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Use of *Hissopus officinalis* L. Culture for Phytomelioration of Carbonate Outcrops of Anthropogenic Origin the South of European Russia

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Abstract: Eurasian-African species of the *Lamiaceae* family – *Hissopus officinalis* (L.) gradually enters the culture of the South of European Russia. This semi-shrub has high resistance to carbonate soils, overground productivity, and longevity. Field experiments were conducted including the study of *H. officinalis* value to phytomeliorate cretaceous exposures in comparison with standard *Agropyron cristatum* Gaertn. crops and natural succession on the chalk outcrop of anthropogenic origin in the Belgorod region in 2008-2016. During nine years the *H. officinalis* crops were significantly higher than those of *A. Cristatum* Gaertn. and options with natural succession for the accumulation of overground and underground phytomass. It has been established that over an average nine-year period the *H. officinalis* crops generated 370.5 $g\cdot(m^2)^{-1}$ of absolutely dry substance of aboveground organic mass per year in comparison with the *A. cristatum* (213.6 $g\cdot(m^2)^{-1}$ per year) crops and natural substrate overgrowth (59.7 $g\cdot(m^2)^{-1}$ per year). On a chalk outcrop, the total carbon tends to increases by 1.971% in absolute terms as compared to the initial state for nine years of life in fine-grained soil under the *H. officinalis* crops. The content of humic acids increases by 1.109% in absolute terms, including an increase in the content of fulvic acids by 0.793%.It is concluded that the *H. officinalis* crops have greater environmental and technological value for phytomelioration of cretaceous exposures as compared with standard grass stands and natural vegetation communities.

Keywords: *Agropyron cristatum, Carbonate exposures, Phyto melioration, Hissopus officinalis, Soil-forming process*

It is typical for carbonate soils and outcrops that are related both to natural soil-forming process and in most cases to anthropogenic effect to be spread in the geographical coverage of many Russian and world's regions. According to estimates, they occupy 800 million ha in the world(The State… 2011) and more than 800 thousand ha in the Central Black Earth Region of Russia and it is expected to increase up to >3 million ha the future. Carbonate soils and carbonate outcrops have extremely low productivity, low recovery potential, and adverse effects on vegetation (Degtyar' and Chernyavskikh 2006). An ecological and cenotic approach for generation of sustainable phytocenoses using different plant species (Sysuyev and Ustuzhanin 2009) that are most adapted to specific cultivation conditions is an important component of measures aimed at recovery of low-yielding soil productivity (Trofimov et al 2009,Kosolapov et al 2013, Savchenko et al 2014). In this regard, it is of great importance to solve the problem of increased organic substance entering carbonate soils subject to within the soil-plant system (Dumacheva et al 2015).

Issues of preservation of plants (Khapugin 2018, Senchugova and Khapugin 2018), their habitats (Erdős et al 2018, Bakhshi et al 2018) under conditions of vegetation mosaicity in forest-steppe belt are discussed in many aspects. Anthropogenic impacts have led to the transformation of both plant cover (Lisetskii 1998, Smirnova et al 2016, Terekhin and Chendev 2018) and soilcover (Goleusov and Lisetskii 2008, Nekhodimova and Fomina 2013, Chendev et al 2018).Particular calcium landscapes can expand the area during the slope development in the forest-steppe system along with the transformation of forests and steppe vegetation (Kudryavtsev 2007, Erdős et al 2018, Shuaibova et al 2018). The southern landscapes of the Central Russian Upland with shallow chalk deposit, marls, and cretaceous outcrops occupy a unique position in the regional biotope structure (Gorbunov and Bykovskaya 2012) due to the presence of calciphilous flora (Gusev et al 2016,Dumacheva et al 2018), including its endemic component (Snegin et al 2017, Dorofeeva et al 2018). For phytomeliorative measures on cretaceous outcrops and for the generation of sustainable grass stands, it is common to use drought-resistant grasses of the *Poaceae* family and it is most often to involve *A. cristatum* of Eurasian species, which is undemanding to soils and can grow on sandy, carbonate, and rocky soils with low moisture and nutrients. The role of *A. cristatum* in the formation of natural and transformed communities is discussed in a number of works (Ambrose and Wilson 2003, Wang 2005, MacDougall and Wilson 2011, Blank et al 2015). This species has been observed on such anthropogenic landforms as earthen mounds during hundreds of years of renaturation (Lisetskii et al 2014, 2016, Deak et al 2018).

Recently, the culture of the region has gained the Eurasian-African species of the *Lamiaceae– H. officinalis* family as a melliferous crop. This semi-shrub has a very high resistance to carbonate soils, high over ground productivity and longevity (Degtyar' and Chernyavskikh 2006). There are selection varieties created with the use of local source material; the system of commercial seed production has been deployed (Titovskiy et al 2017, Dumachevaet al2018). Inside the territory of the region, it is represented by two main types of *H. Officinalis* (L.) and *H. cretaceous* Dub., which is sometimes ranked as a subspecies of the main *H. officinalis subsp. Montanus* (Jord. & Fourr.) Briq. species.In addition to its medicinal value (Rota et al 2004,Tanova and Petrova 2008) and its importance for the formation of apiculture food reserve under harsh conditions of carbonate outcrops on widely occurring ravine systems, it is possible to use this species for phytomelioration of carbonate substrates and improvement of their humus condition. The main purpose of research was to assess the phytomeliorative role of *H. officinalis* varieties during the restoration of anthropogenic cretaceous outcrops in comparison with the use of standard *A. cristatum* crops and with natural succession. The research tasks included an analysis of accumulation dynamics for underground and aboveground organic substances and their influence on changes in humus group composition, as well as an assessment of the total nitrogen production and reclaimable land nitrification capacity.

MATERIAL AND METHODS

The research covers the southern macro slope of the Central Russian Upland (50°29′ N, 37°52′ E). Economic, natural, climatic, and geological characteristics of the region are determined by high-degree development and topographic features with predominant slope-type terrain and with the significant development of a ravine network from0.8 to 1.5 km·$(km^2)^{-1}$ dense. The duration of sunshine is 1800 hours. The average annual air temperature ranges up from 5.4 to 6.7°C. The average frost-free period from 154 to 157 days. The average annual precipitation can vary from 465 to 530 mm. There has been observed annual drought and dry winds of varying intensity within the territory of the region. The probability of semi-arid and arid years is 50%. In 2008-2016, they conducted field studies on the use of *H.officinalis* for phyto melioration of cretaceous out crops in comparison to *A. cristatum* and natural succession on the chalk exposure of anthropogenic origin, which has formed at the site of excavation during the construction of a motor road in the Volokonovka district of the Belgorod region. The substrate is represented by chalk outcrop (residual chalk deposit). The initial soil is residual-carbonate black soil. The slope has south-western exposure. The experiment is based on the streamlined repetition method. The total area of the plot is 4 m^2; the replication rate is 6 times. The used method is early winter, solid, and broadcast planting.

Experiment options:

1. Natural succession of vegetation.
2. *A. cristatum* crop, Pavlovsky variety, with the seeding rate of 5 g·$(m^2)^{-1}$ of germinating seeds.
3. *H. officinalis* crop, Volokonovsky variety, with the seeding rate of 3 g·$(m^2)^{-1}$ of germinating seeds.

The value of above-ground phytomass productivity was determined by mowing method 1 time per season during heavy bearing. An area of the registration plot was 2 m^2. The phytomass was weighed, when it was green. To determine the content of absolutely dry substance a 1.5-2 kg assay sample was taken for analysis from the total mass and then brought to air-dried condition in gauze bags. The air-dry mass was completely crushed to powder in the mill. From the mass obtained, samples were taken out of 50-60 on a four-time repeated basis and dried completely in a thermostat at a temperature of 105-106°C for 8 hours. As a result, the dry substance content (%) was calculated for each repetition. The average value of four repetitions was taken as dry substance content in the experiments. The value of absolutely dry substance (a.d.s.) accumulation in the underground phytomass was determined three times for all years of research. The method of selection of monolith samples of 25x25 in size to a depth of 0-20 cm with subsequent roots washing 6 times using 3 non-adjacent repetitions was applied. The samples were dried to an air-dried condition and then dried completely in a thermostat. Mixed samples for soil analyses were taken by a sampler from the 0-10 cm horizon at 10 places on the plot and then prepared a combined sample. By sifting through round-cell sieves (d=1 mm), fine earth (mechanical substrate separates of < 1 mm in size) and the skeletal part (mechanical substrate separates of > 1 mm in size) were isolated. Fine earth and skeletal parts were analysed separately. Mixed samples were prepared from each of the six plots. After the preparation of mixed samples, the soil was brought to air-dried condition, ground down, and analysed. The biological repetition for all indicators is 2-fold and the total one is 12-fold.The group analysis of humus was fulfilled by Tyurin's method modified by Ponomareva and Plotnikova (Arinushkina 1970). The humus composition (carbon content of humic acid (C_{HA}) and fulvic acid (C_{FA})) was determined before the experiment in 2008 and after its completion in 2016.

The results were statistically processed using formulas to calculate the simple average and the error of mean. The variation proportion for resulting characteristics under the study, which is due to the action of the investigated organized factors, was estimated by the method of total variance decomposition of statistical systems (analysis of variance). To identify the level of close relations between characteristic under study, a pair correlation coefficient was applied (Lakin 1990).

RESULTS AND DISCUSSION

The dynamics of the above-ground mass accumulation is an integral complex indicator showing stability level of both individual species and communities as a whole.The rate of organic substance accumulation is the result of the function of photosynthesis and respiration in the above-ground sphere and the partial transfer of photosynthesis products to the underground. The amount of organic substance generated by phytocenos is per unit time is an essential component of the ecosystem. The higher the speed is, the more efficient the environmental resources are used and the more intensive is the process of soil formation and stabilization of the entire ecosystem (Semenov et al 2004).In both crops high above-ground phytomass capacity in the seeding year was within 1.3-21.3 $g \cdot (m^2)^{-1}$. Significant differences became evident starting from the second year of life (Fig. 1).

As compared to other options, the wheat grass seeds ensured faster grass stand formation with an absolutely dry substance being accumulated in the average amount of more than 213.6 $g \cdot м^{-2}$ (a.d.s.) per year. In the first 3 years of the entire nine-year period of the studies, the common hyssop crops accumulated the above-ground mass by 57.6% more with its average annual yielding capacity of 370.5 $g \cdot м^{-2}$a.d.s. When being used for crops of both wheat grass and hyssop, it showed general tendency related to the stable formation of the above-ground mass starting from the third year of the grass stand use. The process of significant phytomass formation was reported to have place in natural succession areas only in five years after the trial establishment. The higher plant communities only became to form starting from the sixth year. At the initial stage of development of soil-plant groups, lichens and especially *Nostoc cyanobacteria* played the most significant role. During the first five years of the studies, cyanobacteria were 79.3-89.2% of the total phytomass, which had been formed in the overgrowing areas. It was previously mentioned (Nekhodimova and Fomina 2013, Zimonina 2016) that different types of *Nostoc* cyanobacteria are among the most stable ones in natural, anthropogenically disturbed and urban areas. They are highly tolerant to adverse conditions and prefer substrates without higher plants.

According to the trial results, the time (t, years) dynamics of aboveground mass accumulation (F_a, $g \cdot m^{-2}$) is well described by polynomials of different orders for all options: for *A. cristatum*– $F_a=2.44t^3–42.92\ t^2+238.42t+169.12$, $R^2=0.93$; for *H. officinalis*– $F_a=–18.334t^2–251.57t–306.71$, $R^2=0.93$; for natural succession – $F_a=4.54t^2–20.89t+20.19$, $R^2=0.987$.A variance analysis of the single-factor experiment, which was carried out by the method of streamlined repetitions, showed that the share of the "crop" factor in the total variation of the resulting "formation of above-ground phytomass" characteristic made up 61% for the entire period of the studies; that of annual climatic conditions was 26% and that of random factors was 13%.For nine years of the studies, the *H.officinalis* crops) exceeded the *A. cristatum* crops and natural vegetation succession areas in terms of aboveground capacity on the cretaceous exposures of the Southern Russia. The main source of organic substance accumulation in the soil, related turnover of nutrients, and soil formation process is the inflow of underground vegetable matter entering the soil. It is of particular importance to have roots and rhizosphere microflora interacted in the conditions of carbonate outcrops, which is primarily due to the environment-forming role of vegetation and especially individual species that are most stable on any outcrops (Fig. 2).

It has been established that the underground mass accumulation (F_r, $g \cdot m^{-2}$) generally shows an increasing time-related dynamics (t, years) in a soil layer of 0-20 cm with the age of plant groups being incremented; this is described by polynomials of different orders: for *A. cristatum*– $F_r=28.25t^2–38.25t+439.1$, $R^2=0.99$; for *H. officinalis*– $F_r=–430.65t^2–2490.7t–1811.6$, $R^2=0.986$; for natural succession – $F_r= 122.9t^2–343.5t+221.7$, $R^2=0.997$.The underground to aboveground mass ratio from 2010-2016 increased to from 1.6 to 2.1 in the wheat grass crops, from 2.1 to 3.6 in the hyssop crops, and from 0.2 to 1.5 in the natural overgrowing areas. The share of the "crop" factor in the total variation of the resulting "formation of underground phytomass" characteristic made up 76% for the entire period of the studies; that of annual climatic conditions was 14% and that of random factors was 10%.In general, by the ninth year of life, the accumulations under an artificially created hyssop crops were 3.1 times higher than those under the wheat grass crops and 6 times higher than for the natural succession.

The main role of the biomass in the soil formation is reduced to the process of transition of relatively simple

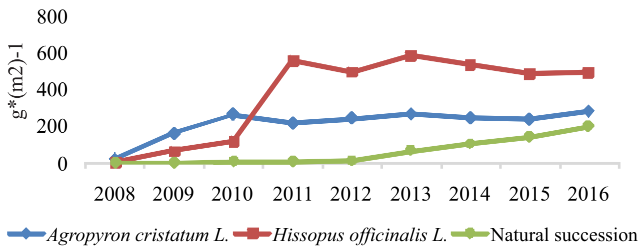

Fig. 1. Dynamics of accumulation of aboveground phytomass

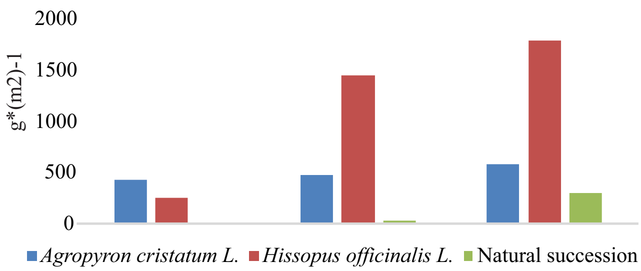

Fig. 2. Dynamics of accumulation of underground phytomass

organic substances into the form of complex organic substances and organo-mineral systems. The content of carbon compounds with different degrees of lability increases in the substrate at a time. The most important indicator is an analysis of carbon accumulation in the composition of various humus substances, which can show the direction of humification processes development and the rate of soil formation process depending on the crops to be grown (Semenov et al 2005). Chalk is a porous material with high adsorption capacity. The skeletal part in the cretaceous substrate was 92.7% at the beginning of the experiment. Therefore, it is very important to assess humus condition, both in the fine-grained soil and skeletal part. According to the analysis of the humus group composition (Table 1), it can be seen that it is primarily increased total carbon content (C_{org}) that caused changes, which have occurred in the humus fractional composition of the chalk outcrop both in the skeletal part and in the fine-grained soil.

As compared to the initial condition, the maximum increase in the C_{org} content was both in the skeletal part and in the fine-grained soil under *H. officinalis* and it was 36.9% in the skeletal part and 197% in the fine-grained soil. The lowest rate of accumulation was typical for water-soluble humus carbon, which was associated with a high content of soil solution calcium ions forming poorly soluble systems during chemical reactions both with minerals and with organic substances. In general, the skeletal part was characterized by a high content of fulvic acids by weight as compared with humic acids both at the beginning and by the end of the experiment. The humic (C_{HA}) to fulvic acid (C_{FA}) carbon ratio is

Table 1. Dynamics of the group composition of humus carbonate outcrop when sowing various crops and natural succession (mean ±standard error)

Indicators (%)	Phytomelioration options			Initial state
	A. cristatum (L.) crops	*H. officinalis* (L.) crops	Natural succession	
Skeletal part (mechanical substrate separates of > 1 mm in size)				
C_{total} [1]	0.423±0.029	0.511±0.030	0.280±0.023	0.142±0.008
C_{WSH} [2]	0.006±0.001	0.007±0.001	0.008±0.001	0.005±0.001
C_{HA} [3]	0.082±0.009	0.114±0.011	0.076±0.009	0.018±0.001
C_{FA} [4]	0.129±0.013	0.198±0.020	0.104±0.012	0.087±0.004
C_{HA}: C_{FA} [5]	0.636±0.014	0.576±0.021	0.731±0.016	0.207±0.004
Fine earth (mechanical substrate separates of < 1 mm in size)				
C_{total}	1.981±0.171	2.833±0.306	1.621±0.162	0.862±0.062
C_{WSH}	0.027±0.003	0.088±0.306	0.052±0.162	0.006±0.062
C_{HA}	0.493±0.052	1.193±0.116	0.214±0.027	0.084±0.005
C_{FA}	0.338±0.035	0.836±078	0.298±0.027	0.043±0.005
C_{HA}: C_{FA}	1.459±0.033	1.427±0.045	0.718±0.051	1.953±0.025

Note: [1]C_{total} – total carbon content; [2]C_{WSH}– carbon content of water soluble humus; [3]C_{HA} – carbon content of humic acids; [4]C_{FA} – carbon content of fulvic acids; [5]C_{HA}: C_{FA} – the ratio of humic and fulvic acids significantly less than one. At the same time, an opposite tendency was noted for fine-grained soils. The greatest gross accumulation of humic acid carbon was reported in the area with *H. officinalis.* By the end of the experiment, its quantity in the fine-grained soil increased by 79% as compared to the initial condition, which is more than twice higher against the *A. cristatum* crops and the natural succession area. A more favourable ratio C_{HA}:C_{FA} was reported for the areas with artificially sowed grass, while in the naturally overgrowing areas there was noted the ratio, which was shifted towards the fulvic-humate humus. The results of the variance analyses of the single-factor study showed the share of the "crop" factor in the total variation of the resulting "total carbon content" characteristic was 73% in fine-grained soils and that of other factors was 27%. The share of the resulting "content of humic acid carbon" characteristic is 87% in fine-grained soils and that of other factors is 13%; the share of the resulting "content of fulvic acid carbon" characteristic is 82% in fine-grained soils and that of other factors is 17%.

CONCLUSION

When developing sustainable crops on the carbonate outcrops in the southern part of European Russia, *H. officinalis* (L.) crops can generate productive plant aggregations to form larger amounts of aboveground and underground phytomass as compared to grass crops (for example *A. cristatum* (L.)) that are widely used in the region. For an average nine-year period of the studies the *H. officinalis* (L.) crops used to generate 370.5 $g\cdot(m^2)^{-1}$ of an absolutely dry substance of aboveground organic mass per year, while the *A. cristatum* crops formed 213.6 $g\cdot(m^2)^{-1}$ per year and the communities produced 59.7 $g\cdot(m^2)^{-1}$ per year in case of natural substrate overgrowth. To increase the gross content of total carbon, fulvic acid carbon, and humic acid carbon in the soil substrate, both in fine-grained soils and in the skeletal part of the soil, the *H. officinalis*(L.) crops significantly superior to the other two examined options. On a chalk outcrop, the total carbon tends to increases by 1.971% (or 197.1% in relative terms) in absolute terms as compared to the initial state for nine years of life in fine-grained soil under the *H. officinalis* (L.) crops. The content of humic acids increases by 1.109% in relative terms (110.9% relative) and the content of fulvic acids-by 0.793% in absolute terms (79.3% relative). Thus, *H. officinalis* (L.) crops have more significant environmental and technological value for the phytomelioration of cretaceous exposures as compared to standard grass stands and natural vegetation succession.

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