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Mile MARKOSKI, Tatjana MITKOVA,
Vjekoslav TANASKOVIK, Velibor SPALEVIC and Rajko NOVICEVIC[1]

SOIL DISTRIBUTION IN CRNA RIVER BASIN AND ITS IMPORTANCE FOR AGRICULTURAL PRODUCTION

SUMMARY

This paper is a result of many years of field and laboratory research of the soils in Crna River Basin, spread out on 497 514,81 ha, with the altitudes ranging from 150 to 2601 m above sea level with the main goal of gaining better understanding of the productive capacities of soils and soil conservation measures for their improvement. The catchment area of the Crna River is a spatial area that extends in two states in the southwest of the Republic of North Macedonia and the northern part of the Republic of Greece. The filed research of the soils and preparation of soil samples has been done according to ISO 10381-1 and ISO 10381-2 protocols. Soil samples were analysed in the laboratory: hygroscopic moisture; mechanical composition; pH of the soil solution; humus content and total nitrogen; content of carbonates; available nutrients P_2O_5 and K_2O. The mechanical composition and chemical properties of the soils were determined by standard methods. Physical-geographical conditions of the studied area are heterogeneous, with numerous relief forms; different expositions and inclinations, and with great differences of altitude. There are several geological formations of a very heterogeneous petrographic-mineralogical composition and climate-vegetation zones. Long-term effects of human participation should also be noted. The vast diversity of the factors required for soil formation in the catchment area of the Crna River are the reason for the formation of many different soil types as well as the lower taxonomic units. There are 14 (fourteen) different soil types distributed in the Crna River Basin together with a considerable amount of subtypes, varieties and forms. The most significant soil types are: Fluvisol and Cambisol. These types of soils are characterized by different properties (chemical, physical, physical-mechanical and productive). Therefore, they have varied effects on agricultural production (field crop, viticulture and fruit production). The aim of this research was to present combined measures of soil conservation for soils from mountain terrains, lake terraces and undulating-hilly terrains, including from sloping terrains and from plain terrains, based on the research that was implemented.

Key words: Soil types, Crna River Basin, Agricultural production.

[1] Mile Markoski (corresponding author: mile_markoski@yahoo.com); Tatjana Mitkova, Vjekoslav Tanaskovik, Faculty of Agricultural Sciences and Food, University "Ss. Cyril and Methodius" Blvd. Aleksandar Makedonski bb., Skopje, REPUBLIC OF NORTH MACEDONIA; Velibor Spalevic, University of Montenegro, Faculty of Philosophy Niksic, Geography, MONTENEGRO; Rajko Novićević, Mediterranean University, Bar, MONTENEGRO.

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INTRODUCTION

Today, the greatest success in agriculture will be to achieve the desired increase in production by reducing the negative environmental conditions. This can only be achieved by implementing sustainable methods and sustainable solutions in agriculture. The fact that the agricultural activities and practices are compatible with the environment and being permanent is great importance in terms of contributing to the sustainability of the ecology (Tuğrul, 2019).

Soils, which form at the interface between the atmosphere, lithosphere, hydrosphere, and bio-sphere (Targulian *et al*., 2018), are at the constant pressure of Land degradation. Land degradation, either natural or induced by humans, is a continuing process. It has become an important issue through its adverse effects on national natural resources, food security, and the livelihood of the world population. Much has been said and documented about land degradation but there are still gaps of knowledge, due to the fact that only a few countries have really developed cost-effective technologies for mitigation. Inappropriate land use is a major cause of declining soil quality (Sestras *et al*., 2019). In many countries there is continuous stress on the limited land resources due to population pressure. Food security is directly related to the ability of land to support the population (Nabhan *et al*., 1997; Kavian *et al*., 2018; Tavares *et al*, 2019; Chalise *et al*, 2019; Dudic *et al*, 2020; Sakuno *et al*., 2020).

In this paper are presented the main aspects of the soil geography. Soil geography seeks to determine the distribution of soils on the earth's surface, to understand the soil-forming processes and environmental factors, and to suggest the most satisfactory methods of using soils. In the first place is based directly upon field mapping and description. Secondly, a broad theoretical background is necessary to understand physical, chemical and biological aspects. Thirdly, field characteristics need to be interpreted in the light of laboratory assessment of soil properties. Fourthly, soil map interpretation for agriculture, forestry, land use planning is part of the soil geographer's map work (Bridges, 1977).

The agro technical and ameliorative measures are determined based on the properties and processes of the various soil types found in this area with the goal of improving their productive capacity to further increase agricultural production.

Finally combined measures of soil conservation for soils from mountain terrains, lake terraces and undulating-hilly terrains, including from sloping terrains and from plain terrains, based on the research that was implemented were presented.

Inevitably there will be many different opinions about the content and measures suggested, but the idea is to provide relevant basis for discussion upon which further studies can be built.

MATERIAL AND METHODS

The area of the Crna River Basin is an area that extends into two states in the south-western part of the Republic of North Macedonia and the northern part

of the Republic of Greece. Map of the Study area of the Crna River basin presented at the Figure 1.

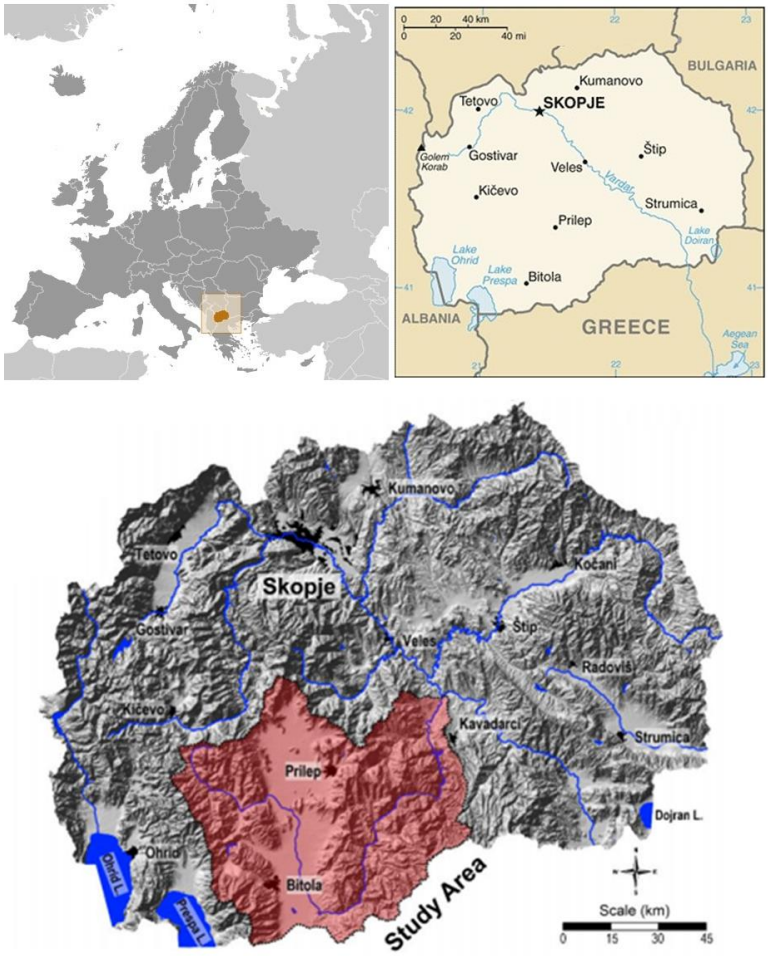


Figure 1. Map of the Republic of North Macedonia indicating the Study area of the Crna River basin (Source of the Maps: The World Factbook 2021. Washington, DC: Central Intelligence Agency, 2021.

On the territory of the Republic of North Macedonia, the Crna River basin extends between 40°51'56" and 41°36'20" north latitude and 20°56'45" and 22°4'58" eastern longitude. Its total length is 207 km with the total area of the catchment area in both countries of 5775 km^2, of which to the Republic of North Macedonia belongs the largest part of 4870 km^2, while the catchment area in the Republic of Greece is 905 km^2.

In the river basin of Crna River the influences of the Mediterranean, Mediterranean-altered, temperate-continental and mountainous climate are

present. The mean annual air temperature ranges from 8.4 ºC to 13.5 ºC over a period of 23 years. The average absolute maximum air temperatures in the Crna River are within the limits of 32 ºC. The absolute minimum air temperature for the same period is within the limits of –15ºC. The amplitudes of the extreme temperatures are quite large and they range from 51.5 ºC to 66.6 ºC (Filipovski, 1996 and Koteski, 2009). The warmest months for all meteorological stations in the Crna River basin are July and August and the coldest month is January. According to the regions of this basin, in Tikveš Valley the influence of the sub-Mediterranean climate is generally present, in the central part of the basin (Pelagonia Valley) the continental climate is represented, while the influence of the moderate continental climate appears in the upper part of the basin (Tomovsk *et al*., 2017).

The Crna River basin belongs to three geotectonic structural units: the upper western part lies in the area of the West-Macedonian zone, the middle part is on the Pelagonian zone and the lower part to the Vardar zone (Stafilov *et al*., 2016). The upper western part which lies in the area of the West-Macedonian zone is built mainly from Paleozoic and Triassic formations, primarily from crystalline schists and limestones (marbles and dolomites), as well as from granites. The middle part which belongs to the Pelagonian geotectonic zone is dominated by Precambrian rocks, such as: micas and marbles, as well as Neogene deluvial and alluvial formations. In the lower part of the flow of Crna River, which belongs to the Vardar zone, covering the areas of the eastern part of Mariovo and part of the Tikveš Valley, the most present are the crystalline schists, granites and granodiorites, flysch sediments, volcanic breccias, limestones, marble dolomites etc. (Koteski, 2009; Stafilov *et al*., 2016).

This area (Crna river basin) is very heterogeneous, with numerous relief forms, with different expositions and inclinations, and with great differences of altitude. Additionally, there are several geological formations of a very heterogeneous petrographic-mineralogical composition and climate-vegetation zones. Long-term effects from human involvement should also be noted. The vast diversity of the factors required for soil formation in this area is the reason for the formation of many different soil types as well as the lower taxonomic units.

The soils in the area also appear in the complexes that are presented on the soil (pedological) map. These types of soils are characterized by different properties (chemical, physical, and physical-mechanical, productive). Therefore, they have varied effects on agricultural production. In this paper are presented the main aspects of the soil geography. The agrotechnical and meliorative measures are determined based on the properties and processes of the various soil types found in this area with the goal of improving their productive capacity to further increase agricultural production.

The filed research of the soils has been done according to methods described by Filipovski *et al*. (1967). The filed research of the soils and preparation of soil samples has been done according to ISO 10381-1 and ISO

10381-2 protocols. In laboratory, the following analyses have been carried out on the soil samples: hygroscopic moisture; mechanical composition; pH of the soil solution; humus content and total nitrogen; content of carbonates; available nutrients P_2O_5 and K_2O. The mechanical composition and chemical properties of the soils have been determined by standard methods.

The mechanical composition and chemical properties of the soils have been determined by standard methods described by Bogdanović *et al*. (1966), Mitrikeski and Mitkova, T (2006); Resulović *et al*. (1971), Džamić *et al*. (1996).

RESULTS AND DISCUSSION

Geography of soils

Distribution of soil types and complexes.

The formation, the distribution and the soil properties in this area are in close correlation with the environmental conditions, i.e. the soil genesis conditions, such as the geographical position and the relief, the hydrography, the parent material, the climate, the vegetation, the time period and the human factor. The soil (pedologic) map, figure 2; figure 3 and 4 together with Table 1 on the distribution of the soil types, differentiates the following properties in the geography of soils.

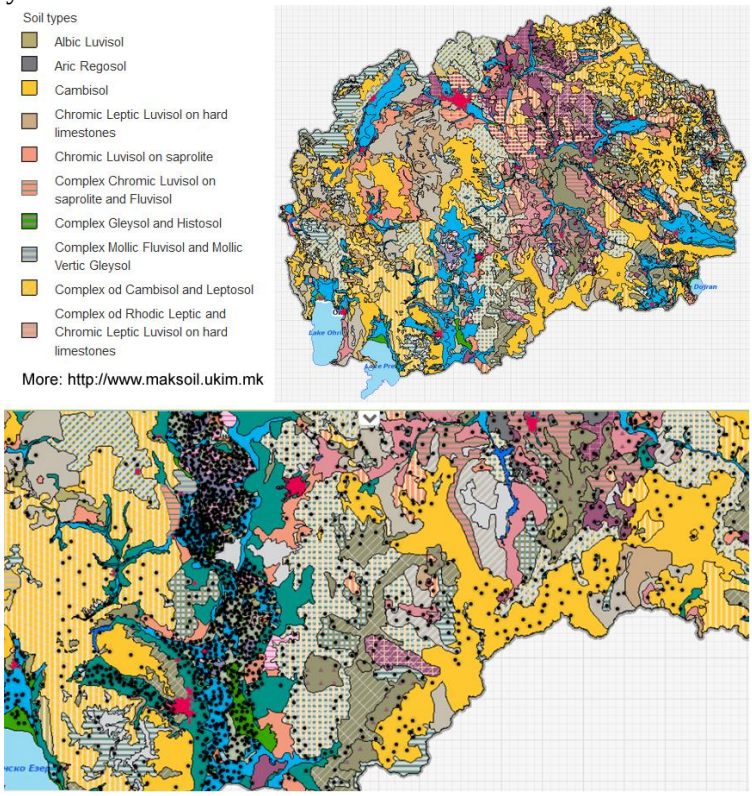


Figure 2. Soil map - Soil types and complexes distribution in the catchment area of the Crna river (http://www.maksoil.ukim.mk/masis/)

In the catchment area of the Crna river, there are 40 (forty) soil types and a number of subtypes, varieties and forms.

Depending on the dominant influence of individual soil forming factors, most part of the areas are covered with soils that are also following the local climate – vegetation zoning (Chromic Luvisols on Saprolite, Cambisols, Humic Eutric and Umbric Regosols, Albic Luvisols), which is also combined with the influence of other soil forming factors (parent material, relief).

Some of the soils demonstrate strong lithogenous character (Leptosols, Regosols, Humic Calcaric Regosols, Vertisols), whereby the influence of other factors (relief) is also significant. Some of the soils have topogenous – hydrologic origin, related to the consequences of the erosion processes (Fluvisols, Gleysols, Fluvisols-Colluvial Soils). Lately, due to the newly planted seedlings (orchards, vineyards), some of the soils also have antropogenous origin (Aric Regosols).

The papers of Filipovski (2015), address these conditions in details.

Table 1. Soil types and complexes distribution in the catchment area of the Crna River (ha and %)

SOIL TYPES AND COMPLEXES (WRB Soil Classification)	**[ha]**	**[%]**
I. SOILS OF THE PLAINS		
Fluvisol	28212.55	5.67
Mollic Vertic Gleysol	6627.15	1.33
Complex of Solonchak and Solonetz	6515.91	1.33
Gleysol	4764.08	0.96
Complex Mollic Fluvisol and Mollic Vertic Gleysol	1025.87	0.21
Mollic Fluvisol	16234.24	3.26
Urbisol	2786.81	0.56
Total	**66166.61**	**13.30**
II. SOILS OF COLLUVIAL FANS		
Fluvisol (Colluvial Soils)	**54664.44**	**10.99**
III. SOILS OF LAKE TERRACES AND OF UNDULATED HILLY RELIEF		
Regosol	4128.85	0.82
Albic Luvisol	3017.5	0.61
Aric Regosol	3574.23	0.72
Chromic Luvisol on saprolite	12590.99	2.53
Humic Calcaric Regosol	16915.98	3.40
Vertisol	1930.17	0.38
Planosol	1168	0.23
Complex of Regosol and Vertisol	10369.59	2.08
Complex of Humic Calcaric Regosol and Regosol	12248.4	2.46
Complex of Chromic Luvisol on saprolite, Humic Calcaric Regosol and Regosol	2470.79	0.49
Complex of Vertisol and Humic Calcaric Regosol	240.8	0.05
Complex of Humic Calcaric Regosol, Regosol and Vertisol	2006.21	0.40
Complex of Chromic Luvisol on saprolite and Regosol	5169.29	1.04
Complex of Humic Calcaric Regosol, Regosol and Leptosol	6248.43	1.26
Complex Chromic Luvisol on saprolite and Fluvisol	1365.25	0.27
Complex of Vertisol, Regosol and Leptosol	4083.91	0.82
Complex of Chernozem and Humic Calcaric Regosol	322.77	0.06
Complex of Humic Calcaric Regosol and Leptosol	105.03	0.02
Total	**87956.19**	**17.68**

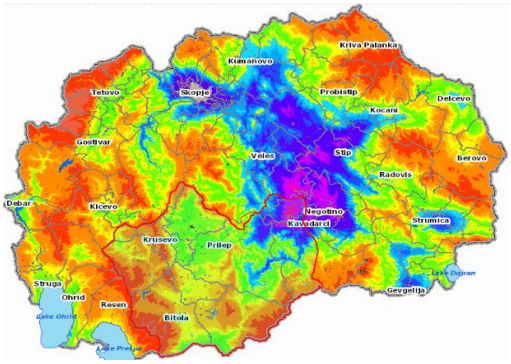
IV. MOUNTAIN SOILS		
Complex of Humic Eutric and Umbric Regosol	13837.12	2.71
Leptosol	12186.31	2.45
Complex of Regosol and Leptosol	26253.86	5.07
Complex of Humic Eutric and Umbric Regosol and Regosol	15576.94	3.13
Complex of Cambisol and Regosol	6492.52	1.30
Rendzic Leptosols	21205.35	4.26
Cambisol	62214.37	12.50
Complex of Humic Eutric and Umbric Regosol, Regosol and Leptosol	45873.64	9.22
Complex of Cambisol, Humic Eutric and Umbric Regosol and Regosol	3708.64	0.75
Complex of Cambisol, Humic Eutric and Umbric Regosol	9741.03	1.96
Complex of Rendzic Leptosol and Leptosol	13101.45	2.63
Chromic Leptic Luvisol on hard limestones	901.29	0.18
Leptosol, Calcaric	61.96	0.01
Complex of Cambisol, Leptosol and Regosol	57573.09	11.57
Total	**288727.6**	**58.03**
Grand Total	**497514.81**	**100**

Table 1 contains data on the soil types and complexes distribution according to the relief forms in the catchment area of the Crna river in ha and %. It can be seen from the Table that the soils spread on lake terraces and of undulated hilly relief dominate in the catchment area and cover an area of 87956.19 ha, or 17.68% of the area, followed by the soils spread on mountainous terrains with 288727.6 ha, or 58.03%. The soils on plains and sloping terrains (colluvial fans) cover small areas (66166.61 ha, or 13.30% and 54664.44 ha or 10.99% of the area).

The plain terrains are mostly covered by Fluvisols (28212.55 ha or 5.67 %), while the percentage of other soils is under 1%. The sloping terrains are mostly covered by Fluvisols (Colluvial Soils) (54664.44 ha or 10.99%). The undulating-hilly terrains and the lake terraces are mostly covered by Humic Calcaric Regosol (16915.98 ha or 3.40 %), followed by Chromic Luvisols on saprolite (2.53%), as well as Regosol (0.82%), and Vertisol (0.38). Most of the mountainous terrains are covered with Cambisols (62214.37 ha or 12.50%) and Rendzic Leptosols (21205.35 ha or 4.26 %), as well as Leptosols with 12186.31ha or 2.45%. On the basis of the many processed data on the map of the graphs, the soil reaction models, organic matter and soil texture of the soils in the Crna River basin are given. (Figure 3, 4 and 5).

The erosion processes, i.e. the human factor are strongly reflected in the geography of the soils in the area. The area of soils that occurred from erosion processes (Leptosols, Regosols, Fluvisols-Colluvial Soils and their complexes) is more than 25% of all areas and unfortunately, the spreading process for these areas is still active, (Markoski *et al*., 2018).

The individual terrain forms differ from each other by their terrain, geological structure, their climate – vegetation and hydrographic conditions and by the degree of anthropogenization. This is reflected on the geography of soils and their properties, as well as on the degree of their utilization and the measures that need to be undertaken in the agricultural production of the area, (Mitkova *et al.*, 2017).



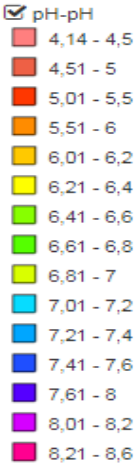
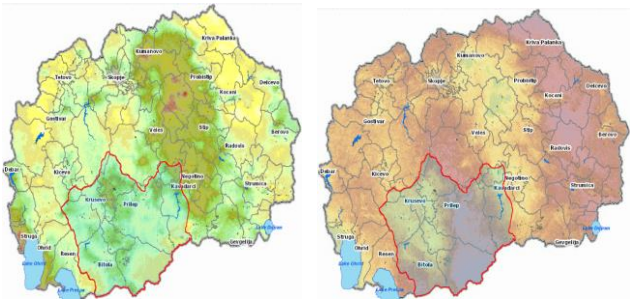


Figure 3. Soil map – pH-reaction distribution in the catchment area of the Crna River (http://www.maksoil.ukim.mk/masis/)

Legend

Figure 4. Soil map – organic matter distribution in the catchment area of the Crna River (http://www.maksoil.ukim.mk/masis/)

Legend



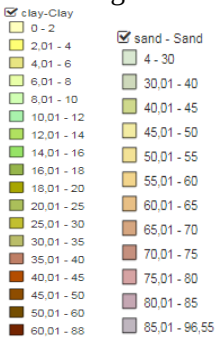


Figure 5. Soil map – soil texture distribution in the catchment area of the Crna River (http://www.maksoil.ukim.mk/masis/)

Legend

Common properties of the soils according to terrain (relief) forms

Common properties of the soils on the mountainous terrains.

The soils spread on mountainous terrains cover 288727.6 ha, or 58.03 % of the area. These are: Leptosols, Humic Eutric and Umbric Regosols, Cambisols, as well as their complexes, in combination with Regosols. Their common properties are: a) very pronounced erosion processes; b) weak chemical weathering resulting in shallow solum over some substrates, and lack of deep regolith and poor clay content; c) absence of carbonate, pronounced acidification (weaker in the soils over acidic rocks than in the basic rocks); d) absence or very poor textural differentiation of the solum; e) clearly expressed changes in the soil properties and the intensity of some processes as the altitude increases; f) clearly expressed dependence of the soil properties from the substrate: soils over acidic rocks contain less clay, they are more acidic and are less texturally differentiated, unlike the soils formed over basic rocks, g) absolute domination of the silicate over the carbonate substrate.

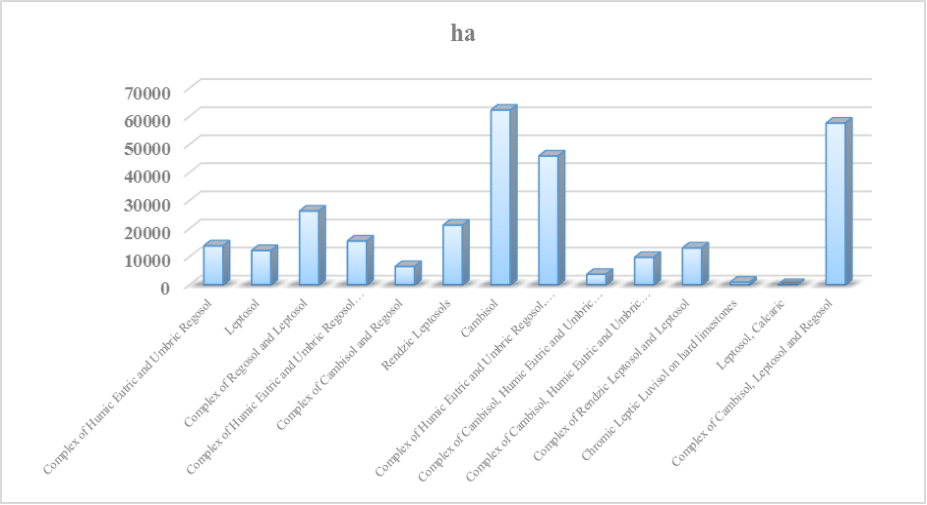


Figure 6. Mountain soils in [ha]

Common soils properties from the lake terraces and of undulated hilly relief.

The following soil types are present on this terrain form: Regosols, Humic Calcaric Regosols, Vertisols, Chernozems, Chromic Luvisols on saprolite and Albic Luvisols. The occurrence of these types of soils is in close co-relation with the substrate, the relief, the climate-vegetation conditions and the degree of erosion. The soils on this terrain (relief) form have the following common properties:

a) very pronounced erosion (occurrence of Regosols and erosion of horizon A or part thereof, in the soils with A-C, A-(B)-C and A-E-B-C profile type);

b) absence of compact rocks as substrate and soil genesis over clastic sediments, resulting in deep solum and physiologically active profiles;

c) greater presence of clay resulting from the substrate or the argilogenesis within

the profile;
d) presence of smectites in some soils (Vertisols, Vertic Chromic Luvisols on saprolite) arising mainly from the substrate and partially from the soil genesis, and in relation to that, deterioration of the physical properties of the soils;
e) occurrence of textural differentiation at some soils (Vertisols and Albic Luvisols), and in relation to that, deterioration of the physical properties;
f) greater presence of the silicate – carbonate substrate in the soil genesis, in comparison to the substrate of the mountainous terrains;
g) relative dryness of the soils (which is lower at the lake terraces), caused from insufficient quantity of rainfalls, surface water flow and very deep underground water;
h) insufficient quantity of humus and nutrients (especially N and P);
i) relatively good chemical properties (the high content of carbonates of Humic Calcaric Regosols and the acidity of the Albic Luvisols are an exception).

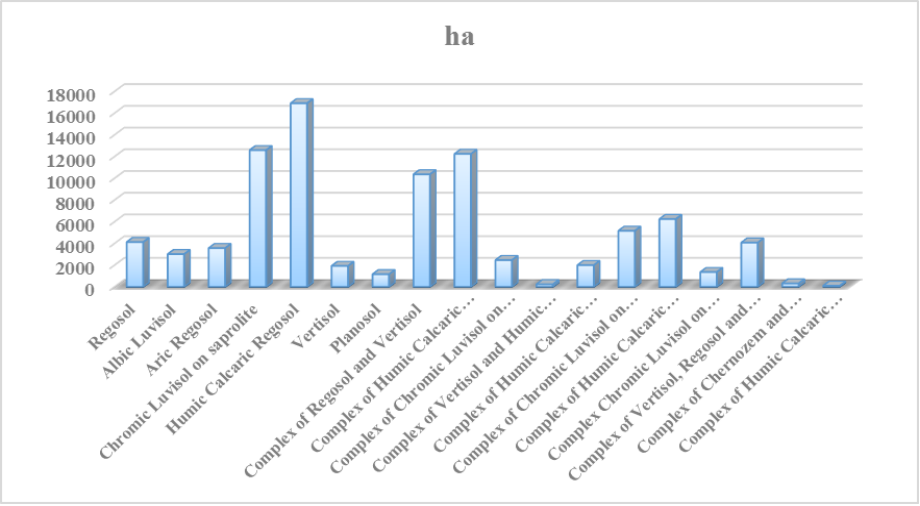


Figure 7. Soils of lake terraces and of undulated hilly relief in [ha**]**

Common properties of soils from sloping terrains
These terrains are covered with Fluvisols (Colluvial Soils), which are characterized by:
a) horizontal and vertical (according to depth of profile) heterogeneity in the mechanical and mineral-petrographic composition;
b) low content of clay, drainage, dryness, good aeration;
c) poor humus content, insufficient stability of the aggregates;
d) good chemical properties with insufficient nutrient elements;
e) increasing the finer particles by descending to the lower parts of the cones (“fans”);
f) short duration of soil genesis (the youth of the soils);
g) unregulated water regimen (floods and sedimentation of coarse material). Common properties of the soils of the plains.

Fluvisols with varying degrees of gleyzation are present in the flat bottom deep in the profile and the Gley soils (Gleysols and Mollic Vertic Gleysols) have the following characteristics:
a) the appearance of non-saline underground waters at different depths;
b) the appearance of a physiologically deep profile;
c) gleyzation at the bottom of the profile;
d) a significant amount of organic matter (especially in Gleysols), where it is of hydromorphic origin;
e) occurrence of unregulated water regimen (floods, riverbad erosion, deposition of coarse sediments, regeneration of fertility by application of fine sediment);
g) absence of texture differentiation of the profile (no occurrence of (B) or Bt horizons);
h) favorable physical and chemical properties.

The occurrence of Halomorphic soils (Solonchak and Solonetz) on small areas (total 6515.91 ha or 1.33%) is characteristic of these terrains in the area. Their formation is related to the presence of salts in the sediments, drier climate conditions and relief-topographical conditions in which there are shallow and saline underground waters.

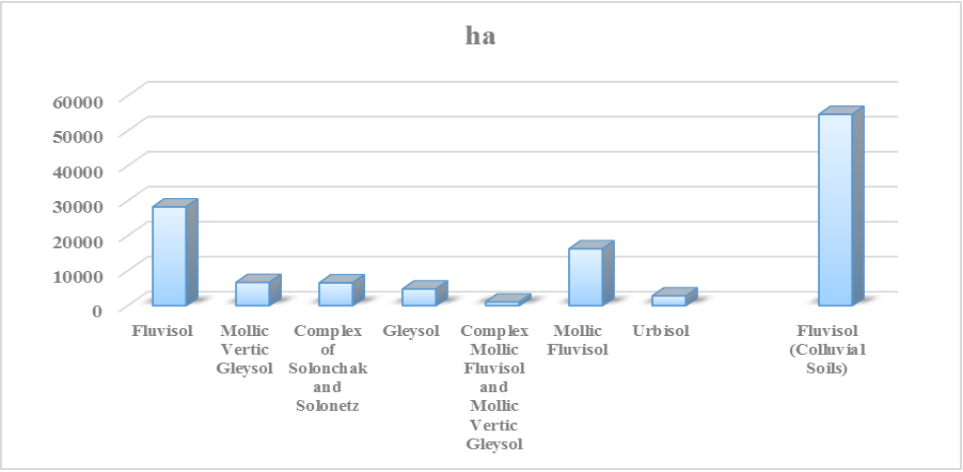


Figure 8. Soils of the plains and soils of colluvial fans in [ha]

Soil significance according to relief forms for agricultural production

The properties (mechanical composition and chemical properties) of individual soils formed in the area are described in detail in the papers of, (Filipovski, 2015) and (http://www.maksoil.ukim.mk/masis). Here, together and according to relief forms, we will explain their significance for agricultural production in the area, the measures for improving their productive ability will be explained in the conclusions.

In mountain reliefs, part of the Humic Eutric and Umbric Regosols is under summer pastures, a smaller part under forests, and a small part is cultivated. Fields are mostly abandoned, and some produce potato and seed

material for it, then rye and oats, and at lower altitudes some fruit trees are cultivated. As for the use of Cambisols, it can be said that they have the greatest significance for forestry, because they produce and then exploit most of the wood mass in our country. By deforestation some of these soils are converted into pastures or into now abandoned fields. A very small part is cultivated, used as fields, and a smaller part as pastures. Potatoes are most commonly cultivated field crops, some forage field crops can be successfully grown, as well as crops for green fertilization. Some of these soils can be successfully turned into artificial grasslands. Several fruit crops can be successfully grown (chestnut, walnut, plums, apples, pears, raspberries, blackberries, ribes).

Among the soils formed on lake terraces and of undulated hilly relief, Vertisols and Humic Calcaric Regosols are characterized by greater productivity in comparison with Regosols, Chromic Luvisols on saprolite and Albic Luvisols. Depending on the conditions for irrigation these soils have heterogeneous use. Field crops, vegetable crops, forage crops, industrial crops, vineyards, orchards are cultivated on them.

Fluvisols (Colluvial Soils) are significantly less productive than Fluvisols (with which they border. They are less sorted, do not have a flat relief, have higher impact from drought, contain less nutrients, and do not supply water from groundwater.

In the plain terrains of the area, Fluvisols are of the greatest significance for agricultural production. This is due to the favorable physical and chemical properties, the deep solum, the provided conditions for irrigation and the presence of available forms of P_2O_5 and K_2O. They provide relatively high yields of all agricultural crops. Mollic Vertic Gleysol and Gleysols are potentially fertile. The former have good chemical properties, but poor physical properties, and the latter have relatively good properties, but have shallow underground waters, occasional floods at some sites, anaerobic conditions and due to this, poor nitrification.

CONCLUSIONS

There are 40 (forty) different soil types distributed in the Crna river basin together with a considerable amount of subtypes, varieties and forms. They are formed on four relief forms (plain terrains, sloping terrains, mountain terrains and undulating-hilly terrains and lake terraces) that have different significance for agricultural production. In order to increase their productive ability, the following joint measures should be undertaken according to relief forms:

- Joint measures for soils from mountain terrains: protection from erosion, fertilization with organic and mineral fertilizers, proper tillage, liming if necessary;

- Joint measures for soils from lake terraces and undulating-hilly terrains: deep tillage, humization: organic fertilizers and phytomeliorations, intensive use of mineral fertilizers N and P_2O_5, and for plants that need potassium during the

entire year and for obtaining much higher yields and K-fertilizers, anti-erosion measures, proper irrigation method;

- Joint measures for soils from sloping terrains: anti-erosion protection measures, irrigation, humization, intensive use of mineral fertilizers;

- Joint measures for soils from plain terrains: regulation of the water regimen, lowering of the level of underground water-drainage, tillage and creating a deep fallow, fertilization with mineral and organic fertilizers with previous soil fertility control, proper irrigation.

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