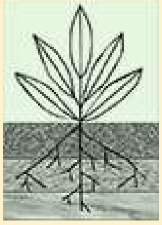
UDK: 631
Serbian Society of Soil Science

ISSN 0514-6658 (print) e-ISSN 2560-4279 (online)
Srpsko društvo za proučavanje zemljišta

ZEMLJIŠTE I BILJKA –

SOIL AND PLANT



ZEMLJIŠTE I BILJKA – SOIL AND PLANT, Vol. 71, No. 1, 2022

BEOGRAD 2022

Editors' Note

Dear Readers and Authors,

In recent years, despite the difficulties, thanks to the joint efforts of the editorial board and the leadership of the SDPS, it was possible to save the journal and even increase its category. Despite tangible progress, we still have a lot to do to improve the quality of the journal and its citation in order to attract more domestic and international contributors. Recently, the official website of the journal has been updated (https://sdpz.rs/casopis-zemljiste-i-biljka/). We have implemented an online submission system as well as online peer review (https://sdpz.rs/submission/).

I would like to take this opportunity to address the journal audience about the recently published book "Advances in Understanding Soil Degradation" by Springer Nature: https://link.springer.com/book/10.1007/978-3-030-85682- 3. Many members of the Soil Science Society of Serbia contributed to the book, which covers wide range of soil degradation issues.

Land degradation is undermining the wellbeing of two fifths of humanity, raising the risks of migration and economic and social conflict, according to the most comprehensive global assessment of the problem to date. As reported by the UN, a third of the planet's land is severely degraded and fertile soil is being lost at the rate of twenty-four billion tonnes a year. A decrease in productivity is observed on 20 % of the world's cropland, 16 % of forest land, 19 % of grassland and 27 % of rangeland

Paradoxically, the COVID-19 pandemic has shown that our environment can recover. Only about couple of years ago, we could not have imagined how nature would behave under the sharply reduced impact of human activity as many activities were forcibly suspended due to the pandemic at the beginning of 2020. However, as reported by a number of studies, even a few months of enforced human inaction not only immeasurably pleased the flora and fauna of the planet; it also had a positive effect on the quality of water and air and ultimately on the drivers of climate change.

This new reality has already shaken up economics and politics, but will the new reality help raise our awareness and change our attitude to natural resources and particularly to soil? I really want to believe that, in spite of the economic difficulties ahead, and thanks to united, collaborative wise decisions and efforts, we will be able to understand and accept that we can get by with fewer needs than we thought. Especially because an excessive consumerist attitude to natural resources, including the soil, will not save the poor from hunger and will not make the rich happier. Although the growing population must be fed and housed while conserving natural resources, we should not forget that 95 % of our food comes from the soil and about a third of the world's soil has already been degraded. It is not the high population density that is necessarily related to land degradation, but it is the attitude of the population to their soil resources that determines the extent of that degradation. This attitude, among others, is reflected in our inability to prevent our soil resources from being lost to degradation and its quality permanently declining, even though soil scientists have been aware of the issue for decades.

The editorial board thanks all the authors and staff of the journal and encourage both young and experienced researchers to contribute to the improvement of its quality by publishing interesting research results, review articles or short communications of ongoing research.

Be healthy and active,

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E. Saljnikov

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PUBLISHER: Serbian Society of Soil Science, Nemanjina 6, Zemun – Belgrade 11080 Serbia
IZDAJE: Srpsko društvo za proučavanje zemljišta, Nemanjina 6, Zemun – Beograd 11080 Srbija
Printed by Akademska izdanja, Zemun, Serbia

CIP– Каталогизација у публикацији
Народна библиотека Србије, Београд
631
ZEMLJIŠTE I BILJKA = Soil and Plant = Почва и растение/Editor-in-Chief
Elmira R. Saljnikov – God. 1, br. 1 (maj 1952) – Beograd – Zemun (Nemanjina 6): Srpsko društvo
za proučavanje zemljišta,
1952 – (Zemun Akademska izdanja). – 24 cm. -

Dva puta godišnje.
ISSN 0514-6658 (print) ISSN 2560-4279 (online) = Zemljište i biljka (online izd.)
COBISS.SR-ID 238151180

Official journal of the Serbian Society of Soil Science
Editorial office: 11000 Belgrade, Teodora Drajzera 7; editor.zib@gmail.com
URL: http://www.sdpz.rs/index.php/sr-yu/casopis-zemljiste-i-biljka#zemljiste-i-biljka—-soil-and-plant

Content

Original paper DOI: 10.5937/ZemBilj2201001D

Land use impact on soil structure of Pseudogleys in southern Mačva and Pocerina, Serbia

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Abstract

The impact of various types of uses of Pseudogley soils in southern Mačva and Pocerina on theiraggregate distributionand stability was studied on soil samples collected from profiles under forest, meadow and arable land, at three localities. The aggregate composition and stability were determined by Savinov'smethod. The soil structure was assessed by using Revut's coefficient of soil structure (Ks) and Vershinin's coefficient of soil aggregate structure (K_A). The results show that the studied Pseudogley soils are characterized by an unfavorable structure, while the type of land use has a significant impact on the aggregate composition and stability, especially in surface Ah and Ahp horizons, where these differences are the most pronounced. The most favorable aggregate composition and highest wet-stability are found in Pseudogley profiles under forest vegetation. The aggregate distribution of meadow profiles was intermediate and of arable land the poorest. Statistical analysis of the collected data shows that Ks values, determined by dry sieving, were the highest in forest profiles (2.26±1.21 on average), while the values for meadow were 1.59±1.09 and of arable land 1.14±0.62. The values of K_A, used to assess the aggregate stability to water, also show that forest Pseudogleys have the highest average values (2.05±1.03), followed by meadow (1.96 ±0.99) and cultivated soils (1.93±1.22). The results of correlation analysis indicate that Ks is negatively correlated with clay, pH value and base saturation, but positively correlated with soil humus (r=-0.77, -0.70, -0.81 and 0.79, respectively, $p<0.01$). Conversely, K_A is negatively correlated with humus and positively correlated with clay, pH value and base saturation (r=-0.21, 0.82, 0.69 and 0.69, respectively, $p<0.01$).

Keywords: Pseudogley, dry aggregate distribution, aggregate stability to water, forest, meadow, arable land

Introduction

Pseudogley is among the most widespread soil types in Serbia. More than 400,000 ha of land has been mapped (Đorđević and Radmanović, 2018) and roughly 75% of this type of soil is found in western Serbia. Pseudogley occupies 70,640 ha in the regions of Mačva, Pocerina and Jadar (Tanasijević and Pavićević, 1953). Forest vegetation used to be the Pseudogley cover in the study area, but was replaced over time by meadow and arable land (Tanasijević and Pavićević, 1953; Tanasijević et al., 1966). Today, there are 3,200 ha of forests in southern Mačva and Pocerina, in the form of small

DOI: 10.5937/ZemBilj2201001D

oases. Meadows occupy only about 2% of the study area. Only a small part are meadows that have been used for decades; the majority are fields grassed in the past 10-15 years. There is roughly 14,000 ha of arable land, where largely cereal crops are grown with generally low yields. It is for those reasons that southern Mačva and Pocerina were selected for this research. The study area is about 18,000 ha and highly suitable for investigating the differences in Pseudogley properties potentially caused by various long-term land uses.

The soil structure from a fertility perspective plays a very important role, especially in the case of soils with a heavy mechanical composition such as Pseudogley, because it directly affects the other physical, chemical and biological properties. Plant access to water and nutrients, aeration, and biological activity directly depend on the soil structure, so that soil structure needs to be considered as the focal point of soil fertility (Hađić et al., 1991; Oades, 1984; Six et al., 2000). From an agricultural perspective, the most favorable soils are those with a lumpy and crumbly structure, with an aggregate size of 1-10 mm, optimally 2-3-5 mm, which are also water-stable and with a high aggregate porosity (Kachinsky,1956; Voronin,1986). Vershinin (1958) determined that the best aggregates for plant growth are 2-3 mm, closely associated 1-2 and 3-5 mm. After studying arable land Pseudogley at southern Mačva (Dugonjić et al., 2008) report that the largest content of the optimal diameter (1-10 mm) aggregate was found in the plow layer and that it was dominated by the most agronomically favorable aggregates –1-5 mm. However, the plow layer also exhibits the lowest stability of structural aggregates, which is a result of intensive use, high acidity and low base saturation, primarily with Ca-ions (Resulović et al., 1969). In addition, long-term use of mineral fertilizers has had a negative effect on macroaggregate stability, at times by as much as 50% compared to the control (Vojinović, 1973). The objective of the present research was to show how land use has affected the Pseudogleys of southern Mačva and Pocerina, in terms of dry aggregate distribution and stability to water.

Materials and Methods

The study encompassed three locations in southern Mačva and Pocerina (Fig.1). The Pseudogley profiles opened at Petkovica (profiles No 1 forest 44°41'34" N, 19°27'01" E; No 10 meadow 44°41'35" N, 19°27'00" E and No 19 arable land 44°41'35" N, 19°27'04" E, 132-133 m al) and Bogosavac (No 3 forest 44°43'59" N, 19°35'05" E; No 12 meadow 44°44’03 N, 19°35'03" E and No 21 arable land 44°44'02" N, 19°35’05" E, 126-133 m al) were in southern Mačva, lowland subtype, and those at Slatina (No 9 forest 44° 38'26" N, 19° 38'05" E; No 18 meadow 44°38'37" N, 19°37'58" E; and No 27 arable land 44°38'35" N, 19° 38'01" E, 205-230 m al) in Pocerina, slope subtype (Škorić et al., 1985).

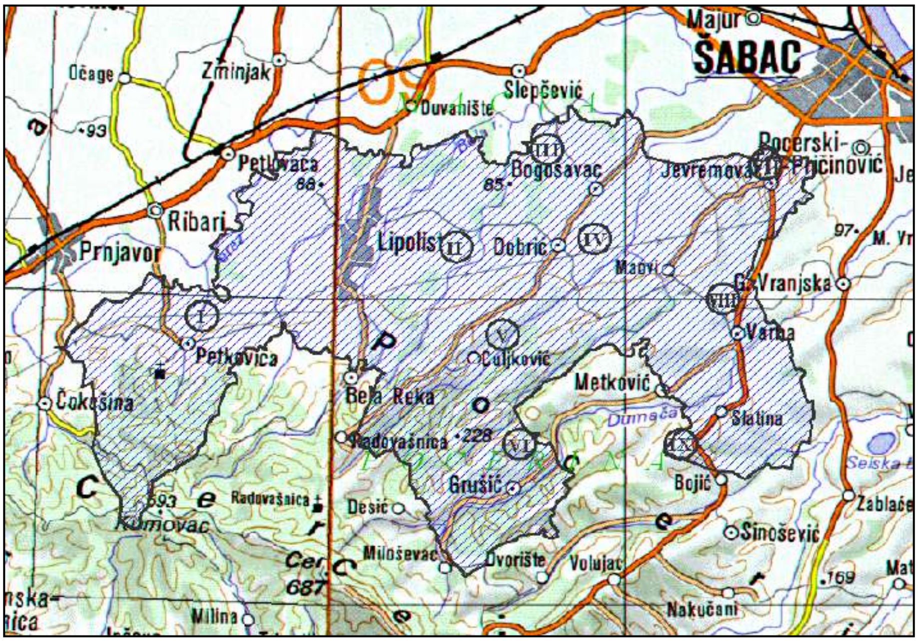

Figure 1. Study area

The soil texture and basic chemical properties were determined by standard methods (JDPZ, 1997; JDPZ, 1966), as follows: texture by the pipette method using samples prepared with sodium pyrophosphate; organic C by Turin's method; pH by the electrometric method; and hydrolytic acidity and total absorbed alkaline cations by Kapen's method. Total adsorption capacity and base saturation were calculated.

The aggregate composition and structural stability were determined by Savinov's method (Korunović and Stojanović, 1989).Soil structure was assessed by calculating:(1) Revut's coefficient of soil structure, K_S= a/b, where a = is the mesoaggregate content (10-0.25 mm), and b is the sum of macro- (>10 mm) and microaggregates (<0.25 mm), after dry sieving (Revut, 1972), and (2) Vershinin's coefficient of soil aggregate structure, K_A= a/b, where a is the mesoaggregate content and b is the microaggregate content, after wet sieving (Vershinin,1958).

The results were statistically processed by correlation analysis and t-test using StatSoft, Inc. Statistica software for Windows, Version 8.

Results and Discussion

Table 1 below contains the results of soil sample analyses after dry sieving. They show large aggregate distribution differences between the various land uses and horizons of the studied Pseudogley profiles.

The structure of the forest Pseudogley in both surface and deeper horizons was more favorable than that of meadow and particularly arable land Pseudogleys.

The content of optimal-diameter (0.25–10 mm) aggregates in the three forest profiles that were studied, taking into account all four depth zones, was 65.8% on average. The largest proportion was found in the surface Ah horizon – 74.9–82.2% (78.8% on average), which constitutes 4/5 of all structural aggregate fractions. Among these aggregates, the most widespread was of the agronomically most favorable diameter, 1–5 mm, whose average content was 50.4%.

Table1. Aggregate distribution of forest, meadow and arable land Pseudogleys

Profile	Horizon	Depth cm	Aggregate diameter (mm)										K_S*
			Macro aggr. > 10	Mesoaggregates							Micro aggr. < 0.25	Total 1-5	
				10-5	5-3	3-2	2-1	1.0 - 0.5	0.5 - 0.25	10.0 - 0.25			
Forest													
1	Ah	0-20	12.6	19.3	13.4	16.9	25.6	4.28	2.77	82.2	5.34	55.9	4.62
	Eg	20-37	19.7	24.1	16.1	14.4	19.1	2.49	1.24	77.4	2.91	49.6	3.43
	Btg	37-75	32.2	28.6	16.2	11.0	8.12	1.07	0.84	65.8	2.05	35.3	1.92
	BtgC	75-102	40.3	29.3	11.4	8.04	8.69	0.47	0.32	58.2	1.50	28.2	1.41
3	Ah	0-18	22.1	26.5	18.3	14.2	11.9	3.06	0.65	74.9	3.07	44.4	2.98
	Eg	18-36	31.4	22.7	12.3	18.0	11.5	0.76	0.52	65.8	2.84	41.8	1.92
	Btg	36-75	47.8	25.2	9.64	6.80	7.54	0.65	0.40	50.2	2.01	23.9	1.01
	BtgC	75-105	47.5	27.3	11.7	6.98	5.00	0.47	0.18	51.6	0.86	23.7	1.07
9	Ah	0-17	16.7	20.0	12.6	17.6	20.8	6.75	1.56	79.4	3.95	51.0	3.96
	Eg	17-33	28.2	23.6	18.6	14.1	11.0	1.34	0.74	69.4	2.36	43.7	2.27
	Btg	33-75	40.2	27.4	15.7	8.06	5.28	1.02	0.51	58.0	1.81	29.1	1.38
	BtgC	75-102	44.8	26.7	13.8	5.68	7.01	0.40	0.26	53.9	1.35	26.5	1.17
Meadow													
10	Ah	0-22	13.2	30.1	23.1	12.9	15.1	4.72	1.28	81.17	3.16	51.1	4.02
	Eg	22-42	32.7	25.7	14.3	13.6	9.37	1.69	0.79	65.47	1.88	37.3	1.90
	Btg	42-75	47.2	22.4	15.9	7.06	5.21	0.69	0.29	51.57	1.19	28.2	1.06
	BtgC	75-102	46.2	26.1	12.8	9.01	4.10	0.56	0.15	52.73	1.09	25.9	1.12
12	Ah	0-23	26.3	28.2	16.0	9.87	11.8	4.11	1.16	68.9	4.81	37.7	2.22
	Eg	23-43	46.0	20.6	11.7	9.03	8.06	1.87	0.90	52.2	1.79	28.8	1.09
	Btg	43-75	58.4	18.8	8.36	4.79	7.14	0.94	0.63	40.7	0.96	20.3	0.69
	BtgC	75-105	64.3	17.1	5.94	6.21	4.88	0.51	0.41	35.0	0.72	17.0	0.54
18	Ah	0-20	18.0	27.1	19.0	11.3	12.7	5.23	1.55	76.8	5.12	43.0	3.31
	Eg	20-35	38.7	20.4	15.2	8.76	10.2	3.02	1.39	59.0	2.27	34.2	1.44
	Btg	35-75	47.1	21.3	12.4	8.41	7.50	1.08	0.62	51.2	1.71	28.3	1.05
	BtgC	75-102	58.4	21.8	9.89	4.82	2.10	0.71	0.34	39.7	1.94	16.8	0.66
Arable land													
19	Ahp	0-24	24.4	28.8	14.9	11.5	10.9	3.14	1.17	70.4	5.12	37.3	2.38
	Eg	24-42	34.1	23.1	16.4	8.60	12.1	2.05	1.08	63.4	2.27	37.1	1.73
	Btg	42-75	56.3	20.9	8.38	5.47	4.79	1.72	0.65	41.9	1.71	18.6	0.72
	BtgC	75-102	53.7	27.6	10.1	3.32	2.71	1.10	0.31	45.1	1.94	16.1	0.82
21	Ahp	0-24	39.0	31.7	10.3	4.06	7.14	3.78	0.47	57.6	3.39	21.5	1.36
	Eg	24-45	49.4	27.2	11.8	3.86	5.03	1.05	0.36	49.3	1.34	20.7	0.97
	Btg	45-75	66.0	20.7	7.83	2.80	1.58	0.50	0.28	33.7	0.27	12.2	0.51
	BtgC	75-105	64.3	20.2	8.71	3.75	2.20	0.47	0.24	35.6	0.18	14.7	0.55
27	Ahp	0-22	31.9	27.7	14.2	10.5	9.40	2.76	1.10	65.7	2.43	34.2	1.91
	Eg	22-38	39.9	24.7	14.5	8.37	10.8	0.56	0.31	59.3	0.79	33.7	1.45
	Btg	38-75	59.9	20.3	10.0	5.68	3.40	0.29	0.14	39.8	0.32	19.1	0.66
	BtgC	75-102	62.1	17.0	10.4	6.23	3.53	0.26	0.61	37.6	0.27	20.2	0.60

*K_S= a/b; K_S– coefficient of soil structure, a – mesoaggregate content, and b – sum of macro- and microaggregates.

Original paper DOI: 10.5937/ZemBilj2201001D

Meadow Pseudogleys exhibited a slightly poorer structure than forest but better than arable land. In the surface Ah horizon, the 1–5 mm aggregate content of meadow Pseudogleys was 43.9% on average and that of arable land Pseudogleys 31.0%. The content of the agronomically most favorable medium-to-coarse crumbly aggregates (1–5 mm) and the finest aggregates (<0.25 mm), as well as those of 0.5–0.25 mm whose proportion was generally small, significantly decreased with depth.

The fraction of the largest-diameter (>10 mm) macroaggregates exhibited the highest values in the plow layer of the arable land Pseudogley, 31.7% on average, which was an 85% and 66% larger content than in the surface horizon of the forest and meadow Pseudogleys, respectively. The content of these aggregates increased substantially with depth, especially in the arable land profiles, compared to meadow and particularly forest Pseudogleys.

In addition to determining the content of the aggregates of various sizes, the aggregate composition was assessed using Revut's coefficient of soil structure (Ks). The value of this coefficient in the case of forest profiles was 2.26±1.21, of meadow profiles 1.59±1.09 and of arable land profiles 1.14±0.62. Large standard deviations suggest major differences in the Pseudogley aggregate compositions, depending on land use. Statistical data processing revealed that the values were much higher in the case of forest profiles, compared to meadow (t=6.84, p=0.01) and arable land (t=6.21, p<0.01), as well as higher of the meadow than arable land (t=2.84, p<0.05). The differences were the largest between the surface horizons (forest vs. meadow t=14.18, p<0.01; forest vs. arable land t=10.74, p<0.01; and meadow vs. arable land t=5.64, p<0.05), suggesting that the effect of land use on the aggregate distribution of this horizon was dominant, relative to the other horizons.

Table 2 shows the results of analyses of wet-sieved soil samples. They also indicate large differences in the water-stable aggregate content between the various land uses and Pseudogley horizons. The largest proportion of water-stable aggregates >0.25 mm was found in the forest Pseudogleys and it amounted to 41.1–81.0% (64.1% on average). The content of water-stable aggregates >0.25 mm in the Ah horizon was in the 51.7–73.9% interval (65.1% on average). Aggregates >1 mm, with an average content of 31.8%, exhibited the highest stability. Among these, the largest proportion was of the fraction >3 mm (15.1% on average).

The surface horizon of the meadow Pseudogley revealed 14.6% fewer water-stable aggregates >0.25 mm, compared to the same forest horizon. The largest proportion was of the aggregates >1 mm (35.8% on average).

The arable land profiles exhibited the smallest proportion of water-stable aggregates >025 mm, which ranged from 38.6 to 79.2% (60.1% on average). The water-stable aggregate content of the plow layer (Ahp) was 46.1% on average, which was 40.1% less than forest and 29.4% less than meadow. The stability of the agronomically most favorable structural aggregates (diameter 1–5 mm) was very low. Their content was 1.2–2.6 times smaller than in the Ah horizon of the forest and meadow Pseudogleys. Contrary to the forest and meadow Pseudogleys, finer aggregates (diameter 1-

0.5 mm, content 16.5.26-2%, or 22.3% on average) of the surface horizon exhibited the highest stability to water, as did 0.5–0.25 mm, whose proportion was 13.0–14.0% (13.4% on average). The lowest stability to water was found in the case of aggregates >1 mm, especially those >3 mm, 1.16–2.27%.

Table 2. Water-stable aggregates (%) of forest, meadow and arable land Pseudogleys

Pro file	Horizon	Depth cm	Aggregate diameter (mm)						Micro aggr. < 0.25	Total 1-5	K_A*
			> 3	3-2	2-1	1-0.5	0.5-0.25	> 0.25			
						Forest					
1	Ah	0-20	7.82	1.48	6.93	24.7	10.3	51.7	48.3	16.2	1.07
	Eg	20-37	2.72	0.50	3.40	21.3	13.2	41.1	58.9	6.62	0.70
	Btg	37-75	2.78	1.14	15.1	27.1	11.2	57.3	42.7	19.0	1.34
	BtgC	75-102	1.98	1.74	21.6	30.8	9.70	65.9	34.1	25.3	1.93
3	Ah	0-18	21.4	6.46	13.0	20.7	12.2	73.9	26.1	40.9	2.83
	Eg	18-36	5.37	2.01	18.3	29.5	9.35	64.6	35.4	25.7	1.82
	Btg	36-75	31.8	10.8	14.5	12.4	6.16	75.9	24.1	57.4	3.16
	BtgC	75-105	38.0	6.92	15.2	17.1	3.74	81.0	19.0	60.1	4.27
9	Ah	0-17	16.0	6.14	16.1	21.7	9.82	69.8	30.2	38.3	2.32
	Eg	17-33	4.32	2.46	12.2	20.3	8.76	48.0	52.0	19.0	0.92
	Btg	33-75	7.56	5.78	16.0	25.2	8.82	63.2	36.8	29.3	1.72
	BtgC	75-102	9.56	7.98	21.6	25.6	6.62	71.4	28.6	39.1	2.49
						Meadow					
10	Ah	0-22	10.7	2.08	9.28	12.9	7.52	42.5	57.5	22.1	0.74
	Eg	22-42	3.70	1.12	7.88	14.1	11.3	38.1	61.9	12.7	0.62
	Btg	42-75	8.24	5.34	14.8	23.8	14.6	66.8	33.2	28.4	2.01
	BtgC	75-102	10.8	8.00	13.1	21.0	11.5	64.5	35.5	32.0	1.82
12	Ah	0-23	29.1	5.20	10.0	14.2	7.72	66.3	33.7	44.3	1.96
	Eg	23-43	6.91	4.47	18.8	17.2	10.0	57.8	42.2	30.2	1.37
	Btg	43-75	35.0	9.02	21.3	11.3	2.60	79.1	20.9	65.3	3.79
	BtgC	75-105	30.4	6.10	23.8	13.8	3.82	77.9	22.1	60.3	3.53
18	Ah	0-20	24.0	4.64	12.5	14.0	6.70	61.8	38.2	41.1	1.62
	Eg	20-35	10.1	6.90	14.4	15.2	7.36	53.9	46.1	31.4	1.17
	Btg	35-75	15.6	8.16	19.5	20.9	6.16	70.3	29.7	43.3	2.37
	BtgC	75-102	12.6	7.74	26.1	19.8	6.12	72.4	27.6	46.5	2.62
						Arable land					
19	Ahp	0-24	1.06	1.26	5.72	16.5	14.0	38.6	61.4	8.04	0.63
	Eg	24-42	0.58	1.04	9.66	14.9	9.76	35.7	64.3	11.3	0.56
	Btg	42-75	0.88	1.84	19.2	23.3	16.6	61.8	38.2	21.9	1.62
	BtgC	75-102	0.86	3.97	27.8	25.2	8.54	66.4	33.6	32.7	1.98
21	Ahp	0-24	2.72	2.04	8.16	26.2	13.3	52.4	47.6	12.9	1.10
	Eg	24-45	3.76	4.71	18.9	25.1	9.59	62.0	38.0	27.3	1.63
	Btg	45-75	31.8	7.56	20.5	11.5	6.42	77.8	22.2	59.9	3.50
	BtgC	75-105	35.7	6.29	18.9	10.8	8.38	79.2	20.8	60.8	3.81
27	Ahp	0-22	1.56	1.72	6.96	24.0	13.0	47.3	52.7	10.2	0.90
	Eg	22-38	0.80	1.96	10.2	21.5	10.7	45.2	54.8	13.0	0.82
	Btg	38-75	2.42	7.52	22.5	28.3	15.1	75.8	24.2	32.4	3.13
	BtgC	75-102	4.78	7.62	25,9	29.3	10.0	77.7	22.3	38.3	3.48

***** K_A= a/b; K_A– coefficient of soil aggregate structure, a – mesoaggregate content, and b – microaggregate content

A much smaller humus content (Table 3), intensive land use, cultivation often beyond the interval of physical maturity, use of mineral fertilizers (primarily nitrogen-based), and a poorer effect of roots and soil fauna on aggregation all result in a considerably smaller proportion of coarse water-stable aggregates >1mm, particularly >3mm, in the surface horizon of arable land Pseudogley, compared with the same meadow and especially forest horizons. The results are consistent with the theory of hierarchical aggregation, according to which microaggregates unite using relatively biodegradable organic matter and create macroaggregates (Tisdall and Oades, 1982). Consequently, a change in land use has a major effect on macroaggregates, compared to microaggregates (Ashagrie et al., 2007; Bouajila et al., 2021; Puget et al., 2000; Spohn and Giani, 2011). Many researchers have associated deterioration of structural properties with reduced content of organic matter in the soil (Six et al., 2000; Spohn and Giani, 2011), which was corroborated by the present research. Namely, compared to the forest Pseudogley, the humus content was much smaller in the meadow ($t=-3.60$, $p<0.1$) and arable land Pseudogleys ($t=-3.11$, $p=<0.01$).

In the eluvial (Eg) horizon, the content of water-stable aggregates in the meadow and especially forest profiles rapidly decreased due to a sudden decrease in humus content. There was slightly more humus in the arable land profiles.

In the illuvial Pseudogley (Btg and BtgC) horizons, due to a considerable increase in clay content, there were more water-stable aggregates >0.25 mm, especially in the case of arable land Pseudogley, by as much as 60%, compared to the Ahp horizon. Among them, aggregates >1 mm were the most stable. The largest content of microaggregates <0.25 mm in the surface horizon was found in the arable land profiles, followed by meadow and forest. The content of these aggregates gradually decreased with depth of all the profiles.

Based on the results of dry and wet sieving of soil samples, it follows that the destruction of primary forest vegetation and conversion to meadow and especially arable land in the study area (Mačva and Pocerina) has led to considerable structural deterioration, particularly of the Ahp horizon. It is the most important horizon for farming and contains fewer agronomically stable structural aggregates (diameter 1–5 mm) by a factor of 1.2-2.6, compared to the Ah horizon of the forest and meadow Pseudogleys.

Vershinin's coefficient of soil aggregate structure (K_A) was used to assess the stability to water. Based on this coefficient, the values of forest Pseudogley profiles were the highest (2.05±1.03 on average), followed by meadow (av. 1.96±0.99) and arable land (av. 1.93±1.22). Taking into account the overall depth of the soil profiles, statistical analysis showed small or insignificant differences (forest vs. meadow $t=0.49$, $p=0.63$; forest vs. arable land $t=0.46$, $p=0.66$; and meadow vs. arable land $t=0.23$, $p=0.81$). The differences were larger in the case of the A horizons (forest vs. meadow $t=3.97$, $p=0.63$; forest vs. arable land $t=3.08$, $p=0.09$; and meadow vs. arable land $t=2.45$, $p=0.13$). Similar to Revut's coefficient of soil structure (Ks), standard deviation indicated that

Vershinin's coefficients (K_A) also varied among the forest, meadow and arable land profiles, but the differences were smaller compared with those based on Ks.

Table 3. Texture and basic chemical properties of forest, meadow and arable land Pseudogleys

Pro file	Depth	Sand	Silt	Clay	Humus	pH in H_2O	T - S	S	T	V
	cm	%	%	%	%		mEq/100 g			%
					Forest					
1	0-20	35.8	43.0	21.2	3.10	4.64	17.6	3.18	20.7	14.9
	20-37	33.2	42.3	24.5	1.44	4.75	13.8	3.48	17.3	20.1
	37-75	28.6	38.2	33.2	0.91	5.20	10.1	10.0	20.1	49.9
	75-102	28.3	37.4	34.3	0.81	5.27	8.49	13.5	22.0	61.4
3	0-18	22.9	41.3	35.8	3.92	4.91	20.1	13.9	34.0	40.9
	18-36	22.8	37.7	39.5	1.84	5.41	11.0	19.7	30.7	64.2
	36-75	20.1	35.5	44.4	0.98	6.03	4.71	26.3	31.0	84.8
	75-105	20.8	35.0	44.2	0.96	7.05	1.89	30.2	32.0	94.2
9	0-17	30.3	42.8	26.9	3.04	4.67	24.8	5.80	30.6	18.9
	17-33	29.6	42.0	28.4	1.45	4.84	20.4	6.60	27.0	24.4
	33-75	24.3	41.9	33.8	0.93	5.50	9.79	15.1	24.8	60.6
	75-102	23.7	37.8	38.5	0.81	5.69	6.29	18.2	24.4	74.3
					Meadow					
10	0-22	34.1	42.7	23.2	1.82	4.97	11.0	4.24	15.2	27.8
	22-42	31.3	40.2	28.5	0.95	5.42	6.92	7.32	14.2	51.4
	42-75	29.8	37.5	32.7	0.90	5.63	6.60	12.0	18.6	64.5
	75-102	29.5	37.2	33.3	0.83	5.72	5.97	13.2	19.1	68.8
12	0-23	27.9	40.2	31.9	2.17	5.28	9.66	12.9	22.5	57.1
	23-43	26.9	38.0	35.1	1.03	5.47	7.23	14.1	21.3	66.1
	43-75	24.3	33.5	42.2	0.80	5.97	6.29	17.6	23.8	73.6
	75-105	24.3	33.1	42.6	0.72	6.39	4.21	21.1	25.3	83.3
18	0-20	29.8	45.5	24.7	2.09	5.94	6.29	12.0	18.3	65.6
	20-35	27.1	42.0	30.9	0.83	5.70	5.97	12.4	18.3	67.4
	35-75	22.7	37.8	39.5	0.64	5.78	5.95	15.5	21.4	72.2
	75-102	22.1	37.0	40.9	0.61	5.81	5.90	16.2	22.1	73.3
					Arable land					
19	0-24	33.1	43.2	23.7	2.04	4.86	13.8	4.08	18.0	23.1
	24-42	32.1	41.7	26.2	0.98	5.06	10.1	5.00	15.1	33.2
	42-75	29.6	37.0	33.4	0.83	5.27	8.80	9.68	18.5	52.4
	75-102	28.8	36.2	34.0	0.79	5.44	7.23	12.8	20.0	63.8
21	0-24	27.6	40.0	32.4	1.99	5.23	13.5	10.4	23.9	43.6
	24-45	27.1	39.7	33.3	1.12	5.78	5.66	13.2	18.8	69.9
	45-75	26.7	32.3	41.0	1.00	6.23	4.71	21.6	26.3	82.1
	75-105	27.0	33.3	39.7	0.73	6.57	3.15	24.0	27.1	88.4
27	0-22	29.0	45.6	25.4	1.75	5.53	11.3	10.0	21.4	47.0
	22-38	27.8	39.5	32.7	0.84	6.16	5.19	15.5	20.7	74.9
	38-75	23.3	39.2	37.5	0.81	6.19	5.03	17.4	22.4	77.6
	75-102	23.7	38.2	38.1	0.74	5.90	5.97	18.8	24.8	75.9

Soil aggregation involves the formation and stabilization of structural aggregates. These two processes essentially take place at the same time (Amezketa, 1999). Stabilization is aided by stabilizing substances, organic or inorganic such as clay, bivalent and trivalent cations, carbonates and gypsum (Cornu et al., 2006). Consequently, the correlation analysis indicated a connection between the aggregate composition and stability of structural aggregates of the studied Pseudogleys and their texture and chemical properties. Ks negatively correlated with clay, pH and base saturation, and positively correlated with humus (r=-0.77, -0.70, -0.81 and 0.79, respectively, $p<0.01$). Conversely, K_A negatively correlated with humus and positively correlated with clay, pH and base saturation (r=-0.21, 0.82, 0.69 and 0.69, respectively, $p<0.01$). Conversion of forest into meadow and arable land has caused significant variations in the aggregate distribution and stability, which are attributable to changes in soil texture and basic chemical properties. According to Six and Paustian (2014), soil cultivation disrupts aggregate formation and stability because soil aggregates cannot be physically protected from microbial decomposition, causing an increase in humus mineralization. Humic substances are considered to be persistent cementing agents related to the formation and stabilization of soil aggregates, where their molecular composition plays a predictive role in the soil aggregation process (Fei et al., 2021). According to He et al. (2021), free and occluded light soil organic carbon (SOC) play major roles in macroaggregate stability, probably because the positive effect of SOC on van der Waals attractive force between soil particles can limit the release of microaggregate. However, an increase in SOC does not always result in a decrease in microagglomeration or re-flocculation of small soil particles. Small particles of some types of soils with high SOC were difficult to re-flocculate when they were released from the mechanical breakdown of macroaggreates. Many other soil properties can limit SOC's roles and induce repulsive forces, which are stronger than attractive forces between soil particles. Thus, apart from a considerable decrease in humus content, compared to the forest Pseudogley, the meadow and arable land profiles showed a substantial increase in pH levels (2.47 and 2.79, respectively, $p<0.5$) and base saturation (t=2.49 and 2.27, respectively, $p<0.5$). Contrary to the chemical properties, the clay content of the arable land Pseudogley decreased, compared to forest and meadow, but the differences were not statistically significant. It follows from the above that the action of certain stabilizing substances improved in arable land Pseudogleys, and decreased in others. This has likely caused a considerably poorer aggregate composition, but also less pronounced differences in aggregate stability, compared to forest and meadow.

Numerous researchers report similar results, attesting to structural deterioration of plow and subplow layers of Pseudogley and other soils, after conversion of forest and meadow into arable land (Dugonjić, 2001; Dugonjić and Đorđević, 2007; Dugonjić et al., 2008, Dugalić, 1998; Dugalić et al., 2019; Vojinović, 1973; Cupać et al., 2006; Gajić, 1998; Gajić and Živković, 2006; Gajić et al., 2010; Marković, 2000; Kretinin and Lenov, 1978; Dilkova and Kerchev, 1986; Beare et al., 1994).

Original paper DOI: 10.5937/ZemBilj2201001D

Conclusions

The studied Pseudogley soils of southern Mačva and Pocerina (Serbia) demonstrated rather unfavorable aggregate distributions and water-unstable structures. Land use appears to have had a considerable effect, particularly on surface horizons.

Compared to meadow and arable land, forest Pseudogley profiles were found to have the best structure and the largest content of optimal-diameter (0.25–10 mm) aggregates, dominated by the agronomically most favorable diameter 1–5 mm, in both surface and deeper horizons.

Arable land Pseudogley profiles showed the smallest content of water-stable aggregates >0.25 mm, which was 40% less in the forest and 29% less in the meadow surface horizons. Among the water-stable aggregates, the least stable were the agronomically most favorable aggregates (diameter 1–5 mm), whose content in the plow layer was smaller than in the surface horizons of the forest and meadow Pseudogleys by a factor of 1.2–2.6.

Statistical analysis showed that Revut's coefficient of soil structure (Ks) was much higher in the case of forest profiles than meadow or arable land. Vershinin's coefficient of soil aggregate structure (K_A), which is used to assess the stability to water of structural aggregates, was higher in the case of forest and meadow profiles, compared to arable land, but the differences were not statistically significant. These differences were found to be larger between the A horizons.

Destruction of primary forest vegetation and conversion into meadows and arable land have caused considerable structural deterioration of the soil, especially of the arable land Pseudogley plow layer, which is one of the main reasons for the low Pseudogley productivity in southern Mačva and Pocerina.

Acknowledgment

This work was partially supported by the Ministry of Education, Science and Technological Development of the Republic of Serbia (Grant no. 451-03-9/2021-14/200116).

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Original paper DOI: 10.5937/ZemBilj2201001D

Uticaj načina korišćenja na strukturu pseudogleja južne Mačve i Pocerine, Srbija

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Izvod

Istraživan je uticaj načina korišćenja pseudogleja južne Mačve i Pocerine na agregatni sastav i stabilnost strukturnih agregata na zemljišnim uzorcima uzetim iz profila pod šumskom, livadskom i njivskom vegetacijom, sa 3 lokaliteta. Agregatni sastav i stabilnost strukturnih agregata određeni su metodom Savinov-a. Za ocenu strukture zemljišta korišćeni su Revut-ov koeficijent strukturnosti i Vershinin-ov koeficijent agregatnosti zemljišta. Rezultati istraživanja pokazali su da se istraživana pseudoglejna zemljišta karakterišu nepovoljnom strukturom, a da način korišćenja ima veliki uticaja na agregatni sastav i stabilnost strukturnih agregata, naročito u površinskim Ah i Ahp horizontima, gde su te razlike najizraženije. Najpovoljniji agregatni sastav i najveću otpornost agregata prema rasplinjavajućem dejstvu vode pokazali su profili pseudogleja pod šumskom, zatim pod livadskom, dok su profili pod njivskom vegetacijom pokazali najlošiji agregatni sastav. Statistička obrada podataka pokazala je da su vrednosti Revut-ovog koeficijenta strukturnosti (Ks), dobijenog suvim prosejavanjem, u profilima pod šumskom vegetacijom najveće, i u proseku iznose 2.26±1.21, pod livadskom 1.59±1.09, a pod njivskom 1.14±0,62. Vrednosti Vershinin-ovog koeficijenta agregatnosti (K_A), za ocenu stabilnosti strukturnih agregata,dobijenog mokrim prosejavanjem, takođe su pokazale da profili pseudogleja pod šumskom vegetacijom pokazuju u proseku najveće vrednosti (2.05±1.03), potom pod livadskom (1.96±0.99), dok su profili pod njivskom pokazali najmanje vrednosti (1.93±1.22). Rezultati korelacijone analize pokazali su da je Ks u negativnoj korelaciji sa glinom, pH i stepenom zasićenosti zemljišta baznim katjonima, a u pozitivnoj korelaciji sa humusom (r=-0.77, -0.70, -0.81 i 0.79, redom, p<0.01), dok je K_A u negativnoj korelaciji sa humusom, a u pozitivnoj sa glinom, pH i stepenom zasićenosti zemljišta baznim katjonima (r=-0.21, 0.82, 0.69 i 0.69, redom, p<0.01).

Ključne reči: pseudoglej, agregatni sastav, stabilnost strukturnih agregata, šuma, livada, njiva

Received 25.06.2021
Revised 18.03.2022
Accepted 24.03.2022

Original paper DOI:10.5937/ZemBilj2201015H

The effects of the „Stomp“ herbicide application on the microbial prevalence in the soil

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Abstract

Agricultural production has benefited a lot from herbicides; however, the use of herbicides caused many environmental problems. Herbicide application can affect the biodiversity of an ecosystem by killing non-target organisms. Microorganisms in the soil are important factors for plant growth; they represent the biological factor of soil fertility. Herbicides can have a beneficial effect on the development of some microorganisms and a negative on others, leading to depletion of microbial diversity in soil. The objective of this work is to determine microbial activity in the soil and to isolate herbicide-resistant bacteria after the use of the “Stomp” herbicide. Agar plate method was used for the determination of microbial prevalence in the soil. The results showed an increase in the total number of bacteria, ammonifiers, fungi, and actinomycetes. Nine isolates, mostly Gram-positive spore-forming rods, showed an ability to grow in the mineral salt medium with different concentrations of “Stomp” herbicide. Isolates G1/1 and G1/2, showed high level of tolerance at the initial pendimethalin concentration of 25 mg/l. Those isolates have the potential to be used to decontaminate herbicide affected ecosystems.

Key words: “Stomp” herbicide, microbial prevalence, pendimethalin, soil

Introduction

Herbicides are a broad group of agrochemicals that, regardless of benefits they have on plants, may cause environmental problems (Kanissery and Sims, 2011). During the last several decades, herbicides are intensively rinsed through agricultural soils which caused contamination of the surface and subsurface water (Graymore et al., 2001).

Herbicide that widely used in plant production is Pendimethalin [N-(1-ethylpropyl)-3,4-dimethyl-2, 6-dinitrobenzenamine] is in the focus of presented research. Its brand name is “Stomp 330 E”.

Stomp belongs to the dinitroaniline group (Ni et al., 2016). This herbicide controls various weeds during the production of field crops, fruits and vegetables (Kočarek et al., 2016). Regardless of its low solubility in water, pendimethalin can enter the water ecosystems and exceed the concentration limits in groundwaters proposed by EU legislative (Kjær et al., 2011), furthermore, half-life of pendimethalin depends on the various abiotic and biotic factors; Rose et al. (2016), and Walker and Bond (1977) reported the half-life of 90, and 563 days, respectively. Several studies also showed that cancer incidence was associated with pendimethalin exposure (Hou et al., 2006; Andreotti et al., 2009). Meister (1992) and Strandberg and Scott-Fordsmand (2004) found the toxicity of pendimethalin for aquatic living organisms.

Although microorganisms play a key role in nutrient cycling and decay of organic residues (Kumar et al., 2016), they are also involved in biodegradation of xenobiotics, i.e. environmental pollutants such as nitroaromatic pesticides (Kulkarni and Chaudhari, 2007). Microbes have ability to grow on organic pollutants and degrade them to less toxic or non-toxic products (Diez, 2010). Several pendimethalin-degrading microorganisms have been isolated from various environments and described, including *Bacillus* (Megadi et al., 2010; Ni et al., 2016), *Pseudomonas* (Elsayed and El-Nady, 2013), *Clavispora* (Han et al., 2019) etc. Therefore, selection of indigenous microbial strains capable of rapid growth on pendimethalin as a unique carbon and energy source may have a practical application in contaminated environments.

The objective of this paper is to determine the microbial prevalence in soil after application of “Stomp” herbicide, containing pendimethalin as an active constituent, and to select autochthonous microbial strains capable of growth on pendimethalin as the sole carbon and energy source.

Material and Methods

The experiment was performed at Kakanj municipality Central Bosnian Canton, Bosnia and Herzegovina during spring 2019. “Stomp” herbicide (BASF, Germany) in the amount of 2 and 0.5 l/ha was applied by spraying the soil cultivated with onion (*Allium cepa* L.). Two samples of soil were taken, control sample (before herbicide treatment), and one composite sample (zero to 20 cm) after ten days from herbicide application.

Microbial presence in soil was determined using standard methodology, i.e. agar plate method. Tryptic soy agar (Torlak, Serbia) was used for determination of total bacterial number, Rose Bengal streptomycin agar (Peper et al., 1995) for fungal count, Nutrient agar (Torlak, Serbia) for estimation of ammonifiers, and starch-ammonia agar for actinomycetes prevalence. The experiment was performed in triplicate. Microbial count was expressed as colony forming units (CFU) per gram of dry soil. The obtained results were statistically processed using the software package SPSS 20. To determine the statistical significant differences of the obtained results was used the Independent Sample t-test (p = 0.05), as well as ANOVA post hoc Tuckey test (p = 0.05) were performed.

Herbicide-tolerant bacteria were isolated using the modified Talaie et al. (2010) method, “Stomp” herbicide was added to Nutrient agar reaching the final concentrations of 0.5; 1.0 and 2.0 % (v/v). After isolation, bacteria were purified and stored at 4°C.

In order to describe bacterial growth, Nutrient agar supplemented with „Stomp“ at final concentrations of 1.3; 2.2; 3.5; 5.4 and 10 g/l (v/v) was used. Growth rate was estimated (0 without growth; + slow growth; ++ moderate growth; +++ intensive growth) after an incubation at 30°C for five days in incubator (Binder, Germany). The isolates with most pronounced growth were chosen for the testing in the presence of „Stomp“ as a unique carbon and energy source. The mineral salt medium (Talaie et al., 2010) supplemented with pendimethalin solution (up to final concentrations 25; 125; 250; and 500 mg/l) was inoculated by bacterial isolates suspended in saline solution containing 10^8 CFU/ml. Bacterial growth was measured using the spectrophotometer (T70 Ltd. Instruments, UK). Optical density (OD_{600}) was estimated at the start of the experiment, and after 24; 48; 72; 96; 120; and 144 h of incubation in orbital shaker (GFL-3005, Germany) at 30ºC and 150 rpm.

Results and Discussion

The presented results showed that the prevalence of major microbial groups depends on the herbicide application (table 1).

Our results show the increase of microbial abundance after ten days of “Stomp” application in all samples. In the control sample, total average number of bacteria was 150.0 x 10^5 CFU/g, while in soil treated with herbicide 340.0 x 10^5 CFU/g. A high increase of ammonifiers population after herbicide treatment was recorded: from 120.0 x 10^5 CFU/g in control to 270.0 x 10^5 CFU/g after the „Stomp“ treatment. A high increase of fungal prevalence after the herbicide application was observed (from 0.4 x 10^5 CFU/g in control to 3.0 x 10^5 CFU/g after the herbicide treatment). In contrast with other groups of microorganisms, statistically significant differences regarding average number of actinomycetes between control sample and the „Stomp“ treatment were not observed.

Table 1. Prevalence of the major microbial groups in soil sample

Microbial group		Control	Stomp-treated soil
	n	x 10^5 CFU/g dw	
		$\bar{x}$ ± SD	$\bar{x}$ ± SD
Total number of bacteria	3	150.0 ± 12.59^{aA}	340.0 ± 26.84^{aB}
Ammonifiers	3	120.0 ± 10.41^{bA}	270.0 ± 27.44^{bB}
Fungi	3	0.4 ± 0.06^{cA}	3.0 ± 0.36^{cB}
Actinomycetes	3	1.6 ± 0.26^{dA}	1.9 ± 0.29^{dA}

$^{a, b, c, d}$ - values of the same sample of different microbial groups marked with different letters, have a statistically significant difference (*p*<0.05), ANOVA, post hoc Tuckey test.

$^{A, B}$ - values of different samples of the same microbial group, marked with different letters, have a statistically significant difference (*p*<0.05), T-test.

Table 2. Morphological characteristics of bacterial isolates

Isolates	Herbicide concentration (%)	Colony shape	Colony color	Colony diameter (mm)	Cell shape	Sporulation	Gram staining
G1/1	2.0	cocci	white	1.3	rod	+	+
E1/1	0.5	cocci	yellow	2.8	rod	+	+
G*	2.0	cocci	white	0.9	rod	+	+
G1/2	2.0	cocci	yellow	1.2	cocci	-	+
E1/2	0.5	cocci	yellow	2.6	rod	-	-
F2	1.0	cocci	yellow	1.7	rod	+	+
G1/3	2.0	cocci	yellow	1.0	rod	+	+
G2	2.0	cocci	yellow	0.9	rod	+	+
F1	1.0	cocci	yellow	1.1	cocci	-	+

Nine bacterial isolates with different morphologies are selected from the soil treated with „Stomp“. Macromorphological and micromorphological characteristics of isolates are presented in table 2. Most of them were isolated in the presence of the highest initial herbicide concentration (2.0 %), having small yellow colonies and Gram positive spore-forming rod-shaped cells.

Different growth rate of bacteria cultivated on Nutrient agar supplemented with herbicide was obtained. The results of this research are presented in the table 3.

Table 3. Bacterial growth rate on nutrient agar supplemented with herbicide

Isolate	Herbicide concentration (g/l)	Growth rate	Isolate	Herbicide concentration (g/l)	Growth rate	Isolate	Herbicide concentration (g/l)	Growth rate
G1/1	1.3	+++	G1/2	1.3	+++	G1/3	1.3	++
	2.2	+++		2.2	+++		2.2	++
	3.5	++		3.5	+++		3.5	+
	5.4	++		5.4	++		5.4	+
	10.0	++		10.0	++		10.0	0
E1/1	1.3	++	E1/2	1.3	+++	G2	1.3	++
	2.2	+		2.2	++		2.2	++
	3.5	+		3.5	++		3.5	++
	5.4	0		5.4	+		5.4	+
	10.0	0		10.0	+		10.0	0
G*	1.3	++	F2	1.3	+	F1	1.3	++
	2.2	++		2.2	+		2.2	++
	3.5	++		3.5	+		3.5	+
	5.4	+		5.4	0		5.4	+
	10.0	+		10.0	0		10.0	+

At the lowest initial concentration of the herbicide (1.3 g/l), pronounced bacterial growth was present in three bacterial isolates. Further increase of the „Stomp“ concentration in agar was followed by a decrease of bacterial growth rate in most isolates. Only the isolates G1/1 and G1/2 showed no differences in growth rate at the „Stomp“ concentrations of 1.3 and 2.2 g/l. These isolates showed moderate growth in the highest herbicide concentration (10 g/l) and are selected for further research.

Bacterial growth (OD_{600}) in the presence of the pendimethalin is presented in tables 4 and 5.

At the lowest initial concentration of pendimethalin (25 mg/l), a decrease of OD_{600} of isolate G1/1 up to 24 h of incubation was observed (table 4). Further incubation resulted in an increase of OD_{600}, with maximal value after 96 h of incubation (0,199). The end of incubation (120 and 144 h) was characterized by a decrease of OD_{600}. Similar growth curve characteristics were noticed at the concentration of 125 mg/l. Inhibitory effects of the highest pendimethalin concentrations (250 and 500 mg/l) on bacterial growth were noted (table 4).

Table 4. Growth of isolate G1/1 in the presence of pendimethalin as unique carbon and energy sources (OD_{600}).

Herbicide concentration (mg/l)	Time of sampling (h)							
	0	8	24	48	72	96	120	144
25	0.122	0.101	0.084	0.142	0.178	0.199	0.187	0.152
125	0.164	0.155	0.134	0.142	0.139	0.155	0.147	0.122
250	0.174	0.166	0.162	0.142	0.133	0.130	0.141	0.131
500	0.184	0.175	0.161	0.149	0.127	0.102	0.088	0.082

Compared to G1/1, G1/2 isolate showed lower growth rate. At the lowest concentration of pendimethalin (25 mg/l), a decrease of OD_{600} up to 24 h of incubation was observed (table 5). Further incubation resulted in an increase of OD_{600}, with the highest value (0,139) after 120 h of incubation. The end of the incubation (144 h) was characterized by a decrease of OD_{600}. In other concentrations of pendimethalin, weak bacterial growth was noted. After initial adaptation, the highest value of optical density (OD_{600}) at concentration of 250 mg/l was obtained (table 5).

Table 5. Growth of isolate G1/2 in the presence of pendimethalin as unique carbon and energy sources (OD_{600}).

Herbicide concentration (mg/l)	Time of sampling (h)							
	0	8	24	48	72	96	120	144
25	0.055	0.048	0.033	0.061	0.079	0.101	0.139	0.101
125	0.075	0.055	0.036	0.041	0.045	0.051	0.047	0.033
250	0.082	0.074	0.070	0.072	0.065	0.062	0.056	0.059
500	0.088	0.081	0.074	0.064	0.052	0.048	0.045	0.041

Our results indicate the stimulatory effect of herbicide „Stomp“ on microbial prevalence in soil. Shetty and Magu (1998) confirm that soil microbial population is influenced by pendimethalin application. A significant increase in bacterial and fungal abundance after “Stomp” application was noticed. On the other hand, Singh and Singh (2020) found that pendimethalin did not influence the actinomycetes number in soil, which is confirmed in this research. As shown previously (Belal et al., 2008), microbes can utilize xenobiotics as nutrient and energy sources; these microbes can be used to alleviate environmental pollution caused by herbicide application, which leads to an increase in microbial diversity in soil (Yu et al., 2015).

Two isolates that were obtained using the enrichment method, have shown a low growth rate at all herbicide concentrations except at concentration of 25 mg/l. From this result, it was evident that both isolates were able to use low concentrations of herbicide as a unique carbon and energy source. Das et al. (2012) claimed that pendimethalin application led to the increase of aerobic bacterial populations in soil, which is in accordance with our results. In contrast, Nayak et al. (1994) noted a decrease in microbial abundance in soil after pendimethalin treatment; however, 15 days after the treatment, increase of the microbial activity was registered. Chikoye et al. (2014) also found the decrease of microbial activity after pendimethalin application. This finding is similar to our results, indicating that after the initial adaptation to the stress condition caused by the application of the herbicide, microbial populations in soil were capable of growth in the presence of pendimethalin.

Conclusion

The results of the study confirm that the application of „Stomp“ led to the increase of microbial abundance in soil, particularly the rapid increase in the prevalence of bacteria and fungi was observed. Nine different colonies and cell morphologies were observed, from which two isolates (G1/1 and G1/2) were capable of moderate grow on Nutrient agar with the addition of 10 g/l of „Stomp“. Our results showed an increase in bacterial growth during incubation on mineral salt medium supplemented with 25 mg/l of pendimethalin; this indicates that those two isolates have the potential for application on the soils contaminated with pendimethalin.

Acknowledgements

This experiment was conducted with support of the Ministry of Education, Science and Technological Development of the Republic of Serbia (Grant No. 451-03-68/2022-14/200116).

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Original paper DOI:10.5937/ZemBilj2201015H

Efekat primene herbicida „Stomp“ na zastupljenost mikroorganizama u zemljištu

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Izvod

U poljoprivrednoj proizvodnji, primena herbicida ima višestruke koristi. Međutim, njihova upotreba izaziva i probleme u životnoj sredini. Primena herbicida utiče na biodiverzitet ekosistema, uništavajući neciljane organizme. Mikroorganizmi u zemljištu su važan faktor za rast biljaka; oni predstavljaju biološki faktor plodnosti zemljišta. Herbicidi imaju korisni efekat za neke mikroorganizme, dok su za druge negativni, što dovodi do smanjenja mikrobnog diverziteta u zemljištu. Cilj ovog rada je determinacija mikrobne aktivnosti zemljišta i izolacija bakterija rezistentnih na herbicid nakon primene “Stompa”. Metod agarnih ploča je korišćen za determinaciju prisustva mikroorganizama u zemljištu. Rezultati pokazuju povećanje ukupnog broja bakterija, amonifikatora, gljiva i aktinomiceta. Devet izolata, uglavnom Gram pozitivnih sporogenih štapića, pokazalo je sposobnost rasta na mineralnoj podlozi obogaćenoj različitim koncentracijama pendimetalina. Izolati G1/1 i G1/2 pokazali su visoku toleranciju prema koncentraciji pendimetalina od 25 mg/l. Ovi izolati imaju potencijal za primenu u dekontaminaciji ekosistema kontaminiranih herbicidom.

Ključne reči: herbicid “Stomp”, zastupljenost mikroorganizama, pendimetalin, zemljište

Received 07.02.2022
Revised 15.05.2022
Accepted 19.05.2022

Original paper DOI:10.5937/ZemBilj2201024E

Climate change as the driving force behind the intensification of agricultural land use

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Abstract

Climate change in Europe will lead to new precipitation patterns over the coming years and the annual temperature will increase significantly. These changes in climate variables and the resulting effects on agricultural productivity must be differentiated regionally. Plant production depends on sufficient rainfall in summer and, in some regions, on the amount of rainfall in winter. In Central Europe, the amount of precipitation in summer will decrease in the coming decades due to climate change, while in some regions, the amount of winter precipitation will increase significantly. Agricultural production is likely to suffer severely as a result of rising summer temperatures and low water retention capacities in the soil. The effects of reduced summer precipitation and increased air temperatures are partially offset by the expected increased CO_2 concentration. Therefore, the effects that changed climatic conditions have on crop production are sometimes less drastic in terms of crop yields. The greatest impact of climate change on land use is expected from increasing evapotranspiration and lower amounts of precipitation in the production of leachate. In addition to the expected mean changes, the occurrence of extreme weather conditions is key. Periods of drought in the growing season and heavy flooding as a result of extreme rainfall are to be expected. However, these events are very difficult or even impossible to

Original paper DOI:10.5937/ZemBilj2201024E

predict. In addition to the effects that climate change will have on regional crop production, global changes will have a strong impact on world markets for agricultural products. Another consequence of climate change and population growth is a higher demand for agricultural products on world markets. This will lead to dramatic local land use changes and an intensification of agriculture that will transform existing crop production systems. The intensification caused by rising land and lease prices will primarily affect the maximization of the use of fertilizers and pesticides.

Keywords: climate change, crop production, intensification of land use, water balance, global agricultural production, sustainability, population growth

Introduction

Regional changes in precipitation and air humidity are associated with global climate change. As a result of the rise in temperature, the annual atmospheric demand for water is increasing. This is leading to an acceleration in the hydrological cycle of evaporation and precipitation. The temperature-dependent increase in the humidity capacity of the atmosphere is leading to an increase in latent energy in the troposphere. This is also resulting in a worldwide increase in the number of extreme climatic events, such as storms, droughts and heavy precipitation with subsequent flooding. The main problem with these extreme events is that they cannot be predicted by any currently available climate models and that their occurrence is becoming more and more frequent as a result of climate change. In addition, the principles developed by humans—not only rules of conduct in everyday life but also production methods relating to agricultural land use—are geared to typical, average weather situations. Planning and reacting in such uncertain circumstances is very difficult and has not been developed well or not yet developed at all in most of our economic and social fields. In addition to changes in the economy, population aging and migration, climate change is the central element of global change. The climate changes to be expected in the coming decades cannot be underestimated in terms either of productivity (e.g., due to water shortages or excesses), or of the landscape ecology functions of land use systems (e.g., the habitat's function for species, groundwater recharge). It can already be foreseen today that in the short and medium term, the direct effects of climate change on the productivity of land use systems will significantly influence the world markets for agricultural products and thus also the energy supply. For this reason, the investigation and assessment of how climate change will affect agriculture in terms of production and landscape ecology must be subdivided into three areas:

- Impact of climate change on the productive function of land use systems
- Impact of climate change on the ecological functionality of land use systems and
- Impact of climate change on the world markets for agricultural products, with expected repercussions for agriculture.

This is the focus of the present study. The effects of climate change must be examined with this degree of complexity to show clearly, based on the results of the analyses, that agriculture will both win and lose in terms of socio-economic aspects and landscape ecology.

Materials, Methods and Results

Impact of climate change on the agricultural landscape's functioning in terms of production and landscape ecology

Using the example of two specific study areas with typical land use and similar soils, Eulenstein et al. (2005, 2006) examined how the components of the soil water balance, and especially the water availability for agricultural crops, could change as a result of the expected climate change. When selecting the study areas, emphasis was placed on the fact that both study areas were dominated by sandy soils with low field capacity. This factor represents the maximum amount of water that can be retained in the soil (which corresponds to the deep root zone). In the sandy areas, agricultural conditions, which are already difficult during the growing season, become even more unfavorable. Between 1961 and 1990, the mean precipitation in Germany determined over many years was 790 mm (1 mm water column corresponds to an amount of one liter of water per square meter of soil). For regions in eastern Germany, however, the long-term mean precipitation is only 615 mm. In the area around Müncheberg (a small town to the east of Berlin) it is only 520 mm a year, and further east in the Oderbruch it is only 460 mm a year. In addition to the low rainfall, it is noteworthy that we are mainly dealing with soils with low water storage capacity in northeast Germany and western Poland. The soil values determined by the official soil assessment correlate very well with the amount of water that is available for plants and stored in the root-penetrated soil zone. The soils that dominate the regions are predominantly ground and terminal moraines shaped by the Ice Age, as well as sand areas with relatively low soil values. These sandy soils have a storage capacity of around 100–150 mm down to a depth of one meter. The soils that are considered to be the best in this regard, on the other hand, the chernozems in Central Germany, can store approx. 240 mm of water at the depth available for plants. On warm days in midsummer, approx. 6 mm of water evaporates (corresponds to 6 l / m^2). Under these conditions, a chernozem would be able to provide the plants with water for 40 days. In purely mathematical terms, a population on sandy soils reaches the end of the water replenishment from the soil after just 17 days. Results from lysimeter and field tests (Roth et al. 1997; Schindler et al. 2001; Müller et al. 2004, Schindler et al. 2007) on the relationship between water consumption, effectiveness of water use and yield formed the basis for deriving the water availability classes. In eastern Germany and western Poland, these problems of poor soil storage capacity and low rainfall come together in a way that is unique in Central Europe. It is precisely in these regions that the effects of the expected climate change are likely to be most serious. These location conditions—with a shortage of the most important production factor, water—in combination with soils that store very little water mean that the production conditions for farms in these regions must be considered problematic, especially during periods of low precipitation during growing seasons. In the course of the predicted warming, the decline in precipitation and its intra-annual redistribution from the summer to the winter half-year (Gerstengarbe et al. 2003), this situation may worsen in the future.

Effects on the water balance and the yields of agricultural production systems

Wiggering et al. (2008) and Eulenstein et al. (2016) carried out studies to analyze how the expected climate change would affect land use and the landscape water balance of agricultural locations in northeast and central Germany. The first step taken was to elucidate in detail how the climatic water balance will change in future climatic conditions, along with discharges of substances (nitrate and sulphate) into agriculturally used areas and the yields of agricultural crops. An agricultural landscape located directly at the east of the German capital Berlin was selected for these calculations. It covers 54,000 ha. Precise surveys on crops, yields and fertilization at a total of 54 farms in the 1993–2001 period served as the basis for the calculations. The period from 1993–2001 serves as the reference period for the climate scenario defined by Gerstengarbe et al. (2003) (Fig. 4.3-3). The scenario calculations are based on a temperature increase of approx. 1.4 °K for the period 2001–2055. This trend was determined from the data gathered by the ECHAM4-OPYC3 model from the Max Planck Institute for Meteorology, Hamburg. This model run is based on the IPCC (2001) emissions scenario A1B-CO_2, which results in a relatively moderate increase in temperature.

Effects on the agricultural water balance

It was shown that during the growing season, the plant population already completely depletes the water supply of the soil under today’s climatic conditions. Therefore, there is no difference in the calculated current evapotranspiration during the summer half-year between the current climate and the assumed climate scenario. With the help of the HERMES/SULFONIE models developed by Kersebaum (1995), a potential evapotranspiration of 510 mm a year was calculated. Taking into account the cultivated crops and the limited water availability in the summer months, the current evapotranspiration is almost 100 mm lower, at 417 mm a year. Leaching loss is around 140 mm a year on average over the years. In the model, the groundwater that is displaced downwards is shown as seepage water that is displaced deeper than 2 m. The data on the weather patterns in the climate scenario, generated synthetically using the results from the climate models, indicate that the evapotranspiration largely follows the precipitation rates, while the seepage water rate falls to a very low level.

From these calculations (Fig. 1) it can be deduced that with the average climate changes to be expected in the future, stress situations for plant populations caused by water availability could increase. Evaporation is likely to increase due to a rise in temperature, especially in the winter months. From the overall extent of the change in evaporation, however, the increase in water shortage for arable crops can be classified as quite moderate.

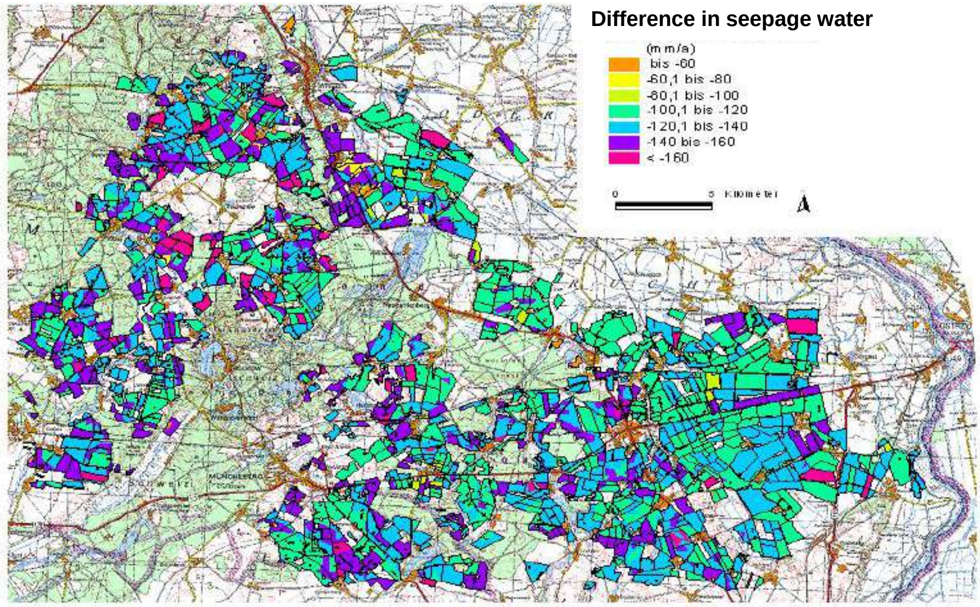


Figure 1. Spatial distribution of percolation water [mm/year] decrease as a result of the scenario comparison (2050 scenario v. 2000 scenario)

Therefore, the negative consequences for the generation of income should remain quite manageable under medium conditions. However, the frequency with which extreme weather conditions occur, such as 2018, 2019, 2020 (summer drought) or 2002, 2013, 2021 (precipitation-related floods), is certainly crucial for the economic situation in agriculture. The accumulation of such extreme years could become the real problem for agricultural crop production.

Effects on the yields of arable crops

The ZALF (Leibniz Center for Agricultural Landscape Research eV, Müncheberg; www.zalf.de) has developed a model approach for regional yield estimation and, by integrating it into the Spatial Analysis and Modeling Tool (SAMT) (Wieland et al. 2004), has developed an expanded spatial simulation tool. The yield models developed with the help of this tool make it possible to examine how changing weather patterns influence yield. Calculations made with these models for the study area result in a yield depression of between 14 % for potatoes and approx. 5 % for barley, wheat, rye and triticale; the main grain types. Taking into account the effects of increased CO_2 concentrations known from other studies (such as free-air CO_2 enrichment or FACE experiments), the estimated yield decreases for all crops are less than 10 % and they are especially marginal for the cereals that are dominant in terms of cultivation. This means that ultimately the emission-related increase in the CO_2 content in the atmosphere promotes plant growth and the more efficient utilization of the water supply, and can help compensate for the drop in yield. Numerous experiments and valuable data have recently been obtained on the relationships between the CO_2 concentration and the temperature-dependent reaction of cultivated plants. This was done experimentally in sunlit, controlled chambers, “open top chambers,” FACE studies and to a limited extent, phytotron studies (Boats et al. 2011; Hatfield et al. 2011; Jones et al. 2011). The spatial distribution of the climate-related decline in yields at the 2050 climate level compared to the 2000 climate level shows clear differences on a small scale. The lowest yield losses are to be expected in the investigation area within the sphere of influence of the Oderbruch. This can be explained by the better groundwater supply in this floodplain area. The yield losses there are mostly only in the range of up to 5 %. On the other hand, on the fields with sandy soils, the losses are higher, usually reaching more than 5 % and sometimes more than 10–15 %.

Table 1: Simulated impact of climate change (2050 scenario vs. 2000 scenario) on crop yields for the study area (two CO_2 levels)

Crop	Cropping rate (%)	Mean crop yield change (%) at 370 ppmv CO_2	Mean crop yield change (%) at 465 ppmv CO_2 [*)]
Winter rye	17	-6	-0.3
Winter wheat	16	-5	0.5
Silo corn	9	-8	-3
Winter rape	9	-11	-6
Winter barley	6	-5	0.5
Triticale	6	-4	0.1
Sugar beets	2	-9	-4
Alfalfa	3	-12	-7
Spring barley	2	-5	0.3
Spring rape	<1	-7	-2
Spring wheat	<1	-4	0.9
Clover gras	1	-13	-8
Oat	1	-5	0.2
Potatoes	1	-14	-9

[*)] Basis: CO_2 fertilization effects obtained in the FACE-experiment of the Federal Research Centre for Agriculture Brunswick, Germany (at 550 ppmv→10.7% yield increase in average)

The effects on the yield of agricultural crops to be expected locally with the 2050 climate level (PIK climate scenarios) are summarized in Table 1 in comparison to the yields of fields representing the most important fruit species cultivated in the study area at the 2000 climatic level. Taking into account the effect of CO_2, the yield losses caused by changes in temperature and precipitation are compensated for in the cultivated cereals.

However, this is not the case with root crops, silage maize, rapeseed, alfalfa or grass clover, and yield losses are likely.

Impact of climate change on the ecological function of the agricultural landscape

The decline in groundwater recharge is likely to have a much more serious impact on the feeding of the ecologically valuable wetlands than on agricultural yields. Unlike the alternative of forestry, agricultural land use is currently leading to significant new groundwater formation rates (Eulenstein et al. 2005b). From seepage and lateral runoff, groundwater supplies the numerous ecological wetlands found in Brandenburg (lakes, brooks, moors and other lowland areas). Should leaching loss from the agricultural land actually develop as the scenario suggests, then the ecological functionality of these ecosystems will have to be questioned. According to the climate scenarios, a lower nitrogen discharge is initially forecasted. This is mainly explained by the fact that, as a result of lower seepage water rates, nitrogen and sulfur are not shifted into the subsoil as quickly and thus ultimately the supply of these substances initially accumulates in the upper soil layer, which is 2 m deep. The modeling for the fields recorded and accounted for in the study area was carried out using the HERMES / SULFONIE models developed by Kersebaum (1995). Figs. 4.3-5 and -6 show, in addition to the components of the water balance, the sulphate and nitrate discharges from the root-penetrated zone and their concentrations in the seepage water. With the exception of the peak, nitrogen discharges vary between 25 and 100 kg/ha per year.

Discussion and Conclusion

Impact on the world markets for agricultural products and expected repercussions for agriculture

The previously known and generally applicable influences on agriculture will change considerably over the next few years. In addition to the predicted climate change, the economic framework conditions in particular have a major influence on how farmers make strategic decisions for their farms and production in both the long and short term. Alongside technical progress and new markets, this decision-making behavior is primarily shaped by agricultural policy and social requirements. As well as the significantly increasing importance of market mechanisms, these include:

- Decreasing the liberalisation of policy; fewer restrictions for agricultural trade policy or agricultural market and pricing policy
- Increasing the requirements for the quality of the production process in environmental, animal welfare and consumer policies at the same time
- Intensifying production processes as a result of increasing demand and prices worldwide.

Looking at the global climatic changes that are emerging, it becomes clear that other agricultural regions that were previously used intensively will be more severely affected by climate change than Europe due to rising temperatures and falling amounts of precipitation. For this reason, it will not be possible to significantly expand the range of agricultural products from the regions affected, such as Australia and the Midwest of the USA. On the other hand, as recent studies show, there are certainly favorable locations such as in southern Brazil. Using yield simulations for maize and soybeans, Lana (2013) was able to show that with the right choice of varieties, no significant yield losses are to be expected in southern Brazil under the conditions of future climate change. The same applies to New Zealand (in contrast to Australia). With increasing demand and a constant or decreasing supply, prices will rise and with them farmers' incomes. These are farms which have previously not made adequate earnings and have sometimes been on the verge of ruin. The prospect of charging higher prices for the farmers' products is therefore fundamentally positive from the point of view of maintaining the farms. As a result of the supply shortage and increases in energy prices, the price of animal feed, fertilizers and fuels is also rising and the costs of agricultural production are thus higher. Rising revenues due to rising market prices for agricultural products are thus partially negated by the increasing cost pressure.

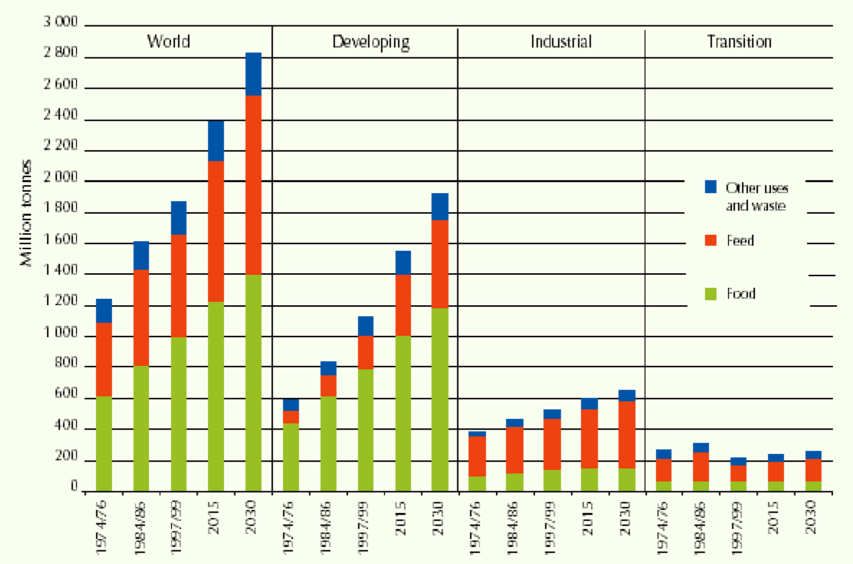
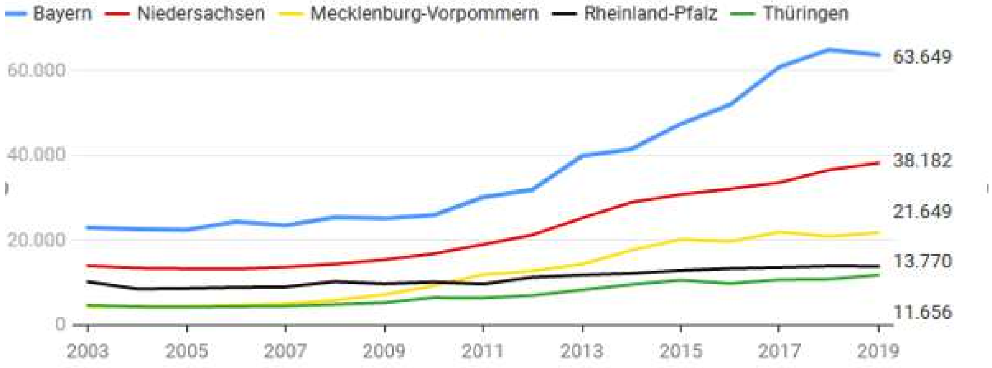


Figure 2: Aggregate consumption of cereals by category of use, from World Agriculture: Towards 2015/2030. An FAO perspective.

Increasing variability in the climate is leading to higher uncertainties in production, which will result in greater risks/failures and therefore higher costs.

Nevertheless, due to the high productivity of the agricultural locations in Central Europe and the often very good, flexible management of the farms, it is to be expected that the vast majority of agricultural areas in Central Europe will continue to be used for agriculture in the future, with the exception of a few border locations. Considering that the world population will increase from over 7.7 billion in 2020 to 8.5 billion by the mid-2030s, there is also likely to be an increase in demand for agricultural products. The FAO anticipates an increase in annual demand of one billion tonnes of plant products by the mid-2030s (Fig. 2).

The competition for land for the agricultural production of biomass for nutritional purposes, as animal feed, for industrial raw materials and as an energy source, as well as for available water resources (with water retention in the landscape for ecological functions, for irrigation, etc.) will therefore increase. The following graph (Figure 3) already illustrates the trend of price increases for agricultural land in Germany.



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Quelle: Statistisches Bundesamt (2020): Kaufwerte für landwirtschaftliche Grundstücke (versch. Jgg.), Statistische Berichte, Fachserie 3, Reihe 2.4, Wiesbaden.
• Daten

Figure 3: Trend of price increases for agricultural land in some regions in Germany

This trend is particularly evident where agricultural land is traded on the market. The intensification caused by rising land and lease prices will primarily affect the maximization of the use of fertilizers and pesticides.

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Original paper DOI:10.5937/ZemBilj2201024E

Klimatske promene kao pokretačka snaga inteziviranja poljoprivrednog korišćenja zemljišta

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Original paper DOI:10.5937/ZemBilj2201024E

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Izvod

Klimatske promene u Evropi dovešće do novih obrazaca padavina tokom narednih godina i godišnja temperatura će značajno porasti. Ove promne klimatskih variabli i rezultirajući efekti na poljoprivrednu produktivnost moraju se regionalno razlikovati. Biljna proizvodjna zavisi od dovoljne količine padavina leti, a nekim regionima i od količine padavina zimi. U centralnoj Evropi, količina padavina leti će se smanjiti u narednim decenijama zbog klimatskih promena, dok će u pojedinim regionima, količina zimskih padavina značajno porasti. Poljoprivredna proizvodnja ce verovatno ozbiljno patiti zbog porasta letnjih temperatura i niskog kapaciteta zadrzavanja vode u zemljištu. Efekat smanjenja letnjih padavina i povišene temperature vazduha delimično su neutralisani očekivanom povećanju koncentracije CO_2. Stoga su efekti koji promenjeni klimatski uslovi imaju na biljnu proizvodnju ponekad manje drastični u pogledu prinosa useva. Najveći uticaj klimatskih promena na korišćenje zemljišta se očekuje od povećanja evapotranspiracije i manjih količina padavina u proizvodnji procednih voda. Pored očekivanih srednjih promena, ključna je pojava ekstremnih vremenskih uslova. Očekuju se periodi suše u vegetacionoj sezoni i jake poplave kao rezultat ekstremnih padavina. Međutim, ove događaje je veoma teško ili čak nemoguće predvideti. Pored efekata koje će klimatske promene imati na regionalnu biljnu proizvodnju, globalne promene će imati snažan uticaj na svetska tržišta poljoprivrednih proizvoda. Još jedna posledica klimatskih promena i rasta stanovništva je veća potražnja za poljoprivrednim proizvodima na svetskim tržištima. Ovo će dovesti do dramatičnih promena lokalnog korišćenja zemljišta i intenziviranja poljoprivrede koja će transformisati postojeće sisteme proizvodnje useva. Intenziviranje izazvano poskupljenjem i zakupom zemljišta uticaće na maksimizirajuću upotrebu đubriva i pesticida.

Original paper DOI:10.5937/ZemBilj2201024E

Ključne reči: klimatske promene, proizvodnja useva, intenziviranje korišćenja zemljišta, vodni bilans, globalna poljoprivredna proizvodnja, sustainability, rast stanovništva

Received 14.04.2022
Revised 27.05.2022
Accepted 27.05.2022

Original paper DOI: 10.5937/ZemBilj2201040S

Measurement of hydraulic properties of growing media with the HYPROP system

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Abstract

Knowledge of hydro-physical properties is an essential prerequisite for assessing the suitability and quality of growing media. The method used for sample preparation is important for the measurement results. Three different sample preparation methods were compared. The methods differed in terms of the way the 250°cm^3 steel cylinder was filled and the height of preloading. Measurements on loosely filled cylinders were included. The comparison was carried out on 15 growing media using the HYPROP device. HYPROP enables a complex analysis of the hydro-physical properties with high accuracy and reproducibility. The water retention curve, the unsaturated hydraulic conductivity function, the dry bulk density, the shrinkage and the rewetting properties can be measured simultaneously. The air capacity and the amount of plant-available water in pots depend on the height of the pot. In the field, it is related to the field capacity. The quality assessment was carried out both for flowerpots of different height and for field conditions with free drainage. Loosely filled samples consolidated hydraulically shortly after the start of the measurement. These geometric changes can be taken into account with the HYPROP. The sample preparation method – preloading or loose filling – yielded significantly different results for the pore volume, dry bulk density, plant available water and air capacity. The total pore volume of the loosely filled cylinders varied between 86.8 and 95.2°% by vol. (preloaded 81.3 and 87.7°% by vol.). The most critical factor was the air capacity. Loosely filled substrate samples achieved the highest air capacities, but also did not reach the critical value of 10°% by volume in shallow flowerpots, e.g. in 10 cm pots with 5.8°% by volume. The sample preparation method, measurement and quality assessment of the hydro-physical properties of growing media should be adapted to the conditions of use – whether they are used in a field with free drainage or in pots or containers in greenhouses.

Keywords: sample preparation, water retention curve, unsaturated hydraulic conductivity function, Extended Evaporation Method (EEM), HYPROP

Introduction

Knowledge of hydro-physical properties is an essential prerequisite for assessing the suitability of soils in agriculture and of growing media in horticulture (Raviv and Lieth, 2008, Schindler et al., 2015, Schmilewski, 2017). Beside the capillarity, the tendency to shrinkage and swelling and the rewetting properties, the most important hydro-physical variables are the air capacity and the plant-available water.

According to the Garden Industry Association (IVG, Schmilewski, 2017), the average total pore volume of growing media is 94°% by volume. Such high values could not be confirmed by Schindler and Müller (2017a). Previous studies (Schindler and Müller 2017a) showed that the air capacity can assume especially critical values in shallow flowerpots. The air capacities recommended by different authors in Schmilewski (2017), however, varied between 10 and 40°% by vol. This range of air capacities is in strong contradiction to the results gained by Schindler and Müller (2017a). In that study, the air capacity of 36 different growing media was a crucial variable. The limit of 10°% by vol. was exceeded in only very few cases. The study included growing media consisting of pure peat, pure coir, peat-free substrates and very different mixtures of peat with compost, bark, perlite and other materials. The average air capacity in line with DIN EN 13041 (2012) was 5°% by vol. (max. 17.5°% by vol., min. 1.6°% by vol., standard deviation 3.3°% by vol.).The question is, how can these extreme differences be explained and what is the cause – the measurement method, the evaluation procedure, the sample preparation, the growing medium itself or other factors?

The standard means of measuring hydro-physical properties is the sandbox method (Raviv and Lieth, 2008, DIN EN 13041, 2012). The measurement is time-consuming, and the results are limited to a tension range between saturation and 100°hPa. Only the water retention properties can be measured as the basis for calculating the air capacity and the plant-available water. The HYPROP (HYdraulic PROPerty analyzer), however, simultaneously enables an accurate, effective and reproducible measurement of all the hydro-physical properties required of growing media, including capillarity, shrinkage and re-wettability (Schindler et al., 2017a).

The sample preparation method for measuring and evaluating the physical properties of growing media is an important issue. Methods are used with mechanical preloading (PPO in Wever, 1999; Schindler et al., 2017a) or loosely filled cylinders with pre-wetted material (DIN EN 13041, 2012). These individual procedures can lead to different results.

The assessment of growing media quality must be directly related to horticultural practice. In practice, flowerpots are loosely filled with the growing medium by hand or with a potting machine (Fig. 1), planted and watered so that water emerges at the base (Fig. 2). The preparation and measurement of hydro-physical properties must correspond to these conditions to be sufficient. The conditions in the field are different. There, the substrate is under free drainage and can be driven over with machines. Here, we studied the effect of different sample preparation procedures. The measurements were carried out with the HYPROP system, focusing on the air capacity and the plant-available water. The following results are presented and discussed.

Original paper DOI: 10.5937/ZemBilj2201040S

Figure 1. Potting machine

Figure 2. Samples on a water-saturated fleece after filling and planting in the market

Materials and Methods

Hydro-physical basics

DIN EN 13041 (2012) defines the air capacity as a fixed value. It is calculated as a difference in water content ranging between saturation and a tension of 10°hPa. This value is suitable to compare growing media, but of limited significance for practical issues such as evaluating the air and water capacity in flowerpots or in the field.

The air and water capacity in flowerpots are not fixed values, but depend on the height of the pot. In horticultural practice, flowerpots are watered after filling and planting so that water drains at the base (Fig. 2). Then, the flowerpots are placed on a water-saturated fleece. In this case, there is a tension of 0 at the base of the flowerpot. The water and air content in the flowerpots is calculated from the water retention curve (Eq. 1, Fig. 3, left). The air capacity of 10hPa as defined in DIN EN 13041 (2012) is assumed to be available throughout the pot (Fig. 3, right). The air capacity in the field (Fig. 3, right) is a fixed” value in the profile with free drainage and corresponds to the water content at field capacity (FC) at 60°hPa (AG Boden, 2005).

$$\int_0^{\Psi} \Theta(\Psi)\, dz \qquad (1)$$

With Ψ being tension and Θ being water content.

Sample preparation procedures

Method A

The cylinder (250 cm^3, 5 cm high) was loosely filled with the substrate directly from the package (Schindler et al., 2017). The water content of the sample was not changed. The sample surface was loaded for one minute with a 10 kg weight (0.2 kg cm^{-2}). A second cylinder was placed on top of the first, half-filled with substrate, and the compression procedure was repeated. The surface was smoothed. The sample was saturated and prepared for the HYPROP measurement.

Method B

The substrates were loosely poured into plastic tubes (diameter 15 cm, height 60 cm). The pipes were placed in a bowl with water and saturated by capillary action for about 48 hours (Fig. 4).

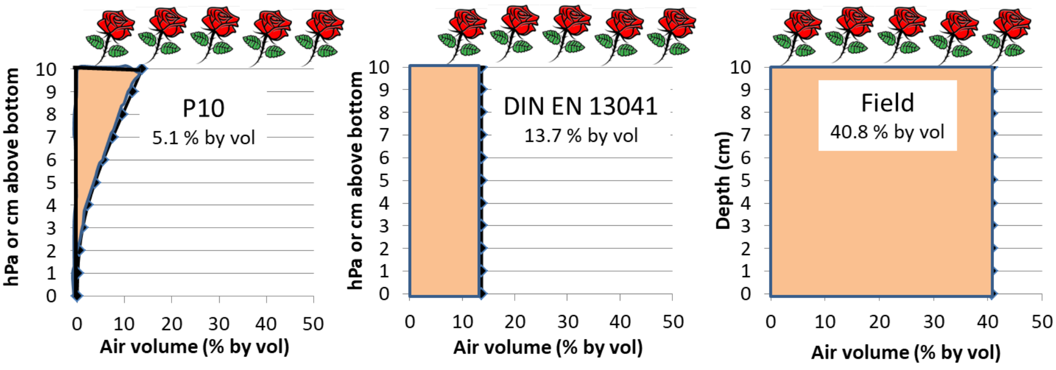

Figure 3. Air capacities in 10°cm high pots: left, Air_$_{DIN}$ at 10°hPa: middle and right: in the field. Substrate 25W1.

After capillary saturation, the tension at the surface varied between 50 to 55°hPa. In the following, the upper 5 cm of the substrate were removed and mixed and the 250 cm^3 cylinders were filled loosely. The filling took place in 2 stages. First the cylinder was completely filled and rammed onto the table 5 times by hand. The sample material compressed hydraulically. A second cylinder was then placed on top, half-filled with substrate and the two were rammed onto the table another five times. The second cylinder was removed and the sample surface was smoothed. The samples were saturated and the measurement with the HYPROP could start.

Method C

Comparable to practice, the substrate was loosely poured into the cylinder directly from the package. The sample was saturated, the surface smoothed and prepared for the HYPROP measurement. Immediately after the start of the measurement, the sample material consolidated hydraulically. The consolidation process was finished shortly after the start of the measurement at a tension between 1 and 3°hPa. The geometric changes were taken into account with the HYPROP. This procedure is comparable to DIN EN 13041 (2012), the difference being that the DIN-defined hydraulic consolidation already took place before the measurement (capillary pre-saturation to 50°hPa).

Figure 4. Capillary saturation to 50°hPa.

Growing media

Table 1 gives an overview of the composition of the tested growing media.

Table 1. Composition of the substrates for the comparison of sample preparation

No.	Ingredients
9W	75°% H3-H5, H6-H7, Co, Cl, Ca
9W1	80°% H3-H5, H6-H7, Ko, Cl
16W	H2-H5, G, R, Ca
25W	60°% H3-H5, H6-H7, R, G, Co, Ca
25W1	60°% H3-H5, H6-H7, Co, Cl, P
27W	50°% H3-H5, G, R, Cl
K1	80°% Hh,(H3-H4), 20°% Hh (H7-H9), Cl, gramoMicro
K2	45°% Hh /H3-H4), 30°% Hh (H7-H9), 25°% F, Cl, gramoMicro
HTC_150C	K1 plus 10°% HTC, 150°C
HTC_150D	K1 plus 20°% HTC, 150°C
HTC_170D	K1 plus 20°% HTC, 170°C
HTC_190C	K1 plus 10°% HTC, 190°C
HTC_190D	K1 plus 20°% HTC, 190°C
HTC_190E	K1 plus 30°% HTC, 190°C
DK	50°% Hh (H2-H4), 50°% Hh (H7-H9), Cl, Ca

Hh – bog peat, H3 – degree of decomposition 3, HTC – hydrothermally carbonized plant material at different temperatures, F – compost from forest residues, Ca – lime, G – compost from garden residues, Cl – clay, Co – coir, P – perlite, R – bark mulch.

Original paper DOI: 10.5937/ZemBilj2201040S

Hydro-physical measurement with HYPROP

The HYdraulic PROPerty system (HYPROP, UMS 2012) was used to simultaneously measure the water retention function (pF curve), the hydraulic conductivity function (K-function) and dry bulk density in the range between saturation and the permanent wilting point (Fig. 5; Schindler et al., 2010; Schindler et al., 2017a). With minimal additional effort, the shrinkage and rewetting properties can be quantified simultaneously (Schindler et al., 2015). The function is covered with a large number of data. The measurement accuracy and reproducibility are high (Schindler et al., 2012). The measured values are recorded online. It is possible to measure multiple samples in parallel.

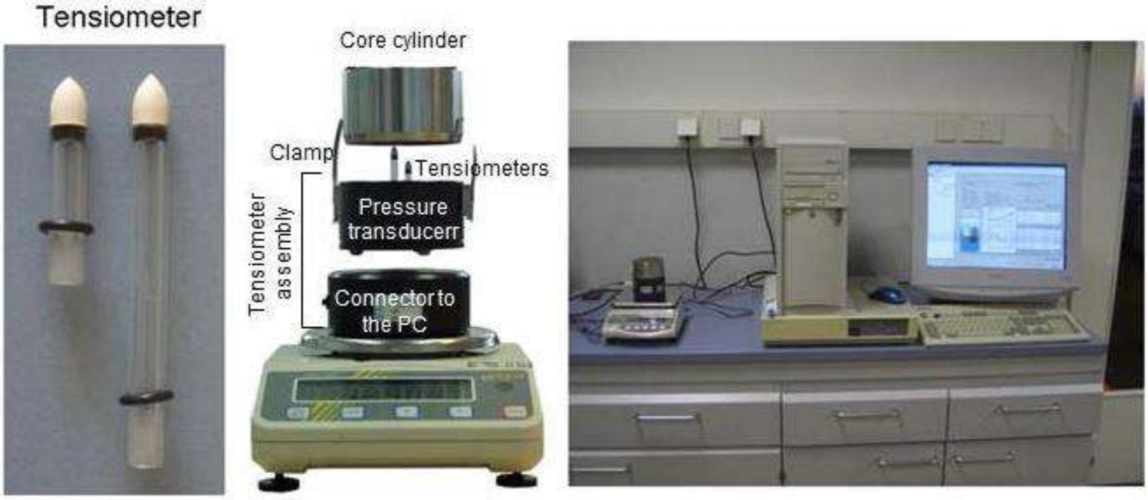

Figure 5. HYPROP system

Brief description: Hydro-physical properties of soils or growing media can be measured with the HYPROP at undisturbed or disturbed cylinder samples (100 or 250 cm^{-3}). The sample is saturated, connected to the HYPROP and placed on a scale. The scale and the HYPROP are connected to the PC. The sample surface is exposed to free evaporation and the measurement data (tensions, sample mass) are recorded at time intervals. When the evaporation measurement is finished, the sample is dried at 105°C in the oven to measure the amount of residual water and the dry bulk density. The evaluation (calculation, fitting, data export) takes place with the HYPROP-Fit software (UMS 2015). The measurement takes about 3 to 10 days and depends from the water content of the sample. The measurement can be stopped at any tension between saturation and the permanent wilting point (pWP, AG Boden, 2005).

Results and Discussion

The high reproducibility of the HYPROP measurements is shown as an example in Fig. 6 for 3 replicates of substrate K1. Statistical results for the replicates are given by the HYPROP software.

The results of sample preparation are summarized in Table 2 and Table 3. Methods A and B were carried out with mechanical preloading. Method B corresponds to the PPO standard (Wever, 1999). Method C was without any mechanical preloading. This method was close to horticultural practice and comparable to DIN EN 13041 (2012).

Fig. 7, left shows the example of minor differences in the water retention functions of the sample preparations A and B with preloading for substrate 25W1 as an average function of three replicates. Table 2 presents average values of three replicates as the basis for statistical evaluation (average of the tested substrates, standard deviation and t-test (Excel, Windows 10). The air capacity in 10°cm high pots (A: 3.2% by vol. and C: 5.4°% by vol.) did not reach the 10°% by vol. threshold value (Raviv and Lieth, 2007; Fischer, 2010). The air capacities as defined in DIN EN 13041 (2012) were, as expected, more than twice as high. With the exception of air and water, no other variables were significantly different. The dry bulk density (A: 0.23 g cm^{-3}, B: 0.22 g cm^{-3}) and the pore volume differed only slightly (A: 81.7°% by vol., B: 81.5°% by vol.) but did not come close to the values in Schmilewsky (2017) of 90°% by vol. and more. Under field conditions, the air capacity was very high (A: 36.9°% by vol., B: 38.3°% by vol.); however, due to this, the plant-available water was reduced by 10°% by vol. and more (A: 24.2°% by vol., B: 22.7°% by vol.).

The results of comparing methods B and C are presented in Table 3 and Fig. 7, right. The substrate in the loosely filled cylinders (C) compacted hydraulically shortly after the start of the measurement. The sample height and the volume decreased from 5 cm to a minimum of 4.5 cm, or from 250 to 225 cm^3. These geometrical changes were taken into account by the HYPROP Fit software. This process is comparable to the hydraulic compaction during pre-saturation as defined in DIN EN 13041 (2012), but more effective because no pre-saturation step to 50°hPa is required. As expected, the differences between Method B with preloading and the loosely filled cylinders from Method C were highly significantly different for all variables. The pore volume exceeded 90°% by vol. with Method C. These values were comparable to the results gained by Schmilewski (2017). With Method B, the average pore volume was 83°% by vol. The air capacities in shallow, loosely filled pots (Method C) were considerably higher than with the preloaded samples of Method B (C: 5.8°% by vol., B: 2.8°% by vol.). However, even when the cylinder was loosely filled (C), the air capacity was far from the threshold value of 10°% by vol. The air capacities Air_{DIN} were also twice as high as Air P10. In higher pots, and especially under field conditions, the air capacity was sufficient. For growing media with sufficient air capacity in the upper part of the pot, intelligent knowledge-based water management can reduce the air problem. Under field conditions, however, the plant-available water was reduced by more than 10°% by vol. compared to cultivation in pots.

Table 2. Hydro-physical results of growing media after applying sample preparation methods A and B.

M$^{1)}$	No.	DBD	PV	FC	Air_DIN	Air				Water			
					10°hPa	P10	P20	P30	Field	P10	P20	P30	Field
		gcm^{-3}					%°by vol						
A	9W	0.24	81.8	43.4	4.5	2.0	8.8	15.5	38.4	43.2	36.4	29.7	18.4
A	9-1W	0.22	87.1	46.8	7.0	3.0	10.0	18.9	40.3	41.8	34.7	25.8	25.5
A	16W	0.26	75.9	37.0	14.9	6.7	14.4	19.8	38.9	37.2	29.6	24.2	17.5
A	19W	0.20	82.9	51.2	2.2	1.1	4.9	15.2	31.7	35.6	31.8	21.5	25.0
A	25W	0.22	81.3	44.0	6.6	2.7	9.9	17.5	37.3	40.0	32.9	25.3	35.1
A	25-1W	0.24	82.2	44.2	8.9	5.3	11.0	17.8	38.0	40.0	34.3	27.5	25.7
A	27W	0.25	80.8	46.8	3.4	1.4	6.4	15.5	34.0	36.7	31.7	22.6	22.4
B	9W	0.22	80.7	38.8	14.0	7.3	14.8	21.4	41.9	40.1	32.6	26.0	23.9
B	9-1W	0.18	84.4	44.1	13.6	6.9	14.5	20.9	40.4	38.1	30.5	24.1	24.3
B	16W	0.28	78.8	43.2	10.8	4.8	12.4	17.0	35.6	36.1	28.5	23.8	21.4
B	19W	0.19	83.4	49.0	4.3	2.5	8.7	16.2	34.4	36.0	29.8	22.3	24.4
B	25W	0.19	81.1	39.8	14.6	7.1	15.6	21.6	41.3	39.1	30.6	24.6	21.3
B	25-1W	0.23	80.8	40.8	13.6	6.4	14.7	20.4	40.0	39.5	31.2	25.5	19.9
B	27W	0.26	81.5	47.1	6.6	2.5	7.8	15.6	34.4	36.4	31.1	23.3	23.7
A	Av	0.23	81.7	44.8	6.8	3.2	9.3	17.2	36.9	39.2	33.1	25.2	24.2
B	Av	0.22	81.5	43.3	11.1	5.4	12.6	19.0	38.3	37.9	30.6	24.2	22.7
A	stabw	0.02	3.3	4.3	4.2	2.1	3.1	1.8	3.0	2.8	2.3	2.8	5.8
B	stabw	0.04	1.9	3.8	4.1	2.1	3.2	2.6	3.3	1.7	1.3	1.3	1.8
t-test		0.20	0.79	0.33	0.05	0.06	0.02	0.13	0.21	0.06	0.003	0.15	0.56

1) Preparation method, DBD - dry bulk density, PV - total pore volume, FC - field capacity at pF 1.8 (AG Boden 2005), stabw - standard deviation, P10 - pot, 10°cm high, Av - average.

According to information from the Garden Industry Association (IVG), the average pore volume of gardening substrates is between 90 and 94°% by vol. The results from these studies confirmed these high pore volumes only for the samples of Method C. In those, the pore volume varied between 86.8 and 95.2°% by volume. The recommended air capacities published in Bohne (2006), Raviv and Lieth (2007), Huntenberg (2016), Fischer (2016) and Schmilewski (2017) varied between 10 and 40°% by vol. This range is in strong contrast to the results of this paper and Schindler et al., (2017a, b, c). The main reason for the differences is seen in the methodology.

As defined in DIN EN 13041 (2012), the air capacity corresponds to the difference in the water content, comparing the total pore volume and the water content at a tension of 10°hPa. However, this value cannot be determined exactly with the standard method (sandbox), since the tension applied is related to the centre of the sample. The tension at the lower and upper edges of the sample is -7.5 and -12.5°hPa, respectively. Linear averaging is not permitted and can lead to uncertainties. Another uncertainty arises from the determination of the total pore volume, since only fixed particle density values (also known as the true density or particle density) are used of the mineral and organic substance. This could result in very high values for the total pore volume and also for the air capacity, whose relevance for horticultural practice has to be questioned. The air capacity and the plant-available water are different under field conditions compared to pots.

The measurement and evaluation methods for assessing the quality of the hydro-physical properties of growing media must be adapted to the conditions of use. Under field conditions, the air capacity and the amount of plant-available water are calculated from the field capacity (AG Boden, 2005). In the greenhouse, the height of pots and containers must be taken into account. In addition, the sample preparation should also be adapted. Under field conditions, the substrate may be walked on by people and driven over by machines, so sample preparation methods with preloading are required and used (PPO in Wever, 2012 and Schindler et al., 2017a). Pots in the greenhouse are filled loosely.

Table 3: Hydro-physical results of growing media after applying sample preparation methods B and C.

M$^{1)}$	No.	DBD	PV	FC	Air_$_{DIN}$	Air				Water			
					10°hPa	P10	P20	P30	Field	P10	P20	P30	Field
		gcm^{-3}	%°by vol.										
B	K1	0.22	83.5	47.6	6.2	2.7	7.3	15.4	35.8	39.2	34.6	26.5	29.5
B	K2	0.25	82.9	49.5	5.5	2.8	7.4	12.0	33.4	36.3	31.7	27.1	28.0
B	HTC_150C	0.23	81.3	49.9	6.3	3.6	7.8	11.6	31.3	34.4	30.3	26.4	31.2
B	HTC_150D	0.22	80.5	45.6	7.6	2.1	7.8	12.9	34.9	38.5	32.8	27.7	27.9
B	HTC_170D	0.23	82.6	49.5	9.5	3.8	9.3	13.6	33.1	34.9	29.4	25.1	28.2
B	HTC_190C	0.24	84.9	54.5	2.9	0.9	4.2	22.5	30.3	43.7	32.1	22.1	29.2
B	HTC_190D	0.23	83.3	55.0	3.0	1.0	3.6	7.3	28.4	33.4	30.8	27.1	30.2
B	HTC_190E	0.22	80.6	50.8	7.9	4.9	9.2	12.7	29.9	30.2	25.9	22.5	26.9
B	DK B170	0.17	87.7	47.4	8.7	3.3	10.0	24.5	40.3	42.5	35.9	21.3	27.6
C	K1	0.19	95.2	46.7	11.6	7.6	14.4	28.6	48.6	47.9	41.1	26.9	27.7
C	K2	0.20	89.8	41.6	16.3	8.2	16.7	22.9	48.2	44.6	36.1	29.8	19.1
C	HTC_150C	0.21	93.5	43.3	17.7	6.4	14.9	21.7	51.8	55.2	46.6	39.8	20.7
C	HTC_150D	0.19	88.2	40.7	13.3	4.0	13.0	20.1	47.5	48.3	39.4	32.3	21.6
C	HTC_170D	0.22	90.6	42.5	12.9	5.8	13.6	20.5	48.0	46.8	39.0	32.1	19.8
C	HTC_190C	0.22	92.8	50.1	9.6	5.4	11.4	27.5	42.7	43.6	37.6	21.5	26.4
C	HTC_190D	0.20	91.0	42.5	16.7	7.7	17.0	23.8	48.6	45.5	36.1	29.4	20.5
C	HTC_190E	0.22	86.8	44.5	10.3	4.1	11.2	17.4	42.3	42.4	35.2	29.1	22.1
C	DK B170	0.17	88.8	47.0	7.4	2.9	8.6	25.0	41.9	44.7	39.0	22.6	27.9
B	Av	0.22	83.0	50.0	6.4	2.8	7.4	14.7	33.0	37.0	31.5	25.1	28.7
C	Av	0.20	90.7	44.3	12.9	5.8	13.4	23.1	46.6	46.6	38.9	29.3	22.9
B	stabw	0.022	2.3	3.1	2.3	1.3	2.2	5.4	3.6	4.4	2.9	2.5	1.4
C	stabw	0.017	2.7	3.1	3.5	1.9	2.7	3.6	3.5	3.8	3.5	5.5	3.5
t-test		0	0	0	0	0	0	0	0	0	0	0.02	0

1) Preparation method, DBD - dry bulk density, PV - total pore volume, FC - field capacity at pF 1.8 (AG Boden 2005), stabw - standard deviation, P10 - pot, 10°cm high, Av - average.

The samples for hydro-physical measurements should also be prepared accordingly. It has been shown that there are significant differences in air capacity and the plant-available water between the sample preparation with and without preloading. Method C is comparable to DIN EN 13041 (2012). The difference lies in the way hydraulic consolidation occurs. According to DIN EN 13041 (2012), this happens in the 50°hPa cylinder. With the HYPROP, the sample consolidated directly in the cylinder during the measurement. Under these conditions, it would not be possible to measure the retention properties in the sandbox. However, HYPROP can take the geometric changes into account. This can save equipment, labour, time and money.

Intelligent growing media water management requires knowledge of hydro-physical properties. The air capacity in shallow pots can assume critical values.

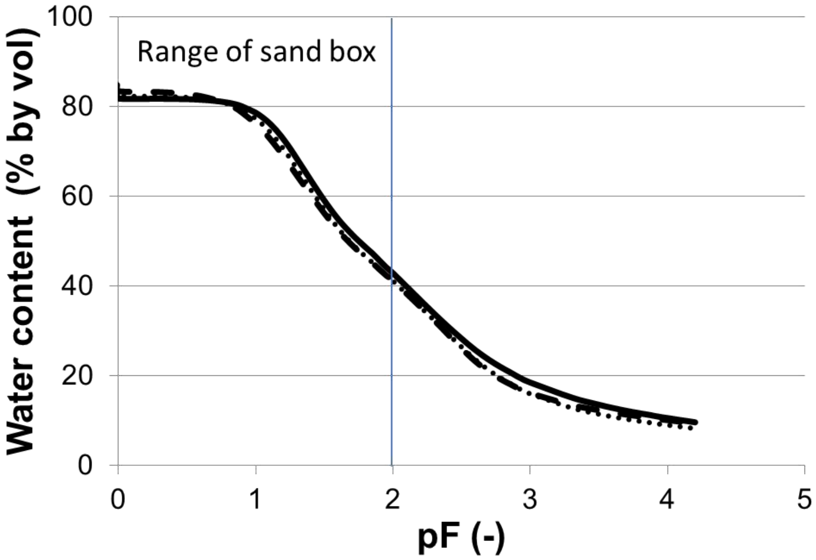

Figure 6. Reproducibility of water retention curves, K1 sample, preparation Method B, three replicates.

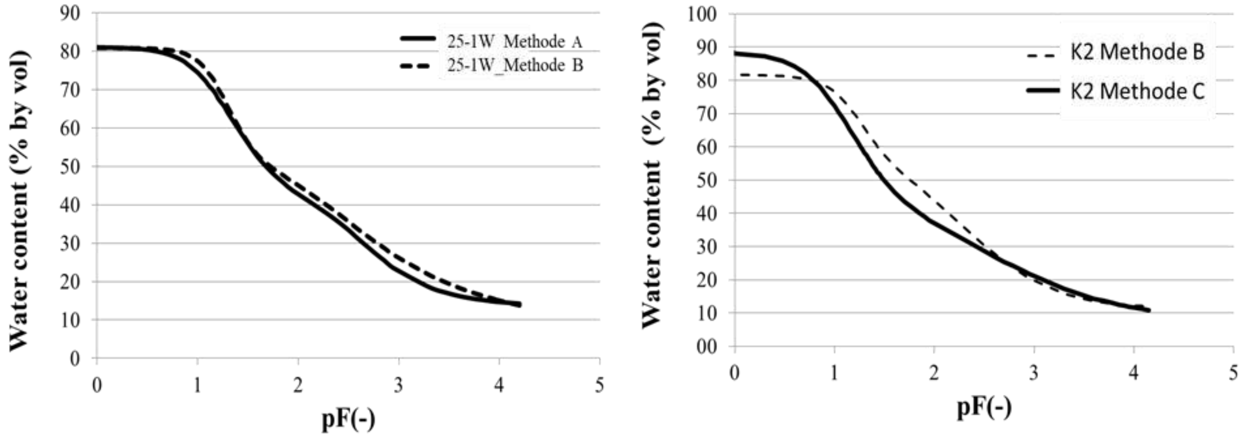

Figure 7. Example of the water retention functions, preparation methods A and B (left), B and C (right).

Conclusions

1. HYPROP is an effective system for the complex measurement of hydro-physical properties of growing media with high quality and reproducibility. It is the basis for intelligent, knowledge-based air and water management in horticulture. Beside the water retention curve and the unsaturated hydraulic conductivity function, the dry bulk density, capillarity, shrinkage and rewetting properties can be simultaneously measured and enable a complex hydro-physical evaluation of soils and growing media.
2. The sample preparation method – preloading or loose filling – yielded significantly different results in terms of the pore volume, dry bulk density, plant-available water and (especially and most critically) air capacity.
3. The sample preparation method, the measurement and the assessment of the quality of hydro-physical properties of growing media must be adapted to the conditions of use: a field with free drainage or a greenhouse with pots or containers. The air capacity and the amount of plant-available water in pots depend on the height of the pot. In the field, they are related to the field capacity.
4. The air capacity as defined in DIN 13041 (2012) can be used to compare different growing media. However, this value is of limited significance for air and water management and quality assessment in horticulture.
5. For growing media with sufficient air capacity in the upper part of the pot, intelligent knowledge-based water management can reduce the air problem.
6. Further investigations are required to study how the sample preparation method affects the hydro-physical properties of a wide variety of growing media.

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Original paper DOI: 10.5937/ZemBilj2201040S

Merenje hidrauličkih osobina podloga za uzgoj sa HYPROP sistemom

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Izvod

Poznavanje vodno-fizičkih svojstava je suštinski preduslov za procenu podobnosti i kvaliteta podloga za uzgoj. Metoda koja se koristi za pripremu uzoraka je važna za rezultate merenja. Upoređene su tri različite metode pripreme uzoraka. Metode su se razlikovale u pogledu načina punjenja čeličnog cilindra od 250°cm^3 i visine predopterećenja. Uključena su i merenja na slabo napunjenim cilindrima. Poređenje je obavljeno na 15 podloga za uzgoj pomoću HYPROP uređaja. HYPROP omogućava kompleksnu analizu -fizičkih svojstava sa visokom preciznošću i ponovljivošću. Kriva zadržavanja vode, funkcija nezasićene hidrauličke provodljivosti, zapremiska specifična masa, skupljanje i svojstva ponovnog vlaženja mogu se meriti istovremeno. Kapacitet vazduha i količina vode dostupne biljci u saksijama zavise od visine saksije. Na terenu je povezan sa poljskim vodnim kapacitetom t. Procena kvaliteta je vršena kako za saksije različite visine, tako i za terenske uslove sa slobodnom drenažom. Labavo napunjeni uzorci su hidraulički konsolidovani ubrzo nakon početka merenja. Ove geometrijske promene se mogu uzeti u obzir sa HYPROP -om. Metoda pripreme uzorka – prethodno punjenje ili rastresito punjenje – dala je značajno različite rezultate za zapreminu pora, zapreminska specifična masa suvog zemljišta, kapacitet vode i vazduha koji je dostupan biljci. Ukupna zapremina pora labavo ispunjenih cilindara varirala je između 86,8 i 95,2°% zapremine. (prednapunjeno 81,3 i 87,7°% po zapremini). Najkritičniji faktor je bio kapacitet vazduha. Slabo napunjeni uzorci supstrata postigli su najveće vazdušne kapacitete, ali takođe nisu dostigli kritičnu vrednost od 10°% zapremine u plitkim saksijama, npr. u posudama od 10°cm sa 5,8°% zapremine. Metod pripreme uzoraka, merenje i procenu kvaliteta vofizičkih svojstava podloga za uzgoj treba da budu prilagođeni uslovima upotrebe – bilo da se koriste u polju sa slobodnom drenažom ili u saksijama ili kontejnerima u plastenicima.

Ključne reči: priprema uzorka, kriva zadržavanja vode, funkcija nezasićene hidrauličke provodljivosti, metoda produženog isparavanja (EEM), HYPROP

Received 07.02.2022
Revised 15.05.2022
Accepted 19.05.2022

Original paper DOI: 10.5937/ZemBilj2201053T

Microgranular fertilizer and biostimulants as alternatives to diammonium phosphate fertilizer in maize production on marshland soils in northwest Germany

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Abstract

The eutrophication of groundwater through widespread diammonium phosphate (DAP) fertilization and excessive farm fertilizer is one of the major problems in European agriculture. Organomineral microgranular fertilizers that have a reduced phosphorus (P) content, alone or in combination with biostimulants, offer promising alternatives to DAP fertilization. We conducted a field experiment with maize (*Zea mays*) on a marshland soil site in order to compare the yield increase and the phosphorus balance of DAP and microgranular fertilizer variants. P content of the soil on the study site is 3.9 g P per 100 g soil. Treatments involved a combination of two fertilizers, namely DAP or a P-reduced microgranular slow-release organomineral fertilizer (Startec) and the biostimulants mycorrhiza, humic substances and soil bacteria, applied individually or along with two of the above biostimulants. Fertilizer variants were also tested individually without additional biostimulants. One in four plots was used as a control, treated only with biogas slurry, to identify site-specific spatial variability and to implement correction factors to process raw data using standardized methods. Startec performed as well as DAP in terms of both the yield and corn cob ratio, while the P excess was lower in plots treated with Startec (av. = 4.5 kg P_2O_5 ha^{-1}) compared to DAP (av. = 43.7 kg P_2O_5 ha^{-1}). The latter differences are of statistical significance. Individual biostimulants and a combination of multiple biostimulants rarely resulted in significantly higher yields, with the exception of some combinations with humic substances and mycorrhiza in individual years. The influence of the climatic conditions in each of the years was higher than the influence of the biostimulants. However, average increases in yield over three years would be economically beneficial for farmers in the case of the applied humic substances product and mycorrhiza. An adequate alternative to DAP was found in the form of a P-reduced microgranular fertilizer from Startec.

Keywords: microgranular fertilizer, diammonium phosphate, eutrophication, phosphorus balance, biostimulants

Introduction

Though the extent of existing phosphate rock reserves is a subject of heated debate in the literature, it is undisputed that these resources for conventional fertilizer production are finite (Edixhoven et al. 2014; Kisinyo and Opala 2020). Further ecological problems, such as the eutrophication of ground and surface water systems by agricultural phosphorus inputs (Torrent et al. 2007; Ulén et al. 2007), have led to policies in the European Union placing strict regulations on fertilizing-related nutrient management (91/676/EWG, 2000/60/EC). Thus, a more responsible usage of phosphorus fertilizer is necessary. Recently, new fertilizing systems, such as the application of microgranular fertilizer, also known as pop-up fertilizer, and biostimulants have been successfully tested (Balawejder et al. 2020; Olbrycht et al. 2020). In contrast to DAP and other fertilizers, which are applied as a fertilizer band at a distance of around 10 cm to the seed, microgranular fertilizer is ideally put in the soil together with the seed, at a distance of a few centimeters. The direct contact between the fertilizer and the seed both requires a lower amount of fertilizer and nutrients, especially phosphorus (P), to be used per plant and calls for the components of the fertilizer itself to have a lower salt index (Alley et al. 2010). Further, the dispersal of the granules, that are smaller than 2 mm in diameter, prevents long-term osmotic gradients. While microgranular slow-release fertilizer has started to be used more frequently in German agricultural practice, and thus begun to develop into a promising tool to counter the above ecological challenges, the application of biostimulants has not spread to the same extent. This is in contrast to the numerous studies at laboratory scale (germination assays), in greenhouses and successful field trials for different plant taxa (Mackowiak et al. 2001; Nardi et al. 2002; Cavaglieri et al. 2005; Jakobsen et al. 2005; Anjum et al. 2011; El-Hassanin et al. 2016; Eulenstein et al. 2016; Fan et al. 2018). However, the world market for biostimulants has been growing fast in the last decade (Calvo et al. 2014).

In the present study, field trials were carried out over three years in maize (*Zea mays*) cultivation to compare the effect of the standard fertilizer diammonium phosphate (DAP), which is rich in P, and a microgranular slow-release fertilizer with a lower P content (Startec) both individually and in combination with biostimulants, namely liquid humic substances extract, soil bacteria and mycorrhiza.

Materials and Methods

Area studied

The experiments were carried out as a field trial from 2018 to 2020 near Wanna in northwest Germany (53.729995, 8.810990). The region is classified as having a European Atlantic climate (Cfb) as defined by Köppen and Geiger (1930), characterized by mild winters and moderate summer temperatures. The average precipitation per year for Wanna is 735 mm and the average annual temperature is 9.9 °C. 45% of annual precipitation is during the maize crop season from April to September.

The study site contains hydromorphic loamy marshland soil, rich in humus and contains 3.9 g P and 5.2 g K per 100 g soil. Ground water levels are 40–60 cm below the surface, with insignificant changes over the year due to the presence of drainage channels communicating directly with the regulated system of a small stream called the Emmelke. The site has been used for maize cultivation for years and treated with the plant protection products Laudis, Spectrum Gold, Milagro Forte and

Nagano (with 1, 2, 1, 0.5 and 0.3 liters per hectare). Regular tillage operations involve plowing and land clearing.

Experimental setup

The maize cultivar Amaroc S230 was sown with a density of 8.5 seeds per square meter using the AMAZONE single corn seeder system (EDX 6000-2C precision air seeder). Eleven different fertilizer combinations were repeated five times and regularly separeated by five control parcels on plots each measuring 50 m x 6 m.

DAP fertilizer was applied in a band 12 cm below the soil surface and Startec microgranular fertilizer (De Ceuster Meststoffen NV (DCM) Bannerlaan 79, 2280 Grobbendonk, Belgium) was applied a few centimeters beneath the corn, respectively. DAP was applied in amount of 100 kg ha^{-1}. The latter contains 18% total N, all in the form of NH_4-N, and 46% P_2O_5. Startec can be classified as a microgranular organomineral fertilizer, of which 80% (of the original substance) is made up of the organic industrial by-products oil cake and bone meal and the mineral components ammonium phosphate, ammonium sulfate, EDTA-chelated Fe, Mn, Zn, zinc sulfate and zinc oxide. The nutrient composition of Startec is 7.5% N, 22% P_2O_5, 4% K_2O, 10% S, 0.5% Fe and Mn respectively, plus 1.5% Zn. In the present study, Startec was applied at a rate of 25 kg ha^{-1}. The study site was treated with biogas slurry (30 m³ ha^{-1}) containing 4.3 kg of total N, 1.3 kg of P_2O_5 and 5.2 kg of K_2O per m³. The nutrient types and input rates are given in Table 1.

Table 1. Application rates and nutrient inputs per hectare of used fertilizer

Fertilizer (type[1])	Application rate per hectare in kg	Nutrient type and input rate per hectare						
		N	P_2O_5	K_2O	SO_3	Fe	Mn	Zn
Diammonium phosphate (mineral fertilizer)	100	18	46	-	-	-	-	-
Startec (organomineral microgranular fertilizer)	25	1.75	5.5	1	2.5	0.125[2]	0.125[2]	0.375[2, 3]
Pre-treatment of the soil with biogas slurry	30000	129	39	156	-	-	-	-

[1] For seed band application; [2] EDTA-chelated; [3] EDTA-chelated and as oxide; - Absent or no data available.

Mycorrhiza, grown on expanded clay, and soil bacteria, sprayed on natural zeolite (clinoptilolite) as a carrier material, were pulverized and poured into separate chambers of the AMAZONE precision seeder for exact, plot-specific application along with a fertilizer treatment. Humic substances were sprayed directly on the soil after treatment with biogas slurry. This form of application was used for organizational reasons and differs from the manufacturer’s instructions. The manufacturer of the humic product (GeoFert Germany GmbH, Koppelbergstraße 4, 17166 Tetrow, Germany) recommends mixing the humic substances directly into the slurry to reduce the technical effort in agricultural practice.

Treatments were realized as a combination of two mineral fertilizers, namely DAP or the P-reduced microgranular slow-release fertilizer from Startec and the biostimulants mycorrhiza (abbreviated as M), humic substances (abbreviated as HS) (GeoOrganic®, GeoFert Germany GmbH) and the soil bacteria *Bacillus subtilis* (abbreviated as Bac) (BactoFert®, GeoFert Germany GmbH) either alone or together with one or two of the above biostimulants. Mineral and organomineral microgranular fertilizer variants were also tested alone, without any additional biostimulant. One in four plots was used as a control, treated only with biogas slurry, to identify site-specific spatial variabilities and to implement correction factors in data analysis. Manual harvesting was performed by randomly removing 20 plants per plot. The cobs and the remaining plants were weighed and shredded separately using a garden shredder (AL-KO Master 32-40). For each of the five repetitions of a variant, the shredded cob and corn material was used to prepare samples for the measurement of dry matter, and afterwards pulverized for NIRS analyses using a FOSS 5000-M NIRS spectrometer (FOSS NIRSystems). The P and K contents were measured after aqua regia dissolution via ICP-OES. The latter data were used to calculate the year-specific removal of N, P_2O_5 and K_2O by harvesting.

Statistical analysis

Control plots without additional fertilization were used to detect soil spatial variability on the study site. Differences in control plots were used to implement correction factors as described in Thomas (2006) and Dospechov (1979). To ensure that the distribution was normal, the yield was transformed using an exponential function. Differences between the fertilizer variants were tested using Student's t-test. All statistical analyses were performed in R (R Core Team 2014). For data selection, the package dplyr (Wickham et al. 2018) was used. Visualization in R was conducted using the package ggplot2 (Wickham 2009).

Results

The high range of fluctuation in the repetitions of certain fertilizer variants mainly resulted in statistically insignificant differences in yield. The average dry matter yields of DAP in combination with all the individually and jointly applied biostimulants that were tested were 14.8% higher than the dry matter yield of plots only fertilized with DAP. Biostimulants had a negligible effect on Startec. Statistically significant differences were found in the case of the effect of HS plus M on DAP in 2018 ($P = 0.0127$), the effect of Bac plus M on DAP in 2019 ($P = 0.0041$) and the effect of HS on Startec's yield in 2018 ($P = 0.0087$). Differences in the phosphorus balance between all the Startec variants compared to all the DAP variants were of the highest statistical significance across the entire study time and in the individual years ($P < 0.0001$). The average P excess of plots fertilized with Startec was 4.5 kg per hectare and year. DAP fertilization resulted in a P excess of 43.7 kg per hectare and year.

Discussion

In the present study, the amounts of phosphorus per unit of area vary over the two different fertilizing systems using DAP and Startec (Table 1). The reduction of macroelements, especially phosphorus, is known to play a yield-limiting role in plant growth (Sharpley 1997). The low solubility of P in water makes it necessary to use mineral fertilizer (such as DAP) containing P compounds, which dissolve in an irrigated soil matrix in a highly plant-available form. Thus, mineral fertilizer is usually an important source of P in commercial crop fertilization. However, P is also found in organic form in Startec fertilizer. The organic P in Startec is predominantly present in bone meal as hydroxyapatite ($Ca_5(PO_4)_3(OH)$), which is typically present in bone structures (Kattimani et al. 2016). When designing the experimental setup, it was expected that the organically bound P and other organically bound nutrients in Startec would be converted into a plant-available form better if biostimulants were used. Contrary to the hypothesis that the joint application of biostimulants and Startec would have a higher benefit, the effect on DAP-fertilized plants was higher. The average dry matter yield during the three-year study of all DAP combinations with biostimulants was 14.8% higher than DAP without any biostimulant. In comparison, biostimulants had less effect on Startec; the impact was insignificant overall, resulting in a 4% higher yield compared to Startec without biostimulants. One possible explanation may be the positive effect that Startec's organic compounds such as oil cake and bone meal have on microbial activity. Oil cakes are used to increase microbial activity during soil bioremediation (Govarthanan et al. 2015) and other types of biotechnological application (Ramachandran et al. 2007). Bone meal is also known to increase the mineralization dynamics and thus the amount of extractable macronutrients in soils (Mondini et al. 2008) and to act as a biostimulant for bacteria (Liu et al. 2019). In other words, the supposed positive effect of biostimulants on microbial activity may already be affected by the organic compounds in Startec acting in the direct periphery of the roots of young maize plants. The concept behind Startec's mode of action on root growth is that it is promoted by the fine microgranular dispersal of organic nutrients. In that form, they can be mineralized during the growing season. It also promotes direct root growth into the soil's microgranular matrix by mineral NH_4-N. On the other hand, the DAP fertilizer band, which is more distant from the seed within the soil, also attracts root growth by providing ammonia, but may not be able to support microbial activity to the same extent as Startec's organic mineralizable pool of macro- and micronutrients. However, adding humic substances (HS) and/or mycorrhiza (M) can support beneficial plant–microorganism interactions (Artursson 2005; Canellas et al. 2011; Olivares et al. 2017; Cozzolino et al. 2021; Rozmoš et al. 2021). Another hypothesis to explain why the biostimulants used have a lower effect on yields gained with Startec is that the soil P is sufficient, and not a limiting factor. Thus, lower mineral P inputs will not result in lower yields. It is noteworthy that when soil bacteria (Bac) were applied, the effects were neutral on the dry matter yield of DAP and insignificantly negative on Startec (–10.3%) (data are not presented). Further, with a combination of mycorrhiza plus humic substances (HS_M) and soil bacteria plus mycorrhiza (Bac_M), no effect was found on the yield with Startec (data are not presented), while these combinations resulted in higher average yields over three years in the case of DAP (HS_M +11.7%; Bac_M +32.1%). The highest positive impacts on the average yield gained with Startec over the three years were found when HS (+13.75%) and M (+14.9%) were applied. Statistically significant differences were only present in the case of the effect of HS_M on DAP in 2018 (P = 0.0127), the effect of Bac_M on DAP in 2019 (P = 0.0041) and the effect of HS on Startec's yield in 2018 (P = 0.0087) (Figure 1).

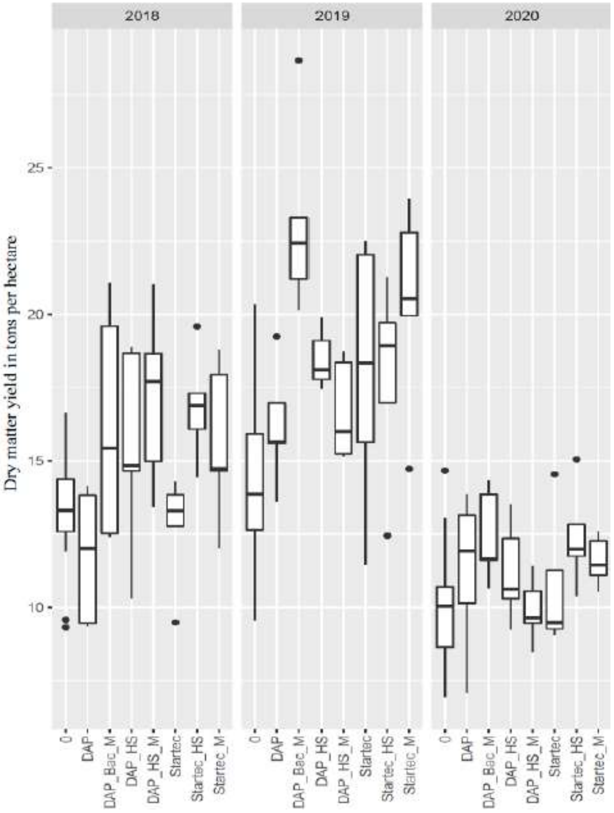

Figure 1. Dry matter yield per hectare gained with the DAP and Startec fertilizer variants individually or in combination with the biostimulants soil bacteria (Bac), mycorrhiza (M) and humic substances (HS) in 2018, 2019 and 2020; 0 represents the yield of the control plots.

Variants not shown: Startec_Bac, DAP_Bac, Startec_HS_M, Startec_Bac_M

The absence of statistically significant differences in 2020 can be traced back to the high precipitation spread equally over that year. Thus, while the biostimulants used during the comparatively dry springs of 2018 and 2019 are thought to have alleviated osmotic stress during the early development of the maize plants, this may not be relevant in 2020. The discontinuous impacts of biostimulants over the years were caused by the higher influence of climatic conditions. In other words, the influence of the year was higher than the influence of the biostimulants. The study site was chosen to minimize fluctuations in soil water and temperatures over the three cropping periods. However, compared to the other years, 2018 and to a certain extent also 2019 were dry in spring, which may lead to osmotic stress in DAP-fertilized plants without biostimulants and accordingly to a lower yield. The alleviation of osmotic stress by mycorrhiza and humic substances (Ruiz-Lozano 2003; Anjum et al. 2011; Aydin et al. 2012; Santander et al. 2017) may play a role in the better performance of the DAP–biostimulant combination compared to the DAP control application in 2018 and 2019. The increase in plants' resistance to drought through mycorrhizal symbiosis depends on the long-term water supply. If a lack of water limits their carbon uptake, the nutrition of mycorrhizal fungi may decrease shoot growth (Tinker et al. 1994; Ruiz-Lozano et al. 1995; Aikio and Ruotsalainen 2002). The locations of the plots were not precisely the same each year. If a shift occurs, this can prevent soil P contents in the control plots from gradually decreasing over the years. To avoid shifts in the plots on the study site and for higher statistical validity, future studies should be realized with a fully randomized experimental setup. While the average dry matter yield gained with Startec applied without biostimulants is slightly higher than DAP (without biostimulants), at 4.8%, the phosphorus balance of all Startec variants over the three years study is close to neutral (4.5 kg excess per hectare and year) compared to DAP phosphorus excess of 43.7 kg ha^{-1} over all DAP variants (Figure 2).

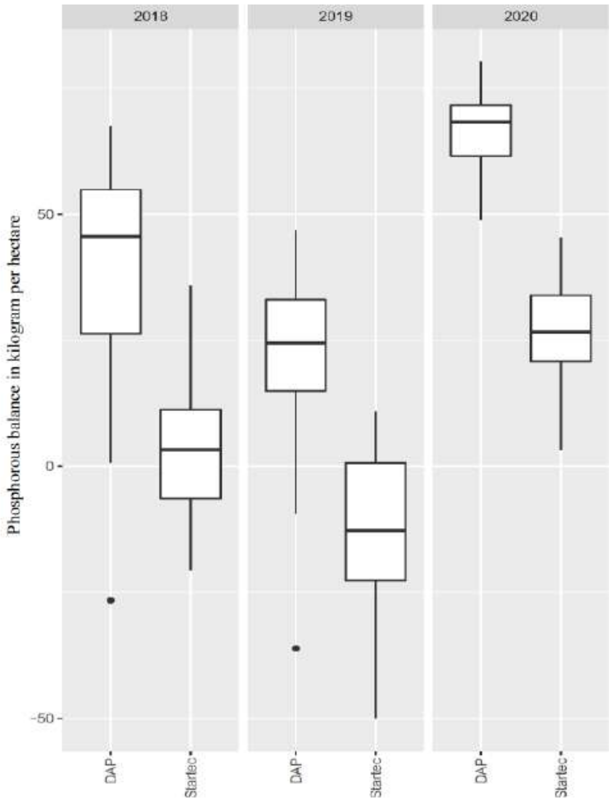

Figure 2. Phosphorus balance (P_2O_5) of all variants with and without biostimulants gained with DAP and Startec in 2018, 2019 and 2020.

Differences in phosphorus balance between all the Startec variants compared to all the DAP variants were of the highest statistical significance across the entire study period and in the individual years ($P < 0.0001$). Thus the Startec organomineral microgranular slow-release P fertilizer turned out to be an adequate alternative to DAP fertilization in maize on fertile, well-watered marshland soils. No differences were present in the corn cob ratio over all variants. For regions with high densities of livestock units and biogas plants, exporting slurry and manure is resource-consuming and puts farmers under financial pressure. By using alternative fertilizers with a lower P content, more organic P from regional farm fertilizers can be used, and inefficient exports to regions with lower densities of livestock units can be avoided. Potential modes of action affecting P availability for plants of each biostimulant used in the study were hypothetical, based on the present state of knowledge. However, it is known that the conversion of soil P into a plant-available form is driven by both plant–soil interaction and microorganism–soil interaction. The latter types of interaction are not independent, but instead characterized by interrelated processes within the rhizosphere. Microorganisms solubilize soil P, for example, by releasing small organic anions with two to six C atoms (Khan et al. 2007) and incorporating them into unstable structures as membranes and metabolism-related molecules (Achat et al. 2010). Due to the short lifespan of dominant soil bacteria, microbial P has habitat-specific turnover rates which are shorter than one growing season (Oberson et al. 2001; Bonkowski 2004). In other words, organic and inorganic bound soil P can be transferred in plant-available form through its incorporation into soil microorganisms and the mineralization of the latter. The use of soil bacteria, as performed in the experiment by using Bac or the application of leonardite-derived humic substances (HS), and thus increasing microbial activity (Lovley et al. 1996; Field et al. 2000), has the potential to support the above process of soil P conversion by microorganisms. Further, the nutrient uptake and root growth can be increased by humic substances (Adani et al. 1998; Nardi et al. 2000), soil bacteria (Araújo et al. 2005; Hansen et al. 2020; Rozmoš et al. 2021) and mycorrhiza (Vessey and Heisinger 2001; Bashan et al. 2014; Cozzolino et al. 2021) by raising the effective root surface for P uptake and other modes of action. In the case of the mycorrhizal effect on plant P uptake, Vessey and Heisinger (2001) point out that the effect can be traced back to the increase in the effective root surface and is thus indirect. However, microorganisms can also have a negative effect because of direct competition between plants and microorganisms for orthophosphate (Oehl et al. 2001; Bünemann et al. 2007; Ehlers et al. 2010). In the case of mycorrhizal fungi in particular, it is known that positive effects on plants are limited in soils with high biological activity before the treatment (Eulenstein et al. 2016) and the effect can even be negative on well-watered sites (Lahde 2016). Mycorrhiza applications can also have adverse effects if an unsuitable soil microbiome is present (Bowen and Theodorou 1979; Garbaye et al. 1994; Founoune et al. 2002; Frey-Klett 2007). Moreover, in terms of the microbial P turnover, the potential competition between plants and mycorrhiza may be higher due to the longer lifespan of fungi compared to bacteria, which lack the robust chitin structures present in fungi, and fungi’s higher symbiosis-related resistance to environmental fluctuation (Kassim et al. 1981; Simpson et al. 2004). In general, the positive effects of biostimulants predominate both in the literature and in the present study.

Conclusion

The microgranular fertilizer Startec performs as well as DAP in terms of yield and can be considered an adequate alternative to DAP fertilization in maize cultivation on fertile marshland soils. The phosphorus balances of Startec variants were around nine times lower than all DAP variants ($P < 0.0001$). The impact of biostimulants was discontinuous in general: in some years there was a significant positive effect and in others there was no notable impact. The influence of the climatic conditions in each of the years was higher than the influence of the biostimulants. On average, the effects of humic substances and mycorrhiza were economically beneficial if established in agricultural practice under comparable conditions to those at the study site. The influence of humic substances on less fertile or less watered soils is believed to be higher. Further studies must be carried out comprising parallel trials on different soil types, including soils with a low P content, in the same year and with additional microbiome monitoring to prove the above hypothesis regarding the biostimulants' mode of action and possible limitations in agricultural practice.

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Mikrogranularno đubrivo i biostimulansi kao alternative diamonijum fosfatnom đubrivu za proizvodnju kukuruzana močvarnim zemljištima u severozapadnoj Nemačkoj

Original paper DOI: 10.5937/ZemBilj2201053T

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Izvod

Eutrofikacija podzemnih voda usled široke rasprostranjenosti đubrenja diamonijum fosfatom (DAP) i prekomernih farmskih đubriva je jedan od najvećih problema u evropskoj poljoprivredi. Organomineralna mikrogranularna đubriva koja smanjuju sadržaj fosfora (P), samostalno ili u kombinaciji sa biostimulansima, nude obećavajuće alternative DAP đubrenju. Sproveden je poljski eksperiment sa kukuruzom (*Zea mays*) na močvarnom zemljištu kako bi se upredili povećanje prinosa i ravnoteža fosfora u varijantama sa DAP i mikroglanuralnim đubrivom. Sadržaj fosfora u zemljištu oglednog polja je 3.9 g P na 100 g zemljišta. Tretmani su uključivali kombinaciju dva đubriva, DAP ili P-redukovano mikrogranularno organomineralno đubrivo sa sporim oslobađanjem (Startec), i biosimulansa mikoriza, humične materije i zemljišne bakterije, primenjenih pojedinačno ili zajedno sa dve od gore navedenih biostmulanasa. Varijante sa đubrivom su takođe testirane pojedinačno bez dodavanja biostimulanasa. Jedna od četiri parcela je korišćena kao kontrola, i tertirana je samo sa muljem biogasa, za identifikuju prostorne varijabilnosti specifične za lokaciju i za implementaciju factora korekcije za obradu sirovih podataka korišćenjem standarizvanih metoda. Startec se pokazao dobar kao i DAP u pogledu prinosa i odnosa kukuruza i klipa, dok je višak P bio manji na parcelama tretiranim Startec-om (pros.= 4.5 kg P_2O_5 ha^{-1}) u poređenju sa DAP (pros. = 43.7 kg P_2O_5 ha^{-1}). Poslednje razlike su od statističkog značaja. Pojedinačni biostimulansi i kombinacija više biostimulanasa retko su davale značajno veće prinose, sa izuzetkom nekih kombinacija sa humičkim materijama i mikorizom u pojedinim godinama. Uticaji klimatskih uslova u savakoj od godina je bio veči od uticaja biostimulanasa. Međutim, prosečno povećanje prinosa tokom tri godina bilo bi ekonomski korisno za poljoprivrednike u slučaju primenjenog proizvoda od humičkih materija i mikorize. Pronađena je adekvatna alternativa za DAP u obliku mikroglanuralnog đubriva sa redukovanim P iz Startec-a.

Ključne reči: microgranularno đubrivo, diamonijum fosfat, eutrofikacija, ravnoteža fosfora, biostimulansi

Received 14.04.2022
Revised 20.05.2022
Accepted 24.05.2022

Original paper DOI: 10.5937/ZemBilj2201067P

Adaptation to climate change in agricultural sector - a proposal for rational management measures

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Abstract

Agriculture, as one of the most important branches of economy, depends on climate conditions and has a significant contribution to climatic changes process, primarily by releasing greenhouse gases (GHG). It is estimated that agriculture directly emits about 9% of the total amount of GHG, of which 5% originates from soil and about 4% from livestock production (ruminants). Emissions of carbon dioxide into the atmosphere from cultivated soil are 27% to 90% higher compared to natural grasslands. For greater climate neutrality of agriculture, two-way action is necessary: towards the reduction of GHG and towards the sequestration of carbon in the soil. Recommended measures and practices in the management of organic carbon content in soil include a wide range of agronomic, biological, technical and technological procedures, management and structural practices on agricultural soil. By encouraging organic plant production, which should contribute to maintaining and increasing the natural fertility of the soil, as well as preserving and improving biodiversity and stabilizing the structure of the soil, it can contribute to mitigating climate change.

Keywords: climate change, GHG, measures of more rational soil management

Introduction

Soil is a natural resource that arises as a result of the joint and mutual effects of the lithosphere, atmosphere, hydrosphere, and biosphere. It plays an important role in the global cycle of carbon, nitrogen and other elements in nature and is the source of the three most common greenhouse gases (GHG): nitrogen suboxide (N_2O), methane (CH_4) and carbon dioxide (CO_2). The observed climate change Prather and Ehhalt (2001) is attributed to increased GHG emissions. Anthropogenic disturbance of natural ecosystems has led to an increase in GHG emissions, which have escalated from changes in soil use, intensification of agriculture and soil management. It is estimated that agriculture directly emits about 9% of the total amount of GHG, of which 5% originates from soil, and about 4% from livestock production (ruminants).

Climate change resulting from extreme droughts or floods is becoming more pronounced and as such has a major impact on soil degradation. Adopting the practice of sustainable soil management can be part of the solution when it comes to reducing GHG emissions into the atmosphere and adapting to changed climatic conditions (Manojlović and Pivić, 2020; Ikanović and Popović, 2020; Popović et al., 2020). As soil is an integrated part of the food, energy and water network, it is a functional component of environmental sustainability, which is associated with climate change, declining biodiversity, water, energy and food security (Bouma 2014; Gupta et al. 2019).

In the past and this century obviously, anthropogenic activity has led to climate change. Compared to the pre-industrial period, to date, the temperature on Earth has increased by about 1˚C (0.8-1.2˚C). Estimates point to predictions that the global average temperature will increase between 1.8˚C and 4 ˚C by 2099 (IPCC 2018). Projections of regional climate models according to two IPCC scenarios of GHG emissions, RCP8.5 and RCP4.5, predict further increase in temperature, change in precipitation regime, as well as intensification and higher frequency of extreme events.

The IPCC report (2001) indicates a direct link between anthropogenic activities and observed climate change. Globally, as a result of burning fossil fuels and cement production, from 1850 to 1998, approximately 270 ± 30 Pg CO_2 was released into the atmosphere Lal (2004), while changes in soil use, in the same period, in atmosphere was released 136 ± 55 Pg CO_2 (IPCC, 2001). During the 1990s, total C emissions consisted of fossil fuel combustion, amounting to 6.3 ± 0.3 Pg C per year and 1.6 ± 0.8 Pg C per year, released due to change in soil use. Of the total amount released of 7.9 Pg C per year, 3.3 ± 0.2 Pg C per year was accumulated in the atmosphere, 2.0 ± 0.8 Pg C per year in the oceans, while 1.9 ± 1.3 Pg C per year has accumulated in the terrestrial ecosystem (IPCC, 2001). In the long run, the concentration of CO_2 in the atmosphere has increased from 180 to 280 ppm since the last glacial period, i.e. adding 220 PgC to the atmosphere over a period of 10.000 years, with an increase of 4.4 PgC per year (Baldocchi et al. 2016).

Temperature and precipitation are the most important factors controlling the dynamics of organic matter content (SOC) (Deb et al. 2015). Although an increase in temperature can have a positive effect on crop production, increasing carbon uptake into the soil (due to higher residue mass), microbial decomposition of SOC (so-called priming effect) also increases, Keestrea et al. (2016). According to Crovther et al. (2016), an increase in temperature will stimulate net carbon loss in the soil by switching to the atmosphere and accelerate climate change (Figure 1).

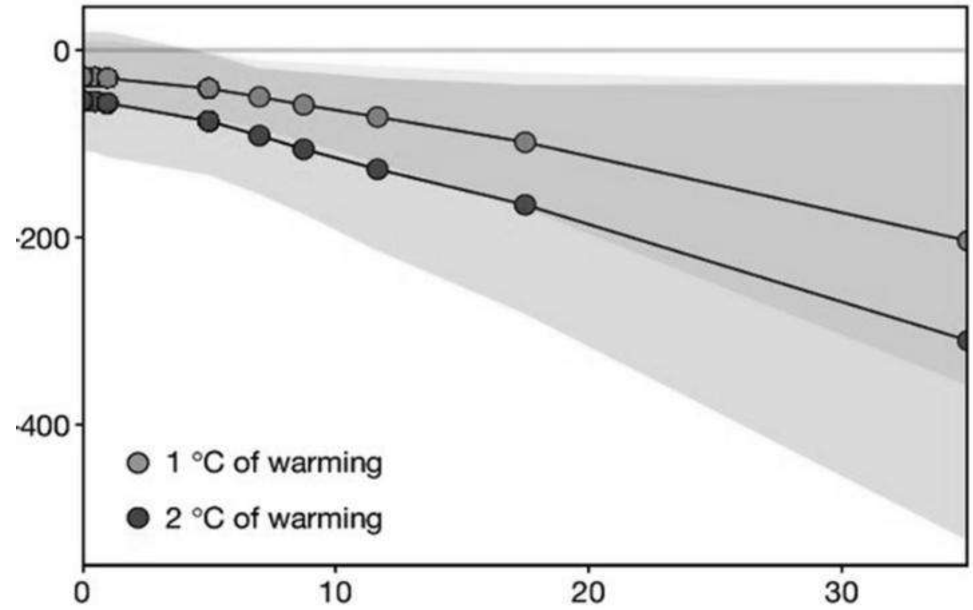

Figure 1. Total reduction of global reserves C with 1^{o}C and 2^{o}C of soil surface warming expected by 2050, in a number of different scenarios of weather impact off soil X axis: Impact-time (years), refers to the speed at which full impact will be achieved; Y axis: Estimated loss of C by 2050 (Pg); shaded areas indicate a 95% confidence interval around the average C (point) loss for each scenario (adapted from FAO and ITPS 2015).

With climate change, more frequent extreme rainfall and drought events are predicted that may have a greater impact on ecosystem dynamics than single or combined effects of rising CO_2 and temperature (IPCC 2014). This increase in the frequency of extreme events can increase the speed and susceptibility to accelerated erosion, salinization, and other degradation processes, leading to further carbon losses.

Materials and Methods

The proposal of measures for mitigating the impact of intensive agricultural production on climate change is given on the basis of available literature, ie given guidelines of the IPCC and FAO.

Results and Discussions

According to some estimates, agricultural production is thought to be responsible for a quarter of global anthropogenic GHG emissions. Intensive agricultural production can cause the loss of organic matter and intensification of soil erosion, which releases CO_2, contributing to global warming and the emergence of climate change.

According to Đurđević et al. (2018), in the period from 1961 to 2017, in the Republic of Serbia, the trend of temperature increases of 0.36°C per decade was observed, and in the period from 1981-2017, 0.6°C per decade. In the same period, the amount of precipitation increased to 10%, and in the South of the country to 20% compared to the reference period. The changes were more pronounced during the summer season, which became warmer by about 2.5°C, while summer precipitation decreased by 10 to 20% in most parts of the territory, to 30% in the South. Extreme occurrences of extreme events, heat waves, drought, floods, and intense precipitation, have also been observed.

According to Maksimović et al. (2018) mean air temperatures of 18.6°C were observed during the vegetation period according to the 30-year data (1987-2016) collected in Bački Petrovac. Compared to data from the previous period (1948-1990), increase in mean daily air temperatures is observed in all the months, especially July and August (1.4°C) as well as throughout the whole vegetation period (1.0°C)

There are two ways to reduce the increase in GHG concentration in the atmosphere: reducing CO_2 and N_2O emissions and/or their binding (immobilization) in the soil. Some measures of agricultural production have a positive effect on reducing the concentration of CO_2 in the atmosphere by its binding by the process of photosynthesis and the accumulation of organic carbon compounds in the soil after the death of plants. Carbon sequestration, which presents the storage of carbon from the atmosphere into the soil, can contribute to mitigating climate change. The strategy includes increase in the content of soil organic matter through greater biomass production and the development of the root system of plants, as well to encourage humification and the formation of an organo-mineral complex that improves and stabilizes soil structure.

Climate change mitigation refers to changes in management strategy, behavioral changes and technological innovations that reduce GHG emissions. In this way, soils can play an integral role in reducing CO_2 emissions due to their carbon storage potential (Lal 2004). On the other hand, adaptation to climate change refers to efforts aimed at achieving greater resilience to climate conditions that help human and natural systems to adapt to changing climate (IPCC 2014). In contrast to mitigation, adaptation measures can be both reactive and proactive, and the benefits presented are usually local and short-term (IPCC 2007). Currently, due to the already present warming, adjustment measures are needed despite the higher associated financial costs, regardless of the extent of mitigation efforts (IPCC 2007). Given the role of soil in climate change mitigation and adaptation and the constraints of SOC saturation in the accumulation of additional carbon inputs, sustainable soil management needs to be implemented to ensure that soil becomes a reservoir, and not a source of atmospheric CO_2 (Paustian et al. 2016). For this reason, it is necessary to study and determine, for different ecosystems, the current SOC reserves and the appropriate point of carbon saturation in order to determine the potential for carbon sequestration in soil.

Sustainable soil management is the basis of sustainable agriculture and is a strategic component of sustainable development. Studies show that by degradation of a third of the world's soil, up to 78 Gt of carbon has released in the atmosphere. Anthropogenic CO_2 emissions of 25% are absorbed by the ocean, while deeper soil horizons/layers can store 760 to 1520 Gt of additional carbon (FAO 2017). In addition to the above, the change in the purpose of soil cover, the so-called anthropogenic reduction of agricultural soil, which primarily refers to the transfer from natural or semi-natural to arable agricultural soil, leads to a decrease in the concentration of organic carbon.

Sustainable soil management practices can be applied to any ecosystem or type of soil use (Znaor 2019). The results of scientific research projects and numerous examples of good practice from all over the World testify to that.

One example of a new green model, shown in Table 1, is carbon sequestration in agriculture and encouraging practices that store CO_2 in soil organic matter by binding it to a stable humus fraction (Ugrenović et al. 2020; 2021).

Table 1. Proposed methods for reducing GHG emissions and encouraging carbon sequestration

Expected goals	Methods
Reduction of GHG emissions	Input management: - increased participation of legumes in the crop rotation, - wider crop rotation with the inclusion of green manures; Reduction of energy consumption on the farm: - application of reduced, conservation tillage; Management of plant residues and organic fertilizers, composting. Crop management and optimization of fertilizer use.
Encouraging carbon sequestration in soil	Inclusion of cover crops, green mulch and green manure in crop rotation. Introduction of protection belt methods. Agroforestry.

Conclusions

Recommended measures and practices in the management of organic carbon content in the soil include a wide range of agronomic, biological, technical-technological procedures, management and structural practices. Recommended measures for the preservation of organic matter in the soil, and thus alleviate soil degradation and impact on the GHG reduction, may be as follows:

- afforestation (organic carbon sequestration process);
- lawning (have a great potential to store additional amounts of carbon and can act as carbon reservoirs for more than 100 years, after which most of them reach a balanced C amount);
- maintenance of lawns (application of manure and plant residues of grass on lawns; defining grazing plan and number of animals that are optimal for breeding; growing legumes, fertilizer management, pasture cultivation with a chain harrow, sowing, etc.);
- use of peatlands as a type of agricultural soil (prevention of degradation by banning drainage, plowing and burning of plant residues, as well as limited exploitation);
- ban on burning crop residues (straw, corn and other crop residues);
- tillage in a way that reduces degradation processes, especially its erosion (on agricultural soil with a large slope of, e.g. 15% or more, plowing must be carried out only perpendicular to the slope, ensuring the existence of plant cover during rainy periods on plots in areas with a slope higher than prescribed);

- soil cover with cover crops, crop residues or mulching (these are multifunctional measures to prevent and/or reduce soil compaction and erosion caused by wind (which can be a problem in flat, loose and dry areas, especially on bare sandy and peat soil), or by water, which also contributes to reducing carbon and nitrogen losses and translocations to surface and groundwater)**;**
- growing a large number of different cultures;
- application of crop rotation (method of agricultural production recognizable for organic agriculture, which, in addition to the above, includes the use of compost and other breeders that maintain the content of organic matter in the soil at an optimal level).

The application of these measures enables and encourages the accumulation of organic carbon in the soil, contributes to the protection and preservation of terrestrial biodiversity and mitigation of climate change.

Acknowledgements

The study was financially supported by the Ministry of Education and Science of Republic of Serbia, Project 451-03-68/2022-14/200011.

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Original paper DOI: 10.5937/ZemBilj2201067P

Adaptacija na klimatske promene u sektoru poljoprivrede - predlog mera racionalnog upravljanja

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Izvod

Poljoprivreda, kao jedna od najvažnijih grana privredne delatnosti, zavisi od klimatskih promena, ali ima i znatan doprinos u navedenom procesu, pre svega ispuštanjem gasova sa efektom staklene bašte. Procena je da poljoprivreda neposredno emituje oko 9% od ukupne količine GHG, od čega je 5% poreklom iz zemljišta, a oko 4% iz stočarske proizvodnje (preživari). Emisija ugljen dioksida u atmosferu iz obrađenog zemljišta veća je za 27% do 90% u poređenju sa prirodnim travnjacima. Za veću klimatsku neutralnost poljoprivrede neophodno je dvosmerno delovanje: ka smanjenju GHG i ka sekvestraciji ugljenika u zemljištu. Preporučene mere i prakse, u upravljanju sadržajem organskog ugljenika u zemljištu obuhvataju širok spektar agronomskih, bioloških, tehničko-tehnoloških postupaka, upravljačkih i strukturnih praksi na poljoprivrednom i neobradivom prirodnom zemljištu. Podsticanjem organske biljne proizvodnje, koja treba da doprinese očuvanju i povećanju prirodne plodnosti zemljišta, kao i očuvanju i unapređenju biodiverziteta i stabilizaciji strukture zemljišta, može se doprineti ublažavanju klimatskih promena.

Ključne reči: klimatske promene, GHG, mere racionalnijeg upravljanja zemljištem

Received 28.04.2022
Revised 09.05.2022
Accepted 13.05.2022