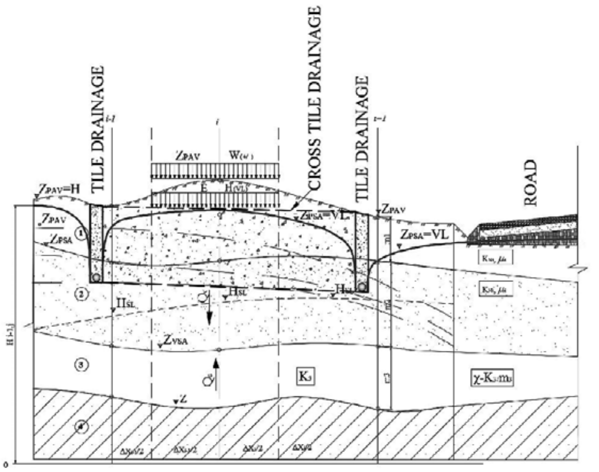

Fig. 1. The scheme of steady water flow into perfect drain

Note: μ – water retention coefficient; $Z_{PAV}(H)$ – height of water pressure with regard to reference plane, m; M – saturated permeability of upper watery layers; W – intensity of infiltration or filtration, m/day; $Z_{PSA}(VL)$ – altitude of layer surface, m; Z_{VSF} – altitude of layer bottom, m; $\varepsilon(z)$ – intensity of evaporation from water surface; E_0 – evaporation from the modelling area, m/day; γ_n – empiric coefficient, dependent on species of flora; z – depth of groundwater; K_3 – 3rd layer filtration coefficient, m/day; m_3 – 3rd layer filtration thickness, m; H_{SL} – pressure height of pressure water (in the 4th layer).

included iteration in every cell node until the water level change obtained was not greater than 0.001 m. The data of groundwater level was carried out as registered in field data and used for calibration and validation of this model. The most effective way to calculate the filtration value is based on water-table measurements, where lateral drains are already installed in the field (Moustafa 2000; Oosterbaan 2002).

The following 3D form of differential equation to calculate geofiltration is employed in the programme:

$$\mu\frac{\partial H}{\partial t}=\frac{\partial}{\partial x}\left(M\frac{\partial H}{\partial x}\right)+\frac{\partial}{\partial y}\left(\frac{\partial H}{\partial y}\right)+W-\varepsilon(z)-\chi\left(H-H_{SL}\right), \quad (1)$$

where μ – water retention coefficient (for labelling – Fig. 1); t – time, days; H – height of water pressure with regard to reference plane, m; M – saturated permeability of upper (1 and 2) watery layers.

$$M=K\left(H-Z_{PSA}\right)+K_N\left(Z_{PSA}-Z_{VSP}\right), \quad (2)$$

where W – intensity of infiltration or filtration, m/day; Z_{PSA} – altitude of layer surface, m; Z_{VSF} – altitude of layer bottom, m; $\varepsilon(z)$ – intensity of evaporation from water surface.

$$\varepsilon(z)=E_0\exp\left(\gamma_n z\right), \quad (3)$$

where E_0 – evaporation from the modelling area, m/day; γ_n – empiric coefficient, dependent on species of flora; z – depth of groundwater, $z = Z_{PSA} - H$, m; χ – coefficient of water overflow through half-permeable impervious layer.

$$\chi=\frac{K_3}{m_3}, \quad (4)$$

where K_3 – 3rd layer filtration coefficient, m/day; m_3 – 3rd layer filtration thickness, m; H_{SL} – pressure height of pressure water (in the 4th layer).

Estimating the conformity of geofiltration and regression model difference, non-parametric Wilcoxon criterion was selected to identify statistical significance.

Designing the geofiltration model of groundwater recession, the potentially shorter period with regard to two dominating factors that could affect the process of groundwater modelling between drains, i.e. the amount of rainfall during the recession and air temperature was used (Khan *et al.* 2002).

When selecting the area of calibration and validation, it was supposed to be as little affected by surface and ground water flowing from the field as possible.

Designing the layer of primary water levels, approximate water level values of separate internal nodes within the network were used. Water levels were taken whereas factual heights of groundwater level were specified during the model calibration process. Water levels were calibrated and validated according to water levels measured in piezometers.

Designing water surface massive, ground surface altitude for each point in the network node formed by experimental field was identified. Unknown intermediate altitudes were identified by using linear interpolation.

Designing the massive of altitudes in geological layers within the mathematical network, altitudes of all layers were calculated according to the provided reclamation topographic map (scale – 1:2000). Altitudes of separate mathematical network nodes were calculated using the method of linear interpolation.

Designing mathematical layer of geological and hydrogeological lateral condition characteristics, filtration coefficients of 1st and 2nd geological layer areas as well as water retention coefficients of these areas and coefficient of water overflow through half-permeable impervious layer were identified. It was taken into consideration the difference of potential filtration and the use of different water retention coefficients in the modelling area. The following areas were distinguished in the nodal network.

In order to estimate the impact of cross drains trenches on recession of ground water level different variants of cross drains trench spacing were modelled. Cross drains were equipped every 20 m, 30 m and 40 m from each other in the model drains of laterals having already been laid (Fig. 2). Such a filtration coefficient in cross drains existing trenches and zone close to drains trenches as well as area between drains was accepted as it was defined during model calibration and validation processes.

2.2. Calibration and validation of geofiltration model

During the model calibration procedure, it is important to identify a geofiltration coefficient. It is a serious problem to define geofiltration qualities. Natural research into filtration coefficients performed by numerous scientists manifested that their identification is rather complicated. Measurements of saturated hydraulic permeability in the field are costly, time-consuming and relatively cumbersome as hydraulic permeability exhibits a large spatial variability. It becomes difficult to find accurate representative values to correctly predict soil-water flow and design drainage systems and it is one of the most difficult factors to evaluate in any drain spacing situation (Moustafa 2000). It all impedes selection of correct geofiltration values. Using geofiltration model, this parameter can be adjusted and modified according to the simulation conditions. In addition, wide use of this geofiltration model in Lithuania for modelling of different geofiltration processes determined the selection of digital modelling.

Data of 1999–2005 was used for modelling calibration and validation. The period of calibration of water level recession was 12.01.2001–26.01.2001. The period from 11.04.2005 to 27.04.2005 was correspondingly selected for modelling validation. Non-parametric Wilcoxon criterion for dependent samples test was selected for values measured in the field and calculated by the model to identify statistical validity. This criterion was selected with regard to the fact that samples compared are small ($n \leq 25$). The measured and calculated meanings of geofiltration model alter within the interval from 0 m to 1.07 m, the depth of the trench. In this context, a statistical analysis of the data can only be used nonparametric criteria (Oosterbaan 2002).

The amount of rainfall had the minimum influence on the process of ground water level recession within the period selected. The average day temperature of the modelling period was about 6 °C.

2.3. Field measurements

The experimental site is located in the central part of the country, at Pikeliai, a village in the Kėdainiai district. The relief of the central zone is slightly to moderate rolling plain, diversified by river and stream valleys, where soggy clay soils of light to medium moraine sandy loam are predominant.

The field measurements were made of hydraulic heads in midway between drains, near the drain trenches (at a distance of 0.40 m from the drain) and above the

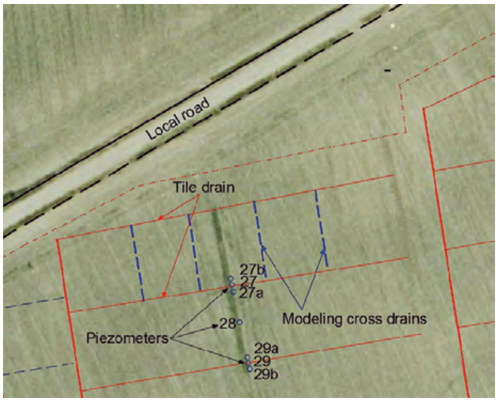

Fig. 2. The experimental site (at Pikeliai, a village in the Kėdainiai district)

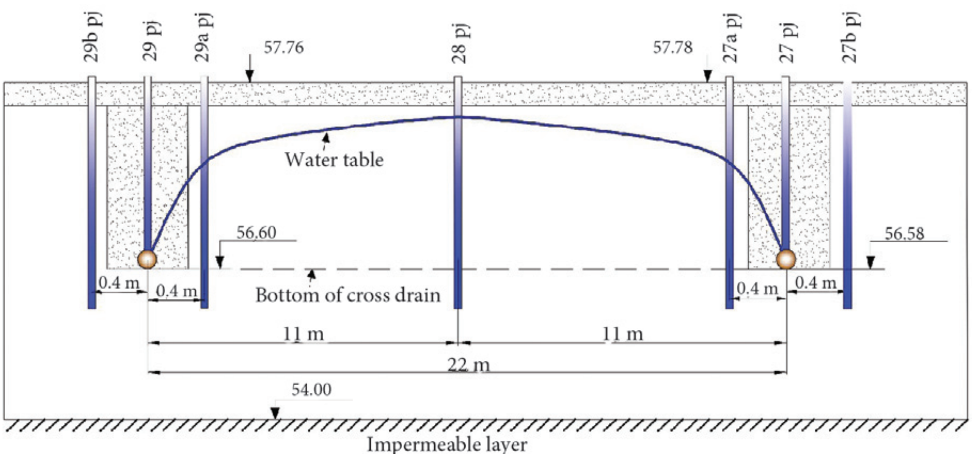

Fig. 3. The piezometers of experimental site

drain (Fig. 3). The drains where installed at a depth of 0.90–1.10 m and their spacing was 22 m.

The soil of the experimental site mainly consists of sandy to sandy clay loam. To measure these hydraulic heads, 7 piezometers were installed in one row in each of experimental plots. The piezometers were made of 1.50 m long smooth polyethylene pipes with a diameter of 50 mm. The bottom part of the pipe was perforated over a length of 30 cm with 5 mm holes. Water levels in the piezometer tubes were measured with an electric gauge.

The majority of observations took place in spring and autumn, when the level of ground water is highest. In spring observations are undertaken at the end of the summer and finished at the end of May. The start of observations in spring was determined by the amount of rainfall during the cold period, air temperature, and the depth of the frozen ground. In order to identify water level fluctuations between drains, the data was sampled every 3–4 days (Rimidis, Dierickx 2004).

3. Results and discussion. Influence of spacing between the cross drainage lines

In order to determine the average values of the collected data, descriptive statistics was used (Table 1).

Evaluating the standard deviation values showed that the variables are not spread far from the centre of analysed values. This suggests that the values do not have data exclusions. Analysis of the distribution asymmetry coefficient found that greater part of data have left asymmetry, what means that most data accumulates below the average.

As the main aim of drainage systems is to lay surface water as quickly as possible, the average meanings of recession intensity under different spacing between cross drains

Table. 1. Descriptive statistics of measured field data in Pikeliai experimental site (1999–2005)

Time of field data collection	Number of data	Water level average in piezometers	Standard error of mean	Standard deviation	Variance	Skewness	Standard error of skewness	Kurtosis
Piezometer 28 in 2 drainage system								
Spring	149	44.65	1.04	31.13	969.04	0.05	0.08	–1.42
Autumn	69	45.78	1.31	26.76	715.38	0.19	0.12	–1.17
Piezometer 29a in 2 drainage system								
Spring	149	13.07	0.386	11.54	133.19	1.32	0.08	3.54
Autumn	69	13.64	0.470	9.56	91.33	0.98	0.12	1.00
Piezometer 27a in 2 drainage system								
Spring	149	14.68	0.507	15.17	230.16	1.20	0.08	1.65
Autumn	69	15.69	0.667	13.55	183.54	0.33	0.12	–1.23

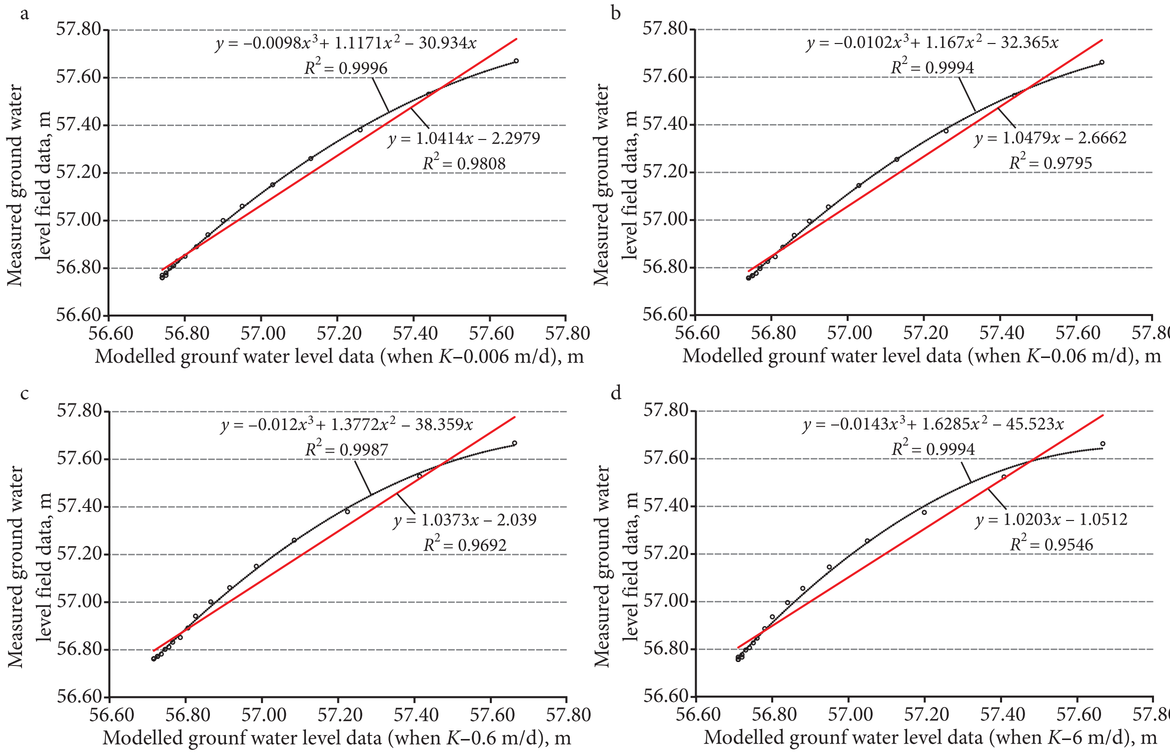

Fig. 4. Impact of the modelled cross drains on the water table depression in area being drained when the spacing between trenches is 20 m

trenches and without them were compared. Modelling results are provided in Figs 4–6.

During the analysis of cross drain impact on the scope of recession, it was defined that having equipped cross trench drains close to the distance between drainage trench (namely every 21 m), and having taken soil permeability similar to one of soil permeability of previously equipped drainage trenches (0.006 m/day) (Fig. 4a) water table receded more than 13% (13 cm). Having increased permeability of previously equipped drainage trenches

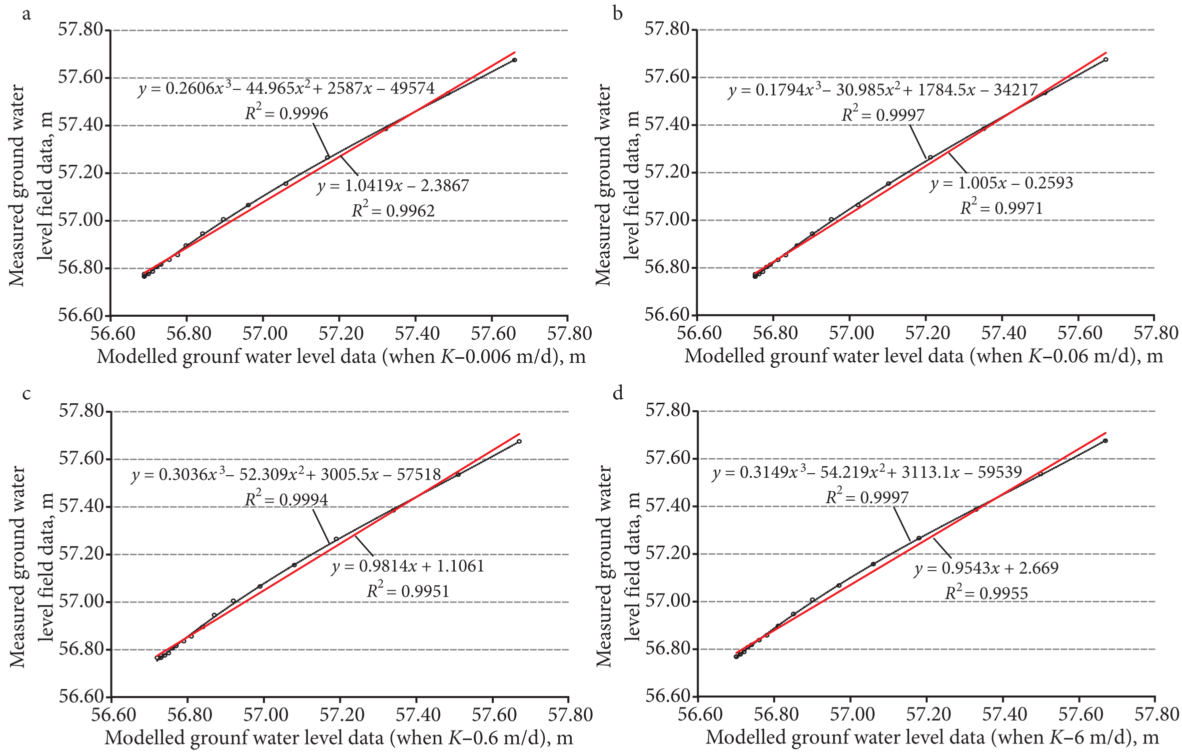

Fig. 5. Impact of the modelled cross drains on the water table depression in the area drained when the space between trenches is 30 m

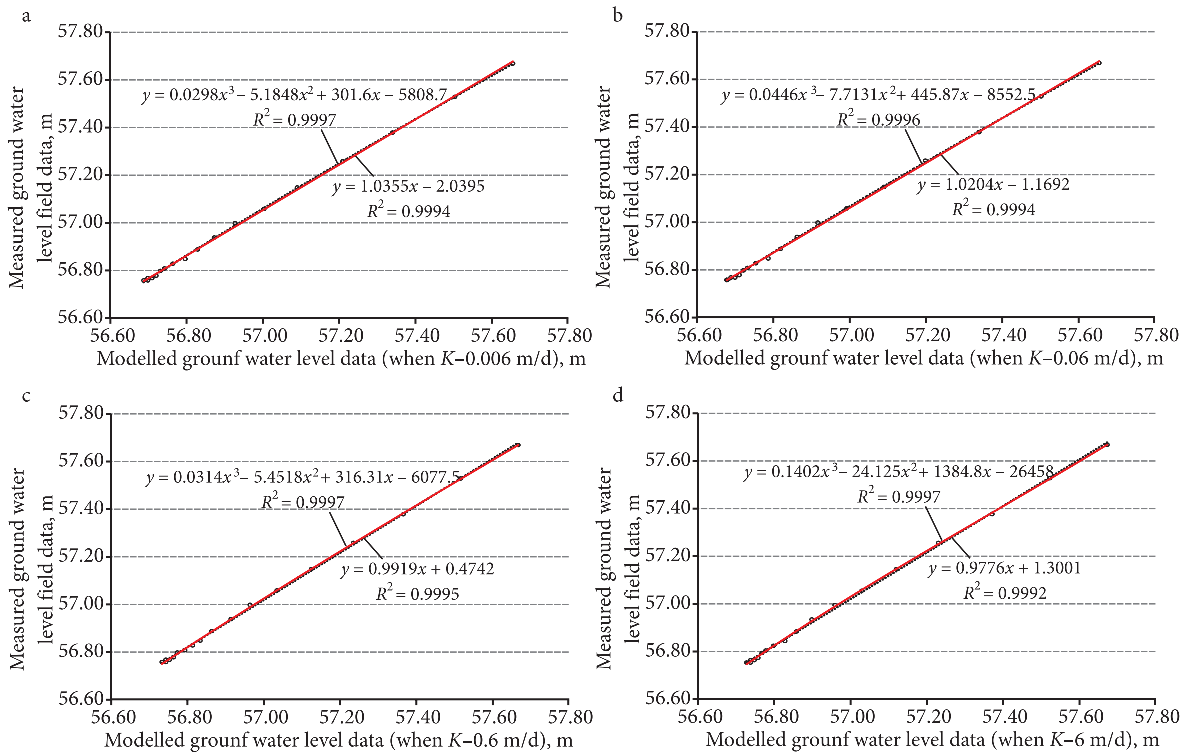

Fig. 6. Impact of the modelled cross drains on the water table depression in the area drained when the space between trenches is 30 m

and cross drainage trenches up to 6 m/day (Fig. 4d), water table level in the area between drainage trenches receded more than 32%, i.e. about 20 cm. The obtained values of the modelling allow to lower ground water table recession intensity in the area between drains trenches about 13–32% when distance between cross drains trenches 20 m. The explanation of this phenomenon is that water from the area between previously equipped drains trenches under the influence of groundwater pressure flows not only into more permeable regular drainage trenches but in cross drains trenches also.

When comparing the obtained values (cross drains trenches being equipped every 20 m), it was identified that the averaged ones obtained in the area between drains trenches of water table recession (permeability being 0.006 m/day and 0.06 m/day) are the same (Figs 4a, 4b). Thus, increased permeability of drainage trenches allows some lowering the water table of ground water without increasing intensity of its flow.

The analysis of the impact of cross drains trenches equipped every 30 m on recession of ground water table, allowed stating that water table recession efficiency was twice as lower (Fig. 5).

When the permeability of cross drainage trenches was close to the previously equipped drainage trenches (0.006 m/day), water table recession increases only by 6%., i.e. 5 cm (Fig. 5a). Having increased permeability of previously equipped drainage trenches and cross drainage trenches up to 6.0 m/d, water table recession increases up to 15% (10 cm) (Fig. 5d). It is explained that in this case the bigger part of water from the area between drainage trenches flows into previously equipped drainage trenches. The spacing between drainage trenches is 22 m, whereas significantly smaller part of water reaches cross trenches because the spacing up to them is 30 m.

Having increased spacing of cross drains trenches up to 40 m (Fig. 6), visually the impact disappears. Regardless that having increased permeability of drainage and cross drainage trenches up to 0.6 m/d and 6 m/d, the obtained recession values is statistically significant, their physical impact is minimal (Fig. 6). It is explained by the fact that when the space between cross drains trenches is twice as big than between previously equipped drainage trenches, the biggest part of water flows into drainage trenches. Since water enters cross drainage trench later and has no significant influence on water table in the area between drains.

When equipping such drainage systems, it is important to assess soil filtration qualities of areas close to drain trenches and between drains as well as permeability of trench filling. Not only the velocity of water flow to drainage trench but also water drainage depends on the qualities mentioned. The clayey soils have low hydraulic permeability. Their hydraulic permeability being low, the subsurface drainage systems will work not satisfactorily and one has to resort to a surface drainage system or to improvement of hydraulic permeability of the subsoil by filling the drainage trench with coarse materials and adding material like lime. The survey has shown that increase of drainage trench filtration permeability is effective when the spacing between cross drains trenches is close to one between laterals equipped previously. Improvement of drainage trench filling permeability qualities ensures faster removal of water from the trench while the spacing ensures rapid flow of water into the trench. It was also confirmed by the survey conducted by scientists from other countries that a significant impact on ground water regime has different trench filtration properties.

The modelling results show that equipping additional cross drains in Lithuanian loamy soils close to the subgrade is efficient when distances between them are close to ones between already equipped drainage trenches. Equipment of such drains accelerates intensity of ground water table recession after 2–3 days. Afterwards this intensity of recession slows down and becomes close to usual drainage recession. This drainage technology allows lowering the table of ground water in the areas between the road and drains during the first days without increasing intensity of ground water drainage (accumulating part of water in cross drains trenches). Drainage systems equipped in such a way allow saving soil moisture in deeper layers, which is important for plants growing near the road as well as for drainage of park roads, tracks of green areas in cities, etc.

4. Conclusions

1. The modelling results show that additionally equipped cross drains trenches in existing drainage systems in Lithuanian loamy soils are efficient when spacing between them is close to one between already equipped drainage laterals. Values obtained during modelling manifested that the selected technology allows to lower recession of ground water table in the area between the road and drainage system from 13% to 32%. When analysing the impact of cross drains trenches equipped every 30 m on recession of ground water table between the road and drainage system, it was determined that recession efficiency decreased in half, namely 6–15%. Having increased the spacing of cross drains trench up to 40 m regardless that having increased permeability of drainage trenches the obtained recession values are statistically significant, their physical impact would be minimum.

2. Analysing intensity of recession from point of view of time, it was defined that maximum recession value is earliest achieved when the spacing between cross drains trenches is 20 m. The biggest recession was recorder after 2 days. When increasing the spacing between cross drains trenches 30 m, maximum recession values were recorder 1 day later, i.e. after 3 days. Having equipped cross drains trenches every 40 m, their impact becomes insignificant.

3. The modelling showed that additional equipment of cross drains trenches in existing drainage systems in Lithuanian loamy soils could improve water table recession from 13% to 32% (depending on cross drain trenches spacing).

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