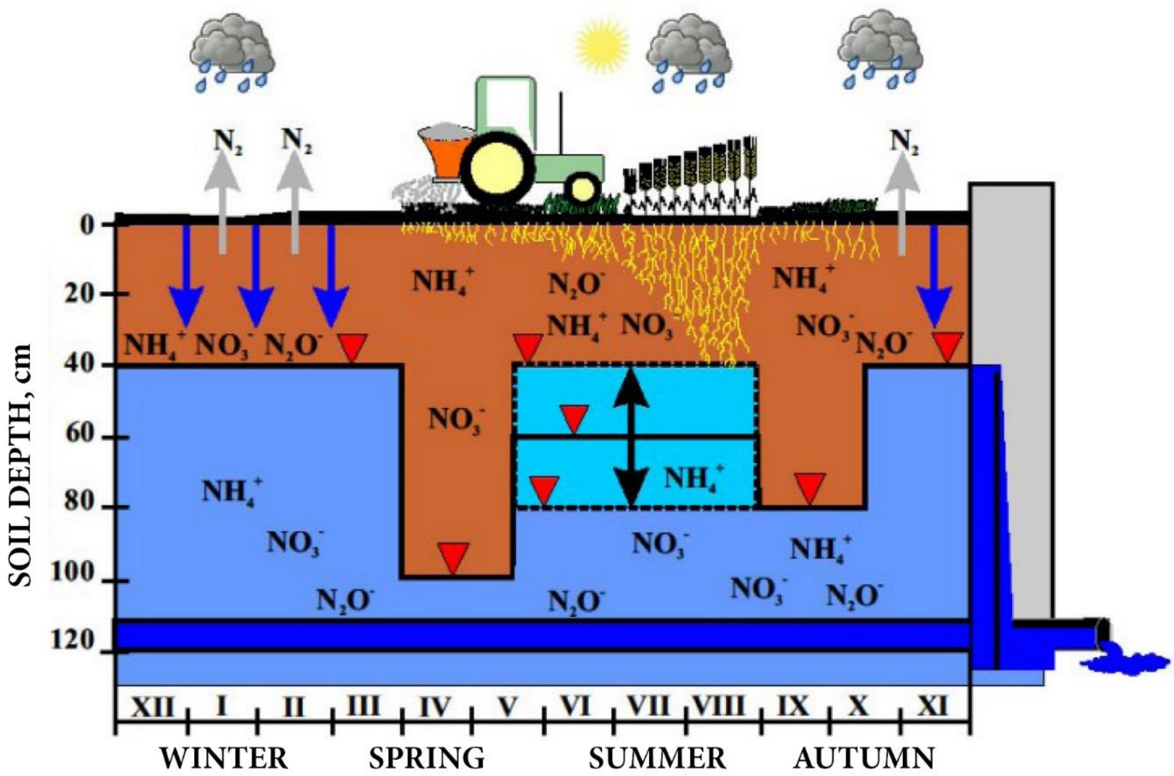
VYTAUTAS MAGNUS UNIVERSITY AGRICULTURE ACADEMY

GENERAL RECOMMENDATIONS FOR INTRODUCTION OF CONTROLLED DRAINAGE INNOVATION

(An abbreviated version of the document)



Scheme of water level-controlled drainage system

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Introduction

In 2017–2018 11 drainage runoff controlling wells were designed and installed in six project partner farms located in different regions of Lithuania. The plots for controlling soil moisture regime were selected taking into account the topography of land surface, soil structure, parameters of the existing drainage systems, location and boundaries of land holdings.

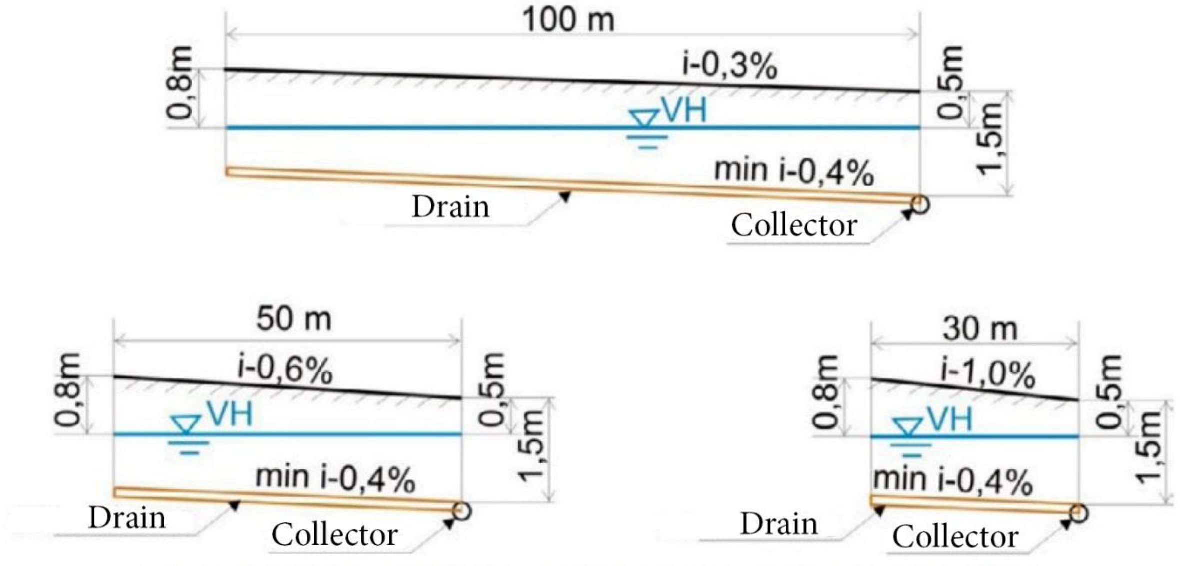

Fig. 1. ***Influence of land surface slope on drainage head length***

From a territorial point of view, the differences in agrometeorological conditions during individual years of the project implementation were not significant between the analysed farms. The beginning and duration of the growing season depended more on the weather conditions than on the climatic area in which the farm was located. While comparing the curves of hydrothermal coefficient values in 2017–2019, it can be seen that in May–June there is often a lack of rain, therefore the moisture reserves in soil are rapidly decreasing. The dewatering effect of drainage at the beginning of the growing season also contributes to the decrease of moisture reserves when the groundwater level is lowered to the depth of the drainage network installation in a relatively short time. When drainage stops working, which usually happens during the first ten-day period of May, soil moisture depends only on the amount of precipitation and, if it is lacking, moisture reserves quickly run out.

Raising or lowering the water level in drainage runoff control facilities is related to the needs of plants and the off-road capability of the machinery, which depends on weather conditions and soil moisture reserves. Controlled drainage operates in normal drainage mode during spring flood season. It is advisable for the water level control device to have an intermediate position that lowers the water level by 30 cm from the maximum. This allows the water level to be lowered during rainy periods, but not to drain all the water from the drainage system at all. This saves the soil moisture reserves in deeper layers so that water can rise to the root zone via capillaries in the event of drought.

When spring droughts last longer, drainage runoff control has no effect. In summer, the water level is adjusted to the needs of plants: in the event of drought, the adjusting device is kept in the highest position; if rainy periods occur, the water level is lowered so that the root zone is not flooded.

Moisture levels at the end of the growing season affect autumn tillage and sowing of winter plants. If there is so much rainfall that the drainage starts functioning (as in 2017, for example), the runoff control devices must be lowered to the lowest position and the drainage must be allowed to run in a drainage mode.

In the autumn of a year with normal humidity levels or a dry year, the devices of drainage runoff control may be kept in an elevated position to accumulate soil moisture for the next growing season.

When growing winter cereals, it is advisable to keep the raised drainage devices over winter, without changing their position during spring snowmelt. This does not harm plant growth in any way, it is important that there are no closed ditches in the controlled area for the accumulation of surface water.

Without changing the adjustment mode, more moisture reserves are accumulated, and the measure efficiency is higher. Nitrogen denitrification is stimulated during winter. This is environmentally beneficial as it prevents the leaching of nitrate nitrogen by drainage into water bodies.

Technical aspects

Drainage runoff control in selected areas was started in March–April 2018. Due to the lack of precipitation, some farms were not even able to reach the planned hydraulic head, and the moisture reserves accumulated in soil quickly evaporated as the weather warmed. Due to the agro-meteorological conditions of low humidity in the whole territory, the drainage runoff control devices were maintained in the highest position (60–70 cm from the ground surface at the lowest relief point) since their installation in the spring of 2018. This means that runoff in controlled systems was accumulated during the autumn and winter periods in 2018 and the spring of 2019; and only when the maximum level was reached the drainage started functioning in a normal mode (drained excess water). Such a mode did not have any negative effect on the growth of winter cereals and did not interfere with tillage operations.

The ability of soil to accumulate and retain moisture reserves required by plants depends on its texture. The heavier the soil and the more clay particles it has, the more water it can accumulate. However, the hydraulic conductivity of such soils is low and the hydraulic head from the drainage pipes is difficult to transfer to the spaces between drains, and when controlling drainage, it is very important that the moisture reserves are distributed as evenly as possible throughout the area.

When the outflow level of drainage water is raised, water rises to the surface layer of soil via capillaries from the drains upwards. Depending on soil conductivity, the accumulated moisture reserves do not always reach a depth of 40 cm. The effect of drainage runoff control on soil moisture is best seen at depths of 0.6 and 1.0 m.

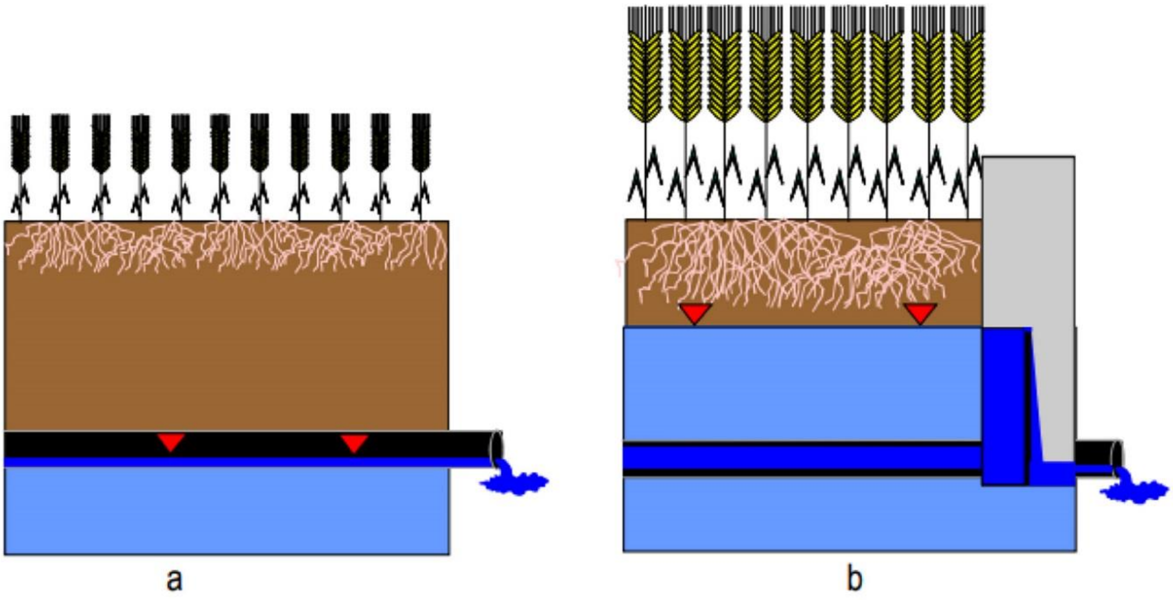

Fig. 2. ***Conventional (a) and controlled (b) drainage systems***

Due to the diversity of soil cover, even the moisture reserves accumulated in adjacent areas are very unevenly distributed. Therefore, the results of moisture tests can be influenced by both soil properties and measurement site selection.

Drainage runoff control did not affect groundwater level fluctuations on all farms. On some farms, it was significantly higher in controlled systems, on others, the piezometers installed in between drains showed higher water levels in the non-controlled systems. It is likely that such results are due to the fact that in the controlled systems, during the phase of water level rise, the depression curve takes the reverse shape (it is curved), therefore, the water level in the space between drains is lower than at the drains.

The efficiency of drainage runoff control was assessed by runoff duration, total runoff and runoff volume. During drainage operation in spring 2018 and winter 2019, keeping the control devices in the highest position of 0.7 m above the ground, the runoff duration was reduced by an average of 43 percent. On individual farms, this indicator varied from 27 to 67 percent. The runoff volume was reduced by an average of 60 percent. (30 to 91 percent).

The total runoff height of controlled and non-controlled systems differed on average by 58 percent. (44 to 78%). Differences between the farms were determined by the size of controlled areas and water conductivity of the soils.

Effect and benefits

Studies show that higher efficiency of the measure is obtained when moisture reserves are accumulated during autumn, winter and spring. When controlling is started only after spring sowing (as in 2018), less moisture accumulates in soil due to insufficient water level rise, resulting in smaller runoff differences between controlled and non-controlled systems (30 days in 2018, 58 days in 2019), lesser volume of retained water (352.63 m^3 in 2018, and 838.44 m^3 in 2019), and smaller differences in total runoff height (7.66 mm in 2018, and 22.45 mm in 2019). This conclusion is based on the data obtained by comparing the controlled and non-controlled systems on one farm (Kėdainiai district).

Controlling drainage runoff had a positive effect on drainage water quality (nitrogen compound concentrations). The resulting hydraulic head in the controlled systems reduced NO3-N and NH4-N concentrations in drainage water by 71 and 100 percent, respectively. However, it should be taken into account that on farms where runoff control wells are installed in the systems of larger areas, the effect of the measure is functional only in a certain part of the area, therefore, the water flowing out of such drainage systems only partially reflects the changes in water quality indicators due to runoff control.

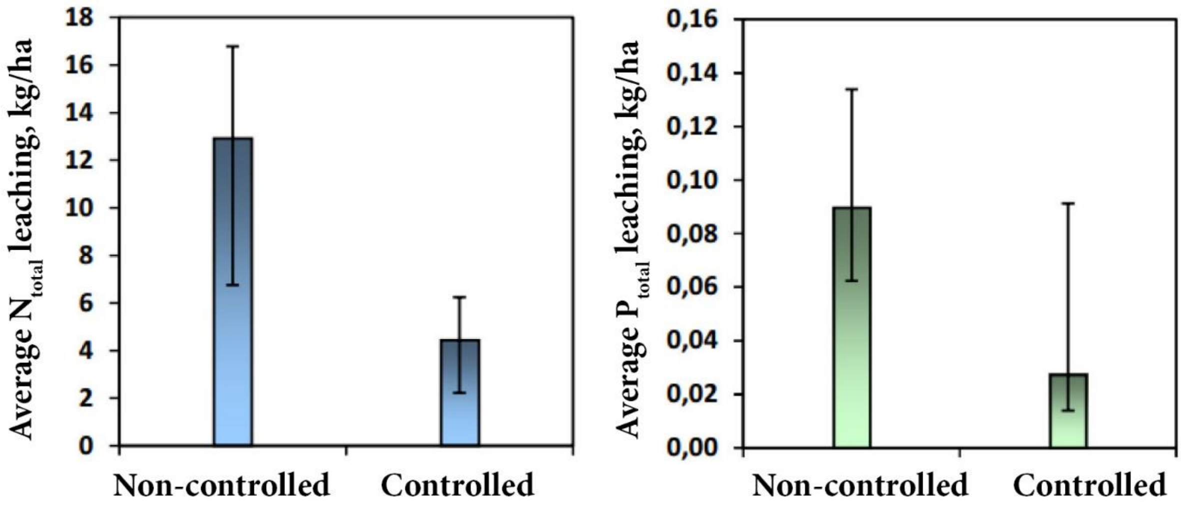

Fig. 3. ***Average N total and P total leaching by drainage in 2019 reference period (average values for four farms)***

From an environmental point of view, the main advantage of controlled drainage is the reduction of nutrient leaching from soils. Drainage runoff has a decisive effect on this. Leaching, although not as strongly but statistically reliably, is also determined by the concentration of these substances in drainage water.

On some farms, nutrient stocks in soil and fertilization affected water quality indicators, nevertheless, to a lesser extent than drainage runoff.

Of the controlled drainage systems in 2018, 7–36% of nitrogen and its compounds were leached less, and in 2019, the leaching of the tested nutrients was 16–94% lower compared to non-controlled systems.

During the project of moisture regime control in soil in different demonstration areas of farms in Lithuania, the observations of nutrient (fertilizer) use in 2017–2019 were carried out. The use of fertilizers for crops on farms was compared with the actual nutrient demand (determined from the results of soil tests) and the yield obtained.

Calculations were performed on the basis of the fertilization plan development programme "e. GEBA Crop Production". The results showed that over 3 years, 47 kg/ha of nitrogen fertilizer had been applied in the observed areas per year on average, or in other words, 137 kg/ha of ammonium nitrate had been used in excess of plant nutrient requirements.

Fertilization with phosphorus fertilizers is balanced, and the active ingredient of potassium fertilizer is lacking at an average of 37 kg/ha per year or, expressed as fertilizer, 62 kg/ha of potassium chloride is lacking.

Based on 3-year data of plant fertilization, total nitrogen leaching from the project farm fields observed was similar: the leaching from the controlled drainage systems was 5.3 kg/ha, and the leaching from the non-controlled ones was twice as high – 13 kg/ha.

12.2 kg/ha of total nitrogen leached from an organic field (ASU Training Farm), where in 2018 clover had been ploughed up and manure spread, (for comparison, according to other studies, an average of about 25 kg/ha nitrogen is leached from intensive farming areas every year). In other words, due to the droughty weather conditions in 2018–2019, nitrogen leaching was twice less than normal. Since 2018 was particularly dry and due to the lack of precipitation on some farms, it was not even possible to reach the planned hydraulic head, even a short retention of drainage runoff allowed increasing the soil moisture reserves at the beginning of active plant growth. This had a significant impact on the development and yield of agricultural crops.

Moisture regime control had the greatest effect on the rate of productive tillering of cereals, grain number per ear and grain size; the weight of 1000 grains was higher in the controlled systems compared to the non-controlled ones.

Table 1. ***Biometric indicators of winter wheat yield in 2019***

Farm	**Rate of productive tillering**		**1 ear productivity, g**		**Weight of 1000 grains, g**	
	R	**N**	**R**	**N**	**R**	**N**
E. Varkalys, Rietavas d.	0,99	0,98	2,00	1,84	49,53	47,37
A. Bardauskas (1), Raseiniai d.	0,97	0,93	1,42	1,23	41,91	41,50
A. Bardauskas (2), Raseiniai d.	0,99	1,00	1,19	1,09	35,93	41,08
P. Pikšrys, Kėdainiai d.	0,98	0,91	0,77	0,66	26,15	26,64
A. Baltrūnas, Biržai d.	0,94	0,91	1,44	1,50	44,69	44,92
ASU training farm Kaunas d.	0,99	0,98	1,27	1,17	41,85	42,11

R – controlled drainage, **N** – non-controlled drainage.

During the project implementation period, statistically significant differences in agricultural crop yields were identified between the controlled and non-controlled systems. Under the meteorological conditions of 2018, the yield of winter wheat obtained was 37% (3.1–3.8 t/ha), that of spring barley was 25% (1.0–3.2 t/ha), peas – 12% (0.7 t/ha), and beans – 24% (2.1 t/ha) higher.

Table 2. ***Economic benefits of additional yield in controlled drainage areas in 2018–2019***

	Average yield, t/ha		**Yield difference, t/ha**	**Average price, EUR***	**Economic effect, 1 ha/EUR**
	R	**N**			
2018					
Winter wheat	9,30	5,86	3,45	172,76	595,63
Barley	8,15	6,06	2,09	165,19	344,97
Peas	5,61	4,92	0,68	168,98	115,12
Beans	8,56	6,47	2,10	198,35	416,01
2019					
Winter wheat	8,81	7,16	1,65	163,65	270,02
Barley	6,23	5,33	0,90	142,78	128,51
Winter rapeseed	4,07	3,93	0,14	360,62	50,49

* According to the data of the State Enterprise Agricultural Information and Rural Business Centre, in July, August and September; **R** – controlled drainage, **N** – non-controlled drainage.

The peculiarities of meteorological conditions in 2019 led to a lower impact of moisture regime controlling on crop yields. The yield of winter wheat (5 farms) in the controlled systems was 1.22–2.93 t/ha higher than in non-controlled ones, barley – 0.91 t / ha, and winter rapeseed – 0.14 t/ha higher. Differences in barley and rapeseed yields, judging by the results of farm 1, are statistically insignificant.

Conclusions

In summarizing the 2018–2019 research period, the control of moisture regime proved successful in the cultivation of winter wheat, barley, peas and beans. The impact of the measure on winter rapeseed yield was insignificant.

The economic benefits of moisture regime control are manifested through changes in average crop yields in controlled and reference areas. With an average cost of equity in agriculture of around 8%, investments are completely insensitive to the discount rate for cultivating winter wheat, barley and beans, and sensitive to growing peas, but inefficient for rapeseed growing.

The return on investment in the system of drainage runoff control is relatively fast while cultivating winter wheat (1.5 and 3.7 year) and barley (2.9 and 7.7 year). Slightly different results were obtained for growing winter rapeseed: zero NPV is reached at 3.2 percent discount rate.

Table 3. ***NPV of investments at discount rates and payback period of cash flows 2018–2019****

Name of agricultural crop	**NPV at different discount rates, EUR**			**Simple cash flow payback time in years**
	2 proc.	**5 proc.**	**10 proc.**	
2018				
Winter wheat	24 696	16 329	9 246	1,5
Barley	13 468	8 622	4 520	2,9
Peas	3 172	1 555	186	8,6
Beans	16 650	10 806	5 859	1,6
2019				
Winter wheat	10 111	6 318	3 107	3,7
Barley	3 772	1 967	439	7,7
Winter rapeseed	277	-432	-1 032	19,6

* In addition to saving mineral fertilizers.

The economic benefits regarding mineral nitrogen and phosphorus leaching for the farms studied were not significant. Nevertheless, this method of soil moisture control is recognized as less polluting and promising because ammonium ions (NH_4) are not transformed into nitrate ions (NO_3) and are therefore not leached from soil; more nitrate ions (NO_3) are converted to free nitrogen (N_2) in the root zone, and less nitrates are released from soil into the environment.

The process of soil moisture controlling has a positive impact on all aquatic ecosystems by trapping nutrients where they are assimilated by agricultural crops. Controlled drainage allows for adaptation to or mitigation of climate change, as the denitrification process in soil accelerates and, according to literature sources, the release of nitrogen oxides (greenhouse gases) into the atmosphere decreases.