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The values of different types of acidity of pseudogley soils in the Kraljevo basin under forest, meadow and arable land uses

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Abstract

This paper presents the results of active (pH in H_2O), exchangeable (pH in KCl), hydrolytic (Y1) and total acidity (T-S) in humus–accumulative (A_h, A_{hp}) and subsurface (E_g, B_{tg}) horizons of Pseudogley Soils in Kraljevo Basin for 14 soil profiles excavated in forests, 16 in meadows and 24 on arable land. The results showed that acidification was weaker or more pronounced in all three most important tested horizons of Pseudogley Soils, and that the differences in the value of different forms of acidity existed among forest, meadow and arable land uses, as well as between the horizons of the same profile. The chemical reaction of soil solution ranged from very weak to extremely acid. The highest active acidity was found in forest profiles, especially in deeper horizons. Exchangeable acidity ranged from 3.7 to 4.9 pH units, with the forest profiles as the most acid, while the differences between meadow and arable land were less pronounced. The highest hydrolytic acidity was obtained in the forest profiles, while acidity in meadow and arable profiles was significantly lower and the lowest, respectively. Total acidity of the Kraljevo pseudogleys ranged from 6.2 to 24.8 meq/100 g soil and similarly to hydrolytic acidity, the value of total acidity was affected by the land use.

Keywords: different types of soil acidity, Pseudogley Soils, different land uses, Kraljevo basin

Introduction

The group of the most widespread soil types in the lower altitude zone of Serbia. Pseudogley Pseudogley Soils are very common type of soils in Serbia, alongside Chernozems, Brown forest soils, Smonitza (Vertisols) and a group of alluvial plain soils (Fluvisols, Humofluvisols, Humogleys and Marsh black soils), and belongs to Soils in the Čačak-Kraljevo Basin are spread over approximately 32,000 ha and this basin is one of the most famous regions of their distribution in Serbia (Živković, 1970; Dugalić, 1998). In the Kraljevo Basin, Pseudogley Soils have been formed on the diluvial holocene terraces above the West Morava River and is tributaries, at the altitude between 180–290 m above sea level, mainly by pseudo-gleisation of leached soils, mostly on flat and gently sloping land (Živković, 1970). The geological substratum consists of multilayered, very clayey in deeper layers, compacted and very poorly water permeable sediments (Dugalić and Gajić, 2012). Agrophysical properties of Pseudogley Soils of the Kraljevo Basin can be characterised as unfavourable both in the surface A_h–horizon, and subsurface E_g and in the deeper B_{tg}–horizon (Dugalić i Gajić, 2002). Although quite uneven, the chemical properties of Pseudogley Soils of this Basin are considerably unfavorable (Živković and Dugalić, 2001; Dugalić and Gajić, 2012). A low content of hums, acid chemical reaction, increased content of mobile aluminum, and poor supply of available phosphorus are the main properties of these soils (Krstić et al., 2012).

Since soil acidity is considered to be the most important factor that limits the plant growth on acid soils, the aim of this study was to compare different types of acidity of Pseudogley Soils under forest, meadow and arable land use, in humus and subsurface horizons, in order to better and more rationally propose chemical reclamation measures.

Materials and Methods

Study area

Soil samples for laboratory analysis were collected using the open pit method during 2001 (forest Pseudogley) and during 2012 (meadow and arable Pseudogley Soils). This method was applied in 10 villages, namely Jarčujak, Ratarsko imanje, Mrsać, Kovanluk, Drakčići, Ratina, Samaila, Bapsko polje, and Konarevo. Open test pits were selected so that a soil profile could be examined in its natural state, meaning the open pits uniformly represented different land/relief and vegetation conditions of Pseudogley Soils of the Kraljevo Basin. There were 54 open pits (14, 16 and 24 with forest, meadow and arable land, respectively) that were dug to a depth of 100 cm. Disturbed soil samples for laboratory analyses were collected from the depths of the humus or the ploughed horizons, while in subsurface horizons the samples were taken successively every 15-20 cm along the entire thickness of the soil profile.

Soil analysis

The laboratory analyses encompassed the determination of active (pH in H_2O) and exchangeable (pH in KCl) soil acidity using the potentiometric method in a suspension with water and 1M KCl (1:2.5), while hydrolytic and total acidities were determined by the Kappen method (Kappen, 1929).

Results and discussion

The acidity status of observed Pseudogley Soils of the Kraljevo Basin, in almost all analysed profiles , for all three most important horizons (A_h, E_g and B_{tg}), showed poorer or stronger acidification. The exceptions are A_{hp} and E_g–horizons of the profile number 2 from Ratarsko imanje - the experimental field of the Agricultural School, where calcification had been probably been used. Active acidity of the soils in the humus horizon (Table 1–3), with the exception of the profile in the experimental field in Ratarsko imanje, varied from 4.45–6.10, i.e. from the very weak to the extremely strong acid chemical reaction, most frequently between 4.7–5.0. A significantly narrow range of variation (pH in H_2O between 4.78– 5.98) was observed in the humus horizon of Pseudogley Soils on meadows.

Table 1. The value of different types of acidity in Pseudogley Soils of the Kraljevo basin under forests

Profile number	Depth (cm)	pH H_2O	pH KCl	Y_1 (cm^3)	T-S (mEq/100 g)
	Forest profiles				
1	0-20	4.78	3.72	33.91	11.91
	20-40	4.82	3.82	18.45	8.69
	40-60	5.22	3.96	16.25	7.49
	60-80	5.62	4.24	12.42	6.08
	80-100	5.95	4.62	9.10	4.46
2	0-15	4.60	3.98	36.46	18.96
	15-35	4.80	3.86	20.71	9.75
	35-60	5.10	3.96	15.97	7.36
	60-80	5.38	4.10	12.68	6.21
	80-100	5.70	4.42	9.30	4.56
3	0-4	4.80	4.00	40.78	24.87
	5-20	4.53	3.61	31.44	14.00
	20-35	4.46	3.46	24.64	11.19
	40-60	5.00	3.56	24.84	12.23
4	0-10	4.45	3.67	47.90	21.68
	10-30	4.78	3.63	30.09	13.12
	30-50	4.84	3.64	23.58	10.43
	50-70	5.34	3.64	20.25	8.42
5	0-20	4.82	3.64	31.44	14.14
	20-35	4.93	3.61	25.73	11.43
	35-60	5.24	3.58	29.58	13.69
	60-80	5.35	3.60	26.03	11.93
	80-100	5.38	3.74	20.39	10.19
6	0-15	4.68	3.82	32.26	14.22
	15-35	4.80	3.64	28.73	11.51
	40-60	5.19	3.66	31.48	13.74
7	0-10	4.72	3.83	28.19	12.61
	10-20	4.66	3.64	36.95	14.34
	20-40	4.92	3.44	32.89	13.43
	40-60	5.01	3.46	24.36	10.00
	60-75	5.34	3.48	24.22	10.84
8	0-5	5.17	4.35	26.82	14.27
	5-25	4.72	3.61	30.90	13.52
	25-45	4.96	3.59	26.55	11.11
	45-65	5.24	3.70	19.90	8.99
9	0-10	5.03	4.09	33.67	17.83
	10-25	4.84	3.76	24.94	12.58
	25-40	5.06	3.71	20.80	10.38
	40-60	4.85	3.70	27.77	14.02
10	0-20	4.84	3.98	23.85	12.42
	20-40	5.10	3.69	21.14	9.49
11	0-5	5.26	4.42	32.57	16.48
	5-20	4.82	3.80	27.65	12.93
	20-30	4.96	3.60	23.81	10.86
	30-45	5.24	3.71	23.10	11.59
12	0-7	6.10	5.36	13.68	8.97
	7-15	5.13	4.03	20.87	11.02
	15-30	5.06	3.69	21.90	9.59
	30-45	5.07	3.60	28.15	12.61
	45-60	4.78	3.66	24.17	12.19
13	0-4	4.79	4.02	42.70	21.25
	4-20	4.56	3.51	39.57	15.94
14	0-10	4.83	3.87	23.31	12.39
	10-30	5.04	3.56	24.91	12.89
	30-45	5.07	3.47	25.91	18.04

Table 2. The value of different types of acidity in Pseudogley Soils of the Kraljevo basin under meadows

Profile number	Depth (cm)	pH H_2O	pH KCl	Y_1 (cm^3)	T-S (mEq/100 g)
	Meadow profiles				
1	0-15	5.40	4.38	18.32	10.08
	15-30	5.24	4.22	16.73	8.43
	30-50	5.34	4.16	15.25	7.68
	50-70	5.42	3.96	19.10	8.80
	70-100	5.62	4.24	13.97	6.44
2	0-15	5.98	5.38	11.00	6.05
	15-30	5.70	5.22	8.20	4.13
	30-50	5.30	4.12	18.23	8.97
	50-70	5.38	4.08	13.76	6.77
	70-100	5.56	4.42	10.78	5.28
3	0-15	5.03	4.01	22.23	12.04
	15-30	4.95	3.77	17.52	9.31
	30-45	5.15	3.76	18.61	9.67
	45-60	5.27	3.73	21.21	11.27
	60-80	5.46	3.90	16.18	8.41
	80-100	5.90	-	10.60	5.84
4	0-15	5.23	4.31	17.35	9.93
	15-35	5.30	4.04	15.72	8.42
5	0-15	5.70	4.77	14.64	8.77
	15-30	5.44	2.25	14.64	8.39
	30-45	5.44	3.97	14.51	8.64
	45-60	5.57	3.91	18.41	10.41
	60-80	5.72	4.02	17.18	8.98
	80-100	5.92	-	12.96	7.14
6	0-15	5.17	4.23	18.70	10.79
	15-35	4.80	3.74	18.43	8.80
	35-50	5.28	3.61	24.63	11.41
	50-70	5.63	3.67	22.32	10.89
	70-90	5.65	3.80	17.30	9.05
7	0-15	4.97	3.90	25.48	13.39
	15-30	5.22	3.73	22.44	10.70
	30-50	5.37	3.70	30.71	15.12
8	0-20	5.35	4.26	12.74	10.76
	20-40	5.47	4.00	16.26	9.07
	40-60	5.40	3.66	30.98	15.12
9	0-15	4.78	3.94	21.41	10.46
	15-30	4.87	3.69	24.36	10.92
	30-50	5.22	3.61	35.21	14.39
	50-70	5.37	3.70	26.76	10.87
	70-90	5.66	3.92	18.03	9.43
	90-110	5.74	-	13.35	7.35
10	0-15	5.24	4.18	19.52	10.54
	15-35	5.17	3.82	18.70	8.69
	35-50	5.53	3.71	27.21	12.24
11	0-15	5.62	4.50	16.80	9.26
	15-35	5.36	3.82	14.51	8.99
12	0-15	5.06	3.94	18.97	11.86
	15-30	5.00	3.62	22.44	11.63
	30-50	5.40	3.59	32.39	16.45
13	0-15	5.18	4.18	21.68	10.54
	10-25	5.26	3.87	21.35	10.22
	25-40	5.20	3.71	25.59	12.67
	40-60	5.23	3.74	23.03	11.54
	60-80	5.38	3.94	17.34	9.02
	80-100	6.02	-	10.24	5.64
14	0-15	5.27	4.22	20.25	10.97

Profile number	Depth (cm)	pH H_2O	pH KCl	Y_1 (cm^3)	T-S (mEq/100 g)
		Meadow profiles			
	15-30	5.20	3.78	20.80	10.43
	30-40	5.26	3.73	24.39	11.68
	40-60	5.27	3.72	25.59	12.16
	60-80	5.40	3.95	20.59	10.36
	80-100	5.65	4.34	15.64	8.60
15	0-10	5.07	4.28	19.24	11.30
	10-30	5.04	3.97	18.89	10.40
	35-50	5.17	3.70	26.48	12.72
	50-65	5.34	3.73	26.27	13.39
	65-80	5.50	3.94	22.01	11.00
	80-100	5.55	4.23	19.16	9.56
16	0-15	4.95	3.91	24.94	13.04
	15-35	4.96	3.74	22.99	11.30
	40-60	5.37	3.77	22.18	11.20
	60-80	5.68	4.05	14.90	8.78
	80-100	6.30	-	9.95	5.47

Table 3. The value of different types of acidity in Pseudogley Soils of the Kraljevo basin under arable land use

Profile number	Depth (cm)	pH H_2O	pH KCl	Y_1 (cm^3)	T-S (mEq/100 g)
		Arable profiles			
1	0-15	4.95	3.91	24.94	13.04
	15-35	4.96	3.74	22.99	11.30
	40-60	5.37	3.77	22.18	11.20
	60-80	5.68	4.05	14.90	8.78
2	0-20	6.84	6.10	1.25	0.81
	20-40	6.21	5.90	1.75	1.14
	40-60	5.68	4.50	10.36	5.02
	60-80	5.52	4.40	10.94	5.47
	80-100	5.94	4.82	7.62	3.73
3	0-15	4.55	3.74	30.36	15.10
	15-30	4.63	3.77	30.63	15.81
	30-45	4.68	3.58	22.77	8.78
4	0-20	5.44	4.41	17.62	9.82
	20-35	5.34	3.64	16.70	8.97
5	0-15	5.49	4.58	13.28	8.67
	15-30	5.13	3.80	19.43	10.70
	30-50	5.18	3.68	24.00	12.60
6	0-20	4.88	4.12	24.91	13.49
	20-40	5.07	3.90	17.58	9.57
7	0-20	5.05	4.16	18.43	9.82
	20-40	5.24	3.92	15.87	8.21
	40-60	5.65	3.76	22.98	11.57
	60-80	5.73	3.81	20.17	10.31
	80-100	6.14	4.00	14.54	7.99
8	0-20	5.50	4.52	17.89	10.92
	20-40	5.67	4.33	13.14	8.21
	40-55	5.60	4.16	15.49	9.98
9	0-20	5.36	4.34	17.08	9.69
	20-35	5.40	4.12	14.78	8.97
	35-55	5.63	4.17	12.83	8.40
10	0-20	5.42	4.42	14.36	9.47
	20-35	5.51	4.20	12.59	8.42
	35-55	5.57	4.04	15.49	10.23
	60-75	5.78	4.13	12.39	6.82
11	0-23	5.49	4.37	13.82	9.18

Profile number	Depth (cm)	pH H_2O	pH KCl	Y_1 (cm^3)	T-S (mEq/100 g)
		Arable profiles			
	23-40	5.30	3.91	13.46	8.80
	40-60	5.70	3.77	23.03	13.03
12	0-20	4.87	4.23	16.80	13.37
	20-40	4.93	3.73	16.70	9.97
	40-60	5.30	3.70	26.20	14.55
	60-80	5.72	3.92	19.43	11.71
13	0-20	5.71	4.78	10.30	7.43
	20-40	5.17	3.90	15.87	9.21
14	0-15	5.30	4.46	13.28	9.20
	20-35	5.26	4.01	16.53	10.54
	35-55	5.27	3.73	27.41	15.43
15	0-20	5.34	4.29	16.53	10.08
	20-40	5.17	3.88	17.62	10.01
	40-60	5.24	3.67	30.25	14.55
16	0-22	5.08	4.29	15.99	10.89
	22-40	4.87	3.77	25.28	11.11
	40-60	5.00	3.70	26.51	12.82
	60-80	5.43	3.73	24.00	11.99
17	0-20	5.13	4.20	17.89	10.12
	20-40	4.54	3.64	21.14	9.95
	50-70	5.30	3.57	32.39	14.64
18	0-15	5.82	4.86	9.76	6.79
	15-35	4.97	3.67	17.62	9.44
	35-55	5.00	3.51	38.03	16.28
19	0-20	5.42	4.56	15.72	9.38
	20-40	5.74	4.56	10.95	7.66
	40-55	5.53	4.17	12.43	8.94
	55-70	5.66	4.16	12.28	7.98
20	0-15	5.21	4.25	17.89	11.40
	15-35	5.03	3.70	15.99	9.61
	35-50	5.22	3.56	30.42	15.53
	50-70	5.40	3.62	25.41	13.63
21	0-20	5.23	4.33	17.08	10.27
	20-40	4.98	3.78	18.97	9.56
22	0-20	5.46	4.22	14.36	8.59
	20-40	5.28	4.13	14.91	8.98
	40-60	5.42	3.75	21.58	12.43
23	0-20	5.27	4.32	16.80	10.40
	20-40	5.08	3.62	21.41	9.92
	50-70	5.30	3.60	30.14	14.89
24	0-20	5.11	4.17	18.70	11.72
	20-40	5.20	3.63	24.91	12.38
	40-60	5.15	3.59	28.45	14.11

The first subsurface, E_g–horizon, showed rather high active acidity that varied from pH 4.46 to 5.74. In this horizon, the highest acidity was recorded in forest profiles. On the other hand, meadow and arable profiles were quite similar, which is understandable because these soils were largely used alternately for field crops and meadows. Active acidity in observed Pseudogley Soils was, as a rule, high in the upper part of the B_{tg}–horizon, which usually started at a depth of 40–50 cm, less often at a much greater depth. According to data presented in Tables 1–3, pH in H_2O at the depths of 30–40 and 50–80 cm varied from 4.8 to 5.7 in 43 examined profiles. The highest active acidity in the B_{tg}–horizon was recorded in forest profiles of Pseudogley Soils. These data testifies that roots of forest trees, mainly oaks, significantly affect acidification of deeper parts of the soil profile, both by absorbing great amounts of base elements by plants, and by excreting large amounts of CO_2 and various organic acids, especially tannins, which are mostly found in oak forests (Blume et al., 2016). Oak forests prevail in the forest vegetation on Pseudogley Soils of the Kraljevo Basin. There is no doubt that a significant part of tannic and other organic acids, among which fulvic acids dominate, reach the surface part of the B_{tg}–horizon of forest Pseudogley Soils by leaching from surface horizons, and due to poor water permeability of the B_{tg}–horizon increases active and especially potential acidity in the soil. This is evidenced by strong increase in exchangeable acidity and the content of easy mobile Al–ions in the stated horizon (Đalović et al., 2012).

Increased exchangeable acidity is characteristic for soils in which acidification processes are very pronounced. Therefore, the reaction of the soil solution became quite acidic, with the pH values < 5.0, which is, as already stated, a distinctive property of Pseudogley Soils in the Kraljevo Basin, particularly in their A_h, E_g and the upper part of the B_{tg}–horizon, down to the depth of 60–80 cm, frequently even deeper. As presented in Table 1–3, exchangeable acidity (pH in KCl) in the humus horizon varied from 3.7 to 4.9. In the E_g–horizon, exchangeable acidity increased, except in the profile in the experimental field. The highest exchangeable acidity in the E_g–horizon was recorded in the forest profile, while this acidity was the highest in approximately 2/3 of observed profiles in the B_{tg}–horizon, as previously determined by Dugalić et al. (2019).

In addition to high active and exchangeable acidity, Pseudogley Soils of the Kraljevo Basin are also characterised by high values of hydrolytic and total acidity not only in eluvial but also in illuvial horizons. The highest hydrolytic acidity, both in the Ah horizon and the E_g and B_{tg}–horizons, was recorded in the forest profile of Pseudogleys, which is in agreement with studies carried out by Čakmak et al. (2009), who found that about 71% of extremely acid soils were covered by forest and meadow vegetation. The meadow profiles of Pseudogley Soils had lower hydrolytic acidity than forest profiles in A_h and E_g–horizons, while the difference in hydrolytic acidity between forest and meadow profiles in the B_{tg}–horizons was insignificant. Values of hydrolytic acidity in arable profiles in the A_h–horizon were lower than in meadow, and especially forest profiles. These data showed that the conversion of forest Pseudogley Soils into arable lands significantly reduced hydrolytic acidity in the A_h, i.e. A_{hp}–horizon, but also in the E_g–horizon. Observed by Y_1 values, meadow Pseudogley Soils ranked between forest and arable soils, although they were much closer to arable soils, which can be explained by the fact that the majority of today's Pseudogley Soils had been occasionally used as arable lands.

Total acidity of Pseudogley Soils in the Kraljevo Basin is quite high. It ranged from 6.2 to 24.8, 6.9 to 15.9 and from 6.2 to 18.0 mEq/100 g soil in A_h, E_g and B_{tg}–horizons, respectively (Table 1–3). Similarly to hydrolytic acidity, effects of the methods of Pseudogley Soils utilization reflected upon the value of total acidity.

Conclusion

Acid conditions were more or less pronounced in the three most important horizons (A_h, E_g, B_{tg}) in observed Pseudogley soils in the Kraljevo Basin under forest, meadow and arable land use. The highest active and exchangeable acidity was determined in forest profiles in all observed horizons. The difference between meadow and arable land Pseudogley Soils in the values of their active and exchangeable acidity was less pronounced. In addition to high active and exchangeable acidity, Pseudogley Soils of the Kraljevo Basin were characterised by high values of hydrolytic and total acidity, not only in eluvial but also in illuvial horizons. The highest hydrolytic acidity, both in the A_h–horizon, and the E_g and B_{tg}–horizons, was observed in forest profiles of Pseudogley Soils. Meadow profiles have lower hydrolytic acidity compared with forest profiles in the A_h and E_g–horizons, while differences in values of hydrolytic acidity in the B_{tg}–horizon between forest and meadow profiles were insignificant. Total acidity of Pseudogley Soils of the Kraljevo Basin was high and ranged from 6.2 to 24.8 meq/100 g soil, and similarly to hydrolytic acidity, the effect of the land use reflected upon the value of total acidity.

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Vrednosti različitih tipova kiselosti pseudogleja u Kraljevačkoj kotlini pod šumom, livadom i oranicama

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Izvod

U ovom radu su predstavljene vrednosti aktivne (pH u vodi), izmenljive (pH u KCl-u), hidrolitičke (Y_1) i ukupne kiselosti (T-S) u humusnom horizontu (A_h, A_{hp}) i potpovršinskim (E_g, B_{tg}) horizontima pseudogleja, na 14 lokacija u šumi, 16 na livadama, i 24 na obradivim površinama u Kraljevačkoj kotlini. Rezultati su pokazali da je zakišeljavanje slabije ili izraženije u sva tri najvažnija ispitana horizonta pseudoglejnih zemljišta, te da postoje razlike u vrednostima različitih oblika kiselosti u šumama, livadama i njivama, kao i među različitim horizontima pseudoglejnih zemljišta. Hemijska reakcija zemljišnog rastvora se kreće od vrlo slabe do izrazito kisele. Najveću aktivnu kiselost imaju šumski profili, posebno oni u dubljim horizontima. Izmenljiva kiselost se kretala u rasponu od 3,7 do 4,9 pH jedinica, pri čemu su šumski profili bili najkiseliji, dok su razlike između livadskih i njivskih profila bile manje izražene. Najveća hidrolitička kiselost zabeležena je u šumskim profilima, dok je kiselost u livadskim i njivskim profilima značajno niža, odnosno najniža. Ukupna kiselost pseudogleja Kraljevačke kotline kretala se od 6,2 do 24,8 meq/100 g zemljišta, a slično kao i hidrolitička kiselost, na vrednost ukupne kiselosti uticao je način korišćenja zemljišta.

Ključne reči: različiti tipovi kiselosti, pseudoglej, različiti načini korišćenja, Kraljevačka kotlina

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Agrogenic evolution of soddy-podzolic soil: Feasibility of repeated re-involvement in cultivation of the fallow lands formed on band clays

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Abstract

Transformations of the soddy-podzolic gleyic clay soil in a long-term agricultural use (> 200 years) was studied in Leningrad region, northwest Russia. This feasibility study investigated the possibility of re-cultivation of these soils after long term fallowing. Morphological structure, particle size distribution, content and ratio of ferrous and oxide forms of iron in the profile of virgin (indigenous forest) and arable drained soil were analysed. In addition, changes in the organogenic-profile were traced in the course of long-term agrogenesis (> 200 years). In virgin forest soil, during its pedogenesis the loss of fractions <0.01 mm from the eluvial layer was 877.4 kg m^{-2}, and the loss of <0.0001mm was 287.5 kg m^{-2}, as compared with parent material not affected by the processes of pedogenesis. However, long-term agrogenesis (>200 years) led to increased eluvial losses of fine earth particles. The loss of fraction <0.01 mm from the arable horizons was 1244.8, and < 0.0001 mm was 570 kg m^{-2}, respectively. This was due to multiple yearly tillage that increased the porosity of the soil and thus intensified lessivage, which led to increased leaching and eluvial losses. The total loss of colloids from the entire profile of virgin soil was 262.1 kg m^{-2}, and from the arable layer of drained soil - 290.1 kg m^{-2}. The humus enrichment of the colloids of the plough (P) horizon of the arable soil was two times lower than that of the surface (AY) horizon of the virgin soil. The relative share of the participation of colloids in the fixation of humus by the soil was the same (11.6 and 10.9%, respectively). In the subsurface horizons, the absolute content of humus in the colloids decreased, and the share of participation in the fixation of humus increased. When soddy-podzolic gleyic clay soil is brought to cultivation then the water-air regime is improved, content and composition of humus, depth of arable horizon is increased and the soil acidity decreased. At the same time the leaching of fine earth materials is accelerated. When this soil was withdrawn from crop production, the positive changes achieved as a result of cultivation were gradually lost. For the first time we could qualitatively calculate the losses of the fine earth fractions for the given soil from top soil. Taking into account the high costs of re-cultivation of the former land and a high cost of re-installation and maintenance of an optimal hydrological regime (drainage network) we concluded that repeated ploughing and involvement of arable soddy-podzolic gleyic clay soil into cultivation is economically unreasonable.

Keywords: soddy-podzolic clay soil, agrogenic evolution, fine-dispersed fraction, organogenic-mineral profile, colloids

Introduction

Soils formed on band clays are widespread in the west and north-west of Russia in the areas of lakes Onega, Ladoga, Ilmen, etc. In different years, the study of soil formation processes in these soils was studied by Gagarina (1994), Ivanov and Yanko (2019), Matinian et al., (1983), Karavaeva, (1996), Karavaeva (2000), Khantulev et al., (1977), Pestryakov (1977), Shoba et al., (1983), Sokolova et al (1983), Zvereva et al., (1990), Zvereva and Lazareva (1989), Zaydelman (1985). To date, the literature has accumulated a certain factual material devoted to the change in the conservative properties of soils of this genesis under the influence of prolonged agrogenesis (total chemical, particle size distribution and mineralogical compositions) (Litvinovich et al., 2021; Matinyan et al., 1983; Nikolaev et al., 2021; Shein et al., 2009; Shein et al., 2021; Shevchenko et al., 2020). Nevertheless, this information cannot be considered completely exhaustive. Thus, it is considered established that in the process of soil formation in clay substrates there are processes of chemical destruction and physical crushing of particles of fine earth (Gagarina 1994; Karavaeva 2000), which can lead to replenishment of the silty fraction ("silt formation"), but mathematical models for describing this process have not been developed. Nor can the data on the contribution of finely dispersed fractions of turf-podzolic clay soils in the fixation of humus substances be considered sufficiently complete.

The hydrothermal regime of sod-podzolic gleyy clay soils on band clays is characterized by seasonal waterlogging and associated development of the gley process. In the formation of gley, the main role is played by the processes of iron reduction during the decomposition of organic substances in conditions of abundance of moisture and lack of oxygen in the air (Kaurichev and Nozdrunova 1964). When this soil is drained, the processes of iron reduction are attenuated. There are scarce works devoted to the establishment of the content and ratio of ferrous and oxide forms of iron in individual horizons of the profile of native soddy-podzolic gleyic clay soils and their transformation during the laying of a closed drainage network and in a long-term agrogenesis.

During the cultivation of these soils, changes occur in different directions: its water-physical and chemical properties are improved mainly due to the laying of a drainage system and the introduction of appropriate fertilizers and liming. But at the same time, destruction of the colloidal complex and its loss from the arable horizon can occur.

The deep systemic crisis since the early 1990s in Russia has led to the fact that the overwhelming amount of previously drained clay soils of agricultural land has been withdrawn from crop production and are at various ages of fallowing. The amount of fertilizers used on cultivated soils has sharply decreased, liming has stopped.

The new agricultural strategy of Russia assumes re-involvement of 12 million hectares of former croplands into economic circulation again in the period of 2021-2030. Great importance is given to the development of soil reclamation with the mandatory reconstruction of the drainage system, the use of new materials in the construction of drainage, as well as modern technologies for the removal and utilization of woody and shrubby vegetation. This requires a comprehensive assessment of the transformation of soil properties during the period of active use in culture and the economic feasibility of their re-cultivation. Therefore, the study tasks included:

- to establish the influence of long-term agricultural use of soddy-podzolic clay soil on the morphological structure of the profile
- determine the content and ratio of ferrous and oxide forms of iron in individual horizons of virgin and arable drained soil
- to identify changes in the content of fine particles in the process of natural and agrogenic soil formation and develop empirical models describing the transformation of finely dispersed fractions in the soil profile of a given genesis
- calculate the loss of fine soil from virgin and arable clay soils
- to study the change in the natural organoprofile in the process of long-term operation of drained soddy-podzolic clay soil; to find out the contribution of colloidal and pre-colloid fractions in the fixation of humus substances
- assess the feasibility of re-cultivation the soils of this genesis after their prolonged fallowing

Materials and methods

Site description

To identify changes in the composition and properties of soils in the process of natural soil formation and long-term agrogenesis, a comparative geographical method of a conjugate study of virgin and arable turf-podzolic clay clay dusty-silty soils formed in similar geomorphological conditions on the territory of the Prinevskaya lowland (Leningrad region) was used.

The average annual rainfall is 600-650 mm. The amount of evaporation is not more than 400 mm. Excess precipitation over evaporation is one of the main reasons for the formation of soils of temporary excessive moisture. Soil-forming rocks within the territory under consideration, formed by the activity of the glacier, are represented by lake-glacial band clays. The latter are characterized by high water absorption, low water retention and water permeability, which, along with a significant excess of precipitation over evaporation and imbalance in natural drainage, causes waterlogging of soils heavy in terms of particle size distribution and causes unfavorable conditions of water, air and nutrient regimes.

Arable soddy-podzolic clay soil is located 34 km from St. Petersburg (former sovkhoz Detskoselsky). It has been in culture for more than 200 years. It is not possible to reconstruct the history of land use over the years. It is known that before the 1917 there was a rich village on the site of the modern massif. The soil was used for grazing cattle and hayfields. Re-development of the soil began after the Second World War. In 1959, a pottery drainage was laid with a distance between the drains of 10-12 meters. The depth of the drainage system is 90-100 cm. A six-field crop rotation, where three of them were perennial grasses was used. The high level of agricultural technology, characteristic of suburban farms of the Leningrad region, made it possible to obtain in 1976-1980 on the massif: vegetables - 30.8 tons ha^{-1}, fodder root crops - 50.8 t ha^{-1}, hay of perennial grasses - 6.5 t ha^{-1}. Soil profiles was laid out in 1983 on the perennial grass plots. In 1989, the drainage failed. Since 1990, the soil has been used for hayfields for a short time. Currently, the massif is a weakly planted variegated grass meadow, gradually undergoing waterlogging.

The virgin soddy-podzolic clay soil is located in the immediate vicinity of arable soil and is occupied by secondary forest. The vegetation cover is represented by alder (*Alnus*, L.), aspen (*Populus tremuloides*, L.) and birch (*Betula*, L.). The grassy cover is continuous, with a predominance of sedge (*Cyperaceae*, L.).

The particle size distribution of parent rocks indicate that the soils are formed on a material similar in composition (Table 1).

Table 1. Particle size distribution of soddy-podzolic gleyey clay virgin and arable soil

Horizon	Depth	1-0.25	0.25-0.05	0.05-0.01	0.01-0.005	0.005-0.001	<0.001	<0.01
	cm				mm			
				Virgin				
AY	3-10	4.3	21.1	24.2	20.0	18.0	12.4	50.0
ELg	10-20	7.8	19.9	21.6	17.1	22.6	11.0	50.7
BTg	20-30	6.4	12.3	23.0	17.2	22.6	18.5	58.3
BTg	30-40	6.1	12.6	23.8	16.4	21.4	19.7	57.5
BTg	50-60	7.0	11.7	22.0	18.2	21.7	19.4	59.3
BTg	60-70	6.9	11.8	21.5	18.7	22.1	19.0	59.8
BTg	70-80	7.2	10.0	22.1	22.4	19.5	18.8	60.7
Cg	120-130	7.4	9.8	23.0	21.5	19.4	18.9	59.8
				Arable				
P	0-10	4.9	22.1	23.2	18.9	20.9	12.0	51.8
P	10-20	4.4	23.0	23.7	18.0	21.1	11.8	50.9
P	20-30	5.1	21.9	22.5	17.9	21.4	12.2	51.5
BELg	30-40	7.5	15.0	23.9	15.5	16.5	21.6	54.6
BELg	40-55	8.4	18.9	19.7	13.2	17.5	22.3	53.0
BTg	60-70	8.1	13.4	22.0	16.4	18.6	21.5	55.0
BTg	80-90	8.0	10.9	23.2	19.0	18.4	20.5	57.9
Cg	130-140	8.6	10.7	23.2	18.6	18.8	20.1	57.5

Methods

The method of cutting cylinders (100 cm^3) was used to determine the bulk density. The particle size distribution was determined following wet dispersion with the pipette method. The isolation of fine fractions was determined as follows: the fraction <0.001 mm was divided into pre-colloidal and colloidal (<0.0001 mm) phases using a C-100 flow-through centrifuge at 20 thousand rpm. The suspension was coagulated with an HCl solution (Gorbunov 1971). The content of soil humus was determined using the wet combustion method. Oxides of ferrous and trivalent iron were determined by the complexometric method (Novitsky et al 2021).

Results and discussion
Morphology

The structure of the profile of virgin forest soil is typical for soils of this genesis. The upper part is a forest litter (O - 0-3 cm), well mixed with mineral mass. Below is a shallow grey-humus horizon (AY - 3-10 cm), homogeneous dark gray color, densely intertwined with plant roots. At a depth of 10-20 cm, a podzolic horizon (ELg) is formed, whitish in color with small grayish layers and spots of gleying. Below, at a depth of 20-80 cm, there is an illuvial-textured clay horizon (BTg). Soil-forming rock (C) lies from 80 cm depth.

The development and structure of arable soil was formed under the influence of the agrogenic process of soil formation. Soil cultivation, systematic fertilization, liming, crop rotation, engineering land reclamation transform the upper part of the soil profile to the depth of plowing with the formation of an arable layer and the involvement in its composition of the horizons AY, ELg and part of the BTg horizon. The arable layer (P - 0-30 cm) is characterized by uniform dark gray coloring, lumpy structure, densely permeated with the roots of herbaceous vegetation.

Under the influence of agrogenic soil formation in the profile of arable soil, the BELg eluvial horizon (30-55 cm) is formed, which corresponds to the depth of the upper part of the BTg horizon whose depth is 55-90 cm. The change in the hydrological regime due to drainage led to a weakening of the signs of gleying to the depth of the drainage. A similar morphological structure of the middle and lower part of the profile of virgin and arable soils indicates the development of the same processes in cultivated soil as in virgin soil.

Content and ratio of ferrous and oxide forms of iron in the studied soils

Due to the prevailing water-air and oxidative conditions in clay soils, the transformation and redistribution of various forms of iron occur (Table 2). Insoluble forms, represented by crystallized and amorphous non-silicate iron, pass into more mobile compounds of hydroxide of ferrous oxide and oxide and its simple salts (Gorbunov 1971). The studied soils are characterized by a significant content of oxide forms of iron in the entire soil stratum, which gives a characteristic color to their profile. The greatest amount of ferrous oxide is found in forest soil.

There are five groups of iron oxide compounds in soils distinguished. They give a characteristic color to gleyed soils: water-soluble ionic or complex iron; active, represented by precipitated insoluble forms and partly forms of firmly adsorbed by clay minerals; inactive iron, firmly adsorbed by clays, as well as partially iron minerals and some of its insoluble forms; non-extractable iron bound to and contained in clay minerals (Patrick and Turner 1968).

Table 2. Content and distribution of ferrous and oxide forms of iron in soddy podzolic gleyey clay soils

Horizon	Depth, cm	Fe_2O_3	FeO	Fe_2O_3 / FeO
		Virgin		
AY	3-10	1.65	1.21	1.36
ELg	10-20	2.60	1.04	2.50
BTg	30-40	2.89	1.44	2.01
Cg	120-130	2.53	1.47	1.72
		Arable		
P	0-30	2.32	0.99	2.34
BELg	40-50	3.12	0.69	4.52
BTg	70-80	3.03	0.92	3.29
Cg	130-140	3.88	0.93	4.17

When waterlogged soils are drained, ferrous iron is oxidized. Drainage leads to a decrease in the content of ferrous oxide and an increase in its oxide form. The ratio of oxidized and reduced forms of iron in arable soil is expanded. Color signs of glaciation are weakened (Table 2).

However, the complete disappearance of ferrous oxide forms during drainage could not be achieved. This is because not all forms of ferrous oxide are easily oxidized. Active and inactive iron are stable forms and even in air these forms retain their specific color. For the complete disappearance of color signs of glaciation, apparently, a significant period of time is needed.

In general, cultivation and drainage lead to an expansion of the ratio of oxidized and reduced forms of iron in arable soil, which indicates an improvement in the water-air regime and the predominance of oxidation processes in the profile. However, gleying during the drainage of soils of this genesis is not completely eliminated.

Particle size distribution

Particle size distribution shows that the profile of the studied soils is quite clearly differentiated in the content of clay and silty fraction (Table 1). The eluvial zone in virgin forest soil covers a layer of 3-20 cm (AY and ELg). Down the profile in the BTg horizon, the silt and physical clay content increases substantially from 11.0 to 18.5% and 50.7% to 58.3%, respectively. Further, in the deeper layers, the content of clay particles and silt fraction is leveled.

Long-term agrogenesis changed the horizontal structure of the profile of soddy-podzolic clay soil. The eluvial horizon is the entire arable layer (0-30 cm), which is evenly depleted of silt and clay fraction. The BELg transition horizon, located at a depth of 30-55 cm and formed at the site of the illuvial horizon BTg of virgin soil, is also affected by eluvial processes. A decrease in the content of the medium (0.01-0.005 mm) and fine (0.005-0.001 mm) dust in the process of agrogenic soil formation was revealed. In the BELg horizon, the number of these particles is minimal compared to all other soil layers.

The loss of fractions of fine and medium dust in agrogenic soil may well be caused by downward migration through pores and cracks with leaking moisture. According to Motomura (1969), increasing the downward flow of moisture due to drainage contributes to the increased migration of fine soil from the upper horizons of the profile. According to Seidelman (1985), the water permeability of soddy-podzolic soils under the influence of drainage starting from the surface is 1.7-2 times greater than that of an undrained one.

On the other hand, according to Gagarina (1994), the main mechanism for the loss of dusty fractions in soddy-podzolic clay soils is a physical distraction of clastogenic clay minerals, including trioctahedral, kaolinite and hydromica.

Calculation of the correlation coefficient between the content of medium dust and silt fraction, as well as fine dust and silt particles, did not reveal a significant relationship between them. However, this does not mean that the processes of physical and chemical destruction of dusty fractions in the profile of virgin forest soil are delayed at the stage: the medium-dust and fine dust does not lead to replenishment of the content of silty particles. Probably, the ratio of silt intake as a result of "silt formation" and its downward migration in solutions and suspensions is formed in virgin forest soil in favor of the latter. Zvereva and Lazareva (1989) in studying the silt sub-fractions showed the predominance of water-peptized silt (> 90 %).

The calculation of the balance of fractions <0.001 and <0.01 mm, performed for virgin forest soil, showed that the total losses of clay particles from the eluvial layer amounted to 877 kg m^{-2}, silty fraction - 287.5 kg m^{-2}. There wasn’t revealed illuvial accumulation of physical clay and silt (Tables 3 and 4).

Table 3. Balance of the fraction <0.001 mm in the profile of soddy-podzolic clay soil

Horizon	Depth, cm	Bulk density, g cm^{-3}	fraction < 0.001 mm		*output-accumulation, g cm^{-3}	Sum of output-accumulation, kg m^{-2}
			%	g cm^{-3}		
			Virgin			
AY	7	1.02	12.4	12.6	– 19.5	- 136.5
ELg	10	1.55	11.0	17.0	– 15.1	- 151.0
BTg	38	1.68	19.1	32.1	0	0
Cg	–	1.70	18.9	32.1	–	–
			Arable			
P	30	1.29	12.0	15.5	– 19.0	– 570.0
BELg	25	1.64	21.9	35.9	+ 1.4	+ 35.0
BTg	45	1.71	20.7	35.4	+ 0.9	+ 40.5
Cg	–	1.72	20.1	34.5	–	–

* The calculation was carried out for equal in depth layers compared to the parent rock

Table 4. Balance of the fraction <0.01 mm in the profile of soddy-podzolic clay soil

Horizon	Depth, cm	Bulk density, g cm^{-3}	fraction < 0.01 mm		* output-accumulation, g cm^{-3}	Sum of output-accumulation, kg m^{-2}
			%	g cm^{-3}		
			Virgin			
AY	7	1.02	50.4	51.4	– 50.26	– 351.8
ELg	10	1.55	50.7	78.6	– 23.00	– 230.0
BTg	38	1.68	59.1	99.3	– 2.37	– 90.0
Cg	–	1.70	59.8	101.6	–	–
			Arable			
P	30	1.29	51.4	66.3	– 32.60	– 978.0
BELg	25	1.64	53.8	88.2	– 10.67	– 266.8
BTg	45	1.71	56.4	96.4	– 2.46	–110.7
Cg	–	1.72	57.5	98.9	–	–

* The calculation was carried out for equal in depth layers compared to the parent rock

The process of physical and chemical destruction of dusty fractions in arable soil was most active. This is evidenced by a sharp decrease in the content of fractions of medium and fine dust starting from a depth of 30-40 cm. At the same time, an increase in the content of the silt fraction was established at this depth (Table 1).

Probably, the silt content in arable drained soil is strongly related to the content of fine dust and to a lesser extent to the content of medium dust. Probably, as a result of the destruction of medium dust particles in the profile of arable soil, there was a replenishment of mainly fine dust particles, which, in turn, collapsing, replenish the supply of silty fraction. So, the transformation of dusty particles to the size of a silt fraction has a cascade pattern.

The process of physical and chemical destruction (dispersion) of dusty fractions takes place in both soils. However, the intensity of these processes in the profile of drained soil of long-term agricultural use is higher. Eluvial losses of physical clay and silt with prolonged agrogenesis and drainage were enhanced. This is evidenced by the shift of the illuvial maxima of silt (deepening of the illuvial layer) down from the border of ploughing (Table 1). The loss of clay particles from the horizons P and BELg was 1244.8 kg m^{-2} (Table 4). Losses of silt fraction were 570 kg m^{-2} (Table 3).

Thus, in arable drained soil, the processes of destruction of clay and silty fractions in the illuvial stratum are not only not weakened, but, on the contrary, enhanced. This is all the more obvious if we bear in mind that the arable layer in the process of its creation was enriched with fine earth from the upper part of the illuvial layer of virgin soil and experienced a regular introduction of fertilizers and lime. As a result, a decrease in the content of particles of medium and fine dust with simultaneous enrichment of the illuvial stratum with the silty fraction occurred.

Illuvial accumulation of silt in the horizons BELg and BTg was 35 and 40.5 kg m^{-2}, respectively (Table 3). It is likely that in this part of the profile, the processes of silt inflow as a result of migration from the upper layers and the "silt formation" as a result of physical crushing and chemical destruction of dusty fractions compensate for its removal in solutions and suspensions, which leads to an increase in the silty fraction content in the illuvial layers.

The constant replenishment of the already heavy mass of the sub-arable layer with silt is a negative phenomenon, since it leads to colmatation (silting) of these horizons. The redistribution of moisture to the deep horizons of the profile is disturbed. The network of cracks created during loosening is reduced. The role of the illuvial stratum as a water table is enhanced. All this leads to the need for regular deep reclamation loosening of drained clay soils, the positive effect of which is exhausted after 1 year Motomura (1969).

The content and distribution of the colloidal fraction in the profile of the studied soils is given in Table. 5.

Table 5. Content of colloidal fraction in soddy-podzolic gleyey soils

Horizon	Depth, cm	Total, %	Including		Ratio organic/mineral
			Mineral, %	Organic, %	
			Virgin		
AY	3-10	2.0	1.44	0.56	0.38
ELg	10-20	1.5	1.10	0.40	0.36
BTg	30-40	4.1	3.79	0.31	0.08
Cg	120-130	6.0	5.92	0.08	0.01
			Arable		
P	0-30	2.5	2.15	0.35	0.16
BELg	40-50	7.6	7.32	0.28	0.03
BTg	70-80	7.6	7.42	0.18	0.02
Cg	130-140	7.5	7.43	0.07	0.01

The nature of the distribution of the colloidal fraction in the soil profile was determined by the course and development of the soil-forming process and is identical to the distribution of the silt fraction. The upper part of the profile of virgin forest soil is largely depleted of colloidal particles that is typical for the podzolic horizon. The composition of colloids throughout the profile is dominated by the mineral fraction. Organic colloids in the AY horizon account for 28% of colloidal particles. Down the profile, their absolute content gradually decreases. The distribution of mineral colloids in the profile of virgin soil has eluvial-illuvial nature.

The profile of arable drained soil is richer than its virgin analogue in terms of the total content of colloids (Table 5). The total amount of colloidal particles in the arable layer is 2.5%. Organic colloids account for 14% of the total content. This is 2 times less than their content in the AY horizon of virgin soil. Thus, the processes of removal of the organic part of colloidal particles when the soil is cultivated and drained are quite intense. According to Milyauskas (1963), in some periods of drainage runoff, the concentration of organic substances in it can reach 1.4 g l^{-1}.

At a depth of 40-50 cm, the total content of colloidal particles increased to 7.6% and changed little with depth. The composition of colloids is dominated by the mineral fraction. Just as in virgin soil, in arable soil the content of organic colloids decreases with depth. The destruction of the colloidal complex is developed in both soils, what is well confirmed by the removal-accumulation of colloidal particles in the profile of the compared soils (Table 6). This indicates that the prolonged cultivation led to an increase in the destruction and removal of colloidal particles. So, the total loss of colloids from the entire profile of virgin soil was 262.1 kg m^{-2}, while from the arable layer of drained soil, the losses amounted to 290.1 kg m^{-2}.

Table 6. Balance of the fraction < 0.0002 mm in soddy-podzolic soil

Horizon	Depth, cm	Bulk density, g cm^{-3}	fraction < 0,0002 mm		Removal-accumulation, g cm^{-3}	Sum of removal-accumulation, kg m^{-2}
			%	g cm^{-3}		
			Virgin			
AY	7	1.02	2.0	2.04	– 8.16	– 57.1
ELg	10	1.55	1.5	2.32	– 7.88	- 78.8
BTg	38	1.68	4.1	6.88	– 3.32	– 126.2
Cg	–	1.70	6.0	10.20	–	–
			Arable			
P	30	1.29	2.5	3.23	– 9.67	– 290.1
BELg	25	1.64	7.6	12.50	– 0.40	– 10.0
BTg	45	1.71	7.6	12.90	0	0
Cg	–	1.72	7.5	12.90	–	–

These data are confirmed by the reserves of colloidal fraction in 0-30 and 0-50 cm soil layers (Table 7).

Table 7. Reserves of colloids in virgin and arable soddy-podzolic soils, t ha^{-1}

Land	0-30 cm	0-50 cm	removal (–), accumulation (+) compared to an equal layer of the parent rock			
			0-30 cm	%	0-50 cm	%
Virgin	107.6	245.9	– 203.8	65.4	– 274.0	52.8
Arable	96.7	345.9	– 290.3	75.0	– 299.1	46.3

The absolute loss of colloidal particles from the 0-30 cm in virgin soil amounted to 203.8 *t* ha^{-1} and increased to 290.3 t ha^{-1} in arable dried soil. Losses from the 0-50 cm amounted to 274.0 and 299.1 t ha^{-1}, respectively. Consequently, prolonged agricultural use of clay glayey drained soil leads to increased destruction and removal of not only the silty fraction, but also colloidal particles outside the arable horizon.

That begs the question. What is the intensity of the process of removal of silty and colloidal fractions during cultivation and drainage? In all likelihood, these processes proceed quite vigorously. According to Motomura (1969), the removal of silt in the soils of this genesis during the laying of a closed drainage network proceeds “explosively”. Already in the third year, the backfilling of the drains is silted. In addition, part of the silt settles in the drainage pipes, which reduces the lifetime of the drainage system. Obviously, the intensive destruction and removal of finely dispersed fractions from the eluvial stratum in solutions and suspensions during cultivation and drainage are irreversible consequences of agrogenesis.

Organoprofile

A characteristic feature of the humus profile of virgin soddy-podzolic glayey clay soil is the confinement of the maximum content of organic matter to the upper organogenic horizon and its sharp drop directly at the border of the transition of the grey-humus (AY) horizon to the eluvial (EL). In the AY horizon of virgin soil, the humus content is high - 4.9%. During the transition from the AY horizon to the EL horizon, the humus content decreases sharply to 0.9%. Down the profile, there is a further gradual decrease in the humus content (Table 8).

Table 8. Humus content in pre-colloidal and colloidal fractions of soddy-podzolic glayey soil, %

Horizon	Depth, cm	Content of humus, %	Particle size, mm	Content, %	From the weight of		From humus content
					Fraction	Initial soil	
			Virgin				
AY	3-10	4.90	0.001-0.0002	10.4	6.1	0.63	12.8
			<0.0002	2.00	28.5	0.56	11.6
ELg	10-20	0.90	0.001-0.0002	9.5	1.2	0.10	12.1
			<0.0002	1.50	11.3	0.16	18.4
BTg	30-40	0.40	0.001-0.0002	15.0	0.9	0.13	33.3
			<0.0002	4.10	5.8	0.23	59.3
Cg	120-130	0.25	0.001-0.0002	12.9	0.9	0.11	44.7
			<0.0002	6.00	1.1	0.06	28.7
			Arable				
P	0-30	3.36	0.001-0.0002	9.5	6.3	0.60	17.8
			<0.0002	2.5	14.7	0.36	10.9
BELg	40-50	0.60	0.001-0.0002	14.3	1.5	0.21	36.3
			<0.0002	7.6	1.9	0.15	24.6
BTg	70-80	0.24	0.001-0.0002	13.1	1.0	0.14	48.5
			<0.0002	7.6	1.2	0.14	33.7
Cg	130-140	0.22	0.001-0.0002	12.6	1.0	0.13	57.3
			<0.0002	78.5	1.1	0.08	37.4

The content of humus in the arable layer of cultivated soil is inferior to its content in the AY horizon of virgin soil. In the arable layer (layers 0-10; 10-20 and 20-30 cm), the distribution of humus is uniform. Fluctuations range from 3.31 to 3.4%. At a depth of 30-40 cm, at transition to the BEL horizon, the humus content decreases sharply to 0.6%. Consequently, in agrogenic soil, the general nature of the distribution of humus is preserved, but in the arable layer its content is much less than in virgin forest soil. The cultivation effect is manifested in the fact that in the process of operation a deep-humified agrohumic horizon (P) is created, which significantly exceeds in thickness the grey-humic horizon (AY) of virgin soil.

Thus, the agrogenic transformation of the organoprofile is manifested in an increase in the thickness of the humic layer and an increase in humus reserves in equally thick layers. In arable soil in 0-30 cm humus reserves were 130 t ha^{-1}, in 0-50 cm -149. 8 t ha^{-1}. In virgin soil in 0-30 cm - 56.4 t ha^{-1}, in 0-50 cm - 71.5 t ha^{-1}, respectively.

The content of humus in the pre-colloid fraction (Table 8) of the grey-humic horizon was 6.1% of the mass of the fraction, which is 12.8% of the total humus content in the soil. In the lower horizons of the profile the content of humus fixed by pre-colloids decreases and ranges from 1.2 to 0.9%. Humus, fixed by pre-colloid particles, accounts for 12.1% of the total soil content in the ELg horizon and 33.3% of the total soil content in the BTg horizon.

The absolute amount of humus bound to the colloidal fraction exceeds the content fixed by the pre-colloids. The revealed pattern is characteristic of all horizons of the virgin forest soil. The proportion of humus bound to colloidal particles from its total content in these horizons is 11.6% in the AY horizon, 18.4% in the EL horizon and 59.3% in the BTg horizon. Thus, with a decrease in particle size, their role in fixing organic matter in the sub-arable part of the profile increases.

The total contribution of finely dispersed particles (colloids and pre-colloids) in the binding of humus of virgin soil was: in the horizon AY - 24.4%, in the horizon ELg – 30.5 % and in the horizon BTg – 92.6 %. Therefore, the role of fine particles in the fixation of humus in virgin forest soil increases with depth (Table 8).

Long-term cultivation and drainage did not affect the absolute content of humus fixed on the surface of pre-colloid particles of arable soil. In the cultivated layer, its content was 6.3%, in the BEL horizon - 1.9% and in the BT horizon - 1.2% of the mass fraction, differing little from the content in corresponding horizons of virgin soil. However, the relative amount of humus recorded on the surface of pre-colloids, from its total content in agrogenic soil, increased and amounted to 17.8% in the arable layer and 36.3% in the BELg horizon, in comparison with virgin soil, i.e. increased by 1.4 and 3.0 times, respectively. The exception was the BTg horizon, where its content was lower than in the corresponding horizon of virgin soil. Thus, the relative contribution of pre-colloid particles in the fixation of humus during the cultivation of clay soil increases.

With a slightly higher content of colloidal fraction in the arable layer of cultivated soil, compared with the horizon AY of virgin soil (2.5 and 2.0%, respectively), the humus enrichment of colloids of arable soil was 2 times lower than in virgin soil (Table 8). However, the relative proportion of the participation of colloids of virgin and arable soil in the fixation of humus was the same (11.6 and 10.9%, respectively.

In the lower horizons of the profile, the absolute content of humus in the composition of colloids of arable soil decreases, and the share of participation in fixing the total humus of the soil increases. The total contribution of colloidal and pre-colloidal fractions in fixing humus in individual horizons of the profile was: P – 28.7, BELg – 60.9, BTg 82.2 %.

Thus, the total contribution of finely dispersed fractions (colloidal and pre-colloidal) in the fixation of humus in the arable layer was higher than in the grey-humic horizon of virgin soil.

Soddy-podzolic soils on band clays are one of the most difficult objects for land reclamation and agricultural use in the non-chernozem zone of Russia. In the 60-80 years, the soils of this genesis were a frequent object of drainage Motomura (1969). The necessity and economic feasibility of reclamation measures in connection with the high labor intensity and costs of cultivating and exploiting the soils of this genesis, their use for arable land has previously been repeatedly questioned (Karavaeva 1996; Motomura 1969; Pestryakov et al., 1979; Dyushofur 1970).

Drainage of soils on band clays certainly has some positive effect on the moisture regime and topping of these soils. However, the hydrological moisture regime of drained soils on strip clays is very unstable for agricultural production (Motomura 1969). In drained soils on band clays, the necessary hydrological effect can be achieved only if a special, rather complex and regularly carried out set of measures is performed, ensuring the organization and acceleration of surface runoff, and the discharge of intra-soil moisture by drainage lines. The positive impact on the water regime of these soils is achieved only as a result of simultaneous hydraulic engineering, agromeliorative and agronomic measures. Among them are regular, deep reclamation loosening (at least once in two years), carried out to a depth of 60-90 cm, surface agrotechnical loosening with light tools to a depth of 40-50 cm, cultivation measures. The higher the level of farming, the more profound changes the drained soils will undergo and the more favorable conditions are created for drainage operation.

Long-term land cultivation although it leads to a deep transformation of ecosystems, does not eliminate the possibility of their elimination after the cessation or weakening of the anthropogenic load (Tomasson 1972; Litvinovich 2009). Almost all the beneficial properties created by agrogenic exposure are reversible. The achieved level of fertility is a consequence of the level of anthropogenic impact (Litvinovich and Pavlova 2010). Given the high costs of re-cultivation and the duration of this process as well as the impossibility of full regulation of the water-air regime of the soils of this genesis without the re-draining, the economic feasibility of re-involvement into cultivation of these soils is not high.

According to Karavaeva (1996), with the directed cultivation of heavy clay soils on the band clays of the southern taiga of the North-West of Russia for a period of 20-25 years, it is possible to create only "semi-cultivated" arable soils. In the arable layer, despite the homogeneity and positive changes in a number of properties, unfavorable physical and water-physical properties are preserved or enhanced. In the sub-arable part (even during drainage), glayed horizons are preserved, which limits water movement. It is most expedient to use these soils for meadow and hay fields. It also seems appropriate to leave these habitats for the formation of forests on them.

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Agrogena evolucija humusno-podzolastog zemljišta: Mogućnost ponovnog uključivanja u obradu ugara formiranog na trakastim glinama

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Izvod

U Lenjingradskoj oblasti, severozapadna Rusija, proučavana je transformacija humusno-podzolastog glinovitog zemljišta u dugogodišnjoj poljoprivrednoj upotrebi (>200 god.). Ovom studijom izvodljivosti, ispitana je mogućnost rekultivacije ovih zemljišta nakon dugotrajnog nekorišćenja. Analizirana je morfološka struktura, granulometrijski sastav, sadržaj i odnos fero i oksidnih oblika gvožđa u profilu devičanskog (autohtone šume) i obradivog dreniranog zemljišta. Pored toga, u toku dugotrajne agrogeneze (> 200 god.) praćene su promene u organogenom profilu. U devičanskom zemljištu, tokom njegove pedogeneze, gubitak frakcija <0,01 mm iz eluvijalnog sloja bio je 877,4 kg m^{-2}, a gubitak frakcija <0,0001 mm bio je 287,5 kg m^{-2}, u poređenju sa matičnim supstratom koji nije zahvaćen procesima pedogeneze. Međutim, dugotrajna agrogeneza (>200 god.) dovela je do povećanog eluvijalnog gubitka sitnih čestica zemlje. Gubitak frakcije <0,01 mm iz obradivih horizonata iznosio je 1244,8, a frakcije <0,0001 mm iznosio je 570 kg m^{-2}. Ovo je posledica višegodišnje obrade zemljišta koja je povećala poroznost zemljišta i time intenzivirala ispiranje čestica gline, što je dovelo do povećanog ispiranja i eluvijalnih gubitaka. Ukupan gubitak koloida iz celog profila devičanskog zemljišta iznosio je 262,1 kg m^{-2}, a iz obradivog sloja dreniranog zemljišta - 290,1 kg m^{-2}. Humusno obogaćivanje koloida oranog (P) horizonta oranica bilo je dva puta niže od onog površinskog (AI) horizonta devičanskog zemljišta. Relativni udeo učešća koloida u fiksaciji humusa zemljištem je bio isti (11,6 i 10,9%,). U podpovršinskim horizontima, apsolutni sadržaj humusa u koloidima je smanjen, a udeo učešća u fiksaciji humusa povećan. Kada se humusno-podzolasto glinovito zemljište obrađuje, poboljšava se vodno-vazdušni režim, sadržaj i sastav humusa, povećava se dubina obradivog horizonta i smanjuje kiselost zemljišta. Istovremeno se ubrzava ispiranje finih zemljišnih materijala. Kada je ovo zemljište povučeno iz ratarske proizvodnje, pozitivne promene postignute kao rezultat obrade postepeno su se gubile. Po prvi put smo mogli da izračunamo gubitke finih frakcija zemljišta iz gornjeg sloja. Uzimajući u obzir visoke troškove rekultivacije ovog zemljišta i visoke troškove ponovnog postavljanja i održavanja optimalnog hidrološkog režima (drenažne mreže) zaključili smo da je ponovljeno oranje i uključivanje humusno-podzolastog glinovitog zemljišta u obradu ekonomski neopravdano.

Ključne reči: humusno-podzolasto glinovito zemljište, agrogena evolucija, fino disperzovana frakcija, organogeno-mineralni profil, koloidi

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Morphometric and biochemical properties of *Cichorium intybus* L. var. *foliosum* as affected by duration of growing period

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Abstract

Cichorium intybus is a valuable crop due to its high nutritional and pharmaceutical value. In this work, the study of the effect of harvesting time on the biometric and biochemical properties of *Cichorium intybus* L. var. *foliosum* (chicory salad witloof) was carried out on five varieties. The period of vegetation affects rosette diameter, number of leaves and root weight. A strong correlation between the weight of roots before laying for forcing and the weight of forcing heads (r = 0.79) was revealed. The roots of variety Conus, managed to accumulate a sufficient amount of nutrients for the formation of heads in a 98 days. The accumulation of sugars in forcing heads depended on their initial content in roots with a 75% reliability (r = 0.75). The results showed that in the northern latitudes the forcing can be carried out in winter in any room without light at a temperature of 10 to 17°C. In addition, subsurface heating of the substrate or maintaining water in the containers with roots provided a larger yield of heads obtained in a shorter time.

Keywords: *Cichorium intybus*, witloof, forcing, head, root, chlorophyll, sugars, carotenoids

Introduction

The ancient Egyptians cultivated and used chicory (genus *Cichorium* L.) as a medicinal plant, coffee substitute, vegetable crop and as a livestock forage (Aisa et al., 2020). In spite this plant have been used since ancient times it is not well studied yet, in terms of its morphology, genesis, biochemistry, climatic preferences (Street et al 2013; Lavrishcheva and Osipova 2020a,b). The genus *Cichorium* includes six species that generally distributed in Europe and Asia (Bais and Ravishankar (2001). On the http://www.theplantlist.org/tpl1.1/search?q=cichorium, 32 plant name records match the search criteria ***Cichorium intybus*** and 13 plant name records match the search criteria ***Cichorium endivia***. While Shevchenko (2000) reported 10-12 species, which are divided into two groups depending on the parts of the plant used: the first group is plants with thick fleshy roots such as *C. intybus* var. *foliosum* (Lavrishcheva and Osipova 2020a) and the second group includes plants with above-ground storage organ (Lavrishcheva et al 2020).

Chicory is known as a frost-resistant plant that can withstand extreme temperatures in all stages of growth (Bais and Ravishankar 2001), but some species showed to be sensitive to duration of sun-light and amount of precipitation (Lavrishcheva et al 2020). *Cichorium intybus* L., is an erect, fairly woody perennial plant, about 1 m in height with a fleshy taproot up to 75 cm in length and large basal leaves (van Wyk 1997; Bais and Ravishankar 2001). *C. intybus* L., possesses a number of valuable properties of both aboveground and belowground parts, such as nutrients, including carbohydrates, proteins, vitamins, minerals, soluble fiber, trace elements and bioactive phenolic compounds, which are responsible for the various nutritional, preventive, and medicinal properties of chicory (Nwafor et al., 2017). According to its cultivation purposes, Cadalen et al. (2010) categorized this chicory four groups: (1) root chicory is cultivated for its taproot as a coffee substitute or for inulin extraction; (2) witloof chicory is cultivated as industrial chicory for etiolated buds (heads) by forcing; (3) leaf chicory is used as fresh or cooked vegetables; and (4) forage chicory, is used to intensify herbage obtainability in pastures. In the second half the the 20th century, it was discovered that the root of *C. intybus* contained up to 40% inulin, which has a negligible impact on blood sugar and thus is suitable for diabetics (Judžentienė and Būdienė, 2008).

Cichorium intybus var. *foliosum* was obtained in the end of XIX century in Brussel as a result of breeding from the Magdeburg root chicory. It was widely used in some European countries as a delicious vegetable crop. Later, the head form of forcing chicory was called witloof, that is, a white leaf (Shevchenko et al., 2016). Witloof is a valuable agricultural crop due to its high nutritional and pharmaceutical value (Shevchenko et al., 2016; Golubkina et al., 2019). It has been revealed that chicory acid isolated from witloof inhibits the aggregation and fibrillation of human hIAPP, which contributes to the treatment of diabetes mellitus (Luo et al, 2020). The seeds of *C. intybus* germinate more tightly than the seeds of the *C. endivia* (Lavrishcheva, 2019a, b), although in the cotyledon phase these plants are indistinguishable. In the first year of vegetation, chicory lettuce plants form a root weighing from 60 -80 g (Gulyaev, 1991) to 100-400 g (Vyutnova et al., 2008), 10 to 45 cm long and 2 to 8 cm and more in diameter, which is used for forcing and processing. As a biennial plant, chicory lettuce produces seeds in its second year of life. The height of the flowering shoot reaches 110-190 cm, significantly exceeding *C. endivia* in this parameter (Lavrishcheva and Osipova 2018). The number of stems on the testes varies from 1 to 10 or more, depending on the variety (Vyutnova et al., 2008).

Currently, the literature has accumulated a certain theoretical material about the peculiarities of growing chicory salad witloof. Methods for obtaining witloof chicory using the heat from fermentation of cow dung in the cold season have been developed (Kumano et al., 2017a). The effect of potassium regime on the growth and development of witloof has been studied (Kumano et al., 2017b, 2017c). Effective methods of chemical and biological protection of chicory plants from pests have been developed (Bengini et al., 2016). Studies have been carried out on the effect of illumination on the accumulation of bitter sesquiterpene lactones and photosynthetic pigments by witloof in leaves

(Wulfkuehler et al., 2014), as well as ways to reduce their content (Wulfkuehler et al., 2013). Van Arkel et al (2012) found that the degree of polimerization of inulin in *C. intybus* highly dependent on the field conditions and harvest time.

Witloof varieties are difficult to distinguish by morphological characteristics, therefore they are distinguished by the timing of the formation of a marketable root and the period of their use for forcing purposes (Shevchenko et al., 2016). Attempts to link the degree of ripeness of roots with the level of any substances have been carried out earlier, but have not yet yielded the desired results (Krug, 2000). Most of the studies are devoted to the study of the features of growing chicory salad in the regions with a warm climate in the open field. However, currently, there is not enough data accumulated on phytochemistry (Street et al 2013) and morphometric characteristics of *C. intybus* grown in northern latitudes. Until now, in Russia, the northernmost latitude where this crop was cultivated in the open field was the Moscow region (Virchenko, 1984; Shevchenko. 2000). Cultivation of *C. intybus* in a greenhouse in the North-West of Russia is of a particular importance to establish the optimal harvesting time for roots, which will later be used for forcing.

The aim of the research was to study the dynamics of changes in biometric and biochemical parameters of various varieties of chicory lettuce (*C. intybus* var. *foliosum*), depending on the duration of cultivation in a protected soil (greenhouse). The tasks included:

– to study the dynamics of changes in the rosette diameter, number of leaves and root weight of plants of various varieties of witloof, depending on the duration of cultivation;

– to study the influence of timing of harvesting the salad chicory on the formation of storage organs: he size and weight of roots, content of sugar, formation of the pigment system in the leaves and forcing heads.

Materials and methods

Experimental design

The plants of chicory lettuce were grown in a film greenhouse on the territory of the Educational and Experimental Garden of the St. Petersburg State Agrarian University (SPbSAU) on the 2x2 m^2 plots in three random replications in 2014, 2015 and 2016. Sowing scheme was as follows: row spacing - 33 cm, distance between plants - 10 cm. The sowing of witloof was carried out in the greenhouse annually on 23 May. Mass seedlings in all years of research appeared on the eleventh day after sowing. The harvesting of plants was carried out in 2014, on September 28, in 2015 - on September 17, in 2016 - on September 9. Thus, the total duration of the growing season of witloof plants (from the moment of mass germination to harvesting) was: in 2014 - 117 days, in 2015 - 106 days, in 2016 - 98 days.

Studied varieties

Five varieties of witloof were used as objects in the research experiment: Conus, Raketa, Hative, Veneta, Viproda. Two varieties (Conus and Raketa) are included in the State Register of Breeding Achievements of the Russian Federation (2022). Three varieties (Hative, Veneta, Viproda) were obtained from the collection of All-Russian Institute of Plant Genetic Resources named after N.I. Vavilov (VIR) (St. Petersburg, Russia).

Variety Conus (originator is the Federal Scientific Center of Vegetable Growing; selection of the SeDek company) belongs to the group of mid-season varieties. It is a medium early in terms of forcing. The period from mass shoots to technical ripeness is 98-114 days. The period of forcing (from planting roots to mass ripeness of heads) is 17-30 days (State Register 2022). According to the timing of the formation of a commercial root, the Conus variety belongs to the mid-season plant (Shevchenko et al., 2016)

Variety Raketa (selection of the LLC Agrofirmy Poisk) is included in the State Register of the Russian Federation. The period from mass germination to technical ripeness of roots is 130-155 days. The period of forcing (from planting of roots to the economic fitness of heads) is 30 days. (State Register 2022).

Variety Hative is a collection of VIR. The sample number is 48, the introduction number is 351300. The date of inclusion is 1976. The country of origin is France. Biological status is improved variety (Database of Plant and Genetic Resources).

The Veneta variety is a collection of VIR. The sample number is 68, the introduction number is 468051. The date of inclusion is 1984. The country of origin is Netherlands. Biological status is improved variety (Database of Plant and Genetic Resources).

The Viproda variety is a collection of VIR. The sample number is 71, the introduction number is 468053. The date of inclusion is 1984. The country of origin is Netherlands. Biological status is improved variety (Database of Plant and Genetic Resources).

Parameters analyzed

During harvesting, the following biometric indicators were determined: height and diameter of the rosette, number of leaves, weight of the plant, and weight of the root. For these parameters, for each plot, an average value was calculated for one plant per replication. The mass of the above-ground part of the plants was calculated from the difference between the average values of the mass of the plants and the mass of the root for each variant.

At harvest, the plants tops were cut at 2-3 cm from the neck of the root. Roots were stored for 1.5 months in a dark place at a temperature 2ºC and a humidity of 90%. For forcing, the roots were placed in peat soil without covering with a soil substrate. Forcing was carried out in a dark room at t = 12-14ºC for 30 days.

Analytical methods

The assimilation surface area was calculated by the punching method. The dry matter was determined after drying to constant weight at a temperature of 105°C (GOST 31640-2012).

The amount of sugars was determined quantitatively by the Bertrand method (Ermakov, 1987). The method is based on the ability of reducing sugars possessing a free carbonyl group to reduce copper oxide to ferrous one in an alkaline solution. The amount of the formed copper oxide precipitate strictly corresponds to the amount of sugar in the solution. The resulting ferrous oxide was determined permanganatometrically. The amount of permanganate spent on titration was used to calculate the amount of copper oxide and then the sugar content in the solution.

Quantitatively obtained amount of chlorophyll *a*, *b* and carotenoid, and their ratios in varieties of *C. intybus* var. *foliosum* are important indicators sensitive to changes in ambient conditions (Sonobe et al., 2020). The content of pigments (chlorophylls *a*, *b* and carotenoids) was determined spectrophotometrically (Kachnovich, 2003).

The pigments were extracted from fresh leaves with acetone. The features of the absorption spectra of chlorophylls *a* and *b* allow us to determine their amount in the extract without prior separation. When determining the content of chlorophyll *a* and *b*, the following wavelengths are used: 662 and 644 nm. For solutions of pigments in undiluted acetone, the following equations are used:

$$Chl\textit{a} = 9{,}784 \cdot E_{662} - 0{,}990 \cdot E_{644};$$

$$Chl\textit{b} = 21{,}426 \cdot E_{644} - 4{,}650 \cdot E_{662},$$

where Chl*a* – content of chlorophyll ***a***, (mg/L); Chl*b* – content of chlorophyll ***b***, (mg/L); E_{662} и E_{644} – optical density of the solution.

Statistical processing of the data was carried out using analysis of variance (Dospekhov, 1985).

Results and discussion

The research results showed that almost all *C. intybus* plants formed a root in the first year of vegetation. The exception was plants of the Raketa variety. They had a premature formation of a flowering shoot. The share of such plants was not large and amounted to the years of research: 2014 - 2.2; 2015 - 2.8 and in 2016 - 2.5% of the total number of plants of this variety. Such an anomalous way of development of biennial plants was observed about five decennia ago by Kuperman (1968). In nature, this phenomenon is a biological adaptation of plants to the preservation of species in adverse conditions. Under unfavorable conditions, plants tend to accelerate in development, as a manifestation of the general phylogenetic trend towards a reduction in the period of vegetative development and a faster transition of plant organisms into the generative phases of development.

Wiebe (1989) showed that the effect of low temperature (5-10°C) on the mother plant during the formation of chicory seeds enhanced the subsequent stemming compared to the effect of higher temperature (15°C). The development of seeds at lower temperatures enhanced the subsequent stemming even at high temperatures of seed germination. This indicates that the seeds were vernalized on the mother plant before they were harvested. In unfavorable years, the number of root shoots in the first year of vegetation can reach 90% (Ludilov et al. 2010). The biometric indicators of studied varieties of chicory salad witloof by the years of research are summarized in Table 1.

Table 1. Dynamics of the morphometric indicators of studied varieties of *Cichorium intybus* by years of research

Duration of vegetation	Variety	Height, cm	Rosette diameter, cm	Number of leaves, pcs	Aboveground biomass, g	Weight of plant, g	Area of assimilation surface, m^2
				2014			
115 days	Conus	53.6 b	78.0 b	28.0 b	241.8	396.6 b	1.10
	Raketa	52.4 b	74.5 a	23.5 a	231.0	355.6 a	0.98
	Hative	51.0 a	70.4 a	28.6 b	232.0	416.8 c	1.14
	Veneta	53.2 b	77.6 b	22.8 a	341.8	631.2 d	1.61
	Viproda	51.2 a	87.0 c	24.6 a	387.4	639.4 d	1.69
	LSD_{05}	1.0	6.1	2.1	–	15.8	–
				2015			
104 days	Conus	60.7 b	48.0 a	20.2 c	306.3	409.0 d	1.32
	Raketa	55.0 a	46.0 a	15.9 b	252.4	367.0 c	1.07
	Hative	58.4 b	57.3 c	17.6 c	231.3	340.1 a	0.88
	Veneta	54.0 a	50.8 b	13.3 a	256.8	367.6 c	0.91
	Viproda	58.9 b	57.4 c	14.8 b	241.9	348.0 b	1.37
	LSD_{05}	2.2	3.6	1.3	–	6.2	–
				2016			
98 days	Conus	55.8 b	32.1 c	15.7 d	201.2	241.4 d	1.31
	Raketa	57.4 b	25.7 b	10.9 b	107.1	131.0 b	0.75
	Hative	51.2 a	21.2 a	6.8 a	47.7	68.8 a	0.33
	Veneta	50.5 a	37.0 d	18.0 e	272.7	356.5 e	1.21
	Viproda	58.6 b	57.4 e	14.8 c	180.6	213.9 c	0.93
	LSD_{05}	4.8	4.3	1.5	–	2.3	–

† different letter denote statistically significant differences between varieties within a column for each year at $p<0.05$

The data shows that the plant height was predominantly evenly distributed varying within the range from 50.5 to 60.7 cm. Within this deviation the highest plant height was observed in the Conus and Veneta varieties in 2014 and the Conus, Hative and Viproda varieties in 2015, and Raketa and Viproda in 2016, 57.4 and 58.6 cm, respectively.

The formation of a rosette of leaves depended on the duration of the plant vegetation. The smallest rosette diameter in most varieties was recorded in 2016 that varied within 21.2-37.0 cm. The exception was Viproda with 57.4 cm of the rosette diameter, which formed the largest rosette of leaves in all years of study (Table 1).

For all studied varieties, the largest number of leaves over the studied period was formed in 2014. The maximum number of leaves in 2014 and 2015 was found in plants of varieties Conus (28 and 20.2 pieces, respectively) and Hative (28.6 and 17.6 pieces, respectively). In 2016, the largest number of leaves was observed in plants of the Dutch variety Veneta (18 pcs.).

The maximum plant weight in 2014 was found in the Viproda and Veneta varieties (639.4 and 631.2 g, respectively) that significantly exceeded the mass of plants of other studied varieties. In 2015, the differences between varieties in terms of plant weight were less significant, where the highest plant weight showed the varieties Conus (409 g), Raketa (367.0 g) and Veneta (367.6 g). In 2016, the maximum plant weight was recorded for the Veneta variety (356.5 g) that significantly exceeded other studied varieties, which was between 68.8-241.4 g (Table 1). The same patterns were revealed when comparing the weight of the above-ground plants biomass.

The area of the assimilation surface of leaves from a plant strongly correlated with the the above-ground plant biomass (R = 0.89). The maximum leaf area in 2014 and 2015 was found in the Viproda vatiety, which averaged 1.69 and 1.37 m^2 per plant, respectively. In 2016, the largest area of the assimilation surface of leaves was found in plants of the Conus variety (1.31 m^2).

The data on the sizes of roots shows that the average values of the length of roots in most cases do not have significant differences between varieties (Table 2). There were also no clear dependences on the year of research. The largest diameter of the root in 2014 and 2016 was found in the Veneta (5.2 and 3.5 cm, respectively), and the smallest in the Raketa (3.2 and 2.3 cm, respectively). In 2015, the maximum diameter of root was found in the Hative variety (3.8 cm), and the smallest in the Conus variety (2.9 cm).

Table 2. Sizes of the roots of varieties of *Cichorium intybus* by years of research

Variety	Lenth of the root, cm			Diameter of the root, cm			The form index, psc.		
	2014	2015	2016	2014	2015	2016	2014	2015	2016
Conus	16.4 a	13.4 a	16.6 c	3.4	2.9 a	2.7 a	4.82	4.62	6.15
Raketa	15.8 a	14.2 a	15.2 b	3.2	3.0 a	2.3 a	4.94	4.73	6.61
Hative	15.7 a	15.9 b	13.8 a	3.5	3.8 b	2.4 a	4.49	4.18	5.45
Veneta	17.0 b	15.7 b	17.1 c	5.2	3.5 b	3.5 b	3.27	4.49	4.89
Viproda	16.3 b	14.8 b	16.4 c	4.7	3.4 a	2.5 a	3.47	4.35	6.56
LSD_{05}	1.0	1.1	0.9	1.0	0.5	0.5	–	–	–

† different letter denote statistically significant differences between varieties within a column for each year at p<0.05

According to the classification given by Polyanina (2016), roots in shape and size can be divided into three groups: Group 1 - short conical roots, shape index (SI) -the ratio of the length of the root to its diameter is <5.0; Group 2 - long cylindrical and semi-long roots, SI is from 5.0 to 7.0; and Group 3 - spindle-shaped elongated roots with SI> 7.0. In our studies (Table 2), in 2014 and 2015, all studied varieties in terms of the shape index belonged to the first group. In 2016, due to the shortened growing period, the plants did not have time to sufficiently form the thickened shape of the storage organ. With the same length (compared to 2014 and 2015), roots had a small root diameter, which was reflected in their shape index. So, in 2016 varieties Conus, Raketa, Hative and Viproda shifted to the second group. Only the Veneta variety, which formed the largest root, remained in the first group by the morphometric properties of root.

The dynamics of changes in the weight of root of studied varieties of witloof by years of research are shown in Fig. 1. The duration of the growing season had a strong influence on the formation of roots. The largest weight of roots was formed by plants in 2014 (the duration of the growing season was 117 days), with maximum weight found in the varieties Veneta (298.4 g) and

Viproda (252.0 g). In 2015 (the vegetation period was 106 days), the largest weight of root was formed by the Raketa variety (114.6 g). However, it should be emphasized that the lag of other varieties in this indicator in this year was insignificant and fluctuated within 102.7-111.8 g. Reducing the growing season to 98 days had a strong effect on the accumulation of root mass. The weight of the storage organ in 2016 ranged from 21.1-83.8 g, with the highest value recorded in the Veneta variety.

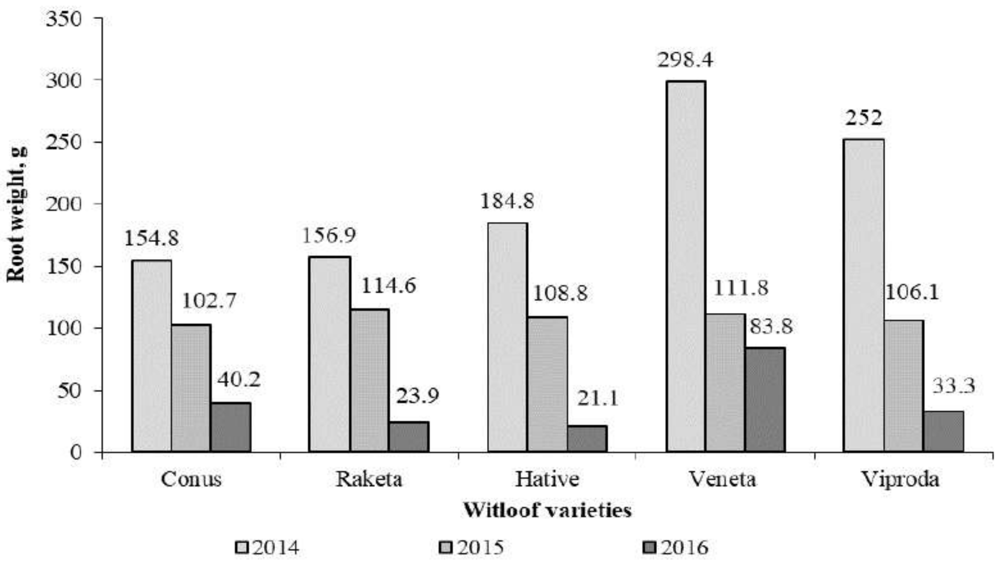


Figure 1. Dynamics of changes in the weight of roots by studied years, g

Table 3 shows the data of the root weight before and after forcing. Before being put into forcing containers, the roots were pruned; therefore, the values of the root weight before forcing were inferior to the values shown in Fig. 1. After forcing, due to the loss of moisture and nutrients, the weight of roots decreased (Table 3). The decrease in the weight of roots in the entire data range ranged from 2 to 17%.

Table 3. Biometric indicators of roots and forcing heads

Variety	Root weight before forcing, g	Root weight after forcing, g	Heads weight, g	Heads height, cm	Heads diameter, cm	Number of head leaves, pcs
			2014			
Conus	135.82 b	130,30 b	13.06 c	11.44 c	4.04 a	10.20 b
Raketa	108.42 a	98.72 a	9.74 b	7.89 a	4.34 a	8.72 a
Hative	159.83 c	149.04 c	7.91 a	10.96 c	4.15 a	12.43 c
Veneta	263.33 e	258.08 e	22.65 d	9.67 b	5.04 a	15.17 d
Viproda	186.44 d	172.90 d	28.17 e	19.21 d	5.69 a	14.43 e
LSD_{05}	9.32	6.91	1.77	1.19	2.22	1.08
			2015			
Konus	76.46 a	67.46 a	12.39 e	11.58 b	4.37 c	15.58 d
Raketa	84.96 b	76.66 b	3.81 a	8.10 a	2.53 a	10.53 b
Hative	93.31 c	89.82 c	6.45 b	8.93 a	2.85 a	9.57 a
Veneta	97.58 d	94.98 d	9.72 c	8.00 a	3.88 b	11.49 c
Viproda	94.11 c	90.28 c	10.56 d	11.04 b	4.07 c	11.78 c
LSD_{05}	2.25	1.23	1.00	1.03	0.32	0.43
			2016			
Conus	40.09 d	33.17 d	10.35 c	7.93 b	3.56 c	9.90 b

Variety	Root weight before forcing, g	Root weight after forcing, g	Heads weight, g	Heads height, cm	Heads diameter, cm	Number of head leaves, pcs
Raketa	22.70 b	20.68 b	3.40 a	7.30 a	2.10 a	6.61 a
Hative	20.86 a	19.49 a	3.18 a	8.42 d	2.00 a	6.58 a
Veneta	74.50 e	72.33 e	3.63 a	8.13 c	2.85 b	11.00 c
Viproda	31.28 c	30.56 c	3.68 b	8.75 e	2.82 b	10.75 c
LSD_{05}	0.78	0.66	0.49	0.26	0.20	0.36

† different letter denote statistically significant differences between varieties within a column for each year at $p<0.05$

A strong correlation was found between the weight of root before laying for forcing and the weight of forcing heads (r = 0.79). In 2014, the maximum weight of heads was found in the varieties Veneta and Viproda, amounting 22.65 and 28.17 g, respectively. The weight of heads in other varieties this year ranged from 7.91-13.06 g. In 2015, the largest weight of heads was observed in the Conus variety (12.39 g), and the smallest in the Raketa variety (3.81 g). The weight of heads in other varieties ranged between 6.45-10.56 g.

In 2016, the smallest root was used for forcing, which affected the formation of heads. In most varieties, their weight varied within 3.18-3.68 g. The exception was the Conus variety with a head weight of 10.35 g. It should be noted that the mass of forcing heads obtained from the root of mid-season Konus variety was stable over the research years and depended little on the duration of growing season. The roots of this variety, apparently, even during the minimum growing period (98 days), managed to accumulate a sufficient amount of nutrients to form full-fledged heads. This is confirmed by the characteristics of the variety given in the state register of breeding achievements, where the period for the formation of a commercial root is indicated from 98 days (Krug, 2000).

In addition to the differences in weight, the heads also differed in shape (Table 3). The highest heights in 2014 and 2015 were distinguished by the varieties Conus and Viproda (11.44 and 19.21 cm in 2014; 11.58 and 11.04 cm in 2015, respectively). In 2016, the highest height was found in the varieties Hative and Viproda (8.42 and 8.75 cm, respectively). The diameter of the heads, depending on the year of research, varied within 4.04-5.69 (in 2014), 2.53-4.37 (in 2015) and 2-3.56 cm (in 2016). The obtained parameters of heads are consistent with the data of other researchers. So, in the work (Fesenko et al., 1984), the authors obtained heads with a height of 15.3-21.2 cm and a diameter of 4.71-5.56 cm. Our results showed that the initial weight of the root (before laying for forcing) influenced the formation of the height and diameter of the heads. The correlation coefficients were r = 0.52 and r = 0.80, respectively.

Analysis the biochemical composition of plants revealed a clear relationship between the duration of growing the chicory salad and the accumulation of sugars in leaves and roots. The longer the growing season lasted, the more the plants accumulated sugars. This pattern was observed in all treatments when comparing the sugar content as % of the crude substance. The only exception was the early ripening variety Conus and variety Viproda. The sugar content in the leaves of these varieties in 2014 was lower than in 2015 (Fig. 2). This is probably due to the outflow of sugars from leaves into roots at this stage of plant development. This is indirectly confirmed by the fact that the sugar content in the root of the

Conus and Viproda in 2014 was the highest in comparison with the other varieties over the entire observation period (Fig. 3a).

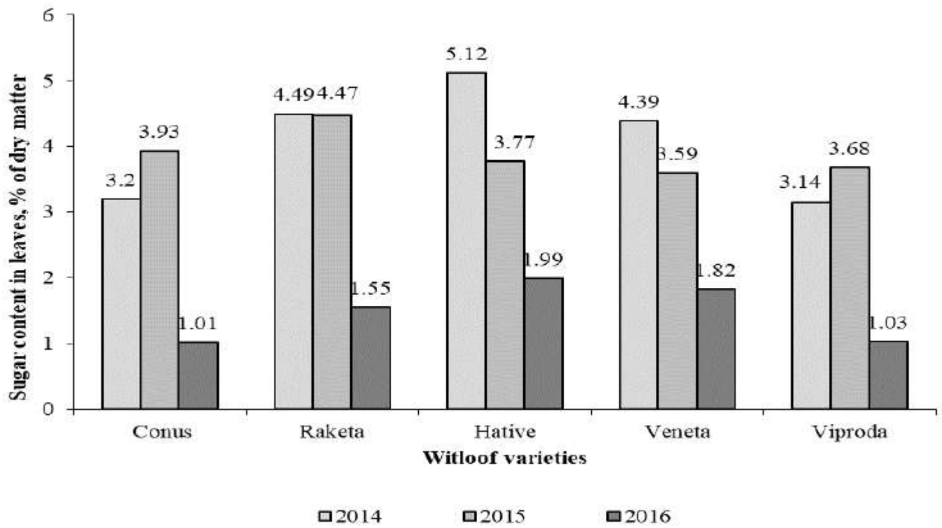
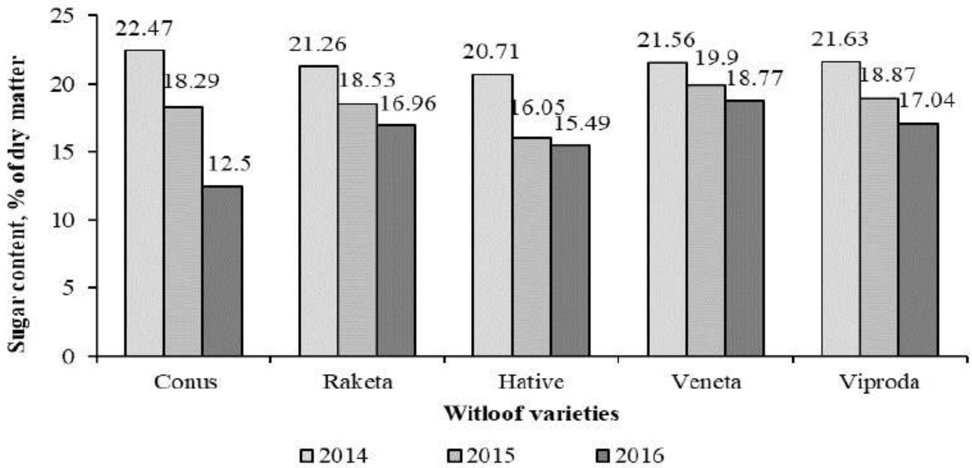


Figure 2. Content of sugars in the leaves of *Cichorium intybus* var. *foliosum*, % of dry matter

a)



b)

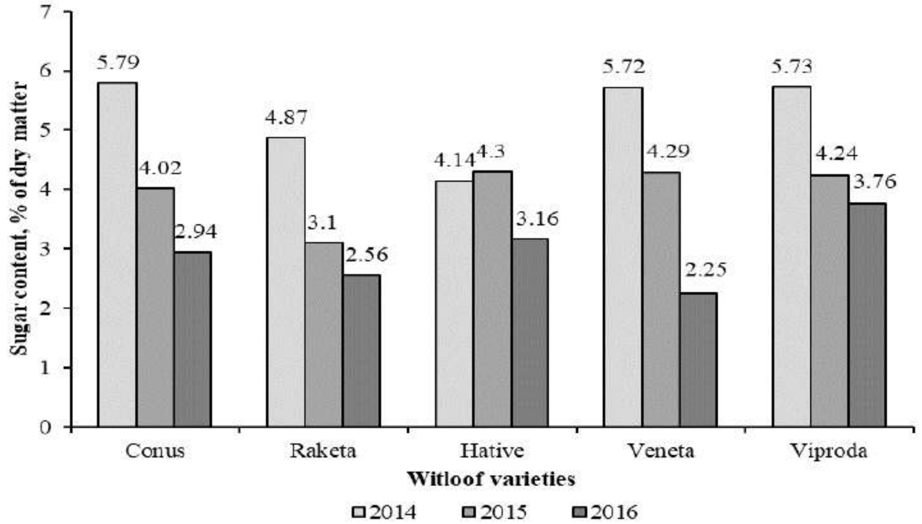


Figure 3. Content of sugars, % of dry matter in a) roots after harvest, b) in heads

The accumulation of sugars in heads depended on their initial content in roots. The higher the initial sugar content in the roots was, the more they accumulated in the heads (Fig. 3b), what is confirmed by strong correlation coefficient (r = 0.75). Thus, the sugar content in the heads decreased as the experiment proceeded. In 2014, this indicator ranged from 4.14 to 5.79; in 2015 from 3.1 to 4.3; in 2016 - from 2.25 to 3.76% of dry matter.

The pigment system of plants is the basis for the photosynthetic conversion of solar energy into the energy of chemical bonds (Liu et al., 2020; Sharma et al., 2020). It is represented by chlorophylls and carotenoids (Hermanns et al., 2020). Chlorophylls perform the main photosynthetic function (Agathokleous et al., 2020; Janik-Zabrotowicz et al., 2020). Carotenoids transfer additional energy to chlorophylls, performing a light-harvesting function, and also remove excess energy from chlorophylls, performing a light-protecting function. The efficiency of the pigment system depends on the compliance of its structure and function with climatic and environmental conditions, primarily lighting conditions (Ivanov et al., 2013). Shade-loving plants usually have higher chlorophyll content than light-loving plants, and a higher proportion of chlorophyll *b*, which increases the light-harvesting ability of the leaf in the far red region. Under conditions of high insolation, carotenoids perform the function of protection against photoinhibition (Ivanov et al., 2013; Tselniker, 1978), and therefore, under these conditions, their proportion is often increased. Results of the pigment content in leaves are given in Table 4.

Table 4. Content of pigments in the leaves of *Cichorium intybus* var. *foliosum* after harvest (1) and in the heads after forcing (2).

Variety	Total chlorophyll		Chlorophyll *a*		Chlorophyll b		Carotenoids		Chlorophyll *a* /Chlorophyll *b*		Total chlorophyll/ Carotenoids	
	mg/100 g											
	1*	2	1	2	1	2	1	2	1	2	1	2
						2014						
Conus	210.6	9,9	133.8	6.5	76.8	3.4	19.6	2.1	1.7	1.9	10.7	4.7
Raketa	200.0	11.9	121.4	7.7	78.6	4.2	18.3	2.3	1.5	1.8	10.9	5.2
Hative	249.0	13.3	162.5	8.0	86.5	5.3	26.6	7.4	1.9	1.5	9.4	1.8
Veneta	208.0	17.6	137.0	10.9	71.0	6.7	13.7	1.9	1.9	1.6	15.2	9.3
Viproda	413.6	15.4	264.9	9.1	148.7	6.3	27.9	7.6	1.8	1.4	14.8	2.0
						2015						
Conus	178.3	12.41	110.6	6.5	67.7	5.9	16.7	6.2	1.6	1.1	10.7	2.0
Raketa	204.7	5.2	118.0	3.3	86.7	1.9	21.0	1.7	1.4	1.7	9.7	3.1
Hative	251.2	23.8	156.9	15.6	94.3	8.2	36.3	2.2	1.7	1.9	6.9	10.8
Veneta	198.8	19.6	121.3	12.8	77.5	6.8	19.7	1.9	1.6	1.9	10.1	10.3
Viproda	263.4	2.9	157.0	2.0	106.4	0.9	29.4	0.7	1.5	2.2	9.0	4.1
						2016						
Conus	120.1	2.6	89.2	1.7	30.9	0.9	32.9	1.4	2.9	1.9	3.7	1.9
Raketa	112.3	2.9	83.9	1.9	28.4	1.0	31.3	1.5	3.0	1.9	3.6	1.9
Hative	149.9	10.4	107.2	6.9	42.7	3.5	41.8	1.5	2.5	2.0	3.6	6.9
Veneta	84.8	2.3	64.0	1.6	20.8	0.7	25.5	1.1	3.1	2.3	3.3	2.1
Viproda	85.2	4.1	61.4	3.0	23.8	1.1	24.8	1.7	2.6	2.7	3.4	2.1

*1- content of the pigments in the leafs at harvest time in September; 2- content of the pigments in forcing heads.

In our studies, the highest content of total chlorophyll in chicory lettuce leaves was observed in 2014 in the Viproda variety (413.6 mg/100 g). In other varieties grown this year, it ranged from 200 to 249 mg/100 g. In 2015, the content of total chlorophyll in the leaves varied in the range of 178.3-263.4 mg/100 g. Moreover, the maximum value of this indicator was also found in the Viproda variety. In 2016, the content of chlorophylls in leaves was the lowest over the entire observation period. Depending on the variety, it ranged from 84.8 to 149.9 mg/100 g

One of the informative indicators characterizing the work of the photosynthetic system is the ratio of chlorophyll *a* to chlorophyll *b* (chl *a*, chl *b*). This ratio is associated with the activity of the "main" chl *a*; the larger it is, the more intense the photosynthesis (Titova et al., 2015; Son et al., 2020). Our results showed that the chl *a* predominated in the composition of chlorophyll over the entire range of presented data. The greatest excess of chlorophyll *a* content over chl *b* was observed in 2016. So, in 2014 and 2015 the chl *a*/chl *b* ratio varied within 1.4-1.9, while in 2016 is was within 2.5-3.1.

The ratio of the chlorophyll to carotenoids (car) (chl a + chl b/car) plays an equally important role in characterizing the functioning of the photosynthetic system. Normally, this ratio is stable and very sensitive to the changes in the environmental factors (Titova and Rozlomy 2015). In our study, a decrease in the ratio (chl a + chl b/car) was observed in 2016, indicating a decrease in the light-harvesting function of the pigment complex, due to the shortest growing period (98 days). This is in line with some previous findings reporting that because chl a and chl b is directly related to the primary production via absorption and conversion of sunlight and water and CO_2, they are sensitive to changes in light intensity (Chen et al 2010). Son et al (2020) confirmed the sensitivity of photophysics of a plant to ambient environmental conditions. This ability may help plant to keep optimal balance between light harvesting and dissipation (Son et al 2020). In our study, forcing the witloof in a dark room influenced the content of the pigment in the heads (Table 4), since lack of light interfered with chlorophyll production. The fact is that cultivation of witloof in the dark was carried out to obtain a white leaf that does not have a bitter taste compared to endive that has a bitter taste.

Conclusion

A clear relationship was revealed between the duration of growing *C. intybus* var. *foliosum* and the biometric parameters (diameter of the rosette and the number of leaves and weight and formation of roots). There was a strong correlation (r = 0.79) between the weight of roots before laying for forcing and the weight of forcing heads. The weight of forcing heads obtained from the root of the mid-season Conus variety was stable in all the years studied and did not depend much on the duration of cultivation. Roots of this variety, apparently, even during the minimum growing period (98 days), managed to accumulate a sufficient amount of nutrients for the formation of heads.

The studied biochemical parameters (content of sugars, chlorophyll *a* and *b*, carotenoids and their ratios) were also influenced by the length of growing period. The longer the growing season lasted, the more the plants accumulated sugars. The higher the initial sugar content was in the roots, the more they accumulated in the heads (r = 0.75). The highest content of total chlorophyll in chicory lettuce leaves was observed during the longest growing season. Forcing the witloof in a dark room influenced the pigment content in the heads.

The study allowed to reveal that both the biometric and biochemical parameters of *C. intybus* var. *foliosum* showed a clear relationship with the duration of growing period. The longer the growing season lasted, the more sugar accumulated in the plants. The studied *C. intybus* varieties showed to be promising at 60°C latitude when cultivating in a foil greenhouse with solar heating, which allows extending the growing season. The study results suggest that in the Northwest of Russia the forcing can be carried out in winter in any room without light at a temperature of 10 to 17°C. Moreover, the results imply that with subsurface heating of the substrate or maintaining water in the containers with roots, a larger yield of heads in weight can be obtained in a shorter time.

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Morfometrijske i biohemijske osobine *Cichorium intybus* L. var. *foliosum* na koje utiče trajanje perioda rasta

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Izvod

Cichorium intybus je vredna kultura zbog svojih visokih hranljivih i farmaceutskih vrednosti. U ovom radu je proučavan uticaj vremena berbe na biometriske i biohemijske osobine 5 sorti *Cichorium intybus* L. var. *foliosum*. Period vegetacije utiče na prečnik rozete, broj listova i masu korena. Utvrđena je jaka korelacija između mase korena pre polaganja za forsiranje i mase forsiranih glava (r=0.79). Korenje sorte Conus uspelo je da akumulira dovoljnu količinu hranljivih materija za formiranje glavica za 98 dana. Akumulacija šećera u forsiranim glavicama zavisila je od početnog sadržaja u korenu sa pouzdanošću od 75% (r = 0.75). Rezultati su pokazali da se u severnim geografskim širinama forsiranje može vršiti zimi u bilo kojoj prostoriji bez svetlosti na temperaturi od 10 do 17°C. Pored toga, podzemno zagrevanje supstrata ili održavanje vode u posudama sa korenjem obezbedilo je veći prinos glavica dobijenih za kraće vreme.

Keywords**:** *Cichorium intybus*, radič, forsiranje, glavica, koren, hlorofil, šećeri, karotenoidi

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Просторне и временске промене у снабдевеност биљака водом применом NDVI у сливовима Тиње и Козлице

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Извод
Abstract

Нормализована разлика вегетационог индекса (NDVI) је индикатор здравља вегетације, али и промене земљишног покривача на основу рефлексије одређених опсега у електромагнетном спектру. Начин коришћења земљишта, годишња доба и климатске промене утичу на просторне промене NDVI вредности. Ова студија се фокусира на сливове река Тиња и Козлица, које се налазе на источним деловима планине Маљен и који се карактеришу доминантним присутвом травнате вегетације. Просторне и временске промене у снабдевеност биљака водом су праћење коришћењем 10-метарских Сентинел-2 снимака, и даље обрађених у QGIS-у за 2020–2021. годину, по месецима. За лакше праћење промене NDVI вредности сливови ове две реке су разграничени на укупно 305 подсливова, на којима је вршена даља анализа. Сви просторни NDVI подаци у току обе године се крећу од < 0,1 – > 0,6. Резултати указују да постоје видљиве промене у вредностима NDVI током различитих годишњих доба, што је у складу са порастом и смањењем водног стреса током проучаваног временског периода, односно са променама климатских чиниоца током вегетације. У летњим месецима највеће вредности премашују вредност од 0,6, а у неким случајевима и 0,8. Вредности NDVI у октобру и новембру се смањују на 0,3 и 0,5, док су у зимским месецима NDVI вредности <0,1. Вредности NDVI су више, и мање променљиве, у подсливовима са заступљеном дрвенастом вегетацијом, међу којим има и четинара. Ова студија доприноси повећању знања о потенцијалној примени даљинске детекције, као и Сентинел-2 снимака високе резолуције за праћење стања снабдевености биљака водом. ГИС алати омогућавају разграничење подсливова, што помаже бољем праћењу просторних варијација NDVI унутар природно издвојених ентитета. Приликом процене утицаја суше на биљну производњу треба узети у обзир тренутни водни режим биљака. Због лакоће израчунавања NDVI и других индекса, и високе резолуције података, Сентинел-2 може играти важну улогу у будућим системима раног упозоравања на сушу, и утврђивања стања вегетационог покривача.

Кључне речи: NDVI, Маљен, разграничавање сливова, Сентинел-2, снабдевеност биљака водом

Увод
Introduction

Водни режим вегетације игра кључну улогу у функционисању биљака и размени воде и енергије са атмосфером, посебно током сушних периода (Peñuelas *et al*., 1993). Хидролози и екофизиолози су користили неке битне особине Земљине површине као што су начин коришћења земљишта и покровност, те фракција апсорбованог фотосинтетички активног зрачења (fPAR) од 400-700 nm које апсорбује биљна крошња (Feagin, 2020) за карактеризацију водног режима. Ови параметри су кључни за описивање својстава вегетације и агроклиматологије, као и модела продуктивности вегетације. Водни режим биљака је такође процењен у многим студијама са различитим бујностима лисне масе и облицима крошње (Zarco-Tejada *et al*., 2003; Chai *et al*., 2021; Ceccato *et al*., 2001; Zhang i Zhou, 2019; Anderson *et al*., 2004).

Индекс нормализоване разлике вегетације (Normalized difference vegetation index – NDVI) се између осталог користи за процену деградације земљишта и промена земљишног покривача на различитим размерама за различите примене, укључујући отпорност агроекосистема (Bartlett *et al*., 1990). То је индикатор здравља вегетације заснован на томе како биљке одражавају одређене опсеге електромагнетног спектра што је фундаментално за разумевање здравља биљака. Он детектује и квантификује присуство активне зелене вегетације користећи ову рефлектовану светлост у видљивом и блиском инфрацрвеном опсегу. На NDVI утичу спектрална својства земљишта (Tuelle i Oleson 1989, Baret i Guyot 1991), посебно у областима са ретким вегетацијом где су посматрања под јаким утицајем сигнала из позадине земљишног простора као што су стене, земљиште и материјали органске простирке. Информације о потенцијалном земљишном покривачу значајно су означене фенологијом вегетације која у великој мери зависи од NDVI да би се знало да ли имамо здраве биљке, биљке под абиотичким или биотичким стресом или голе површине.

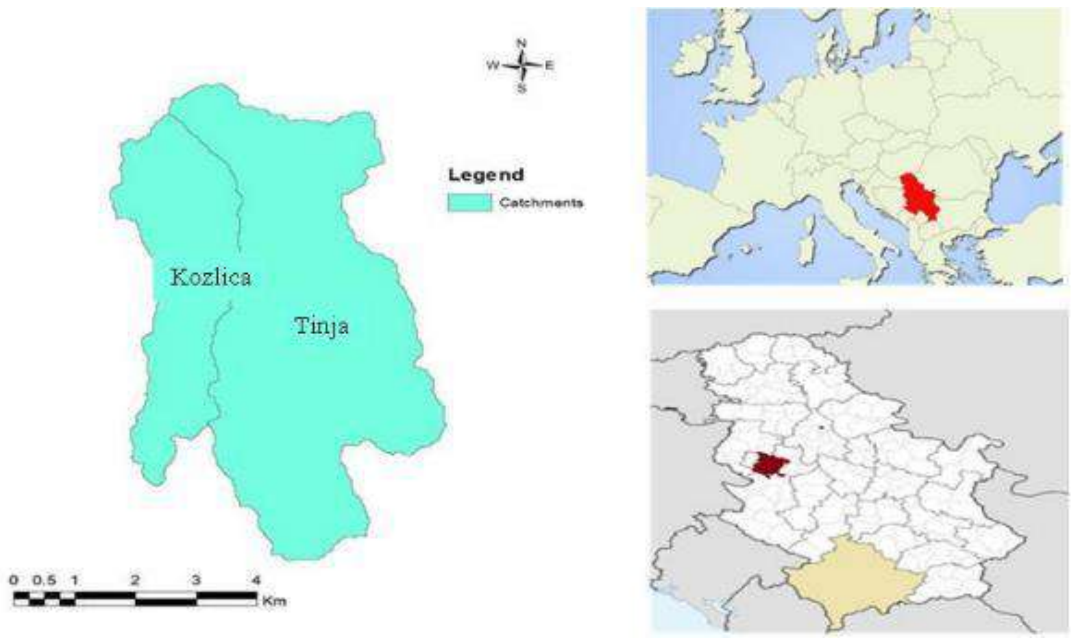
Листови су суштинска компонента структуре биљне крошње, а вода у лишћу има дубок утицај на фотосинтезу, транспирацију и друге физиолошке процесе. Складиштење воде у стабљици обезбеђује тампон између узимања воде из корена и транспирације листова (Deng *et al*., 2017). Према томе, садржај воде у биљци је кључна променлива за утврђивање стања снабдевености биљака водом и откривања адаптације биљака на измењену средину (Rodríguez-Pérez *et al*., 2018; Wang *et al*., 2021). Као главни абиотички стрес, суша има директан утицај на физиолошке и биохемијске процесе и морфолошку грађу биљака, што на крају доприноси губитку приноса или лошем квалитету усева/приноса (Peng *et al*., 2020; Zhang *et al*., 2018). Стога је прецизно праћење садржаја воде у земљишту у реалном времену корисно за побољшање способности управљања водама у пољопривреди, као и за побољшање ефикасности коришћења ресурса (Zarco-Tejada *et al*., 2003; Gao, 1996).

Циљ овог рада је да се утврди просторна и временска снабдевеност биљака водом у сливовима река Тиња и Козлица, у финој просторној резолуцији, преко промена NDVI, коришћењем сателитских снимака и ГИС техника.

Материјал и методе рада
Materials and Methods

Истраживано подручје
Researched field

Истраживано подручје (центар подручја на 44º 04' 37" СГШ и 20º 05' 12" ИГД) представљају два мала слива, реке Тиња и Козлица, које се налазе на источним деловима планине Маљен, Србија (Слика 1). Слив реке Тиње има укупну површину од 2470,50 ha, док је слив Козлице површине од 951,93 ha. Клима подручја је планинска, са снежним зимама и топлим летима. Типови земљишта заступљени на истраживаном подручју су ранкери и литосоли на серпентинитима.



Слика 1. Локација планине Маљен на карти Србије и речни сливови Тиње и Козлице
Figure 1. Location of Mountain Maljen on the map of Serbia, watersheds of Tinja and Kozlica Rivers

Слика 2. Велика пространства природних и антропогених пашњака, ерозиони процеси и појаве каменитости у сливовима Тиње и Козлице
Figure 2. The great area of natural and anthropogenized grasslands, processes of soil erosion, and stoniness on topsoil in the watersheds of Tinja and Kozlica

Прикупљени подаци и обрада сателитских снимака
Collected data and processing of satellite images

Примарни извор података за обраду су били сателитски снимци. Сателитски снимци су преузети са портала USGS (www.usgs.gov) и за њихово преузимање и анализу коришћен је QGIS, коришћењем полуаутоматског додатка за класификацију (Semi-automatic classification plugin, Congedo, 2016). Сателитски снимци су прикупљени са Сентинел-2 мисије за временски период од почетка 2020. до краја 2021. године (Табела 1). Сателит је опремљен опто-електронским мултиспектралним сензором за снимање у резолуцији од 10 до 60 m, који обезбеђује детектовање разлика у вегетационом стању. Сентинел-2 сензор поседује видљиве, блиске инфрацрвене (NIR) и краткоталасне инфрацрвене опсеге (SWIR). Главни опсег интересовања за одређивање NDVI су били опсег 4 (црвени) као и опсег 8 (NIR).

Табела 1. Карактеристике сателитских снимака за 2020. и 2021. годину
Table 1. Characteristics of satellite images for the year 2020 and 2021

Резолуција/ Resolution (m)	Облачност/Cloud cover (%)		Датум набавке/ Acquisition date		Датум преузимања/ Date of extraction
	2020	*2021*	*2020*	*2021*	
10	7,84602	33,5846	7-Jan	6-Jan	
10	2,9253	0,235387	1-Feb	25-Feb	
10	0	14,3738	17-Mar	5-Mar	
10	0,85783	13,2513	16-Apr	24-Apr	
10	1,61758	0,892227	9-Maj	11-Maj	
10	1,69675	0,049316	30-Jun	30-Jun	29-Jun-22
10	0,629872	0,51326	30-Jul	25-Jul	
10	0,043427	0,414537	29-Avg	9-Avg	
10	0,035381	0,1598	6-Sep	13-Sep	
10	0,711185	3,9516	26-Okt	3-Okt	
10	3,52885	3,2321	25-Nov	20-Nov	
10	57,0925	30,3417	5-Dec	22-Dec	

Коришћењем SCP тулбар-а (toolbar) у оквиру QGIS апликације извршена је анализа оригиналних канала снимака, као и њихових метаподатака, након чега је креиран виртуелни растер у боји уносом опсега 2, 3 и 4 (плава, телена и црвена).

Израчунавање нормализоване разлике вегетационог индекса (NDVI)
Calculation of the normalized difference of the vegetation index (NDVI)

За трансформацију необрађених сателитских података у индексе вегетације користи се математичка формула приказана у једначини 1 (Weier and Herring, 2000). NDVI се дакле добија коришћењем математичке формуле, као однос разлике између блиске инфрацрвене светлости (NIR) и црвене (RED), и њиховог збира (NIR + RED). Опсези за одређивање NDVI у Сентинел-2 су опсег 4 (црвени) као и опсег 8 (блиски инфрацрвени). NDVI слике су добијене коришћењем растер калкулатора

$$NDVI = \frac{(NIR-RED)}{(NIR+RED)} \quad (1)$$

Сливови, подсливови и њихова мрежа водотока су разграничени коришћењем података дигиталног модела надморске висине (DEM-а). DEM је креиран помоћу изохипси са карте размере 1:25.000. Преко опције Попуни ДЕМ (fill DEM) у SAGA (System for Automated Geoscientific Analyses) се креира Страхлеров ред (Strahler order; Strahler, 1957) који омогућава да се утврди где се налазе водотоци, а преко њих одреде и вододелнице. Опција Канал (Channel из Terrain analysis) ствара мрежу водотока, као и сливове. Издвајање сливова се врши на основу коришћења топографске карте са изохипсам, у комбинацији са проценом сателитских снимака (Sameh *et al*., 2011). Овај поступак се спроводи да би се пратиле промене NDVI на мањим ентитетима.

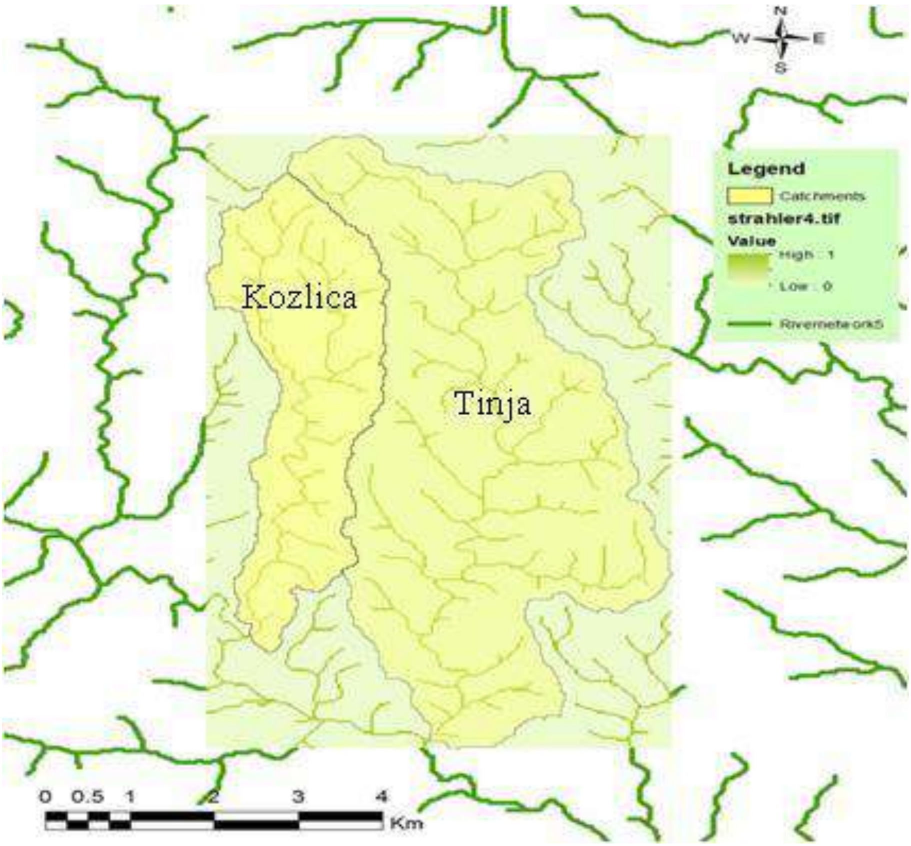
Зонална статистика је коришћена за добијање подскупова података на ширем простору. Зонална статистика користи груписање да би се израчунали основни статистички показатељи за наведене зоне/подручја од интереса, у овом случају подсливове у оквиру сливова Козлице и Тиње. Она омогућава да се израчуна средња вредност, медијана, збир, минимум, максимум, стандардна девијација или опсег вредности у свакој зони.

Резултати и дискусија
Results and Discussion

Издвајање сливова и подсливова
Separation of basins and sub-basins

Слив је подручје земљишног простора које одводи воду, седименте и растворене материјале у заједнички испуст у неком тренутку дуж водотока (Dunne and Leopold, 1978). Његов облик веома варира и зависи од много фактора, укључујући климатски режим, геолошке и геоморфолошке карактеристике, земљиште и вегетацију. Сливови река Тиња и Козлица и њихова мрежа мањих водотока су генерисани из DEM података. Horton (1945) је развио редослед водотока који помаже у класификацији и уређењу хијерархије природних канала унутар вододелнице. Даљом модификацијом Страхлер је уврстио Страхлеров ред који је сада најпопуларнији начин издвајања водотока. Потоци на највећој надморској висини у дренажној мрежи су означени као токови првог реда, а из њих се формира водоток другог реда, испод ушћа два потока/канала првог реда, и тако даље.

Слика 3 илуструје издвојене водотоке речне мреже, односно сливова Тиње и Козлице, док слика 4 приказује укупно 305 издвојених подсливова, од којих је 60 веома мале површине због грешке у аутоматизацији поступка. Дакле, мапа има 246 већих подсливова укупне површине 3599,99 ha, и 6,36 ha подсливова, са површинама мањим од 0,3 ha.



Слика 3. Приказ речне мреже и обрис Страхлеровог реда
Figure 3. River network in the Kozlica and Tinja watersheds obtained by using Strahler order principles

Слика 4. Мапа подсливова у оквиру сливова Тиње и Козлице
Figure 4. Map of all the used sub-catchments from the Tinja and Kozlica watersheds

Просторне промене вредности NDVI
Spatial NDVI value changes

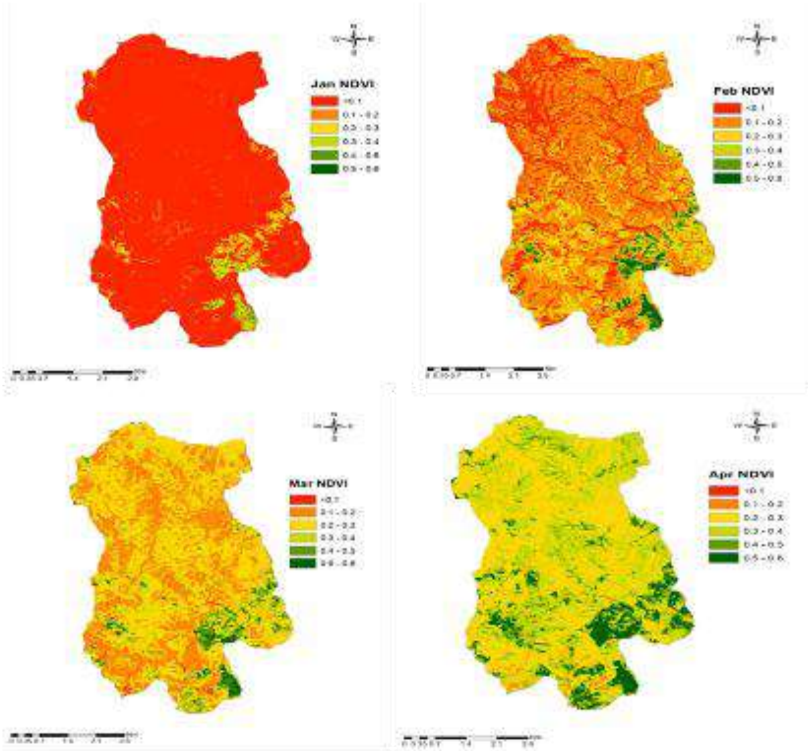
Резултати указују да NDVI варира просторно током обе године, при чему сваки месец има јединствену NDVI просторну дистрибуцију. Сви просторни NDVI резултати су представљени преко класа NDVI вредности од < 0,1 – > 0,6. Ове вредности се разликују у зависности од годишњих доба; када упоредимо зимске периоде као и летње периоде за 2020. и 2021. годину. Зимски месеци, јануар (Слика 5, 8) и децембар (Слика 7, 10) имају најниже вредности NDVI које су последица облачности, вегетационе неактивности, као и снежне покривености. Највише преовлађујуће вредности су испод 0,1, посебно у децембру 2020. Приближне нулте и негативне NDVI вредности указују на класе које претежно нису вегетација, док позитивне вредности представљају различите типове класа вегетације (Yacouba *et al.,* 2009). Agone и Bhamare (2012) повезују вредности NDVI од 0,00 - 0,20 са огољеним подручјима.

У летњим месецима имамо највеће вредности NDVI које су веће од 0,6, а у неким случајевима од 0,8. Промене NDVI у октобру и новембру (слика 7 и 10) указује на прелазне вредности NDVI од 0,3–0,6, које су уобичајене као и сезонске промене. Исти прелази се примећују током фебруара, марта и априла (слика 8). Ови прелази су последица промене климатских услова који се крећу од зиме ка топлијим месецима, који утичу на оживљавање вегетације, што онда утиче на повећање вредност NDVI. У овим месецима доминирају вредности NDVI у распону од 0,2–0,4. Током топлијих месеци видљиво је да се повећава вредности NDVI што може бити последица развијенијег и здравијег вегетационог покривача. Ово се може приметити на сликама 6, 7, 9 и 10.

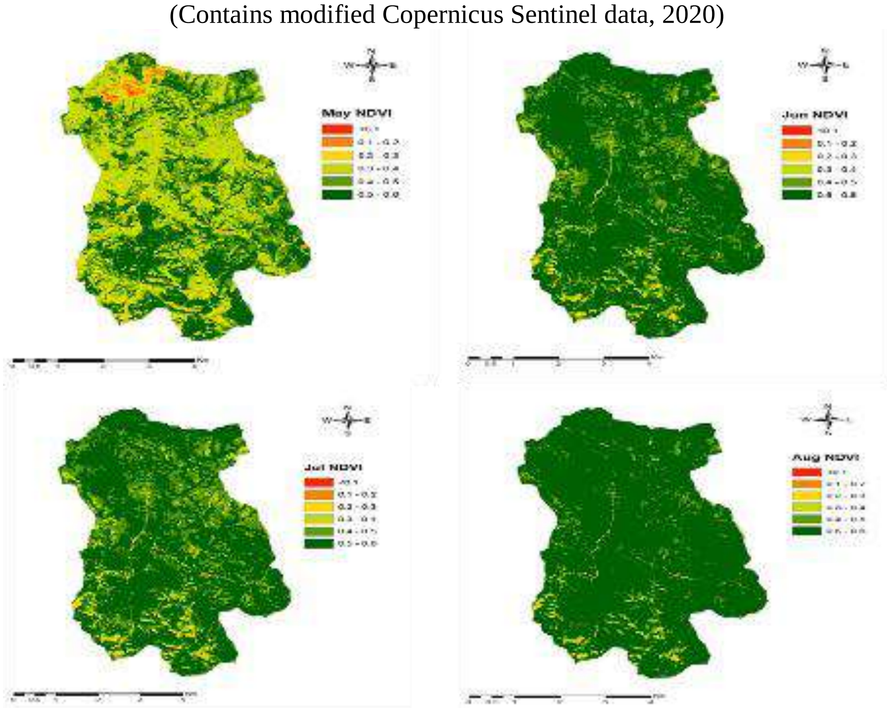
Singh *et al*., (2015) су урадили сличну студију користећи Ландсат NDVI и њихови резултати су открили да су подручја која показују NDVI вредности мање од 0,0396 повезана са воденим површинама. Вредности NDVI између 0,0396 и 0,2813 представљају голу земљу. Подручја са слабом вегетацијом окарактерисана су вредностима NDVI од 0,2813 до 0,4424, док су вредности NDVI од 0,4424 до 0,6036 и NDVI вредности веће од 0,6036 коришћене за класификацију умерено и густо обраслих зона. Према Singh *et al*. (2015) дошло је до све веће просторне промене у NDVI због раста вегетације и смањења огољених површина током летњих месеци у поређењу са зимским периодима.

Утицај тренутног водног стреса може се огледати у смањењу садржаја воде у листовима, што утиче на активност стома и размену гасова између биљака и амбијенталне атмосфере (Ma *et al*., 2018; Farooq *et al*., 2009). Међутим, дуготрајни водни стрес може значајно утицати на структурне карактеристике усева као што су индекс лисне површине, надземна биомаса и принос зрна (Blum, 2011; Zhou *et al*., 2020). Ако се тренутни водни стрес не открије на одговарајући начин и њиме се не управља, он ствара основу за дуготрајни стрес који доприноси великом губитку приноса (Ma *et al*., 2018). Претходне студије су показале да спектрални вегетацијски индекси (SVI) засновани на подацима даљинског истраживања прикупљених у одређеној фази раста могу да предвиде садржај воде у биљци на нивоу листова и крошње (Clevers *et al*., 2010; Perry and Davenport, 2007).

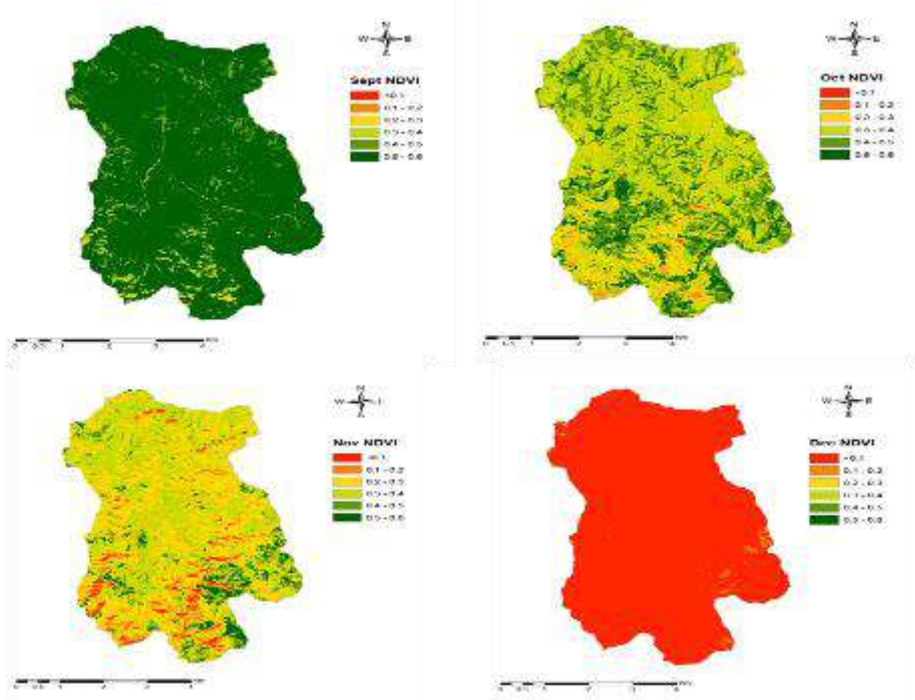
Упркос напорном покушају да се NDVI одреди само за подручја под вегетацијом, спектрално мешање голе земље и земљишта са тек изниклим биљкама изобличавају вредности NDVI. Дакле, постоји минимални праг вегетационог покривача изнад којег се преко NDVI не може разумно закључити о стању вегетације нити о влажности у земљишту због тога што су делови вегетације финији од највеће просторне резолуције доступне за дати сензор (за Sentinel-2 MSI, ово је 10 m).



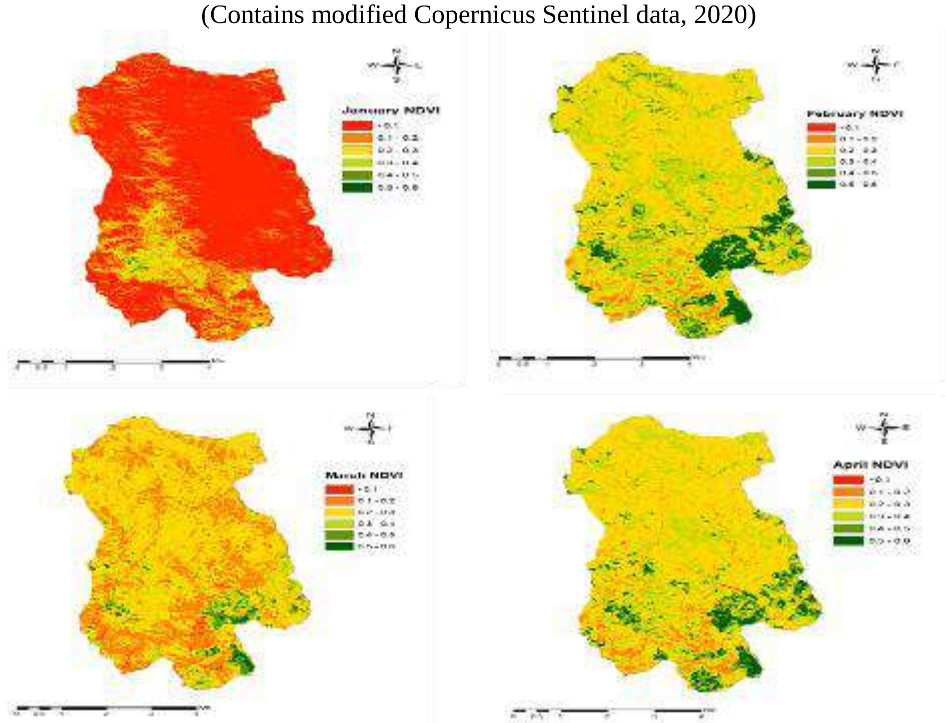
Слика 5. Просторне промене у NDVI за јануар, фебруар, март и април 2020. године
(Contains modified Copernicus Sentinel data, 2020)
Figure 5. Spatial changes in NDVI for January, February, March and April 2020
(Contains modified Copernicus Sentinel data, 2020)



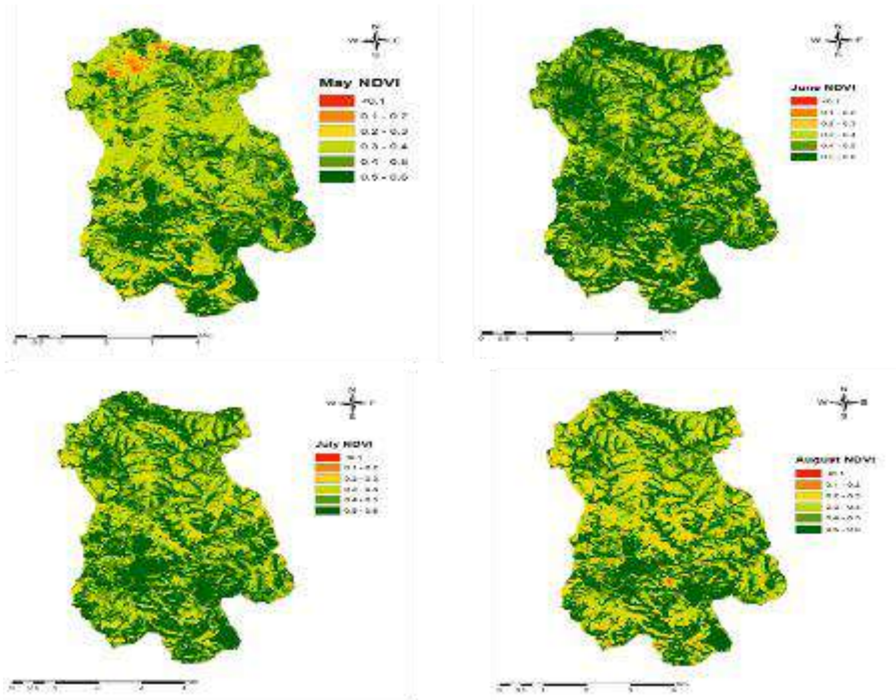
Слика 6. Просторне промене у NDVI за мај, јун, јул и август 2020. године
(Contains modified Copernicus Sentinel data, 2020)
Figure 6. Spatial changes in NDVI for May, June, July and August 2020
(Contains modified Copernicus Sentinel data, 2020)



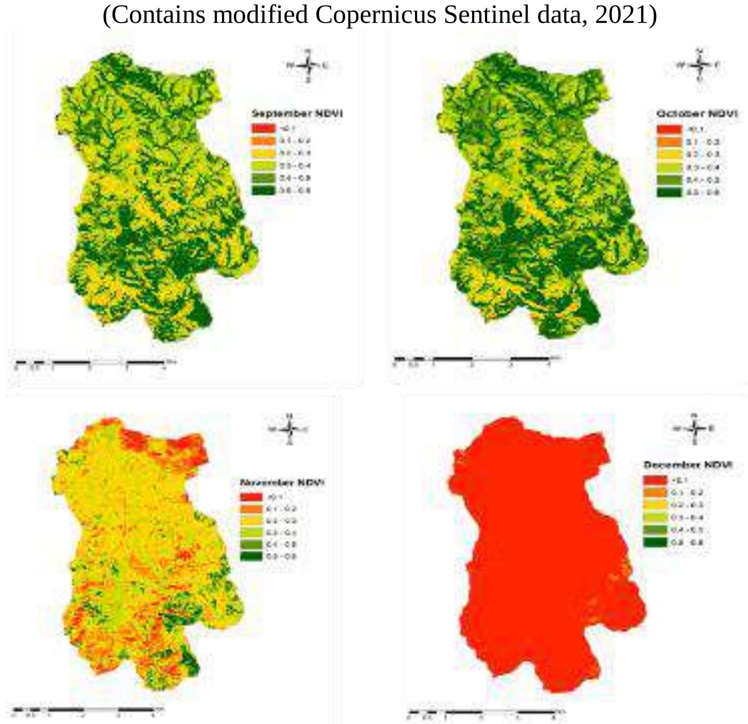
Слика 7. Просторне промене у NDVI за септембар, октобар, новембар и децембар 2020. године (Contains modified Copernicus Sentinel data, 2020)
Figure 7. Spatial changes in NDVI for September, October, November, and December 2020 (Contains modified Copernicus Sentinel data, 2020)



Слика 8. Просторне промене у NDVI за јануар, фебруар, март и април 2021. године (Contains modified Copernicus Sentinel data, 2021)
Figure 8. Spatial changes in NDVI for January, February, March and April 2021 (Contains modified Copernicus Sentinel data, 2021)



Слика 9. Просторне промене у NDVI за мај, јун, јул и август 2021. године
(Contains modified Copernicus Sentinel data, 2021)
Figure 9. Spatial changes in NDVI for May, June, July and August 2021
(Contains modified Copernicus Sentinel data, 2021)



Слика 10. Просторне промене у NDVI за септембар, октобар, новембар и децембар 2021. године
(Contains modified Copernicus Sentinel data, 2021)
Figure 10. Spatial changes in NDVI for September, October, November and December 2021
(Contains modified Copernicus Sentinel data, 2021)

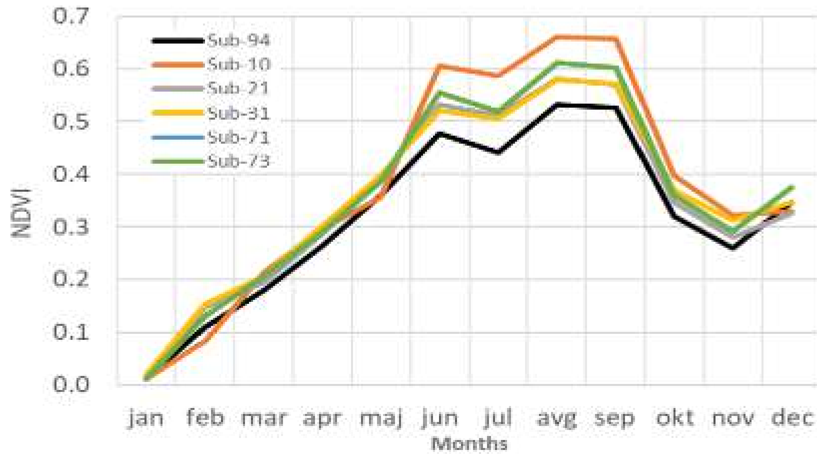
Временске промене у NDVI вредностима
Temporal changes in NDVI values

Основа за избор подсливова је представљала заступљеност пашњака, дрвећа и жбуња у њима. Својства одабраних сливова приказана су у табели 2 и она углавном оцртавају величину површине, нагиб, надморску висину, као и начин коришћења земљишта.

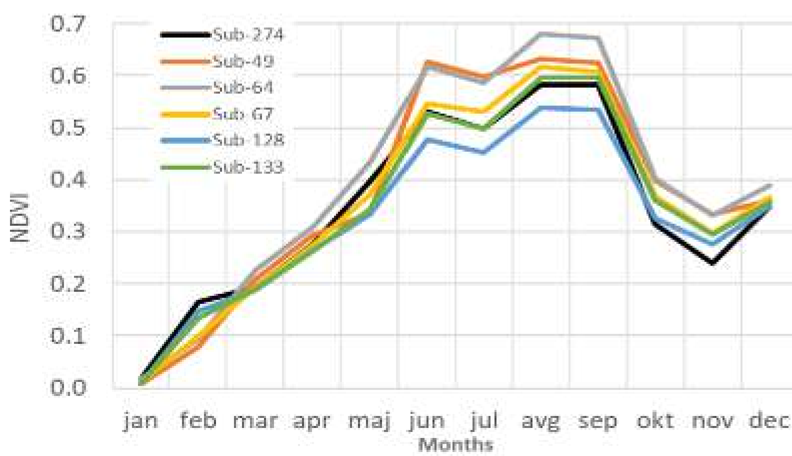
Табела 2. Подаци о изабраним подсливовима
Table 2. Data about chosen sub-catchments

Редни број подслива/ No of subcatchment	Површина /Area (ha)	Надморска висина /Elevation (m a.s.l)	Нагиб/ Slope (%)	Слив/ Watershed	Доминантан начин коришћења земљишта/ Dominant land use
10	26,9	892-931	16,8	Тиња	Пашњаци
21	15,7	809-880	23,7	Тиња	Пашњаци
31	24,8	825-910	26,5	Тиња	Пашњаци
71	13,6	738-768	17,6	Тиња	Пашњаци
73	33,7	722-768	18,4	Тиња	Пашњаци
94	17,4	739-766	15,0	Тиња	Пашњаци
49	19,4	841-899	9,3	Козлица	Пашњаци
64	20,6	807-840	13,6	Козлица	Пашњаци
67	20,0	823-859	13,9	Козлица	Пашњаци
128	9,2	760-795	15,7	Козлица	Пашњаци
133	9,6	755-776	16,4	Козлица	Пашњаци
274	53,7	631-709	27,2	Козлица	Пашњаци
185	16,0	700-724	16,3	Тиња	75% дрвеће
201	10,8	616-683	27,0	Тиња	35% дрвеће
227	9,2	683-706	16,5	Козлица	75% дрвеће
240	8,5	670-694	15,7	Козлица	95% дрвеће

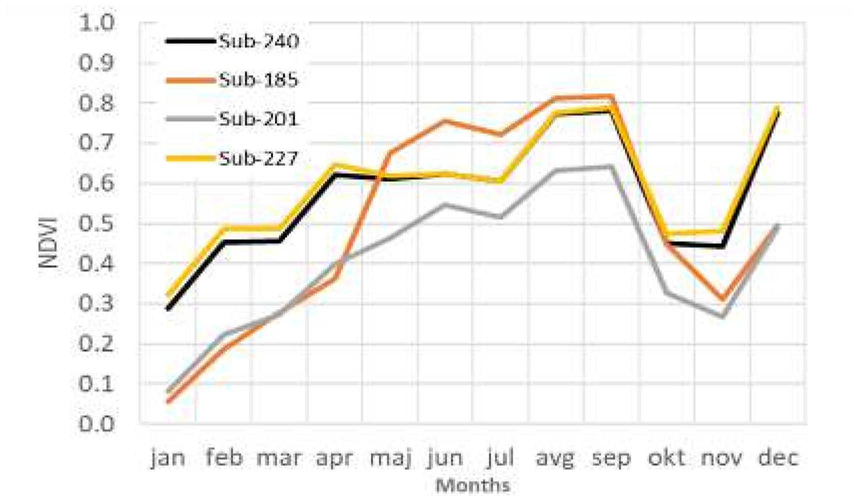
У 2020. години у сливу реке Тиње (слика 11) подсливови 10, 21, 31, 71, 73 и 94 имају различите NDVI вредности. Подслив 10 има највећу вредност NDVI око августа и септембра са вредношћу већом од 0,6, док подслив 94 има најниже вредности, нешто веће од 0,5. Такође је видљиво на сливу реке Козлице (слика 12) да подслив 64 има највиши NDVI у распону од >0,67 током августа и септембра, док подслив 128 има најниже вредности NDVI. На слици 13 приказани су подсливови са заступљенијом дрвенастом вегетацијом. Највишу вредност NDVI је у подсливу 185 који има око 75% дрвенасте вегетације, већа од 0,8, док су најниже вредности NDVI у подсливу 201, са вредностима нешто већим од 0,6, а у којем дрвенаста вегетација покрива око 35% подслива. Најниже вредности NDVI су приметне у подсливовима 94 и 128, док су највеће вредности у подсливовима 10 и 64 и у 2020. и у 2021. години. Дакле, сличне временске промене у NDVI су уобичајене и за 2021. годину у сливовима реке Тиње и Козлице, као и сливовима дрвенасте вегетације (слика 14–16). У оба слива вредности NDVI варирају током година, јер током зимског периода имамо најниже вредности NDVI, а током летњег периода највеће. Између маја и септембра 2020. и 2021. године, вредност NDVI и вегетација пашњака имају тенденцију да се повећају због повољних термичких услова током пролећа и лета, што утиче на појачани раст биљака. Ипак, овај тренд морају да прате и повољни хидрички услови, који могу условити смањење вредности NDVI током летњих месеци. Овако високе вредности NDVI указују на добру снабдевеност вегетације водом у обе године истраживања, што поткрепљују подаци о количинама падавина током вегетационог периода (354 mm и 453 mm за 2020. и 2021. годину, редом).



Слика 11. Годишње промене вредности NDVI у одабраним подсливовима реке Тиње у 2020. години
Figure 11. Annual changes in NDVI values in selected Tinja River sub-catchments in 2020



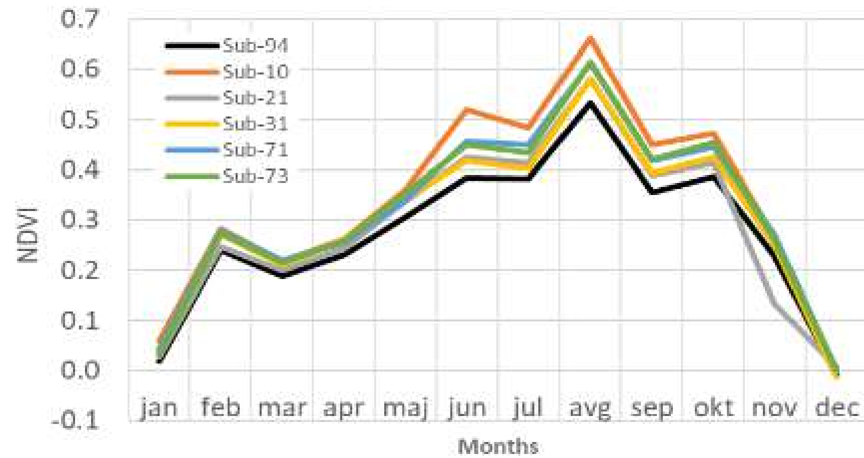
Слика 12. Годишње промене вредности NDVI у одабраним подсливовима реке Козлице у 2020. години
Figure 12. Annual changes in NDVI values in selected Kozlica River sub-catchments in 2020



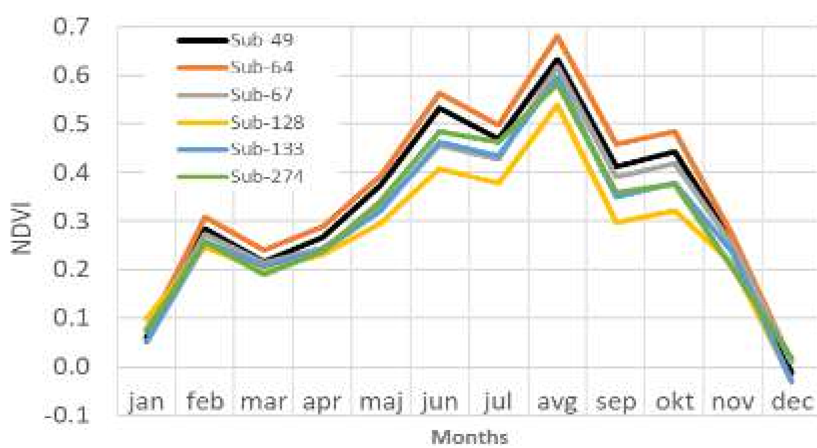
Слика 13. Годишње промене вредности NDVI у подсливовима са дрвенастим растињем у 2020. години
Figure 13. Annual changes in NDVI values in sub-catchments with woody vegetation 2020

Приметно је да су трендови вредности NDVI током лета готово идентични, посебно у подсливовима где постоје пашњаци. На пример, имамо три вршна периода у јуну, августу и октобру (слике 11, и 14). У мају, јулу и септембру вредности су нешто ниже. То се може објаснити кошењем пашњака или испашом. Ниже вредности NDVI у неким подсливовима (нпр. 0,4 у поређењу са 0,6) могу указивати на нижу плодност, због недостатка ђубрења пашњака, или на мање повољна физичка или хемијска својства земљишта, или могу бити услед повећане каменитости земљиштне површине јер је на испитиваном подручју присутан и литосол на серпентинитима. Bai и Dent (2006) су успешно применили даљинску детекцију да квантификују зелену биомасу и нето примарну производњу. Према Bozkurt *et al*. (2011), технике даљинског откривања пружају већу флексибилност и тачност за процену стања травњака, а интеграција извршена у овој студији пружила је доказе у овом правцу. Dwyer (2011) је извршио просторну процену биљне биомасе користећи даљинско испитивање у јужноафричким саванама са великим детаљима и успехом. У овом раду, вредности NDVI су показале прво очигледан динамички тренд повећања, а затим опадања, што је у вези са доступношћу воде за раст и развој биљака, али и са начином управљања површинама од стране човека. Приликом процене утицаја суше на биљну производњу треба узети у обзир водни режим биљака.

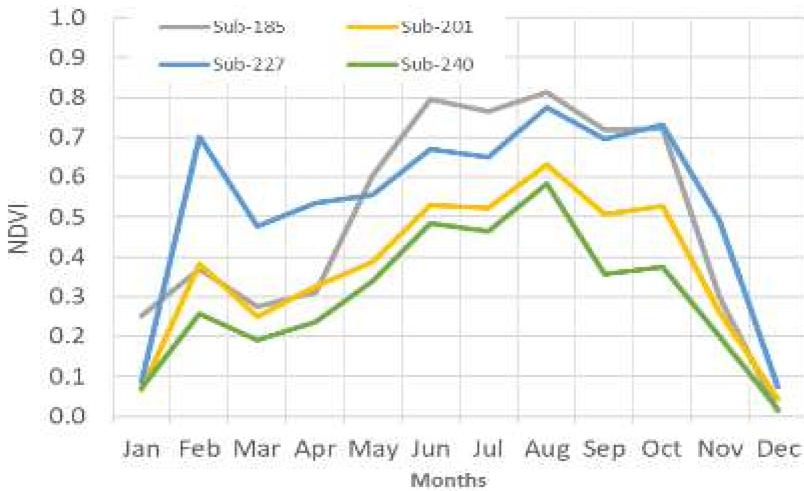
Дефицит влаге у земљишту је најшире прихваћен индикатор за процену пољопривредне суше. Дакле, мапирање влаге је ефикасан начин за препознавање потенцијалне суше код усева. У поређењу са влагом у земљишту, водни режим биљака је више повезан са физиолошким функцијама (Quemada *et al*., 2021; Bowman, 1989). Садржај воде и карактеристике биомасе, као и падавине играју важну индиректну улогу у прилагођавању водног режима биљака. NDVI одражава реакцију вегетације на промену градијента влаге на овим локацијама. Ово може да сугерише да вегетација нема приступ влази јер има довољно влаге или максимална дубина укорењења вегетације није довољно дубока да би приступила влази, посебно током зимских периода.



Слика 14. Годишње промене вредности NDVI у одабраним подсливовима реке Тиње у 2021. години
Figure 14. Annual changes in NDVI values in Tinja river sub-catchments in 2021



Слика 15. Годишње промене вредности NDVI у одабраним подсливовима реке Козлице у 2021. години
Figure 15. Annual changes in NDVI values in Kozlica river sub-catchments in 2021



Слика 16. Годишње промене вредности NDVI у подсливовима са дрвенастим растињем у 2021. години
Figure 16. Annual changes in NDVI values in sub-catchments with woody vegetation in 2021

Закључак
Conclusions

У овом раду је приказана просторна и временска анализа NDVI вредности у 2020. и 2021. години у сливовима река Тиња и Козлица. Сливови ове де реке су доминантно прекривени природним и антропогеним пашњацима и ливадама. Резултати указују да постоје видљиве промене у вредностима NDVI током различитих годишњих доба, што је у складу са порастом и смањењем водног стреса током проучаваног временског периода, односно са променама климатских чиниоца током вегетације. Ова студија доприноси повећању знања о потенцијалној примени даљинске детекције, као и Сентинел-2 снимака високе резолуције (10 m) праћењме стања снабдевености биљака водом коришћењем NDVI. ГИС алати омогућавају разграничење подсливова, што помаже бољем праћењу просторних варијација NDVI унутар сличнијих природних ентитета.

NDVI вредности се крећу од < 0,1 – > 0,6. За летње месеце, узимајући у обзир јун и јул, имамо највише доминантне вредности веће од 0,6, а у неким случајевима и веће од 0,8. Вредности NDVI у октобру и новембру опадају између 0,3 и 0,5, док су у зимским месецима NDVI вредности <0,1. Вредности NDVI су више, и мање променљиве у подсливовима са заступљеном дрвенастом вегетацијом, међу којим има и четинара.

Приликом процене утицаја суше на биљну производњу треба узети у обзир тренутни водни режим биљака. Због лакоће израчунавања NDVI и високе резолуције података, Сентинел-2 може играти важну улогу у будућим системима раног упозоравања на сушу, омогућавајући праћење вегетационих услова преко високе резолуције, што може бити корисно у откривању почетка и развоја пољопривредних суша и утврђивања стања вегетационог покривача.

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Spatial and temporal changes in plant water supply obtained by NDVI in Tinja and Kozlica watersheds

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Abstract

Normalized Difference Vegetation Index (NDVI) is an indicator of vegetation health and land cover changes, based on the reflectance of certain ranges in the electromagnetic spectrum. Land use, seasons and climate changes affect spatial variations in NDVI values. This study focuses on the basins of the rivers Tinja and Kozlica, located on the eastern parts of the Maljen Mountain, and characterized by the dominant presence of grassy vegetation. Spatial and temporal changes in plant water supply are monitored using 10–meter Sentinel-2 imagery, and further processed on a monthly basis in QGIS for 2020–2021. For better elaboration of NDVI values basins of these two rivers were delineated into 305 sub-basins, on which further analysis was performed. NDVI data during both years range from < 0.1 – > 0.6. NDVI values change during different seasons, which is consistent with the increase and decrease of water stress during the studied period, which refers to changes in weather conditions during the growing season. In the summer months, the highest values exceed 0.6, and in some cases even 0.8. NDVI values in October and November decrease to 0.3 and 0.5, while in winter months NDVI values are <0.1. NDVI values are higher, and less variable, in sub-basins with woody, partially coniferous vegetation. This study contributes to increasing knowledge about the potential application of remote sensing as well as high-resolution Sentinel-2 imagery for monitoring plant water supply because the assessment of drought impact on plant production requires the current monitoring of plant water regime. GIS tools enable the delineation of sub-catchments, which helps to better monitor the spatial variation of NDVI within natural landscape entities. NDVI and other indices are easy to calculate, and therefore, Sentinel-2 can play an important role in future drought early warning systemsand in determining conditions of the vegetation cover.

Keywords: NDVI, Maljen, watershed delineation, Sentinel-2, plant water supply

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Uticaj ozimih međuuseva na prinos i komponente prinosa kukuruza u naknadnom roku setve

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Izvod
Abstract

Istraživanje je imalo za cilj da utvrdi koji od odabranih tipova međuuseva ispoljavaju najveći pozitivan efekat na prinos i komponente prinosa kukuruza gajenog u naknadnom roku setve, kao i da li prihrana azotnim mineralnim đubrivom u pečetnim fazama rasta kukuruza u kombinaciji sa zaoranim međuusevima utiče na prinos zrna. Ogled sa ozimim međuusevima sastojao se iz združenog useva ozimog stočnog graška (*Pisum sativum* ssp. *arvense* L.) i tritikalea (×*Triticosecale* Wittm. ex A. Camus) (T+G), čistog useva ozimog stočnog graška (G) i kontrole bez međuuseva (K). Zaoravanje međuuseva na dubini od 27 cm obavljeno je u poslednjoj dekadi maja, a setva kukuruza početkom juna. Đubrenje azotom izvršeno je u vidu prihrane sa 50 kg N ha^{-1}. Setva ozimih međuuseva obavljena je u jesen u prvoj dekadi novembra, a njihovo malčiranje i zaoravanje izvršeno je poslednje nedelje maja. Nakon oranja i pripreme zemljišta, kukuruz (NS4051) je zasejan u prvoj dekadi juna, a žetva je obavljena u oktobru. Statistička značajnost ($p<0,05$) utvrđena je između različitih varijanti u pogledu upotrebe međuuseva. Najveći prinos je ostvaren u smeši (grašak + tririkale bez đubrenja azotom) T+GN_0 8,54 t ha^{-1}. Korišćenjem međuuseva kao zelenišnog đubriva ostvaruje se pozitivan uticaj na produktivne osobine kukuruza uz smanjenje inputa uz moguće niže troškove proizvodnje.

Ključne reči: međuusevi, združena setva, zelenišno đubrivo, kukuruz

Uvod
Introduction

Zbog nedovoljno razvijene stočarske proizvodnje u Republici Srbiji i smanjene količine raspoloživog organskog đubriva, pre svega stajnjaka, u poljoprivrednoj praksi se javlja sve veća potreba za uvođenjem alternativnih rešenja koja će biti od koristi i sa ekonomskog, ali i sa ekološkog aspekta (Vojnov et al., 2019). Šeremešić et al. (2017) smatraju da će se budući pravci razvoja poljoprivrede zasnivati na usaglašenoj primeni ekoloških principa i na ekološko prihvatljivim tehnološko-tehničkim rešenjima. Usled povećanih troškova proizvodnje, poskupljenja inputa neophodnih za proizvodnju, praćeno zahtevima za što jeftinijim izvorima proteina biljnog porekla, gajenje leguminoza sve više privlači pažnju istraživača, a sve u cilju rešavanja izazova sa kojima se poljoprivredni proizvođači suočavaju (Vojnov i sar., 2021).

Yang et. al. (2016) ističu da su međuusevi našli značajnu primenu za zelenišno đubrenje i imaju značajnu ulogu u održivoj poljoprivredi. Leguminoze imaju višestruk značaj jer su osnovni izvor proteina biljnog porekla i doprinose ostvarenju mnogobrojnih agroekoloških ciljeva zbog čega njihova primena kao međuuseva postepeno pronalazi primenu u agrarnoj praksi i u našoj zemlji. Njihovim uvođenjem u strukturu setve, kroz pažljivo definisanu rotaciju useva, čuvaju se prirodni resursi, pre svega zemljište, uz istovremeno ostvarivanje profita i niza drugih pozitivnih efekata (Ćupina i sar., 2004; Vojnov i sar., 2020). Prema Vasić i sar. (2013) sve više se javlja potreba za intenzivnijim plodoredom uz prisustvo useva na parceli tokom cele godine, gajenjem združenih i pokrovnih useva, uspostavljanjem zaštitnih pojaseva i gajenjem biljaka potrebnih za ishranu stoke. Uvođenje međuuseva u poljoprivrednu proizvodnju daje pozitivan efekat na zaštitu životne sredine i podsticanje održivog korišćenja prirodnih resursa (Dabney et al., 2001). Ćupina et al. (2017) smatraju da međuusevi mogu povećati prinose glavnih useva i istovremeno, mogu smanjiti troškove proizvodnje, povećati profit, pa čak i stvoriti nove izvore prihoda. Prema navodima Vujić et al. (2021) neizvesnost prinosa krmnog bilja može biti smanjena uvođenjem ozimih pokrovnih useva koji omogućavaju smanjenu zavisnost od proizvodnje glavne krmne kulture, prevashodno u regionima gde se periodično pojavljuje suša. Pri zasnivanju međuuseva mora se voditi računa o načinu setve, vremenskim uslovima proizvodnog područja, temperaturi i vlažnosti zemljišta, tolerantnosti prema ekstremnim uslovima spoljašnje sredine, ali i o ekonomskoj isplativosti njihovog uvođenja (Bekavac, 2012).

Kukuruz je jedna od najzastupljenijih ratarskih kultura u Republici Srbiji (Živanović i sar., 2017) i prema statističkim podacima Ministarstva poljoprivrede, šumarstva i vodoprivrede u 2021. godini gajen je na površini od 1.020.337 ha sa ostvarenom proizvodnjom od 6.027.131 t (MPVŠ, 2021). U agroekološkim uslovima Vojvodine gajenje kukuruza u naknadnim i postrnim rokovima setve bez sistema za navodnjavanje slabo se praktikuje, pre svega zbog izazova koji se ogleda u neujednačenom rasporedu padavina, naročito tokom letnjih meseci (jul i avgust). Različiti autori ističu da efekat međuuseva na prinos i komponente prinosa zavisi od tipa, odnosno vrste međuuseva (Pantoja et al., 2015; Kaspar and Bakker, 2015; Marcillo and Miguez, 2017; Radanović, 2018). Istraživanje je imalo za cilj da utvrdi koji od odabranih tipova međuuseva ispoljavaju najveći pozitivan efekat na prinos i komponente prinosa kukuruza gajenog u naknadnom roku setve, kao i da li prihrana azotnim mineralnim đubrivom u početnim fazama rasta kukuruza u kombinaciji sa zaoranim međuusevima utiče na prinos zrna.

Materijali i metode rada
Materials and Methods

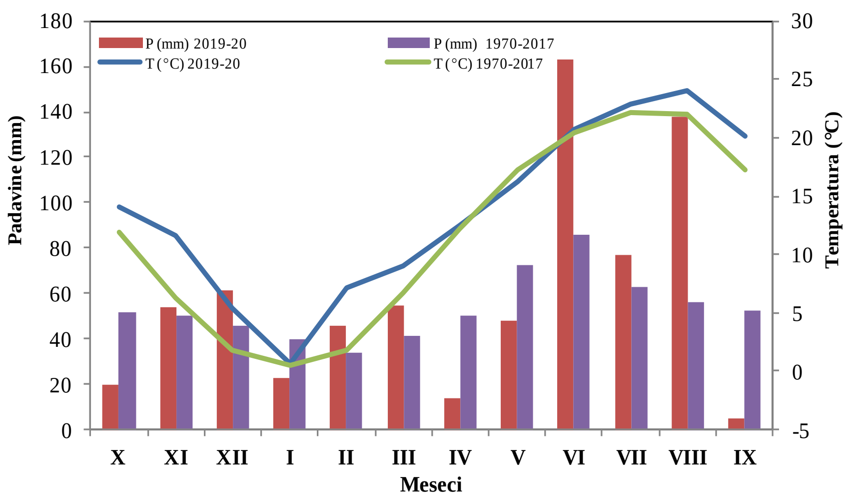
Istraživanje je sprovedeno na oglednom polju Rimski Šančevi Instituta za ratarstvo i povrtarstvo u Novom Sadu (45°19´N 19°50´E). Ogled sa ozimim međuusevima sastojao se iz združenog useva ozimog stočnog graška (*Pisum sativum* ssp. *arvense* L.) i tritikalea (× *Triticosecale* Wittm. ex A. Camus) (T+G), čistog useva ozimog stočnog graška (G) i kontrole bez međuuseva (Ø). Zaoravanje međuuseva i kontrolne parcele obavljeno je u poslednjoj dekadi maja 2020. godine. Zaoravanje međuuseva u vidu zelenišnog đubriva obavljeno je plugom na dubini od 27 cm. Početkom juna obavljena je setva hibrida kukuruza NS4051. Đubrenje azotom (UREA 46%) izvršeno je u vidu prihrane sa 50 kg N ha^{-1}. Istraživanje je obavljeno na zemljištu koje pripada tipu černozema obrazovanog na lesu. Laboratorijske analize rađene su u Laboratoriji za Agroekologiju i zemljište na Poljoprivrednom fakultetu u Novom Sadu. Agrohemijska analiza zemljišta prikazana je u Tabeli 1.

Po reakciji zemljišnog rastvora, zemljište je bilo slabo alkalno, pri čemu je pH vrednost u KCl iznosila 7,61, dok je pH u H_2O iznosila 8,14. Sadržaj humusa u oraničnom sloju je iznosio 2,51%, a ukupnog azota 0,192%. U pogledu sadržaja fosfora i kalijuma, zemljište je optimalno obezbeđeno lakopristupačnim fosforom (13,5 mg 100 g^{-1} zemljišta P_2O_5) i kalijumom (21,4 mg 100 g^{-1} zemljišta K_2O), Tabela 1.

Tabela 1. Osnovna agrohemijska svojstva zemljišta pre postavljanja ogleda
Table 1. Basic agrochemical soil properties before experimental set up

Dubina (cm)	pH y KCl	pH y H_2O	$CaCO_3$ (%)	Humus (%)	N (%)	mg 100 g^{-1} zemljišta	
						P_2O_5	K_2O
0–30	7,61	8,14	11,0	2,51	0,192	13,5	21,4

Temperaturne vrednosti kao i padavine su u toku izvođenja ogleda bile iznad prosečnih vrednosti. Setva je obavljena početkom novembra u kojem je bilo 53,7 mm padavina, sa prosečnom temperaturom od 11,6°C. Ove vrednosti su omogućile povoljne uslove za rast i razvoj međuuseva i pripremu za zimski period (Slika 1)



Slika 1. Meteorološki pokazatelji u vegetacionom periodu za lokalitet Rimski Šančevi za 2019/20. godinu
Figure 1. Meteorological conditions during vegetative period at Rimski Šančevi experimental field in 2019/20 years

Po završetku vegetacije analizirane su sledeće morfološke karakteristike: visina biljaka (cm), broj biljaka, masa 1000 zrna (g), hektolitarska masa (kg hl^{-1}) i prinos zrna po jedinici površine (t ha^{-1}). Uzorci su uzimani sa jednog metra kvadratnog za svaki tretman u tri ponavljanja. Osnovna morfološka svojstva na uzorcima od po deset biljaka, po svakom ponavljanju utvrđena su ručno, brojanjem i merenjem svake biljke pojedinačno, a zatim daljom obradom podataka u programima Microsoft Office Excel i STATISTICA 13.0.

Rezultati i diskusija
Results and Discussions

U našem istraživanju analizom pojedinih parametara, utvrđeno je da su visoku statističku značajnost ispoljili međuusevi na broj biljaka (Tabela 3), dok su međuusevi ispoljili statističku značajnost (p<0,05) na prinos zrna kukuruza (Tabela 4). Analizom ostalih parametara nije utvrđen efekat ozimih međuuseva. Na slici 2. zapaže se da je najveća visina biljaka ostvarena na varijanti GN_0 (235,6 cm) dok je najmanja visina kukuruza ostvarena na T+GN_0 (217,9 cm). Broj, odnosno gustina biljaka kukuruza zavise od cilja proizvodnje, primenjene agrotehnike i povoljnih uslova za prethodno klijanje i nicanje posejane kulture. Sklop biljaka kukuruza po jedinici površine predstavlja značajan činilac u njegovoj proizvodnji, jer optimalna gustina setve nije uvek stalna vrednost, već se menja u zavisnosti od godine, cilja i uslova proizvodnje (Đalović et al., 2021). U našem istraživanju je utvrđeno je da je na kontrolnoj parceli N_0 broj biljaka kukuruza bio najmanji (48,620 biljaka ha^{-1}), dok je najveći sklop biljaka ha^{-1} utvrđen na varijanti T+GN_0 (54340) (Slika 3). Iako je kod ovog parametra utvrđena statistička značajnost u interakciji faktora A (međuuseva) i B (đubrenja) (Tabela 3), na nivou p<0,05 u momentu zaoravanja međuuseva, tj. unošenja zelenišnog đubriva u zemljište mogla se vizuelno zapaziti razlika u strukturi zemljišta, što je uticalo na samu pripremu zemljišta za setvu, kao i sam kvalitet setve, a time i broj poniklih biljaka i formiranje sklopa. Na osnovu slike 4, zapaža se da je najveći prinos ostvaren na varijanti T+GN_0 (8,54 t ha^{-1}), što je pratilo i vrednosti broja biljaka po jedinici površine (Slika 3). Na đubrenoj varijanti GN_{50} ostvaren je prinos zrna kukuruza od 6,93 t ha^{-1}, što je ujedno i najmanji ostvareni prinos u ogledu, dok su se prinosi na kontroli kretali između 7,15 N_0 do 7,70 t ha^{-1} N_{50}. Ostvarene vrednosti prinosa su pratile i sam sklop biljaka, što ukazuje da se pored mogućnosti gajenja kukuruza u uslovima bez navodnjavanja u naknadnom roku retve, posebna pažnja mora posvetiti prilikom obrade i pripreme zemljišta i odabiru najpovoljnijeg međuuseva. Sa aspekta vremenskih uslova, zabeležene vrednosti padavina u aprilu su bile ispod višegodišnjeg proseka za 71%, dok je u tokom maja ostvarena veća količina (48 mm), ali takođe ispod proseka (72,1 mm), što je svakako imalo uticaja na razvoj međuuseva, ali i njihovu potrošnju pristupačne vode u zemljištu (Krstić et al, 2018, Vujić et al, 2021). Srednje mesečene temperature u toku vegetacionog perioda su bile iznad proseka za područje na kojem je ogled postavljen. S obzirom na to da je setva kukuruza obavljena početkom juna kada je prosečna srednja mesečna temperatura bila 20,7°C uz znatno veću količinu padavina (163 mm) u odnosu na višegodišnji prosek od 85,9 mm (Slika 1). Srednja mesečna temperatura u avgustu je bila 24,1°C, odnosno za 2,1°C iznad višegodišnjeg proseka, što je imalo uticaja na oplodnju i formiranje zrna. Bekavac i sar. (2010) navode da meteorološki uslovi tokom poslednjih decenija sve više imaju uticaj na forminje prinosa zrna kukuuza, zbog neujednačenog rasporeda padavina, visokih temperatura tokom kritičnih faza rasta i razvoja ove biljne vrste. Iako se 2020. godina pokazala kao izuzetno povoljna za gajenje kukuruza u naknadnom roku setve, zbog padavina tokom kritičnog perioda vegetacije kukuruza koje su bile iznad višegodišnjeg proseka, brojni autori ističu da u semiaridnim uslovima prinos kukuruza zavisi od prethodno gajenog ozimog međuuseva, tj. količine utrošene vode od strane međuuseva (Ćupina et al., 2017; Radanović, 2018; Meyer et al., 2022). Sa druge strane, analizom različitih studija mnogi autori ističu da, u povoljnim uslovima godine, sa većom količinom padavina u odnosu na prosečne agroekološke uslove Vojvodine međuusevi imaju pozitivan efekat na prinos zrna kukuruza (Miguez and Bollero, 2005; Chen et al., 2011; Kramberger et al., 2014; Marcillo and Miguez, 2017). Prethodno gajeni i zaorani međuusevi nisu ispoljili statističku značajnost na masu 1000 zrna, pri čemu su se vrednosti kretale od 271,9 g T+GN5$_0$ do 287,7 g na kontrolnoj varijanti sa đubrenjem od 50 kg N ha^{-1}, što je bila i najveća izmerena vrednost (Slika 5). Pandurović i sar. (2009) u istraživanju navode da sa povećanom gustinom biljaka dolazi do smanjena mase 1000 zrna, kao i da je povećana količina azota blago uticala na povećanje mase 1000 zrna. U pogledu hektolitarske mase, najveća vrednost utvrđena je na varijanti T+GN$_{50}$ (67,5 kg hl^{-1}), a najmanja na tretmanu T+GN$_0$ (60,6 kg hl^{-1}), dok je varijanta sa ozimim graškom (G) kao međuusevom uz prihranu azotom imala hektolitarsku masu od 64,0 kg hl^{-1}, koja je veoma slična istoj varijati bez đubrenja odnosno, 63,4 kg hl^{-1}. Gajenje useva u naknadnom roku setve u agroekološkim uslovima Vojvodine zastupljeno je u malom procentu i to uglavnom na poljoprivrednim gazdinstvima koja se bave stočarskom proizvodnjom, a u cilju dobijanja sveže i kvalitetnije krme od ozimih međuuseva. Stoga se smatra da koncept proizvodnje koji kombinuje ozime međuuseve i glavne useva nije u velikoj meri zastupljen i može se smatrati kao alternativa u slučaju nemogućnosti obavljanja prolećne setve u optimalnim rokovima, što se najčešće dešava kao posledica nepovoljnih vremenskih prilika.

Tabela 3. Analiza varijanse visine biljaka kukuruza
Table 3. ANOVA maize plant height

Izvori varijabilnosti	Stepeni slobode	Suma kvadrata	%	Sredina kvadrata	F	Verovatnoća p
Efekat A	2	179,8958	18,0	89,9479	2,880	0,0824
Efekat B	1	55,7292	5,6	55,7292	1,785	0,1968
Interakcija A*B	2	311,4375	31,1	155,7188	4,986*	0,0022
Blokovi	2	140,8958	14,1	70,4479	2,256	0,1339
Greška	10	312,2917	31,2	31,2292		
Ukupno	17	1000,2500				

A – uticaj međuuseva, B – uticaj đubrenja, ** visoko značajan uticaj (*P*<0,01) * značajan uticaj (*P*<0,05)

Tabela 3. Analiza varijanse broja biljaka kukuruza
Table 3. ANOVA number of plants

Izvori varijabilnosti	Stepeni slobode	Suma kvadrata	%	Sredina kvadrata	F	Verovatnoća p
Efekat A	2	3639978,7500	1,4	1819989,3750	0,260	0,7768
Efekat B	1	1817713,7500	0,7	1817713,7500	0,260	0,6219
Interakcija A*B	2	69064928,0000	26,6	34532464,000	4,934*	0,0200
Blokovi	2	115422552,000	44,4	57711276,000	8,246**	0,0034
Greška	10	69982888,0000	26,9	6998289,0000		
Ukupno	17	259928064,000				

A – uticaj međuuseva, B – uticaj đubrenja, ** visoko značajan uticaj (P<0,01) * značajan uticaj (*P*<0,05)

Tabela 4. Analiza varijanse prinosa zrna kukuruza (t ha^{-1})
Table 4. ANOVA maize grain yield (t ha^{-1})

Izvori varijabilnosti	Stepeni slobode	Suma kvadrata	%	Sredina kvadrata	F	Verovatnoća p
Efekat A	2	1,2131	7,3	0,6065	1,042*	0,3758
Efekat B	1	1,2797	7,7	1,2797	2,198	0,1535
Interakcija A*B	2	2,5603	15,4	1,2802	2,198	0,1402
Blokovi	2	5,7631	34,6	2,8816	4,948*	0,0199
Greška	10	5,8236	35,0	0,5824		
Ukupno	17	16,6399				

A – uticaj međuuseva, B – uticaj đubrenja, ** visoko značajan uticaj (*P*<0,01) * značajan uticaj (*P*<0,05)

Tabela 5. Analiza varijanse mase 1000 zrna kukuruza (g)
Table 5. ANOVA 1.000 grain mass of maize

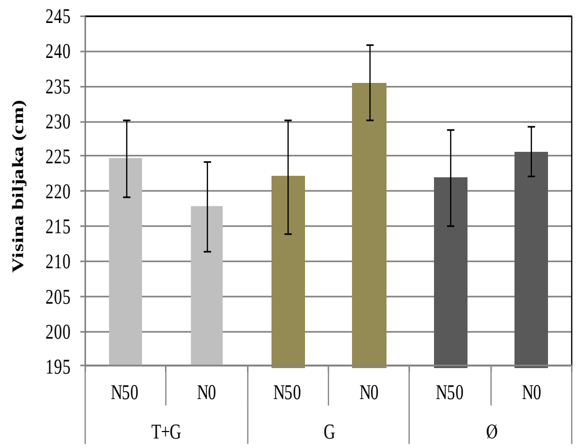
Izvori varijabilnosti	Stepeni slobode	Suma kvadrata	%	Sredina kvadrata	F	Verovatnoća p
Efekat A	2	295,5000	4,4	147,7500	0,443	0,6543
Efekat B	1	100,6667	1,5	100,6667	0,302	0,5956
Interakcija A*B	2	269,3333	4,1	134,6667	0,404	0,6787
Blokovi	2	2645,0000	39,8	1322,5000	3,965	0,0377
Greška	10	3335,1250	50,2	333,5125		
Ukupno	17	6645,6250				

A – uticaj međuuseva, B – uticaj đubrenja, ** visoko značajan uticaj (*P*<0,01) * značajan uticaj (*P*<0,05)

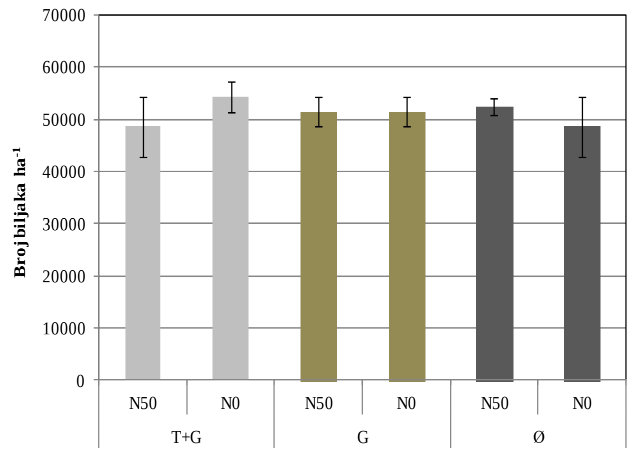
Tabela 6. Analiza varijanse hektolitarske mase kukuruza (kg hl)
Table 6. ANOVA hectolitre mass of maize grain

Izvori varijabilnosti	Stepeni slobode	Suma kvadrata	%	Sredina kvadrata	F	Verovatnoća p
Efekat A	2	3,3620	2,0	1,6810	0,207	0,8165
Efekat B	1	31,9887	19,0	31,9887	3,931	0,0611
Interakcija A*B	2	40,3550	24,0	20,1775	2,479	0,1122
Blokovi	2	11,1589	6,6	5,5794	0,686	0,5210
Greška	10	81,3854	48,4	8,1385		

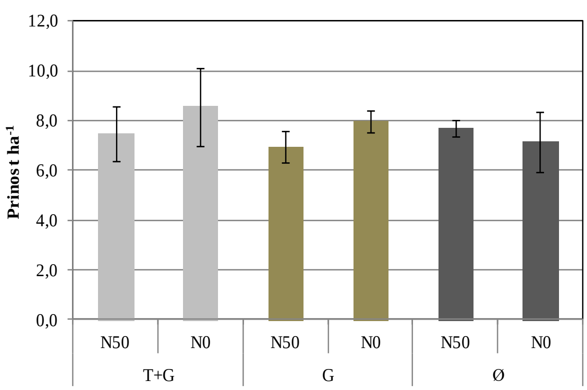
A – uticaj međuuseva, B – uticaj đubrenja, ** visoko značajan uticaj (P<0,01) * značajan uticaj (P<0,05)



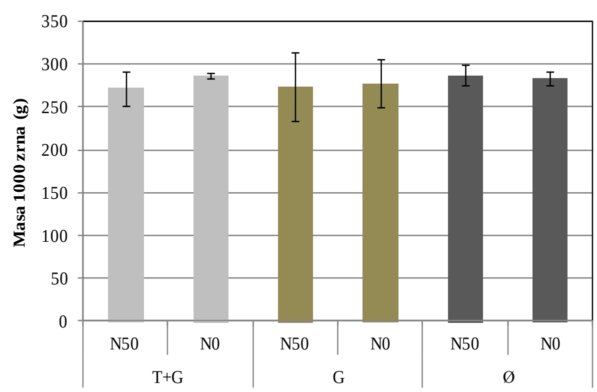
Slika 2. Visina biljaka kukuruza
Figure 2. Height of maize plants



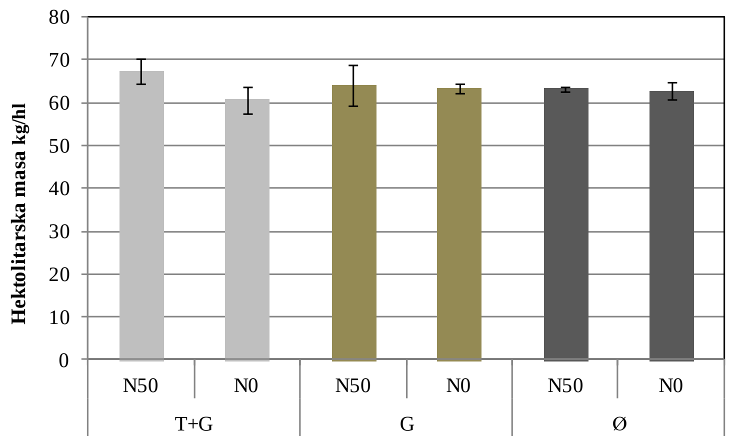
Slika 3. Broj biljaka kukuruza ha^{-1}
Figure 3. Number of plants ha^{-1}



Slika 4. Prinos zrna kukuruza t ha^{-1}
Figure 4. Maize grain yield t ha^{-1}



Slika 5. Masa 1000 zrna
Figure 5. Thousand grain mass



Slika 6. Hektolitar mass of grain
Figure 6. Hektolitar mass of grain

Zaključak
Conclusions

Na osnovu sprovedenog istraživanja uticaja međuuseva na prinos i komponente prinosa kukuruza u naknadnom roku setve, utvrđena je visoka statistička značajnost na broj biljaka. Ozimi međuusevi koga su činile varijante: združena smeša tritikala i graška (T+G) i čist usev graška (G), takođe su ispoljili statističku značajnost na prinos zrna kukuruza. Najveći sklop biljaka kukuruza zabeležen je na varijanti bez đubrenja azotom (N_0) od 54,340 biljaka ha^{-1}, na kojoj je i postignut najveći prinos zrna od 8,54 t ha^{-1}. Kao alternativa sve većim izazovima oko nabavke inputa u poljoprivrednoj proizvodnji, uvođenje međuuseva u strukturu setve će u budućnosti imati sve učestaliju primenu u praksi. Smatra se da koncept proizvodnje koji kombinuje ozime međuuseve i glavne useva nije u velikoj meri zastupljen i može se smatrati kao alternativa u slučaju nemogućnosti obavljanja prolećne setve u optimalnim rokovima, što se najčešće dešava kao posledica nepovoljnih vremenskih prilika. Istraživanje bi dalje trebalo usmeriti na odabir odgovarajućih biljnih vrsta i njihovih kombinacija (smeša) za međuuseve koje će pozitivno uticati na očuvanje plodnosti zemljišta, povoljno uticati na njegovu obradu, a time i na mogućnost proizvodnje kukuruza u uslovima suvog ratarenja.

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The influence of winter intercrops on the yield and yield components of maize in the subsequent sowing time

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Abstract

The aim of this study was to determine the effect of cover crops and interactions on yield and yield components of maize in the semi arid conditions. Research was carried out in the production years 2020 at the Rimski Šančevi experimental station of the Institute of Field and Vegetable Crops in Novi Sad. The winter cover crops consisted of the combined intercrops: winter pea (*Pisum sativum* ssp. *arvense* L.) + triticale (*Triticosecale*) (PT) and single-species cover crops winter pea (P) and control without cover crops (C), all with nitrogen fertilization 50 kg ha^{-1} (N50) and without the use of fertilizer (N0). The sowing of winter cover crops was carried out in autumn in the first decade of November, and their mulching and plowing was done in the last week of May. After plowing and soil preparation, maize (NS4051) was sown in the first decade of Jun and harvested in October. The statistical significance (p<0.05) was found between different variants regarding the use of cover crops. The highest yield was achieved in a mixture of PT (N0) 8.54 t ha^{-1}. The use of cover crops as green manure has a positive impact on the productive properties of maize with a reduction in inputs and possible lower production costs.

Key words: cover crops, mixture cover crops, green manure, maize

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