Soil Moisture Regime of Ameliorated Gelyic Stagnosol

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SUMMARY

The paper presents the results of investigation of performance of drainage systems on ameliorated gleyic stagnosol in the Central Sava Basin, in order to recommend pipe drainage for the purpose of more intensive use of drained land. Investigations of the soil moisture regime were carried out on drained and non-drained gleyic stagnosol in the period from 1987 to 1991, within regular crop production which included monitoring of soil moisture dynamics, ground water levels, occurrence of stagnant water and drain outflows. Subsoil pipe drains on the drained plot were placed at the depth of 0.9 m, with the spacing of 20 m. For the vegetation period (April-September) small differences have been determined between the durations of the wet phase in non-drained and drained gleyic stagnosol. In this period the average annual wet phase lasts 17 days at the depth of 15 cm, 47 days at 30 cm, and 10 days at 60 cm in non-drained soil, and 23 days at 15 cm, 43 days at 30 cm, and 10 days at 60 cm in drained soil. In the non-vegetation period (October-March), the differences in duration of the wet phase between drained and non-drained soil were also small at depths of 15 and 60 cm, while the difference at 30 cm was considerably larger. The average annual duration of the wet phase was 50 days at 15 cm, 140 days at 30 cm, and 17 days at 60 cm in non-drained soil, or 50 days at 15 cm, 97 days at 30 cm, and 13 days at 60 cm in drained soil. Statistically significant difference in the dynamics of soil moisture between drained and non-drained soil was determined only for the depth of 30 cm, and only in the non-vegetation period. The ground water level was practically always below 1.0 m; however in the upper part of the soil profile the presence of stagnant rain water has been determined. No significant difference between the duration of presence of stagnant water in drained and non-drained soil has been determined. Maximum values of drain discharge, which were about 0.003 m/day were over three times less than the design drainage module. The noticed differences between crop yields on drained and non-drained soils are not significant. Research of the soil moisture regime in soil and monitoring of ground and stagnant water in drained and non-drained gleyic stagnosol show that, in drained soils the problem of evacuation of excess water in rhyzospheres still remains, first of all as a consequence of the absence of agricultural measures, i.e. subsoiling, liming and humization. In such conditions, drainage systems have only limited effects.

KEY WORDS

drained soil, ground water, non-drained soil, gleyic stagnosol, soil moisture regime, stagnant water

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Režim vlažnosti hidromelioriranog pseudoglej-glejnog tla

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SAŽETAK

U radu se prikazuju rezultati istraživanja funkcionalnosti drenažnih sustava na hidromelioriranom pseudoglej-gleju u Srednjoj Posavini kako bi se temeljem utvrđenih rezultata mogli preporučiti potrebni daljnji melioracijski zahvati radi intenzivnijeg korištenja dreniranih površina u praksi. Istraživanja režima vlažnosti, provedena su na dreniranom i nedreniranom pseudoglej-gleju u razdoblju od 1987-1991, u sklopu redovite biljne proizvodnje, a u okviru čega je vršeno dekadno praćenje dinamike trenutačne vlage, razine podzemne vode, pojave stagnirajuće vode u tlu te drenažnog istjecanja. Cijevna drenaža na dreniranoj tabli postavljena je na razmak od 20 m i dubini od 0.9 m. Za vegetacijsko razdoblje (IV-IX mjesec) utvrđene su male razlike u trajanju mokre faze između nedreniranog i dreniranog pseudoglej-gleja. U tom razdoblju prosječno godišnje mokra faza traje 17 dana na dubini od 15 cm, 47 dana na 30 cm te 10 dana na 60 cm dubine na nedreniranom tlu, odnosno 23 dana na 15 cm, 43 dana na 30 cm te 10 dana na 60 cm dubine na dreniranom tlu. Tijekom izvanvegetacijskog razdoblja (X-III mjesec) utvrđene su također male razlike u trajanju mokre faze između dreniranog i nedreniranog tla na dubini od 15 i 60 cm, dok je značajno veća razlika utvrđena na dubini od 30 cm. Prosječno godišnje trajanje mokre faze u ovom razdoblju iznosilo je 50 dana na 15 cm, 140 dana na 30 cm te 17 dana na 60 cm dubine na nedreniranom tlu, odnosno 50 dana na 15 cm, 97 dana na 30 cm te 13 dana na 60 cm dubine na dreniranom tlu. Statistički opravdana razlika u dinamici trenutačne vlage između dreniranog i nedreniranog tla, utvrđena je jedino za dubinu od 30 cm i to samo u izvanvegetacijskom razdoblju. Razina podzemne vode kretala se praktički uvijek ispod 1.0 m dubine tla, međutim u gornjem dijelu profila utvrđeno je prisustvo stagnirajuće oborinske vode. Nije utvrđena bitna razlika u dužini trajanja prisustva stagnirajuće vode na dreniranom i nedreniranom tlu. Maksimalne izmjerene vrijednosti trenutnog drenažnog isteka koje su iznosile oko 0.003 m/dan, bile više nego trostruko manje od projektiranog modula odvodnje drenažom. Razlike u prinosu uzgajanih kultura na nedreniranom i dreniranom tlu nisu statistički opravdane. Istraživanja režima vlažnosti tla, te praćenja razine podzemne i stagnirajuće vode dreniranog i nedreniranog pseudoglej-glejnog tla, pokazuju da kod dreniranih tala ostaje problem pravovremene evakuacije viška vode u sloju rizosfere, prije svega kao posljedica izostanka predviđenih agrotehničkih mjera podrivanja, a potom kalcifikacije i humizacije. U takvim uvjetima izvedba cijevne drenaže ima ograničen učinak.

KLJUČNE RIJEČI

drenirano tlo, nedrenirano tlo, podzemna voda, pseudoglej-glej, režim vlažnosti, stagnirajuća voda

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INTRODUCTION

On the major part of agricultural land in Croatia, the conditions for intensive crop production are difficult. One of the major constraints is excess water in the rhyzosphere, which was the reason for construction of subsoil pipe drainage systems in many areas. Thus, drained areas in Croatia amount to 161,530 ha, Marušić (1995). However, in practice it turned out that some of the pipe drainage systems did not operate at full capacity, as expected by design solutions. Therefore it is important to find out whether and how successfully the excess water is regulated, i.e. whether the existing drainage systems are operating, and at what intensity, which is possible by investigation the soil moisture regime of hydroameliorated soil. The soil moisture regime, which represents periodic changes in soil moisture along the profile depth, Rode (1969) characterizes the status, or dynamics of water in soil. The prospects of crop production development in closely connected with the soil moisture regime in soil, and optimization of this regime provides the conditions for intensive utilization of drained soils (Vidaček 1987; Beke et al., 1993; Fisher et al., 1996).

Investigations of performance of drainage in Croatia started in late seventies. Numerous authors, including Pušić et al. (1971 a and b), Škorić et al. (1971), Mayer (1976), Škorić et al. (1986), Šimunić (1986), Racz (1990), Vidaček (1987), Vidaček et al. (1988, 1991 i 1994), Bogunović et al. (1991), determined incomplete performance of some of the constructed pipe drainage system in the post drainage periode.

The objective of these investigations was to provide information, based on several years of stationary research of the soil moisture regime of drained soils, on the performance of existing pipe drainage systems in the Central Sava Basin, and to determine the reasons of possible malfunctioning, as well as to recommend the necessary further amelioration measures in order to reach their full performance.

MATERIALS AND METHODS

Stationary investigations of soil soil moisture regime were carried out in the period from October 1987 to September 1990, at Šašina Greda (with control plots RA-7 and RA-9), Fig. 1.

According to the existed classification, the soil drained gleyic stagnosol, or Gleyic Podzoluvisols according to FAO classification, FAO (1990). The control, plot RA-7 was located on an undrained plot, i.e. a plot with surface drainage by open ditches. On the control plot, a battery of nine piezometers was installed. For monitoring of ground water level, three piezometers 2.0 and 4.0 m deep were installed, and for stagnant water, three piezometers of 1.0 m, according to Dieleman and Trafford (1976).

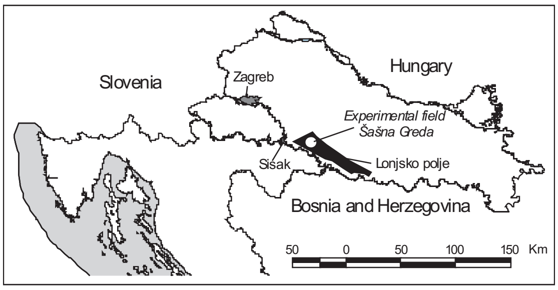


Figure 1. The situation of experimental field Šašina Greda in Republic of Croatia

The control plot RA-9 was on drained soil. The investigation involved the drains No 24, 25, and 26, respectively, with the spacing of 20 m, and depth of 0.9 m. Only the drain No 25 was fulfilled with gravel as hydraulic contanct material. On this control plot, 4 piezometers 1.0 m deep were installed to control stagnant water, and 4 piezometers 2.0 and 4.0 m deep to monitor the ground water level. Water discharge into the ditches was measured by semi-automatic equipment. The dynamics of moisture in soil was determined in the rhyzosphere, by gravimetric method in three replications, at the depth of 15, 30, and 60 cm, respectively. The dynamics of ground water level as well as the occurrence of stagnant water was measured by piezometers of 32 mm diameter, with perforations in bottom 25 cm coated by nylon sieves. All measures were carried out on the ten-day basis (in total 105 measures). The crops in the trial were winter wheat (1987/88 and 1989/90), and oilseed rape (1988/89). Basic physical soil properties were determined according to standard methods, Škorić (1982). Moisture retention at 1500 kPa was determined on the pressure membrane. The water holding capacity is taken to be the limit between the wet and the moisture phase of soil, and the moisture retention at 1500 kPa is taken as the limit between the moisture and the dry phase The statistic processing of the results of soil moisture and crop yields was carried out according to the method ANOVA, Little and Hills (1978).

RESULTS AND DISCUSSION

Physical soil properties

The area of research belongs to Polder No 9 of Lonjsko polje, and it was selected due to considerable percentage of gleyic stagnosol, both in the project area Lonjsko polje and in most of the Central Sava Basin, Marinčić et al. (1984) and Škorić et al. (1986). According to the texture, the soil is in the upper part of the profile silty-loamy to silty-clayey, and in the lower part of soil profile, sandy-loamy, Table 1.

Water holding capacity is medium, air capacity is low in the arable, and very low in the sub-arable layer (only 1.9 do 2.9 percent). In the arable layer these

Table 1. Teksture of soil of experimental field Šašina Greda

Experimental-field	Depth cm	Horizon	Diameter (mm) and percent of particles					Texture*
			2-0.2	0.2-0.05	0.05-0.02	0.02-0.002	<0.002	
RA-7 Undrained	0-25	P	2.9	2.4	40.1	28.2	26.4	PrI
	25-70	Btg	1.7	3.8	23.6	37.0	33.9	PrGI
	70-100	Cg	1.3	9.0	30.3	27.8	31.6	PrGI
	100-230	Gso/Gr	0.9	21.6	33.3	22.0	22.2	PrI
	230-300	Gr	9.9	55.7	20.4	10.0	4.0	PI
R-9 Drained	0-25	P	2.4	9.7	27.1	31.2	29.6	PrGI
	25-75	Btg	3.2	10.0	27.7	24.4	34.7	PrGI
	75-120	Cg	2.5	24.8	29.1	21.4	22.2	PrI
	120-145	Gso	10.4	40.4	24.2	14.2	10.8	I
	145-240	Gso	43.8	35.8	13.6	5.4	1.4	PI
	240-300	Gr	73.6	18.4	4.6	3.4	0.0	P

*Explanation: PrGI-silty clay loam; PrI-silty loam; I-loam; PI sandy loam; P-sand

Table 2. Phsical properties of soil of experimental field Šašina Greda

Experimental-field	Depth, cm	Horizon	Capacity for		Total	Density of soil		Water retention
			water Vol. %	air Vol. %	porosity Vol. %	bulk gcm^{-3}	specific gcm^{-3}	at 1500 kPa, % Vol.
RA-7	0-25	P	45.3	6.1	51.4	1.21	2.49	18.8
	25-70	Btg	45.4	1.9	47.3	1.35	2.56	22.7
	70-100	Cg	43.7	1.9	45.6	1.43	2.63	24.6
RA-9	0-25	P	41.2	7.1	48.3	1.35	2.61	20.1
	25-75	Btg	42.3	2.9	45.2	1.44	2.63	21.6
	75-120	Cg	41.7	4.1	45.8	1.43	2.64	17.6

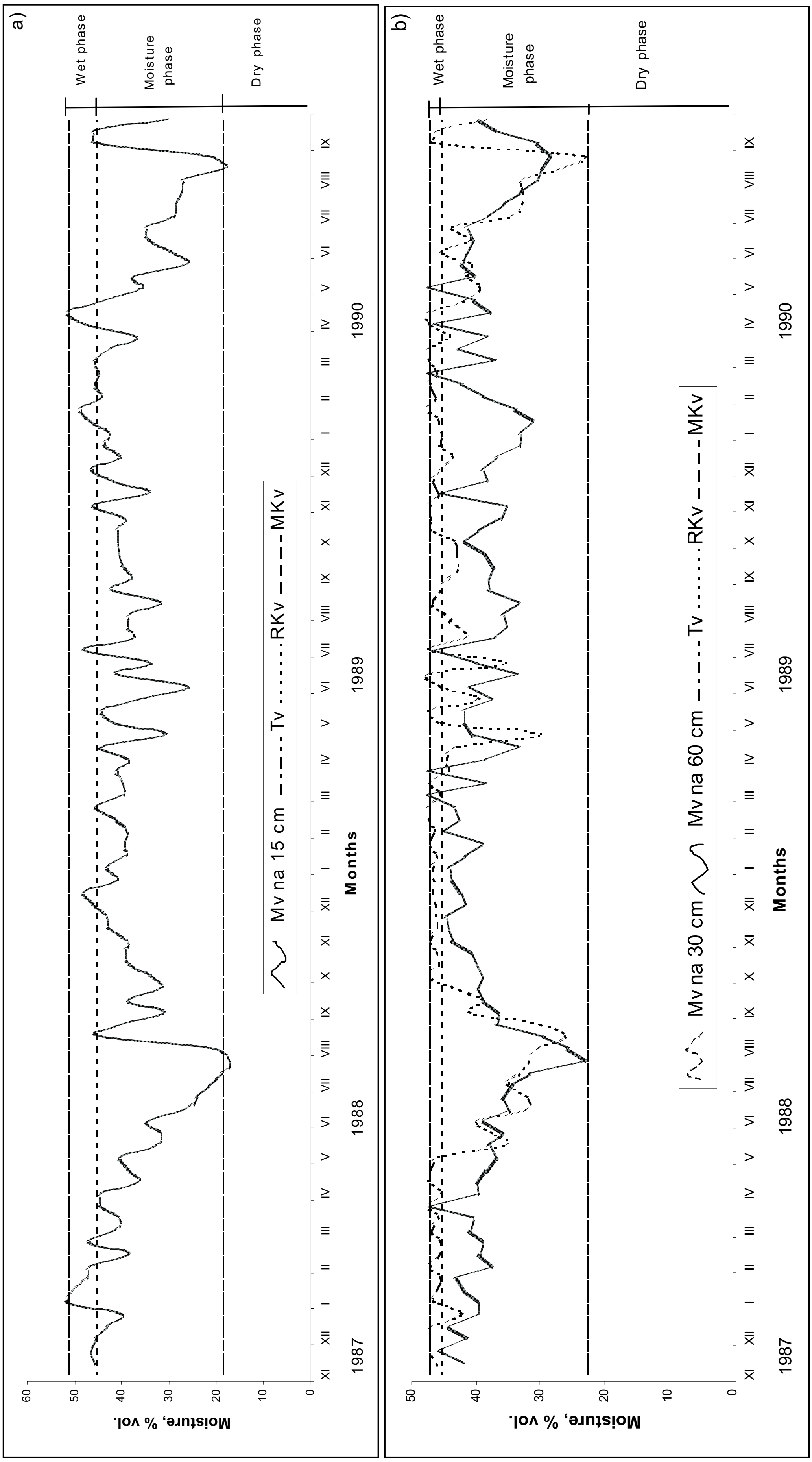
are porous soils, and in the subsoil they are porous to slightly porous. Moisture retention at 15 kPa varies from 18,8% vol. in the surface layer to 22.7 vol. in the subsurface layer, Table 2.

Soil moisture regime

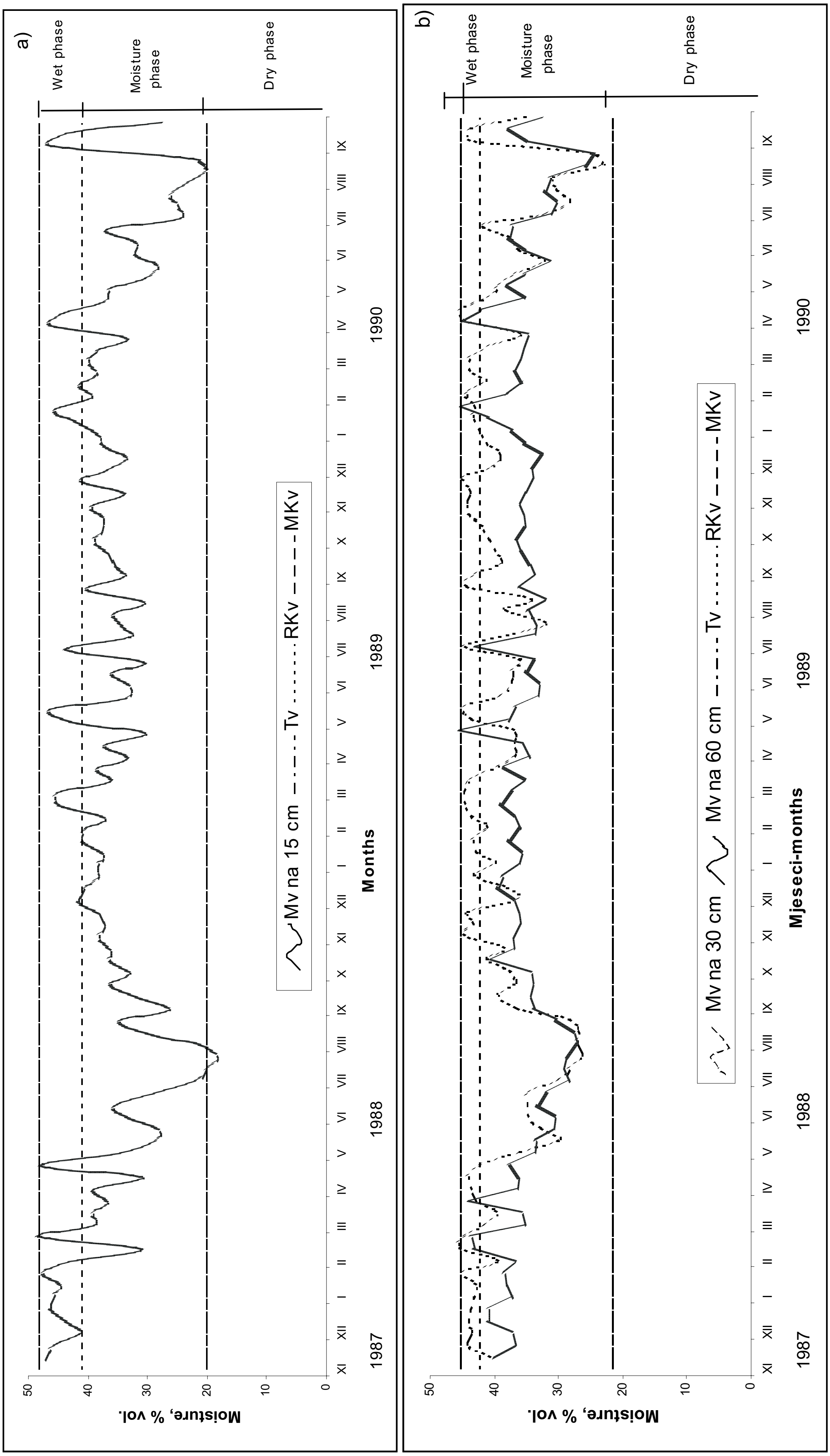
Gleyic stagnosol on RA-7 was before the amelioration exposed to stagnant surface water and medium deep ground water (strong stagnic and medium deep hypogleyic wetting). The occurrence of stagnant water is the result of the presence of the illuvial layer which has a very low water permeability due to high clay content and compaction. The occurrence of medium deep ground water (100-200 cm) is the result of the shallow position of the aquifer layer.

Rode and Smirnov (1972) by soil moisture regime mean the periodic changes of soil moisture along the soil profile, which corresponds to the concept of soil moisture dynamics. Husnjak (1993) holds that the soil moisture regime of a given soil may be defined by the analysis of the dynamics of soil moisture.

Graphs 1 and 2 show the developments of dynamics of soil moisture in relation to the total porosity, the water holding capacity and the wilting point. Analyzing the dynamics of soil moisture throughout the research period, one may notice that moisture at depths of 15 and 60 cm is most frequently between the dry and the wet phase, i.e. within the range of physiologically most favourable moisture phase, with no major difference between drained and non-drained soil. Namely, in relation to the total measurements during the three years of investigations, the moisture phase was recorded at the depth of 15 cm, in 79,8 percent of measurements in non-drained, and in 77.9 percent of measurements in drained soil, and at 60 cm, in 92.3 percent of measurements in non-drained, and 93.3 percent of measurements in drained soil. Moisture at the depth of 30 cm, compared to the other two depths, is considerably more rarely within the range of the moisture phase. Thus, the moisture phase was determined in 45.2 measurements in non-drained soil, and in 59.6 percent measurements in drained soil, which indicates the existence of considerable differences in the dynamics of soil moisture at this depth. Analyzing the moisture dynamics in the unfavourable wet phase did not show any considerable differences between drained and non-drained soil either, at the depths of 15 and 60 cm. The most frequent movements moisture in the wet phase were at the depth of 30 cm, in 54.8 percent of the measurements on non-drianed soil, and 40.5 percent of measurements in drained soil which proves the existence of considerable differences in moisture dynamics at this depth.



Graph 1. Dynamics of soil moisture (Mv) on undrained gleyic stagnosol with connection on wilting point (Tv),water holding capacity (RKv) and total porosity (MKv)



Graph 2. Dynamics of soil moisture (Mv) on drained gleyic stagnosol with connection on wilting point (Tv), water holding capacity (RKv) and total porosity (MKv)

Similar results in duration of the wet phase were obtained by Šimunić (1995) in three years of investigation of performance of combined detailed drainage on the same soil. He determined the occurrence of the wet phase at 30 cm depth in 32 percent of measurements in relation to the total number of observations for drain spacing of 15 m, and in 41 percent of the cases for the drain spacing of 30 m.

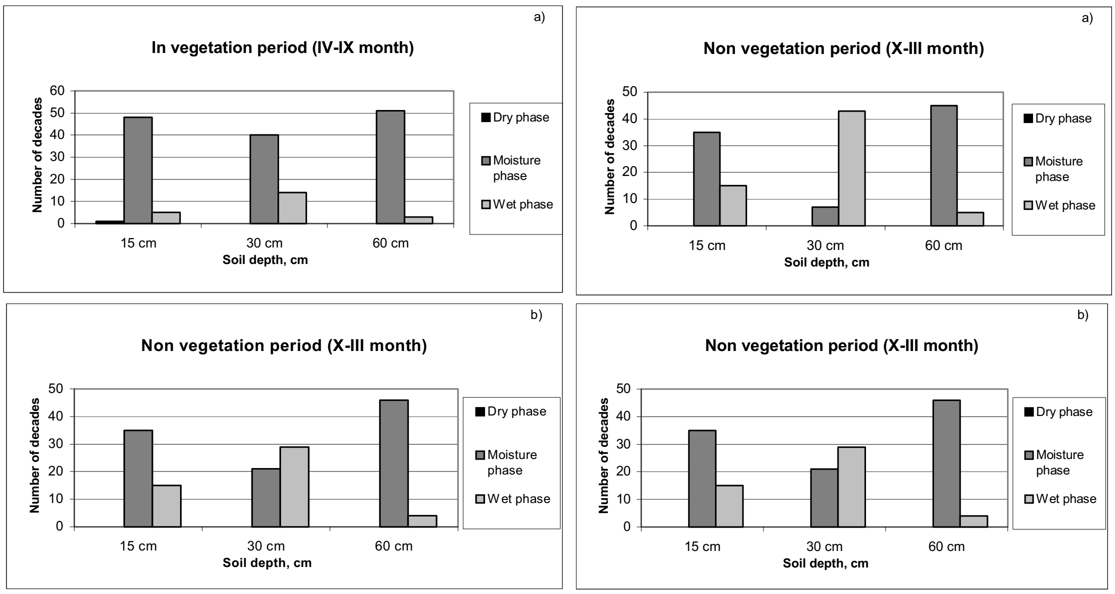
Based on the data of soil moisture in the wet phase in the vegetation period which at the depths of 15, 30 and 60 cm amount to 4.8, 13.5, and 2.9 percent of measurements in non-drained soil, and 6.7, 12.5, and 2.9 percent, respectively, of measurement in drained soil (in relation to the total number of observations in the vegetation period), it was determined that there were no essential differences in the dynamics of moisture between non-drained and drained soil. In the non-vegetation period, at the depths of 15, 30, and 60 cm, the wet phase was determined in 14.4, 41.3 and 4.8 percent of observations in non-drained, and in 14.5, 27.9, and 3.8 percent of measurements in drained soil. Thus, considerable differences in momentary moisture were discovered only in the non-vegetation period, and only at the depth of 30 cm. Momentary moisture within the range of the dry phase was recorded in the vegetation period only at the depth of 15 cm, and only once on both control plots.

The duration of phases, according to ten-day observations, in the vegetation (April-September) and non-vegetation (October-March) period is shown in Graph 3.

In the vegetation period, with regard to the soil moisture regime, it may be noticed that the soil is dominantly in the moisture phase, while the wet phase more frequently occurs at the depth of 30 cm. Wet phase was also recorded at 15 and 60 cm, but it is, like the dry phase (which was recorded only at 15 cm) of very short duration. No significant differences were noticed in the duration of the wet phase between non-drained and drained soil. Namely, the duration of the wet phase at 15 cm is, on average 17 days per annum in non-drained soil, while in drained soil it is even longer, reaching 23 days. At the depth of 30 cm, the duration of the wet phase is 47 days per annum in non-drained, and 43 days in drained soil. At 60 cm, the duration of the wet phase is 10 days per annum in both non-drained and drained soil.

In the non-vegetation period the soil soil moisture regime is characterized by a considerably higher number if ten-day periods with the wet phase, compared to the vegetation period. In a similar way, no differences have been noticed in duration of the wet phase between drained and non-drained soil at the depths of 15 and 60 cm. At 15 cm, the duration of the wet phase is 50 days per annum in both drained and non-drained soil. At 60 cm, the wet phase was 17 days in non-drained soil, and 13 days in drained soil. Considerable differences have been noticed at the depth of 30 cm, where the wet phase, on average, lasts 140 days in non-drained soil and 97 days in drained soil. Such long duration of the wet phase in drained gley soils in the Sava river valley in conditions without subsoiling or moling, was determined also by Petošić et al. (1993. and 1998) and Petošić (1994), who determined the duration of the wet phase from 50 to 180 days annually.

Presented results leads to the conclusion that there are no major differences of the soil moisture regime between non-drained (RA-7) and drained



Graph 3. Duration of dry, moisture and wet phase according to observations at decades on undrained (a) and drained (b) gleyic stagnosol

Table 3. Statistical analyses of soil moisture (% vol.) in vegetation period

Experimental field	Soil depth, cm 15	30	60
undrained soil	34,79	39,78	37,01
drained soil	32,87	36,26	34,03
LSD (P 0.05)	4,384	3,633	3,468

Table 4. Statistical analyses of soil moisture (% vol.) in non vegetation period

Experimental field	Soil depth, cm 15	30	60
undrained soil	42,77	45,1	40,75
drained soil	39,81	42,2	37,42
LSD (P 0.05)	3,225	2,418	4,652

soil (RA-9). With identical agrotechnical measures through the entire period of investigations, the only significant difference is that the wet phase in the non-vegetation period accurs in higher number of decades in non-drained soil, in relation to drained soil. This is proved by statistical processing of the data. The noticed differences of the dynamics of soil moisture between non-drained and drained gleyic stagnosol for the depths of 15 and 60 cm are not statistically significant, either in the vegetation or the non-vegetation period. For the depth of 30 cm, the differences are not statistically significant either for the vegetation period, and only in the non-vegetation period they are statistically significant, (table 3 and 4.

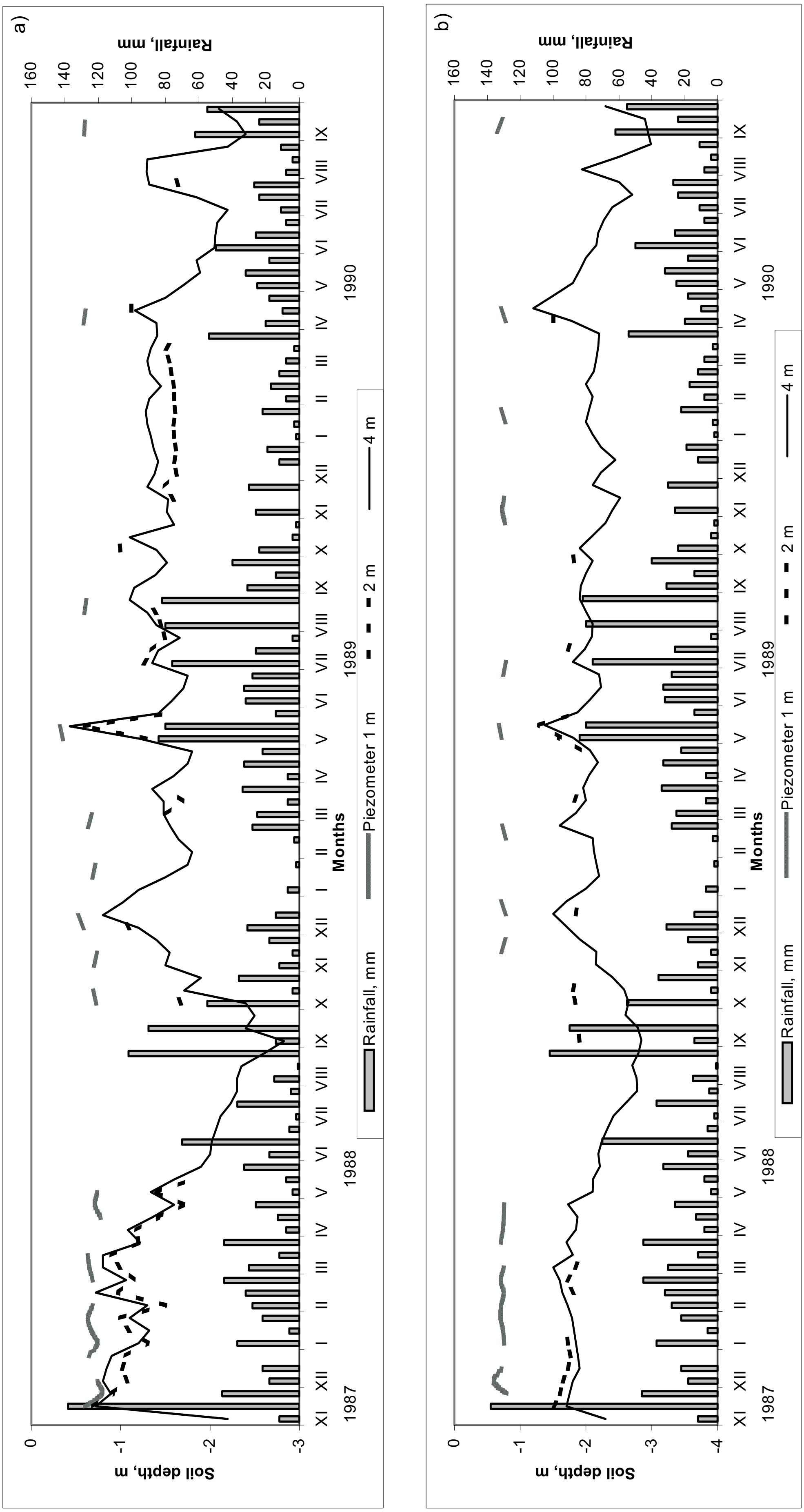
Dynamics of ground water and stagnant water level

Ground water level in piezometers of 2.0 and 4.0 m on the non-drained plot was most frequently between 1.0 and 2.0 m deep, and only in the summer months below 2.0 m, but newer below 3.0 m. Within the soil depth of 1.0 m, presence of stagnant or "perched" water was recorded several times in shallow piezometers of 1.0 m (which is, by origin, surface water, resulting from rainfall). In deeper piezometers ground water level within 1.0 m soil depth was noticed only several times, with shorter duration, Graph 4. On the drained plot, the ground water level in 2.0 and 4.0 m deep piezometers, most frequently varied between 1.5 and 2.5 m, and like in the former case, it was never below 3.0 m. In shallow piezometers of 1.0 m deep, stagnant rain water was also recorded in a number of instances. In deeper piezometers, within 1.0 m of soil depth ground water was not recorded.

By measurements in decade periods in the vegetation period, the presence of stagnant water in shallow piezometers was determined in the duration of 40 days in non-drained, and 37 days in drained soil, on average. In the non-vegetation period, presence of stagnant water was determined in the duration of 73 days per annum in non-drained, and 63 days in drained soil.

As on none of the trial plots in piezometers of 2.0 and 4.0 m ground water level in longer duration has not been recorded, this proved the earlier interpretations that stagnant water in shallow piezometers occurs after major rainfall, first of all due to poor profile permeability of soil. Further, it may be concluded that the combined way of wetting is still present both on drained and non-drained gleyic stagnosol, mostly by medium deep ground water (100-200 cm) and sporadically by stagnant rain water of shorter or longer duration in the upper part of the profile. No significant differences have been determined regarding presence of stagnant water in shallow piezometers in drained and non-drained soil. The maximal drain discharge of 0.003 m/day is by approximately 3.3 times less than the design drainage module.

The basic reason of poor performance of the drainage systems is the absence of agrotechnical measures, first of all subsoiling, folowed by liming and humization in the utilization phase, and therefore the effects of subsoil drainage are limited. These observations are proved by Vidaček et al. (1994), Husnjak (1993), Tomić et al. (1996), and Husnjak et al. (1998) who, on the basis of investigations of soil moisture regime in drained soils in the Sava valley and in the Vučica-Karašica catchment area also determined incomplete performance of subsoil drainage systems. According to them, the basic reason was the absence of agrotechnical measures (which were recommended in the design), i.e. subsoiling in farming practice. Similar results were obtained by Trafford (1972 and 1974), who points out that conventional subsoil drainage systems without subsoiling or moling, have little influence in the water regime in soils of heavier mechanical texture. Forgač (1977 and 1985) also point out that pipe drainage



Graph 4. Dynamics of ground water level on undrained (a) and drained (b) gleyic stagnosol

alone has limited effects on water regime in soil, and recommends regular carrying out of combined drainage systems in the Czech Republic and Slovak Republic. De Jong (1997) says that subsoil drainage systems may perform adequately without additional agrotechnical measures only in well permeable soils of lighter texture.

Analysis of crop yields

From the results of average crop yields it may be concluded that the yields achieved on drained soil are somewhat higher than on non-drained soil. However, on the basis of the data on determined higher yield of winter wheat 1987/88, which is only 1.2 percent, and oilseed rape of 3.7 percent, and winter wheat of the 1989/90 season of only 1.4 percent on drained soil compared to yields on non-drained soil, it may be stated that the differences are not significant, i.e. they do not meet the expectations with regard to the measures of detailed drainage. Namely, according to the designs, after drainage on these soils, minimum yield increases of 10-15 percent could have been expected (Tomić and Petošić, 1989). This is proved also by statistic processing of the yields showing that the existing differences in yields for given crops are not statistically justified, Table 5.

Table 5. Statistical analyses of yields

Experimental field	Winter wheat 1987/88, kg/ha	Oilssede rape 1988/89, kg/ha	Winter wheat 1989/90, kg/ha
undrained soil	5697	1562	5142
drained soil	5764	1619	5215
LSD (P 0.05)	73	64	81

CONCLUSIONS

Investigations of drained and non-drained gleyic stagnosol in the area of Šašna Greda proved the original uniformity of pedophysical and hydropedological properties of the soil. The soil moisture regime shows that there are no significant differences between durations of the wet, moisture and dry phases in drained and non-drained soil, although the wet phase in non-drained soil lasted a little longer. A major difference was noticed only in duration of the wet phase in the non-vegetation period and at the depth of 30 cm, where the wet phase lasted 43 days longer in non-drained soil than in drained soil. Statistically significant difference in the soil moisture dynamics between the drained and non-drained soil was determined only for the depth of 30 cm, and only for the non-vegetation period.

The dynamics of ground water and stagnant water indicate continued combined way of wetting in both drained and non-drained soil, mostly by medium deep ground water (100-200 cm) and sporadically by stagnant or perched rainwater of longer or shorter duration in the upper part of the profile. No essential difference has been recorded regarding duration of presence if stagnant water in shallow piezometers in drained and non-drained. soil. The maximum determined drain discharge of 0.003 m/day is by approximately 3.3 times lower than the design drainage module.

Crop yields are somewhat higher on drained soil, compared to those on non-drained soil; however, these differences are not statistically significant. The investigations of the soil moisture regime and the dynamics of ground water and stagnant water levels in hydroameliorated non-drained and drained pseudogley-gley soil indicate that there is still the problem of timely evacuation of excess rain water stagnating in the upper part of the profile, on both plots, resulting in longer duration of the wet phase. From the above, it may be concluded that installing of pipe drainage alone, without additional agrotechnical measures (subsoiling, liming, humization) does not solve the problem of drainage of excessive water, and that in such conditions the subsoil drainage systems in the area of the Central Sava Basin show only a limited performance.

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