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АКАДЕМИК ЃОРЃИ ФИЛИПОВСКИ
(По повод 100–годишнината од раѓањето)

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Претставува голема одговорност, но, пред сè, чест да се подготват и напишат неколку страници текст во кои треба да се опфати едно столетие од животот и работниот век на академик Ѓорѓи Филиповски. Пред сè поради тоа што најзначајните активности од севкупната наставно-научна и општествена дејност на академик Ѓорѓи Филиповски се случувале во еден многу значаен период за нашата земја – сведочат за почетоците на формирањето на нејзините први високообразовни институции Скопскиот универзитет, Земјоделско-шумарскиот факултет, Македонската академија на науките и уметностите, и траат сè до денес.

Академик Ѓорѓи Филиповски е роден во с. Сорович, Леринско, на 6 мај 1919 година. Родителите му се по потекло од Битола, каде што го завршил гимназиското образование. Студирал на Земјоделско-шумарскиот факултет во Белград и во Софија, каде што и дипломирал во 1942 година со најдобар успех во генерацијата и поради тоа бил избран за асистент. Во 1944 година се враќа во Битола и наскоро заминува во партизани.

Во непрекинатиот работен век на академик Ѓорѓи Филиповски како да било предодредено тој постојано да се соочува со предизвикот на еден градител – постојано нешто да втемелува, да гради и да обновува. За тоа, секако, придонела неговата способност и подготвеност да се зафати со таквите предизвици во почетоците на организирањето на наставно-научната дејност на Земјоделско-шумарскиот факултет во Скопје, но и истовремено и неговата голема смисла и дарба за аналитички, систематски, објективен, многу рационален и прагматичен пристап кон разрешувањето на секој од нив. Тоа би можело да се поткрепи со следново:

– Во декември 1944 година, на повик од АСНОМ, доаѓа во Земјоделскиот испитателен институт во Скопје, каде што го формира Педолошко-агрохемиското одделение, со кое раководи две години.

– Во 1947 година, од матичната комисија е избран како најмлад наставник (на 28-годишна возраст) во првиот Наставнички совет на штотуку формираниот Земјоделско-шумарски факултет во Скопје, каде што со голем ентузијазам се ангажира во организирањето на наставната и научната работа на Факултетот. Во 1949 година ја основа и организира Катедрата за педологија и агрохемија на истиот факултет и со неа раководи повеќе децении, во тој период тоа беше една од најдобро организираните и опремени катедри со модерни лаборатории и богати збирки. Академик Ѓорѓи Филиповски беше еден од првите тројца декани на Факултетот (на 37-годишна возраст) и сè до пензионирањето (1987) важеше за еден од најомилените професори на Земјоделско-шумарскиот факултет (од 1975 година, Земјоделски факултет), чии предавања со големо интересирање беа следени од 40 генерации студенти.

– За ректор на Универзитетот „Кирил и Методиј“ е избран есента 1963 година, по скопскиот земјотрес, при што за кратко време успева да создаде услови за почнување на наставата на Универзитетот, обновување или поправка на оштетените факултети и студентски домови. Истовремено, тој организира обемна помош и опрема од странство, а голем број асистенти беа испратени на постдипломски и докторски студии во странство.

– При основањето на МАНУ (1967) академик Ѓорѓи Филиповски беше избран од Матичната комисија во првиот состав, додека во првото Претседателство на МАНУ беше избран за научен секретар во траење од 8 години, период исполнет со големо ангажирање околу организирањето на МАНУ и почнувањето на нејзината дејност. Посебно треба да се истакне раководењето со Одборот за изградба на новата зграда на МАНУ. Потоа 12 години беше потпретседател на МАНУ.

– Академик Ѓорѓи Филиповски претставува стожер, основоположник на современите педолошки истражувања на територијата на Република Македонија. Уште од самите почетоци на својата научноистражувачка дејност, академик Ѓорѓи Филиповски наиде на широко и речиси неистражено поле во областа на проучувањето на почвите во Република Македонија и со своите истражувања длабоко проникна во разјаснување на најзначајните елементи на тие сложени системи.

– Веднаш по формирањето на Катедрата за педологија и агрономија при Земјоделско-шумарскиот факултет во Скопје, академик Ѓорѓи Филиповски се вклучи во еден од најголемите проекти во Република Македонија, „Мелиорации – одводнување на 65 000 ha и наводнување на 100 000 ha“, во чии рамки се вршени педолошки истражувања во повеќе котлини во Македонија. Притоа, прв пат во Македонија се добиени детални научни и стручни сознанија за почвите кои беа директно користени во големите потфати – одводнување и изградба на системи за наводнување и подигнување десетици илјади хектари лозја и овоштарници.

– Академик Ѓорѓи Филиповски создаде школа за педолошки истражувања, оспособувајќи нови кадри кои ги продолжуваат педолошките истражувања, и таа долги години беше главен центар на агропедологијата во поранешна Југославија. Како резултат на тоа, подготвена е Педолошка карта на Република Македонија (1: 50 000), која е искористена при составувањето на педолошката карта на Европа од страна на ФАО и УНЕСКО.

– Непостоењето единствена светска класификација на почви го насочува академик Ѓорѓи Филиповски кон развивање нови идеи кои се реализирани во проектот „Монографија на почвите во Југославија“. Посебно место заземаат неговите истражувања што се однесуваат на условите за образување, генеза, класификација и својствата на солените почви, област од која има објавено поголем број научни трудови, а од таа област е и неговото пристапно предавање во МАНУ, „Халоморфните почви на СР Македонија“. Академик Ѓорѓи Филиповски се смета за еден од најдобрите познавачи на оваа проблематика, чиишто трудови се многу цитирани во научни списанија во земјава и во странство.

– Неговата посветеност на проблемите поврзани со еколошката и агроеколошката реонизација на Република Македонија, врз основа на меѓусебните односи и влијанието на релјефот, климата, вегетацијата и почвите, резултира со заедничката коавторска монографија „Карактеристики на климатско-вегетациско почвените региони во Република Македонија“ (1996). Ова капитално дело со исклучителна вредност денес се смета за едно од најцитираните трудови од Македонија во последните 15-ина години од страна на голем број педолози, шумари, ботаничари, зоолози, географи и други.

Академик Ѓорѓи Филиповски, објавил околу 90 научни трудови (над 30 % во странство и во поранешна Југославија), 14 монографии (11 во Македонската академија на науките и уметностите и 3 на Земјоделскиот факултет во Скопје). Една од опширните монографии („Земљишта Југославије“, 600 стр.) е преведена на англиски јазик и се користи во многу земји. Негово капитално дело претставува монографијата „Почвите на Македонија“ во 6 тома. Тоа е капитално дело со непроценливо значење и претставува трајна вредност, во кое врз современа научна основа се опфатени и обработени сите сознанија од досегашните истражувања на почвите во Република Македонија. Делото „Класификацијата на почвите во Југославија“ долго време беше користено како единствено од тој вид во поранешна Југославија.

Академик Ѓорѓи Филиповски остварил многу богата **меѓународна активност и соработка**:

– учествувал на голем број научни собири на сите континенти со реферати, од кои голем број биле воведни;

– бил визитинг-професор во Калифорнија, САД (1 година);

– повеќе години држел предавања на постдипломски студии на универзитетите во Белград, Бари (Италија) и на Крит (Грција), каде што бил избран за професор на меѓународен конкурс;

– носител е на титулата Doctor honoris causa, доделена на Универзитетот во Брадфорд, Англија;

– надворешен член е на АНУ на Босна и Херцеговина;

– член е на повеќе меѓународни асоцијации;

– како експерт престојувал повеќе месеци во Египет во врска со користењето на водите од Асуанската брана за мелиорирање на солените почви во делтата на реката Нил;

– член е на Комисијата на ФАО за изработка на педолошка карта на Европа;

– кај него престојувале на усовршување доктори на науки и магистри на науки од странство.

Тој е вистински полиглот кој зборува 8 јазици, од кои 3 светски и 5 балкански.

Академик Ѓорѓи Филиповски е носител на голем број **ордени и одликувања:**

– 6 ордени од поранешна Југославија, од кои највисок е Орденот на Републиката со сребрен венец;

– Орден за заслуги за Македонија, доделен од претседателот на Република Македонија;

– носител е на 7 плакети од странски академии и странски научни друштва.

Академик Ѓорѓи Филиповски бил многу ангажиран во **различни научни друштва и државни органи** како:

– претседател на Републичкиот совет за научна работа;

– претседател на Републичкиот совет за заштита на животната средина;

– претседател на Одборот за наградата „13 Ноември“ и член на Одборот за наградите „11 Октомври“ и „АВНОЈ“;

– претседател на Југословенското друштво за проучување на почвите;

– член на редакциски одбори на повеќе списанија.

По повод 80-годишниот јубилеј на академик Ѓорѓи Филиповски, неговите блиски соработници – проф. д-р Јосиф Митриќески и академик Ристо Лозановски (2000), ќе го забележат следново: „Благодарение на неговиот креативен дух, творечките способности, аналитичкиот приод и критичност во научноистражувачката работа, кои не се намалени ни до овој 80-годишен јубилеј, искрено се надеваме дека такви ќе останат и понатаму, а постигнатите резултати од секое тематско подрачје ќе имаат неодминлива вредност“.

Денес, одбележувајќи го овој голем јубилеј на академик Ѓорѓи Филиповски, со големо задоволство и радост можеме да кажеме дека тие надежи на неговите соработници се наполно остварени, а сето тоа академик Ѓорѓи Филиповски го потврди помеѓу двата јубилеја, во изминатиот 20-годишен период. Во овој период тој подготви и објави уште три тома од монографијата „Почвите на Македонија", две монографии за деградација и класификација на почвите, како и една опширна студија за почвите во Република Македонија образувани под растителни заедници проучувани од академик Кирил Мицевски, еден труд посветен на нашата наука и научните работници, како и еден коавторски труд (заедно со Марјан Андреевски) за условите за образување на, генеза, еволуција, класификација и некои својства на почвите образувани врз гипсен стени во Република Македонија.

1999 – том IV: „Почвите на Република Македонија – хидроморфни почви", 548 стр. (МАНУ, Скопје)

2001 – том V: „Почвите во Република Македонија – халоморфни почви", 435 стр. (МАНУ, Скопје)

2004 – том VI: „Почвите во Република Македонија – антропогени почви (антропосоли)", 253 стр. (МАНУ, Скопје)

2003 – „Деградација на почвите како компоненти на животната средина во Република Македонија", 348 стр. (МАНУ, Скопје)

2006 – „Класификација на почвите на Република Македонија", 341 стр. (МАНУ, Скопје)

2007 – „Почвите на Република Македонија образувани под растителни заедници проучувани од Кирил Мицевски", 35 стр. (МАНУ, Скопје).

2016 – Услови за образување, генеза, еволуција, класификација и некои својства на почвите образувани врз гипсени стени во Република Македонија, Прилози, МАНУ, Одд. за Природно-матемнатички и биотехнички науки, 37 (2):69–78 (со Марјан Андреевски).

2016 – Педолошки карти на Република Македонија, Прилози, МАНУ, Одделение за Природно-математички и биотехнички науки, 37 (2):55–68.

2017 – За нашата Наука и научни работници, Прилози, МАНУ, Одделение за Медицински науки, 38 (1):9–14.

Со тоа е заокружена 6-томната монографија „Почвите на Република Македонија", која претставува обемен капитален труд со трајна вредност, во која врз современа научна основа се опфатени и обработени речиси сите научни сознанија за почвите од територијата на Република Македонија и тие се подредени според класификациониот систем на академик Ѓорѓи Филиповски, компатибилен со класификациониот систем на почвите од западните земји.

Покрај наведените монографски дела, како посебно значаен научен придонес на академик Ѓорѓи Филиповски во изминатиот период треба да се нагласи финализирањето на проектот "Педолошка карта на Република Македонија". Ова капитално дело е резултат на еден долгогодишен истражувачки проект кој траеше скоро 70 години (од 1947 до 2015 година), кој беше раководен од Академик Ѓорѓи Филиповски. Тој, заедно со работниот тим од негови соработници (д-р М. Андреевски, д-р К. Василевски, д-р И. Милевски, д-р М. Марковски, д-р Т. Миткова, д-р Ј. Митрикески, д-р Д. Мукаетов и д-р Д. Петковски) за 10 подрачја од Република Македонија изработија 63 педолошки карти во печатена и дигитална форма (од кои 62 карти во размер 1:50 000 за оделните листови на топографските карти и една карта во размер 1:200 000, за целата територија на Република Македонија). За секое подрачје покрај педолошката карта, напишана е и студија за почвите, како и студија за почвите за целата територија на Република Македонија. За сите педолошки карти е составена заедничка легенда со 63 картографски единици. Опишани се сите користени класификации, извршена е дигитализацаија на сите карти и на базата на податоци за почвните својства. Завршните работи на проектот се финансирани од FAO. Поставена е веб страницата на интернет (www.maksoil.ukim.mk).

Во рамките на овој проект академик Ѓорѓи Филиповски се јавува како автор на Толковникот и почвената карта на Република Македонија на топографска основа 1:200 000 (источно од Гринич), кој претставува скратена верзија на монографијата за почвите на Република Македонија, дополнета со резултати од истражувањата за изработка на повеќе докторати и магистерски трудови, одбранети по објавување на монографијата. Покрај улогата на толковник текстот дава пократок и поупотреблив преглед на сите резултати од истражувањата на почвите на територијата на Република Македонија во периодот 1947–2013 година. Освен тоа, Академик Ѓорѓи Филиповски е автор на почвената карта и толковникот на почвите на подрачјата опфатени со листовите Штип 2 и 4, Берово 1, 2, 3 и 4 и дел од Разлог 3 на топографските карти во размер 1:50 000.

2015 – Ѓ. Филиповски: Почвите на Република Македонија на топографска основа 1:200 000 (источно од Гринич) (толковник), УКИМ, Земјоделски Институт Скопје, 251 стр.

2015 – Ѓ. Филиповски: Почвите на подрачјето опфатено со листовите Штип 2 и 4, Берово 1,2,3 и 4 и дел од Разлог 3 на топографските карти во размер 1:50 000 (толковник), УКИМ, Земјоделски Институт Скопје, 120 стр.

Разбирливо е дека од еден ваков кус приказ не би можело да се добие поширока и поцелосна претстава за големото дело на академик Ѓорѓи Филиповски, како во однос на неговиот научен опус, така и околу неговата ангажираност во формирањето на наставно-научните институции, научните и стручните кадри. Тоа за една ваква пригода не беше ни возможно, меѓутоа, за среќа, постојат голем број пишани документи, многу богата биографија, како и обемна библиографија на академик Ѓорѓи Филиповски, кои го документираат целокупниот негов придонес во изминатиот период.

Честитајќи му го уште еднаш големиот јубилеј на академик Ѓорѓи Филиповски, да му посакаме, пред сѐ, добро здравје и уште многу години неговата творечка енергија и понатаму да ја насочува кон нови изданија од областа на педологијата. Како и досега, посакуваме секогаш да се среќаваме и да не развеселува со своите духовити досетки и анегдоти, во само нему својствен стил, со неговиот вроден шарм, духовитост и младешки дух.

ACADEMICIAN GJORGJI FILIPOVSKI
(On the occasion of his 100th birthday)

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It is both a great responsibility and, above all, an honour to prepare and write a few pages of text intended to encompass a whole century of the life and accomplishments of Academician Gjorgji Filipovski. This is so, first of all, because the most important activities of the whole corpus of the teaching, scientific and public undertakings of Academician Gjorgji Filipovski have taken place in a very important period for our country and witness the beginnings of the formation of its first institutions of higher education – the University of Skopje, the Faculty of Agriculture and Forestry, and the Macedonian Academy of Sciences and Arts.

Academician Gjorgji Filipovski was born in the village of Sorovich near Lerin on 6th May 1919. His parents were from Bitola and this is where he completed his high-school education. He studied at the agriculture and forestry faculties first in Belgrade and then in Sofia. In the latter he graduated in 1942 with the highest grades among the students of his generation and where, correspondingly, he was elected to the position of teaching assistant. In 1944 he returned to Bitola, and soon after he joined the partisan armed forces.

It would appear that the whole uninterrupted working life of Academician Gjorgji Filipovski was predetermined for him to continuously face the challenge of a constructor – to lay foundations, build and restore. There is no doubt that an important contribution to all his undertakings has been his ability and readiness to face the challenge to organize the educational and scientific activity at the Faculty of Agriculture and Forestry, but also his overwhelming gift for an analytic, systematic, objective and very rational and pragmatic approach to the solution of any of them. This could be supported, among others, by what follows.

In December 1944, being summoned by ASNOM (the provisional parliament of Macedonia), he came to the Institute for Agricultural Studies in Skopje where he established the Pedological and Agrochemical Division which was headed by him for two years.

In 1947 he was elected, as the youngest (28 years old) member to the first Educational Council of the newly formed Faculty of Agriculture and Forestry where, with great enthusiasm he engaged himself in the organization of the educational and scientific activities of the Faculty. In 1949 he established and organized the Department of Pedology and Agrochemistry, being its chairperson for several decades, a period during which this department was one of the best organized and equipped units with modern laboratories and abundant collections. Academician Filipovski was (at the age of 37) among the first deans of the Faculty of Agriculture and Forestry.

He retired in 1987, and in the whole period of his teaching engagement he was one of the most admired, respected and beloved professors, his lectures being followed by 40 generations of students.

As the Rector of the Cyril and Methodius University of Skopje (elected to the post in the autumn of 1963, after the earthquake that struck Skopje) he succeeded in creating conditions for restarting the educational activity at the university and for restoring the damaged university buildings and student dormitories. During his Rector's years he organized remarkable aid and equipment donations from abroad, and provided a significant number of teaching assistants with grants for postgraduate or postdoctoral studies abroad.

When in 1967 the Macedonian Academy of Sciences and Arts (MASA) was founded, he was elected as one of its first members, and in its first Presidency he took the position of Scientific Secretary, a post he kept for eight years, years full of engagements in the organization of MASA and the commencement of its activities; particularly important being his chairmanship of the Committee for building the new MASA building. Later on, for twelve years he was Vice-president of MASA.

Academician Gjorgji Filipovski is the founder of the modern pedological studies in the Republic of Macedonia and the leading person in this field.

Since the very beginnings of his scientific work, Academician Gjorgji Filipovski found a vast and practically unexplored area in the investigation of the soils of the Republic of Macedonia, and with his studies he gained deep insights into the interpretation of the most important elements of these complex systems.

Immediately after the establishment of the Department of Pedology and Agrochemistry at the Faculty of Agriculture and Forestry, Academician Filipovski took part in one of the largest projects in Macedonia – *Melioration – drainage of 65 000 ha and irrigation of 100 000 ha*, within which pedological studies were conducted in a number of valleys in Macedonia. As a result of these studies, for the first time in Macedonia detailed scientific and practical knowledge of the soils was obtained and the results were directly used in the large undertakings – drainage and building of irrigation systems, this being the basis for raising of tens of thousands hectares of vineyards and fruit plantations.

Academician Filipovski established a school for pedological studies, educating and training new generations of researchers who would continue the soil investigations. Thus this school was the main center for agrochemistry and pedology in former Yugoslavia. As a result, the soil map of the Republic of Macedonia (1 : 50 000) was prepared, and this map was later used by FAO and UNESCO in the process of creation of the soil map of Europe.

The lack of a unified world classification of soils directed Gjorgji Filipovski toward development of new ideas, later implemented in the project *A Monograph on the Soils of Yugoslavia*. Particularly important are his studies related to the conditions for formation, genesis, classification and properties of the saline soils, an area to which his inaugural speech for MASA *Halomorphic soils in the Socialist Republic of Macedonia* was devoted. Academician Filipovski is considered to be one of the best experts in this area, with publications often quoted in scientific journals both at home and abroad.

The devotion of Academician Filipovski to problems of ecological and agro-ecological regionalization of the Republic of Macedonia on the basis of the mutual relations and the effects of the relief, climate, vegetation and soils resulted in a co-authored monograph entitled *Characteristics of the climate–vegetation–soil regions in the Republic of Macedonia* (1996). This capital publication of extraordinary value is considered to be one of the most cited research works from Macedonia in the last fifteen or so years, being used as a reference by numerous soil scientists, forestry specialists, botanists, zoologists, geographers, etc.

Academician Filipovski has published about 90 scientific articles (over 30 % abroad and in former Yugoslavia), including 14 monographs (11 in MASA and 3 in the Faculty of Agriculture). One of the most voluminous ones (*Soils of Yugoslavia*, 600 pages, in Serbian) has been translated into English and has been used in many countries.

His capital work is the monograph series *Soils of the Republic of Macedonia* in six volumes. It is of an invaluable lasting importance. In this collection of monographs all pertinent knowledge resulting from the investigations of the soils in Macedonia has been treated on a contemporary scientific basis.

Academician Gjorgji Filipovski has a very rich international activity and cooperation.

He is a real polyglote who speaks eight languages of which three are international and five are from the Balkans.

He has participated in many scientific conferences all over the world, presenting contributions of which many were introductory. He was, for a year, a visiting professor in California, USA, and, for a number of years, has lectured at postgraduate courses at the universities of Belgrade, Bary (Italy) and Crete (Greece) where he was elected to professorship in an international competition. He is a holder of the Doctor honoris causa degree given by the Bradford University in UK, a foreign member of the Academy of Sciences and Arts of Bosnia and

Herzegovina and a member of several international associations.

As an expert, he has spent several months in Egypt in relation to the utilization of the Asuan dam water for melioration of the saline soils in the delta of the Nile.

He is a member of the FAO commission for preparation of the soil map of Europe.

As a mentor he was the host of a number of PhD and MS holders from abroad.

Academician Filipovski is a recipient of many decorations of which six are in former Yugoslavia (the one with the highest rank is the Order of the Republic with Silver Garland), the Order of Merits for Macedonia (awarded by the President of the Republic of Macedonia) and seven plaquettes of foreign academies and scientific societies.

Academician Filipovski has had many engagements in various scientific societies and public bodies:

– Chairman of the State Council for Research;

– Chairman of the State Council for Environmental Protection;

– Chairman of the Committee for the *13 Noemvri* award and member of the committees for the *11 Oktomvri* and *AVNOJ* awards;

– President of the Yugoslav Society of Soil Science;

– Member of the editorial boards of a number of scientific journals.

On the occasion of the eightieth birthday of Academician Gjorgji Filipovski (in 2000), his close collaborators Professor Josif Mitrikevski and Academician Risto Lozanovski would say: "Thanks to his creative spirit, inventive capabilities, analytic approach and critical views in research work which have not deminished up to this 80th birthay celebration, we honestly believe that these virtues will remain unchanged and that his results achieved in every thematic field will be of permanent value".

Today, when we celebrate this great jubilee of Academician Gjorgji Filipovski, we can say, with great satisfaction and joy, that the above hopes of his collaborators have been completely fulfiled and that Academician Filipovski has attested that in the 20-year period between the two jubilees. It is in this period that he has prepared and published three volumes of the monograph series *Soils of Macedonia*, two books about the degradation and classification of soils and a comprehensive study of the soils of the Republic of Macedonia formed under the vegetation communities studied by Academician Kiril Micevski, one paper devoted to our science and scientists, as well as a co-authored article (together with Marjan Andreevski) on the formation conditions, genesis, evolution, classification and some features of soils formed on gypsum rocks in the Republic of Macedonia.

1999 – Vol. IV. Soils of the Republic of Macedonia: Hydromorfic Soils, MASA, Skopje, 548 p.

2001 – Vol. V. Soils of the Republic of Macedonia: Salt-affected Soils, MASA, Skopje, 435 p

2004 – Vol. VI. Soils of the Republic of Macedonia: Anthropogenic Soils Anthroposols, MASA, Skopje, 253 p.

2003 – Soil degradation as a component of the environment of the Republic of Macedonia, MASA, Skopje, 348 p.

2006 – Soil Classification of the Republic of Macedonia, MASA, Skopje, 341 p.

2007 – The soils of the Republic of Macedonia formed under the vegetation communities studied by Kiril Micevski, MASA, Skopje, 35 p.

2016 – Formation conditions, genesis, evolution, classification and some features of soils formed on gypsum rocks in the Republic of Macedonia, Contributions, MASA, Sect. of Natural, mathematical and Biotecnical Science, 37 (2):69–78 (togeather with Marjan Andreevski)

2016 – Soil Maps of the Republic of Macedonia, Contributions, MASA, Sect. of Natural, mathematical and Biotecnical Science, 37 (2):55-68

2017 – On our Science and scientific workers, Contributions, MASA, Sect. Of Medical Sciences, 38 (1):9-14.

This completes the six-volume monograph series *Soils of the Republic of Macedonia* in which, on the basis of contemporary scientific knowledge the soils in the Republic of Macedonia have been studied and classified according to the classification system of Academician Filipovski which is compatible with the systems for soils in the western countries.

Among the published monographs, as a significant scientific contribution by Academician Gjorgji Filipovski in the past period, the finalization of the project "Soil maps of the Republic of Macedonia" should be emphasized. This capital work is the result of a long-term research project that lasted almost 70 years (from 1947 to 2015), which was managed by Academician Gjorgji Filipovski. He, together with the working team of his collaborators (Dr. Marjan Andreevski, Dr. Kole Vasilevski, Dr. I. Milevski, Dr. M. Markovski, Dr. T. Mitkova, Dr. J. Mitrikeski, Dr. D. Mukaetov and Dr. D. Petkovski) prepared 63 soil maps for 10 regions of the Republic of Macedonia in printed and digital form (out of which 62 in a scale of 1:50 000 for a specific sections of the topographic maps, and one map in a scale of 1:200 000, for the whole territory of the Republic of Macedonia). For each section along the soil map, a soil study has been written, as well as a study of soils for the entire territory of the Republic of Macedonia. In addition, a common legend has been developed for all soil maps with 63 cartographic units. All classifications used are described, digitization of all maps and the database for soil properties has been performed. The final works of the project are financed by the FAO. A Web site is set up on the Internet (www.maksoil.ukim.mk).

Within this project, Academician Gjorgji Filipovski is author of the Soil map and Interpretation Manual of the Republic of Macedonia of the topographic map in a scale of 1:200 000, which is a short version of the monograph on the soils of the Republic of Macedonia, supplemented with the research results for the preparation of several doctorates and master theses, defended after publication of the monograph. In addition to the role of the Interpretation Manual, the text gives a shorter and more detailed overview of all the results of soil research in the territory of the Republic of Macedonia in the period 1947–2013. Academician Gjorgji Filipovski is also the author of the Soil maps and the interpretation manual of the areas covered by the sheets Stip 2 and 4, Berovo 1,2,3 and 4 and part of Razlog 3 on topographic maps in the scale 1:50 000 .

2015-Gj. Filipovski: Soils of the Republic of Macedonia on topographic maps 1:200,000 (East of Greenwich) (Interpretation manual), "Ss. Cyril and Methodius" University, Institute of Agriculture, 251 pp.

2015-Gj. Filipovski: Soils of the regions outspread on sheets Štip 2 and 4, Berovo 1, 2, 3 and 4 and part of Razlog 3 on topographic maps scaled 1:50,000 (Interpretation manual), "Ss. Cyril and Methodius" University, Institute of Agriculture, 120 pp.

It is clear that in such a short presentation it would be not possible to give a wider and more profound presentation of the fundamental achievments of Academician Gjorgji Filipovski not only regarding his scientific opus, but also regarding his engagement in the formation of institutions for education and research and the development of human potentials for these important needs. Fortunately, there are present numerous documents, a rich biography and comprehensive bibliography of Academician Gjorgji Filipovski which, all together, document all his contributions in the preceding period.

Congratulating once again to Academician Gjorgji Filipovski on his great jubilee, we wish him, first of all, good health and many years of life in which his creative energy will be again directed towards new publications in the field of soil science, especially in terms of the preparation of the Soil Map of the Republic of Macedonia.

As before, we wish always to meet him and to enjoy with his witty jokes and anecdotes in its unique style, with its innate charm, wit and youthful spirit.

БИБЛИОГРАФИЈА НА АКАДЕМИК ЃОРЃИ ФИЛИПОВСКИ
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ЕДЕН ЖИВОТ ЦЕЛ ВЕК ИСТОРИЈА[#]
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Таки Фити
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Денес имаме голема чест и задоволство и ретка пригода да ја одбележиме 100-годишнината од раѓањето на акад. Ѓорѓи Филиповски, единствениот жив член на МАНУ од првиот работен состав, односно од основањето на Академијата во 1967 година.

Размислував како да ја насловам мојата поздравна беседа за акад. Ѓорѓи Филиповски, напишана по повод одбележувањето на неговиот 100. роденден, но не успеав да најдам подобар и поадекватен наслов од насловот на филмот што го изработи и го сними МРТ за акад. Ѓорѓи Филиповски – ЕДЕН ЖИВОТ ЦЕЛ ВЕК ИСТОРИЈА. Се определив за вака сроченото наслов, сеедно што јас не сум негов автор, бидејќи мислам дека насловот е вистински сублимат и одраз на длабоката суштина на приказната (сторијата) за животот и делото на еден извонреден човек, врвен универзитетски професор, со огромна и неспорна репутација, дома и во странство, извонреден научник и истражувач во областа на педологијата, академик од основањето на МАНУ и прв научен секретар на нашата највисока институција од областа на науките и уметностите. Сепак, откако ја напишав беседата, на насловот додадов и поднаслов – *трите аманети на академик Ѓорѓи Филиповски*. Поднасловот, некако, се наметна сам по себе, бидејќи сублимирајќи ги најзначајните придонеси на акад. Филиповски за развојот на нашето образование, наука и култура, дојдов и до три значајни препораки поврзани со дејноста на МАНУ кои, чинам, акад. Филиповски, постојано ни ги сугерира нам, на неговите помлади колеги и пријатели во Академијата.

Акад. Ѓорѓи Филиповски е жива легенда, икона и историја на македонската наука и на МАНУ. Неговите кажувања за сопствениот животен пат и научно творештво, презентирани на јавни настапи по различни поводи, во Академијата, во други образовни и научни институции, во медиумите (дневните весници, радиото и телевизиите) претставуваат драгоцени записи и автентични сведоштва за историјата на македонскиот образовен систем – посебно за високото образование, за Универзитетот „Св. Кирил и Методиј“, за факултетите, за развојот на македонската наука и на македонските научни институции, на македонската уметност и култура и особено за основањето и развојот на Македонската академија на науките и уметностите. Сите негови кажувања се одликуваат со јасна, ударна и остроумна мисла, со нагласена сугестивност и со елоквентност иманентна на искусен и врвен универзитетски професор.

Огромен е придонесот на акад. Ѓорѓи Филиповски за развојот на образованието, науката, уметноста и културата во нашата земја. Фактите и настаните во долгиот и возбудлив животен пат на акад. Филиповски, придружени со бурните и турбулентни настани на балканските простори, недвосмислено го потврдуваат тоа. На 23-годишна возраст (1942 г.), Филиповски е избран за асистент по предметот педологија на Земјоделско-шумарскиот факултет во Софија. Таму ги стекнува првите искуства во наставно-образовниот процес и во научно-апликативната дејност, истражувајќи во лабораториите на софискиот факултет. Во 1945 година се враќа во Македонија и станува шеф на Педолошко-агротехничкиот отсек при тогашниот Земјоделско-испитателен институт во Скопје. Формирајќи свој тим соработници, започнува со интензивна истражувачка работа на педолошките карактеристики на земјиштето во Македонија – активност што ќе стане и ќе остане негова основна научна преокупација до денешни дни. Во период од 13 години (1947 – 1960), младиот и енергичен научник Ѓорѓи Филиповски ќе ги помине сите скалила и звања на Земјоделско-шумарскиот факултет во Скопје – предавач, доцент, вонреден и редовен професор. Во периодот 1955 – 1956 година станува декан

[#]Поздравна беседа на акад. Таки Фити, претседател на МАНУ, на одбележувањето на 100. роденден на акад. Ѓорѓи Филиповски, МАНУ, мај 2019 г.
Welcome address of Acad. Taki Fiti, President of the Macedonian Academy of Sciences and Arts, on the occasion of marking the 100th anniversary of the Acad. Gjorgji Filipovski, MASA, May 2019.

на својот матичен факултет. Во 1963/1964 година и во 1964/1965 година е ректор на Универзитетот во Скопје – тоа е еден од најтешките периоди од развојот на Универзитетот – периодот коинцидира со катастрофалниот земјотрес во Скопје кога беа разурнати Универзитетот, факултетите и домовите на професорите. Искуството на Филиповски, неговата работохоличност, организациски способности и исклучителна посветеност на развојот на високото образование и научната дејност, помошта на Владата и меѓународната помош, придонесоа брзо да се санираат тешките последици од разорниот земјотрес. Во 1967 година, Ѓорѓи Филиповски е избран за член на МАНУ и е единствениот жив академик од 14-те основоположници на нашата Академија.

Може многу да се говори за придонесите на акад. Ѓорѓи Филиповски во сите споменати области, во автономните и витални области на општеството – образованието, науката, културата, т.е. во областите што се нераскинлив дел од основната мисија на МАНУ. За нив станува збор во подготвените изданија на нашето Одделение за природно-математички и биотехнички науки, чиј член е и акад. Ѓорѓи Филиповски. За нив денес ќе говорат промоторите на изданието, потоа неговите колеги и соработници од Земјоделскиот факултет, за нив станува збор и во филмот на МРТ посветен на акад. Ѓорѓи Филиповски и сл. Затоа, дозволете ми во оваа пригода, со големо задоволство, да се обидам да ги сумирам, во најсинтетичка форма, во форма на „аманети“, пораки, што овој голем, исклучителен професор, научник и академик ни ги испорачува нам, на членовите на МАНУ, пораки во кои е содржана мудроста од неговата континуирана, безмалку, осумдесетгодишна посветена работа во споменатите сфери.

Прво, за одделни аспекти на придонесот на акад. Филиповски во сферата на високото образование и научноистражувачката дејност, како што претходно напоменав, доволно говорат неговите биографски податоци, податоците за неговиот животен пат и за неговата академска кариера. Овде сакам да истакнам дека акад. Филиповски континуирано, со нагласен интерес ги следи и ги анализира состојбите во нашата земја во споменативе сфери. Општопознат е фактот дека во последните 10–15 години дојде до евидентно влошување, назадување, па дури и до појава на тенденции на деградирање на состојбите во овие витални сфери на општественото живеење. Изразувајќи длабока загриженост за ваквите тенденции, акад. Филиповски, кон крајот на 2016 година, во „Утрински весник“, објави автентично сведоштво (во три продолженија) за развојот на образованието и науката во изминатите 70 години во Македонија и упати сериозна опомена и предупредување до креаторите на политиките за итни реформи и промени во образованието и науката, бидејќи станува збор за подрачја од круцијално значење за иднината на земјата. Нашиот познат новинар Ерол Ризаов со право го наслови првиот прилог на акад. Филиповски во „Утрински весник „*Аманетот на единствениот жив сведок*. Генералниот став на акад. Филиповски, во слободна интерпретација, е дека одговорна и паметна влада мора да бдее над развојот на автономните сфери на општественото живеење (образованието, науката и културата) и да обезбеди доволно ресурси за нивниот континуиран развој. Во овој контекст, акад. Филиповски, најнапред, ја потсети Владата, ги потсети надлежните ресори и креаторите на политиките во оваа област за односот на раководството на младата македонска држава кон состојбите во образованието и науката. Притоа, тој ќе констатира дека е фасцинантно, зачудувачки, просто неверојатно, за една мала неразвиена земја каква што беше Македонија по завршувањето на војната, во период од само 4 години, од 1945 до 1949 година, да создаде своја азбука, да го кодификува својот јазик, македонскиот јазик и да создаде свој универзитет. Ваквата траекторија на настаните, во вонредно кратка временска секвенција да се формираат клучните атрибути на писменоста, образованието и науката е практично настан без преседан во однос на други земји. Сличен ваков пример, ќе рече Филиповски, мене не ми е познат ниту на балканските простори ниту пошироко. Сето ова се случуваше во услови кога раководителите на Македонија, непосредно по завршувањето на Втората светска војна, не беа доволно образовани, многу од нив немаа завршено ни средно образование, но зачудувачки е, ќе рече Филиповски, како знаеја дека образованието е најзначајно за идниот развој на земјата и вложуваа, за тоа време, големи средства токму во оваа витална и автономна сфера на општеството. И токму ваквиот однос на раководството на младата македонска држава ја избави земјата од големата и неподнослива заостанатост. Денес, 70 години подоцна, во услови на информатичко општество, базирано врз знаење и научни достигнувања, се случуваат обратни, несфатливи и опасни тенденции, кои мора да се спречат, да се пресечат од корен. Таквите тенденции Филиповски ги препознава во недозволено ниското издвојување јавни средства за истражување и развој и за научни проекти, во блокираниот избор на млади научни работници, во малиот број истражувачи во споредба со европските стандарди и во исклученоста на научната фела од креирањето на образовната и научната политика. Првата порака, аманетот од ваквите согледувања, акад. Филиповски ја срочува повикувајќи се на зборовите на нашиот великан Крсте Петков Мисирков, кој пред 100 години ќе нагласи дека развојот на науката и литературата се најзначајниот фактор за развојот на еден народ и дека културните народи владеат со светот, а некултурните робуваат.

Во оваа пригода, сакам посебно да ја истакнам големата грижа, човечка и доблесна, на акад. Ѓорѓи Филиповски кон неговите колеги и пријатели од Академијата и пошироко од македонската научна фела. Никогаш нема да ја заборавиме острата реакција на акад. Филиповски против безумната лустрација која не толку одамна се спроведуваше во нашата земја и која опфати и наши академици. Тогаш, по повод лустрацијата на акад. Славко Јаневски, целата македонска јавност го слушна гласот на разумот на најстариот член на МАНУ – според возраст и академски стаж. Во отвореното писмо до Комисијата за верификација на фактите, акад. Филиповски, меѓу другото, резигнирано ќе констатира: „Не можам да не помислам дека имате други цели, а тоа е да ги уривате столбовите на нашата литература и култура, бидејќи Славко Јаневски заедно со Блаже Конески и Ацо Шопов беше основоположник на нашата литература по ослободувањето. Пред повеќе години имаше обиди да се дискредитира Блаже Конески“. И понатаму „...Зар не можевте да покажете повеќе чувство за опстанок на оваа земја и овој народ?“

Второ, иако за научните достигнувања на акад. Ѓорѓи Филиповски ќе говорат професори и академици од потесното научно подрачје и сродните научни дисциплини со кои се занимава акад. Филиповски, сепак, во оваа пригода, не можам, а да не спомнам две работи кои беа клучни за неговата висока научна репутација во земјата и во странство. Првата е неговиот огромен и неспорен научен придонес во педологијата. Тој е пионер и основоположник на оваа значајна научна дисциплина во Македонија. Рано почнал да ги истражува педолошките карактеристики на земјиштето во Македонија. Тој, со својот тим, за време на летните месеци, собирал примероци на земја од различни подрачја, а во зимскиот период ги истражувал нивните карактеристики во лабораторијата. Овие истражувања му овозможија да ја изработи и одбрани својата докторска дисертација во Белград. Работејќи напорно, систематски и долги години на истражување на почвите на Македонија, тој напишал повеќе од 20 монографии кои ги содржат, така да се каже, сите знаења за оваа проблематика во Македонија и објавил повеќе од 200 научни трудови во наши и во странски списанија од областите педологија, географија, генеза на класификација на почвите и мелиорации и ерозија на почвите. Врз таа основа, настанало и неговото шестомно капитално дело *Почвите на Македонија* во обем од околу 2.400 страници. Тоа е основен, базичен и најрелевантен труд од оваа област во нашата земја. Според кажувањата на акад. Филиповски, негов сон и сон на неговиот истражувачки тим беше изработката на 63 почвени карти и 11 студии за почвите во Република Македонија. Проектот беше завршен пред 10 години, но цели 8 години акад. Филиповски се мачеше да обезбеди средства за објавување на резултатите од проектот и на почвените карти на Македонија. Дефинитивно, благодарение на големото залагање на акад. Филиповски и на неговата висока репутација како меѓународен експерт за почви, средствата за објавување на резултатите од истражувањето во износ од 340.000 американски долари ги обезбеди ФАО. Проектот доживеа и своја промоција во МАНУ. Тој, денес, овозможува со обичен клик на компјутер да се добијат релевантни податоци за педолошките карактеристики на земјиштата во Македонија. Профилирајќи се и афирмирајќи се како врвен научник во областа на педологијата, акад. Ѓорѓи Филиповски стана експерт на ФАО и во тоа својство престојувал и работел во низа земји на Југоисточна Азија, а како југословенски експерт за солени почви, непосредно по изградбата на Асуанската брана, престојувал и работел и во Египет. Акад. Филиповски реализирал студиски престои и специјализации во бројни странски земји, учествувал на меѓународни конференции и настапувал со свои предавања и реферати во САД, Велика Британија, ССР, Франција, Германија, Швајцарија, Австрија итн. Почесен доктор е на Универзитетот во Братфорд (Англија), странски член на Академијата на науките и уметностите на БиХ итн. Ваквите референции и неговите научни истражувања и апликативна дејност го сместуваат акад. Ѓорѓи Филиповски во светската педолошка елита – нешто што претставува не само лична сатисфакција за нашиот Јорго, туку и гордост и афирмација на МАНУ и на македонската наука, воопшто. Кога акад. Филиповски го прашуваме како е можно да се задржи добрата физичка и умствена кондиција до длабока старост и да се постигнат врвни резултати во наставно-образовниот процес и во науката, тој, со луцидност својствена за него, ќе одговори дека во животот му било важно да го зачува здравјето, бидејќи без тоа нема квалитетен живот и нема долгогодишна научна работа, дека во тоа му помогнала неговата смиреност, избегнување состојби на стрес, лутина, гнев, но и неговата континуирана физичка активност – како страстен планинар и љубител на хортикултурата. Кога сите овие предуслови ќе се исполнат, останува и најзначајниот услов за успех и високи достигнувања во науката – континуирана, напорна и самопрегорна работа. Тоа е клучот на успехот и тоа е вториот аманет на акад. Ѓорѓи Филиповски, кој им го испорачува на своите помлади колеги.

Трето, придонесот на акад. Ѓорѓи Филиповски за основањето и развојот на МАНУ е огромен. По неговиот избор за член на МАНУ во првиот работен состав на Академијата (1967 г.), тој веднаш е избран за научен секретар на МАНУ и по автоматизам за член на првиот Извршен одбор на Академијата (во состав: акад. Блаже Конески – претседател, акад. Харалампие Поленаковиќ – потпретседател и акад. Ѓорѓи Филиповски – секретар). Извршниот одбор на Академијата, утредента, по изборот, почна со работа. Присеќавајќи се на тој историски настан од круцијално значење за македонската наука, уметност и култура, акад. Ѓорѓи Филиповски ќе каже: „Нам ни беше многу тешко. Почнавме од ништо и без опит за организирање таква сложена установа со високо научно и уметничко ниво. Пред нас беа тешки задачи: да се обезбеди сместување на МАНУ, да се изработи предлог-статут, да се изберат вработени на раководните функции во администрацијата, да се обезбедат средства за започнување со работа и да се свика Собрание на МАНУ за усвојување на статутот и за избор на другите четворица членови на Претседателството. Сите тие задачи беа успешно завршени за пет месеци“, Акад. Ѓорѓи Филиповски оценува дека реализацијата на олку комплексни задачи и обврски, за многу краток период, беше овозможена благодарение на три олеснителни околности: прво, Академијата беше сестрано поддржана и помогната од целото општество, од републичките органи и од Градското собрание на Скопје; второ, прв претседател на МАНУ беше акад. Блаже Конески, извонреден научник, ерудит, човек со високи човечки и морални доблести и, како што вели Филиповски, човек со „јасна визија за иднината на МАНУ и нејзината улога во младата држава“; и трето, безрезервната поддршка и помош што ја добиваше младата Македонска академија од тогашните четири академии на Југославија. Набрзо, на акад. Ѓорѓи Филиповски му беше доверена и тешка и одговорна задача – да се изгради нова зграда на МАНУ. Филиповски беше назначен за претседател на Одборот за градба. И таа задача беше успешно завршена, меѓу другото, благодарение и на неспорните организациски способности на акад. Ѓорѓи Филиповски. Во врска со тоа, тој ќе констатира: „Малата земја, со скромни можности, смогна сили да финансира таква зграда каква што немаше во балканските земји и пошироко. Тогаш Академијата беше една од најубавите згради во градот“. Огромен е придонесот на акад. Ѓорѓи Филиповски во установувањето, афирмацијата и опстојувањето на основните постулати и принципи на работење и дејствување на МАНУ, кои воедно се иманентни за модерните европски национални академии. Тие принципи акад. Филиповски ги сублимира на следниов начин: Академијата е самостојна јавна научна и уметничка установа, таа ги штити националните интереси во најширока смисла на зборот, не прифаќа политизација и партизација на установата, соработува, врз рамноправни основи, со соседните и со другите академии во светот, активно учествува во изготвувањето меѓународни проекти и негува строги критериуми за избор на членови, т.е. избира кандидати со високи и докажани достигнувања во науката и во уметноста, без оглед на разликите во нивната национална, верска и идеолошка припадност. Застапувањето за ваквите принципи што ја отелотворуваат дејноста на МАНУ е константа во работењето на акад. Филиповски. Во овој контекст, тој потсетува: „...Во МАНУ членувале или членуваат Македонци, Албанци, Турци, Власи, Срби, Евреи, една Полјачка и членови од мешани бракови. Тоа е една од ретките установи што ги обединува сите етнички заедници и негува трајна толерантност кон различните од себе“. Тоа е, почитувани, третиот аманет на нашиот Јорго, аманет упатен до сите членовите на МАНУ, од актуелниот и идниот состав на Академијата, до актуелното и идните раководства на Академијата, нешто што мора да се негува и да се развива, бидејќи ја градиме нашата земја како демократско, мултикултурно и просперитетно општество.

Ете, почитувани, ова се, според моето мислење, основните контури на големата приказна за еден голем човек и научник, за нашиот драг Јорго Филиповски. Ова се основните контури на сторијата насловена ЕДЕН ЖИВОТ ЦЕЛ ВЕК ИСТОРИЈА.

Почитуван акад. Ѓорѓи Филиповски – Ти го честитам 100. роденден! Ти посакувам и понатаму да Те служи добро и крепко здравје! Ти посакувам лична среќа и среќа на твоите најблиски! Моја желба е, а сигурен сум дека го споделувам тоа со сите членови на Академијата, уште долго да се дружиме и да работиме заедно, да ги слушаме твоите мудри совети и тогаш кога ни е добро и тогаш кога се соочуваме со проблеми и тешкотии кои се составен дел на нашата работа и на нашето живеење.

ONE LIFE – A WHOLE CENTURY OF HISTORY

(Three Pledges of Academician Gjorgji Filipovski)

Taki Fiti
President of the Macedonian Academy of Sciences and Arts

Today we have the great honor and pleasure, and a rare occasion to mark the 100th anniversary of the birth of Acad. Gjorgji Filipovski, the only living member of the Macedonian Academy of Sciences and Arts from the first working composition, that is, from the establishment of the Academy in 1967.

I was thinking how to title my greeting speech for Acad. Gjorgji Filipovski, written on the occasion of marking his 100th birthday, but I failed to find a better and more adequate title than the title of the film made by the Macedonian Radio Television about Acad. Gjorgji Filipovski - ONE LIFE – A WHOLE CENTURY OF HISTORY. I selected this title, regardless that I am not its author, because I think that the title is a real sublimate and a reflection of the deep essence of the story about the life and work of a remarkable person, prime university professor, with a huge and undeniable reputation, at home and abroad, an outstanding scientist and researcher in pedology, an academician since the establishing of the Macedonian Academy of Sciences and Arts, and the first scientific secretary of our highest institution in the field of sciences and arts. However, after I had written the speech, I added a subheading to the title – Three Pledges of Academician Gjorgji Filipovski. The subheading, somehow, is imposed by itself, because, by sublimating the most important contributions of Acad. Filipovski for the development of our education, science and culture, I have come to three important recommendations related to the activity of the Macedonian Academy of Sciences and Arts, which, I think, Acad. Filipovski is constantly suggesting to us, his younger colleagues and friends at the Academy.

Acad. Gjorgji Filipovski is a living legend, an icon and a history of the Macedonian science and of the Macedonian Academy of Sciences and Arts. His thoughts about his own life and scientific work, presented at public events on various occasions, at the Academy, in other educational and scientific institutions, in media (daily newspapers, radio and television) are valuable records and authentic testimonies of the history of the Macedonian educational system – especially about the higher education, the *St. Cyril and Methodius* University, the faculties, the development of the Macedonian science and of the Macedonian scientific institutions, the Macedonian art and culture, and especially the establishment and development of the Macedonian Academy of Sciences and Arts. All his statements are characterized by a clear, striking and witty thought, with a pronounced suggestion and eloquence immanent to an experienced and leading university professor.

Huge is the contribution of Acad. Gjorgji Filipovski to the development of the education, science, art and culture in our country. The facts and events in the long and exciting life of Acad. Filipovski, accompanied by the stormy and turbulent events in the Balkan region, unambiguously confirm this. At the age of 23 (1942), Filipovski was elected an Assistant in the subject of Pedology at the Faculty of Agriculture and Forestry in Sofia. There, he acquired the first experiences in the educational process and in the scientific and applicative activity, doing research in the laboratories of the Sofia Faculty. In 1945, he returned to Macedonia and became Head of the Pedological and Agro Technical department at the then Agricultural and Research Institute in Skopje. By establishing his team of associates, he began with an intensive research work on the pedological characteristics of the soil in Macedonia – an activity that will become and will remain his basic scientific interest to the present day. In the period of 13 years (1947 – 1960), the young and energetic scientist Gjorgji Filipovski will pass all the steps and titles at the Faculty of Agriculture and Forestry in Skopje – lecturer, assistant professor, associate professor and full professor. In the period 1955 – 1956, he became a Dean at his home faculty. In 1963/1964 and in 1964/1965 he was a Rector of the University of Skopje – this is one of the most difficult periods in the development of the University – the period coincides with the catastrophic earthquake in Skopje when the University, the faculties and professors' homes were destroyed. Filipovski's experience, his working ability, organizational skills and exceptional commitment to the development of the higher education and the scientific activity, as well as the governmental and international assistance have contributed to the rapid rehabilitation of the severe consequences of the devastating earthquake. In 1967, Gjorgji Filipovski was elected a member of MASA and is the only living academician out of the 14 founders of our Academy.

Much can be said about the contributions of Acad. Gjorgji Filipovski in all mentioned areas, in the autonomous and vital areas of the society – education, science, culture, i.e. in areas that are inseparable part of the basic mission of MASA. They are discussed in the publications prepared by our Department of Natural, Mathematical and Biotechnical Sciences, whose member is Acad. Gjorgji Filipovski. The promoters of the publication will talk about them today, then his colleagues and associates from the Faculty of Agriculture, and they are also discussed in the film of the MRT dedicated to Acad. Gjorgji Filipovski and others. Therefore, allow me on this occasion, with great pleasure, to try to summarize, in the most synthetic form, in the form of "pledge", the messages that this great, outstanding professor, scientist and academician delivers to us, the members of MASA, messages that contain the wisdom of his continuous, of almost eighty years, dedicated work in the mentioned spheres.

First, concerning some aspects of the contribution of Acad. Filipovski in the field of the higher education and scientific and research activity, as previously mentioned, his biographical data and the data on his life path and his academic career articulate sufficiently. Here, I would like to point out that Acad. Filipovski continuously, with high interest, follows and analyzes the situation in our country in the mentioned areas. It is a common knowledge that in the last 10–15 years there has been an evident deterioration, decline, and even tendencies of degradation of the situation in these vital spheres of the social life. Expressing deep concern for such tendencies, Acad. Filipovski, at the end of 2016, in *Utrinski vesnik* newspaper published an authentic testimony (in three sequels) on the development of the education and science in the past 70 years in Macedonia and made serious caution and warning to the policymakers for urgent reforms and changes in the education and science, because it is about areas of crucial importance for the future of the country. Our famous journalist Erol Rizaov rightly named the first article of Filipovski in *Utrinski vesnik* a "Pledge of the only living witness". The general position of Acad. Filipovski, in free interpretation, is that a responsible and smart government must watch over the development of the autonomous spheres of the social life (education, science and culture) and to provide sufficient resources for their continued development. In this context Acad. Filipovski, firstly reminded the Government, and the relevant departments and policy makers in this area about the attitude of the leadership of the young Macedonian state towards the situation in the education and science. In doing so, he will conclude that it was fascinating, astonishing, simply incredible, for a small underdeveloped country that Macedonia has been after the end of the war, for a period of only 4 years, from 1945 to 1949, to have created its own alphabet, to have codified its language, the Macedonian language and to have created own university. Such trajectory of events, in an extraordinary short time sequence, to form the key attributes of literacy, education and science is practically an unprecedented event in relation to other countries. "I'm not familiar with a similar example in the Balkans or beyond", Filipovski says. All of this has happened in conditions when the leaders of Macedonia, shortly after the end of the Second World War, were not educated enough, many of them had not finished secondary education, but it is amazing, Filipovski said, that they knew that education is the most important for the future development of the country and invested, for that time, large funds precisely in this vital and autonomous sphere of the society. And exactly this attitude of the leadership of the young Macedonian state has saved the country from the great and unbearable backlash. Today, 70 years later, in situation of an information society, based on knowledge and scientific achievements, reverse, incomprehensible and dangerous tendencies occur, which must be prevented, cut off from the root. Filipovski recognizes such tendencies in the inadmissible low allocation of public funds for research and development and for scientific projects, in the blocked election of young scientists, in the small number of researchers compared to the European standards and in the exclusion of the scientific profession from the creation of the educational and scientific policies. The first message, the pledge of such observations, Acad. Filipovski addressed in line with the words of our great personality Krste Petkov Misirkov, who, 100 years ago said that the development of science and literature is the most important factor for the development of one nation, and that peoples with culture rule the world, whereas, the peoples without culture are the ones that slave.

On this occasion, I would like to emphasize, in particular, the great care, human and virtuous, of Acad. Gjorgji Filipovski for his colleagues and friends from the Academy, and from the Macedonian scientific vocation. We will never forget the sharp reaction of Acad. Filipovski against the senseless lustration that, not so long ago, has been implemented in our country, and which has included our academicians. Then, on the occasion of the lustration of Acad. Slavko Janevski, the whole Macedonian public heard the voice of the reason from the oldest member of MASA – by age and by academic experience. In an open letter to the Commission for verification of facts, Acad. Filipovski, among other things, reluctantly will conclude: "I can't help but think that you have other goals, which is to destroy the pillars of our literature and culture, because Slavko Janevski together with Blaze Koneski and Aco Sopov was the founder of our literature after the liberation. Many years ago there were attempts to dishonor Blaze Koneski." And further "...Couldn't you have shown more sense for the survival of this country and this people?"

Secondly, although about the scientific achievements of Acad. Gjorgji Filipovski will talk professors and academicians from the closest scientific field and the related scientific disciplines of Acad. Filipovski's filed of interest, however, on this occasion, I can't help but mention two things that were crucial for his high scientific reputation in the country and abroad. The first one is his huge and undeniable scientific contribution to pedology. He is the pioneer and founder of this important scientific discipline in Macedonia. He began early to explore the pedological characteristics of the soil in Macedonia. He, with his team, collected samples of soil from different areas during the summer months, and during the winter period he examined their characteristics in the laboratory. These studies enabled him to prepare and defend his doctoral dissertation in Belgrade. By working hard, systematically and for many years of research of the soils of Macedonia, he has written more than 20 monographs that contain, so to speak, all the knowledge about this subject in Macedonia, and has published more than 200 scientific papers in our and in foreign journals in the areas of pedology, geography, genesis of soil classification and melioration and erosion of soils. On this basis, his six book capital work, *Soils of Macedonia* has been created in the volume of about 2,400 pages. It is the fundamental, basic and the most relevant work in this field in our country. According to the statements of Acad. Filipovski, his dream and the dream of his research team was the creation of 63 soil maps and 11 studies on the soils in the Republic of Macedonia. The project was completed 10 years ago, but for entire 8 years Acad. Filipovski was struggling to provide funds for publishing the results of the project and the soil maps of Macedonia. Definitely, thanks to the great effort of Acad. Filipovski and his high reputation as an international expert on soils, the funds for publishing the results of the research in the amount of 340.000 USD were provided by FAO. The project also experienced its promotion in MASA. Today, it enables by simple click on the computer to obtain relevant data on the pedological characteristics of the land in Macedonia. Profiling and affirming himself as a prime scientist in the field of pedology, Acad. Gjorgji Filipovski became FAO expert, and in that capacity he has stayed and has worked in a number of countries in Southeast Asia, and as a Yugoslav expert on saline soils, he stayed and worked in Egypt just after the construction of the Aswan Dam. Acad. Filipovski has had study visits and specializations in numerous foreign countries, he has participated in international conferences and has held lectures and abstracts in the USA, UK, USSR, France, Germany, Switzerland, Austria, etc. He is an Honorary Doctor at the University of Bradford (England), a foreign member of the Academy of Sciences and Arts of Bosnia and Herzegovina, etc. These references and his scientific research and application work has placed Acad. Gjorgji Filipovski in the world pedology elite - something that represents not only personal satisfaction for our Jorgo, but also pride and affirmation of MASA and of the Macedonian science, in general. When we ask Acad. Filipovski how it was possible to maintain a good physical and mental fitness at an older age, and to achieve top results in the educational process and in science, he, with the lucidity inherent in him, will answer that in his life it was important for him to preserve the health, because without it there is no quality life and no longstanding scientific work, and, that, in doing so helped his calmness, avoiding stress, anger, rage, but also his continuous physical activity – as a passionate mountaineer and lovers of horticulture. When all these preconditions are met, remains the most important condition for success and high achievements in science – continuous, hard and sacrificing work. That is the key to the success, and that is the second pledge of Acad. Gjorgji Filipovski, which he delivers to his younger colleagues.

Third, the contribution of Acad. Gjorgji Filipovski to the establishment and development of MASA is enormous. After his election as a member of MASA in the first working structure of the Academy (1967), he was immediately elected a Scientific Secretary of MASA and automatically, a member of the first Executive Board of the Academy (composed of: Acad. Blaze Koneski – President, Acad. Haralampie Polenakovic – Vice President and Acad. Gjorgji Filipovski – Secretary). The Executive Board of the Academy, the day after the election, started working. Recalling this historic event of crucial importance for the Macedonian science, art and culture, Acad. Gjorgji Filipovski will say: "It was very difficult for us. We started from nothing and without experience in organizing such a complex institution with high scientific and artistic level. Difficult tasks were ahead of us: to provide a building for MASA, to prepare a draft statute, to elect employees of the management functions in the administration, to provide funds for commencement of the work and to convene an Assembly of MASA for the adoption of the statute and for the election of the other four members of the Presidency. All those tasks were successfully completed in five months." Acad. Gjorgji Filipovski estimates that the realization of such complex tasks and responsibilities, for a very short period, was made possible thanks to three facilitating circumstances: first, the Academy was widely supported and assisted by the whole society, from the state authorities and the City Hall of Skopje; secondly, the first President of MASA was Acad. Blaze Koneski, a remarkable scientist, erudite, a man of high human and moral virtues and, as Filipovski says, a man with "a clear vision for the future of MASA and its role in the young state"; and third, the unconditional support and assistance received by the young Macedonian Academy from the then four academies of Yugoslavia. Soon, Acad. Gjorgji Filipovski was entrusted with a difficult and responsible task – to organize the construction of a new MASA building. Filipovski was appointed a Chairman of the Construction Board. That task, too, was successfully completed, among other things, thanks to the undisputed organizational skills of Acad. Gjorgji Filipovski. Regarding this, he will note: "The small country, with modest possibilities, was able to finance such building as there wasn't in the Balkan countries and beyond. At that time the Academy was one of the most beautiful buildings in the city." Huge is the contribution of Acad. Gjorgji Filipovski in the establishment, affirmation and survival of the basic postulates and principles of working of MASA, which are also immanent for the modern European national academies. Acad. Filipovski sums up those principles as follows: the Academy is an independent public scientific and artistic institution, it protects the national interests in the broadest sense of the word, it does not accept politicization and partisation of the institution, it cooperates on equal bases with the neighboring and other academies in the world, it actively participates in the preparation of international projects and fosters strict criteria for the selection of the members, i.e. it elects candidates with high and proven achievements in science and art, regardless of the differences in their national, religious and ideological background. Supporting such principles that embody MASA's activity is a constant in the work of Acad. Filipovski. In this context, he reminds us: "...Macedonians, Albanians, Turks, Vlachs, Serbs, Jews, one Pole, and members of mixed marriages were or are members of MASA. It is one of the few institutions that unites all ethnic communities and nurtures lasting tolerance towards the different ones." That is, dear all, the third pledge of our Jorgo, addressed to all members of MASA, from the current and the future composition of the Academy, to the current and the future leadership of the Academy, something that must be nurtured and developed, because we are building our country as a democratic, multicultural and prosperous society.

In my opinion, these are the basic outlines of the great story of a great man and scientist, our dear Jorgo Filipovski. These are the basic outlines of a story entitled ONE LIFE – A WHOLE CENTURY OF HISTORY.

Dear Acad. Gjorgji Filipovski – I would like to congratulate you on your 100th birthday! I wish you a good and robust health! I wish you personal happiness and happiness to your loved ones! My wish is, and I am sure that I share it with all the members of the Academy, is to associate and to work together for a long time, to listen to your wise advices when we are well, and also, when we are facing problems and difficulties that are an integral part of our work and our living.

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Original scientific paper

THE ROLE OF FOREST ECOSYSTEMS IN THE PROCESS OF MITIGATION AND ADAPTATION TO THE EFFECTS OF CLIMATE CHANGE[#]

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Forest ecosystems provide a wide range of environmental services with an important role in the Earth's life-support system. Climate change in Southeastern Europe (SEE) and forecasts for the period until 2070 have a huge impact on the present and future planning in forestry and watershed management, due to the observed trends: the increment of mean annual air temperature from 2,5–5,0 °C until the end of the XXI century; redistribution of annual precipitation, with much more precipitation in the spring-summer period, during short, intensive rain events; a decrease of annual precipitation and soil moisture of 10–20 %, with extreme consequences: dieback and disappearance of forests in huge areas of hilly-mountainous regions. Degradation and loss of forests leads to spread and intensification of soil erosion, with frequent torrential floods, mudflows, landslides, and avalanches. Stable forest ecosystems are pillars of sustainable development, repopulation and could provide means and resources to battle and overcome poverty in mountainous regions of southeast Europe.

Key words: forest ecosystems; climate change; flood prevention; erosion control; planning

INTRODUCTION

Forest ecosystems are the most complex land ecosystems whose functions are public goods [1]: protection against natural hazards (soil erosion and desertification, mudflows, torrential floods, landslides, avalanches); preservation of biological diversity; water supply; recreation; carbon-dioxide fixation; spiritual and aesthetic values; education. At the same time, they provide raw materials for the wood processing industry.

According to the Serbian National Forest Inventory [2], forests in Serbia cover 2.252.400 ha (29.1 % of the total area of the country). Forests cover approximately 40 % of the SE European countries while the EU average is 42 % [3]. The average volume in state-owned forests is 184 m^3/ha, and the annual volume increment amounts to 4.5 m^3/ha (2.4 %). The average volume in privately-owned forests is 133 m^3/ha and the annual volume increment is 3.5 m^3/ha (2.6 %). Private forests cover some 1.058.400 ha, or approximately 47 % of Serbia's total forest area [2]. There are about 500.000 private forest owners, who on average each possess about 2 ha of forests, often divided into six or seven parcels, which are often not spatially connected. Due to the small size and low productivity, most private forest owners cannot afford to pay for professional forest management.

Protective, productive and social functions of forest ecosystems have to be harmonized through the concept of Sustainable Utilization, which means: "…*to meet the needs of the present without compromising the ability of future generations to meet their own needs by practicing a land stewardship ethics which integrates the reforestation, managing, growing, nurturing and harvesting of trees for useful products with the conservation of soil, air and water quality, wildlife and fish habitat, and aesthetics*" [4].

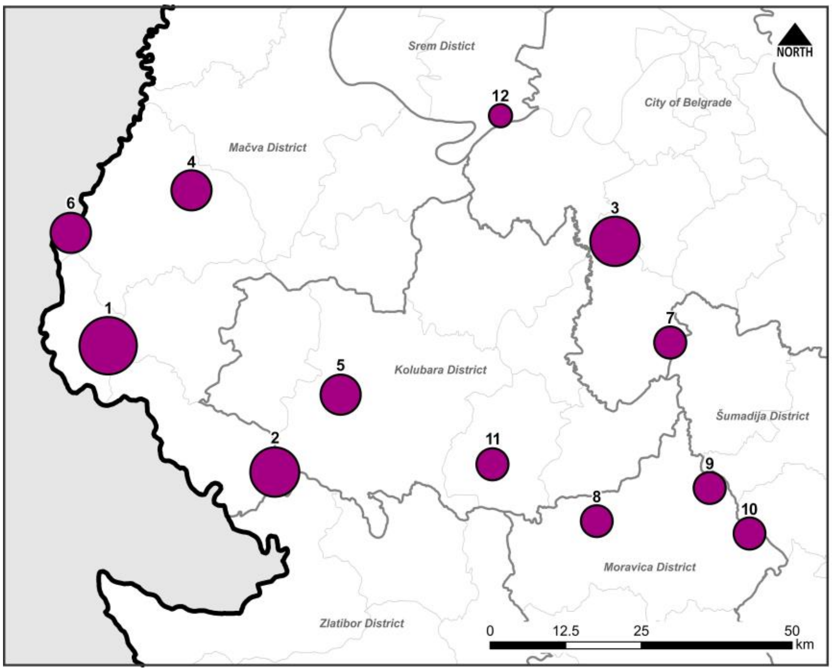
[#]Dedicated to academician Gjorgji Filipovski on the occasion of his 100th birthday

DOMINANT FACTORS THREATENING FOREST ECOSYSTEMS

Climate change

The observed climate data in the period since 1961 until the present, shows considerable changes in temperature and precipitation. Most affected by the temperature increase are central parts of Serbia. The hottest year in Serbia was 2014, and additionally, out of the 10 hottest years on record, 9 happened since the year 2000 [5]. The average temperature increase on the territory of Serbia was 1.2 °C for the period 1996–2015, with the highest increase of maximum daily temperature during the summer season, 2.2 °C [6]. At the same time, mean annual precipitation decreased during the summer period (–9.2 %). The frequency and duration of heat waves showed a sudden increase after 1982 [7]. The flow of warm and dry air from North Africa has caused severe heat waves in Serbia, with an absolute maximum temperature in 2007 (44.9 °C). During the summer of 2012, the worst drought since the beginning of measurement was recorded at several stations in Serbia [7].

The IPCC (International Panel on Climate Changes) created scenarios A1B and A2, known as 'medium' and ‘high’ forcing scenarios: scenario A1B considers a future world of strong economic growth, declining world population, rapid introduction of new and more efficient technologies, and balanced use of all energy sources, with atmospheric CO_2 concentration close to 690 ppm; the A2 scenario describes a very heterogeneous world, with continuously increasing global population and economic growth and technological change more fragmented and slower than in scenario A1B. Considered atmospheric CO_2 concentration at the end of the 21st century is up to 850 ppm (between 1.8 and 2.2 times higher than the present value of ~390 ppm) [8]. By the end of the 21st century, according to scenario A1B, an overall increase of about 2.5–5 °C is expected over Serbia for surface air temperature [5]. The largest warming and decrease of precipitation is projected for summer periods [9]. The most extreme prediction, based on scenario A2, is for the period 2071–2100, with summer temperatures increasing by about 7 °C in the Balkan countries (including Serbia), while changes for the rest of the region will be within the range of 3–4 °C [10]**.** The number of days with an absolute maximum temperature >30 °C (tropical days) is expected to increase (especially in northern parts of Serbia), while the total number of days with an absolute minimum temperature <0 °C (frost days) will decrease [11]. The vegetation period will start earlier, and end later, as is already registered to be happening in the Northern Hemisphere [12].



No	●	Rain gauges	Max in 24h [mm]	Max in 72h [mm]
1	●	Planina	218.00	428.00
2	●	Razbojište	190.00	350.00
3	●	Stepojevac	185.10	293.50
4	●	Joseva	174.10	295.10
5	●	Majinović	172.30	312.60
6	●	Banja Koviljača	168.20	219.50
7	●	Rudovci	160.00	241.30
8	●	Gornji Banjani	153.30	365.90
9	●	Rudnik	153.00	277.00
10	●	Gornja Crnuće	150.20	300.20
11	●	Brežđe	148.50	251.00
12	●	Kupinovo	140.00	219.40

Figure 1. Spatial disposition of the recorded precipitation for 24 h and 72 h at rain-gauge stations in West and Central Serbia, during catastrophic torrential floods in May 2014

Scenario A1B shows a precipitation deficit between 9–18 %, except an increase in spring in northern Serbia. According to scenario A2, precipitation will decrease by as much as 16.4 % in spring in south Serbia and increase by 9.6 % in winter in northern Serbia [11]. According to scenario A2, an increase of number of days with heavy precipitation (precipitation ≥10 mm) is expected. In south Serbia an increase of about 20 % is expected during winter, and in the north, an increase of heavy precipitation days is expected for all seasons. According to scenario A1B, there will be an increase of heavy precipitation days during spring and winter in the north, while at other seasons, and in the south, there be a decrease of less than 15 % [11]. In both scenarios, the duration of the dry period (maximum number of consecutive days with daily precipitation <1 mm) is expected to be extended. For the period of 2079–2100, the reduction of rainfall in the Balkan region might be considerably large, i.e. about 20 % of the mean precipitation found during the period 1961–1990 [13].

The paradigm for altered climate conditions was the giant cyclone formed over the Balkans in May 2014, with the following characteristics: immobility, duration of about 7 days and huge spatial coverage of more than 50.000 km^2 [14]. The cyclone produced intense precipitation which was the dominant input for fast surface runoff generation and torrential flood forming, with recurrence intervals from once in 1.000 years to once in 5.000 years [14]. During this event, historical records for 24 h and 72 h at rain gauge stations were overcome at most measuring points in West and Central Serbia (Figure 1).

Forest fires

Fires are a significant factor of deforestation in Serbia. In 2007 alone, 258 forest fires were registered on an area of 33,000 hectares (of which 16.000 hectares were forests), which caused damage of about 40 million €, with the reclamation cost of 24 million € [15]. During the summer of 2007, heat waves registered in the Balkan region including Serbia, were responsible for the largest fire-damaged area. There was an increased frequency of forest fires (2002, 2007, 2012 and 2017), that corresponds to the appearance of heat waves and drought periods. In the period 2012–2016, in forests managed by the Public Enterprise "Serbian Forests", 316 fires were recorded, on a total area of 8.074,55 hectares [15]. In 15 cases the cause was thunder, in 158 the fires were man-induced and in 143 cases the causes were unknown (likely man-induced).

Forest dieback

The extreme drought recorded in 2012 damaged sensitive relationships between spruce and root pathogens (*Heterobasidin parviporum*), after which there was a collapse of the trees and weakening of their resistance [16]. On damaged and physiologically weakened trees, populations of *Ips typographus* and *Pityogenes chalcographus* have increased manifold [16]. In the following years, these two species also colonized completely healthy trees, which led to extensive spruce dieback in the Golija region. The extension of the vegetation period caused an increase in the number of generations of bark beetles which added to the intensity of damage in the Park of Nature "Golija" (PNG) [16]. The total volume of spruce trees logged because of the dieback (2012-2016) in PNG amounted to 67,434 m^3 [16]. Increases in average annual temperatures and longer periods of drought lead to more frequent outbreaks of defoliators that cause great damage to temperate broad-leaf forests. In 2013, Gypsy moth (*Lymantria dispar dispar*) caterpillars defoliated 60,000 hectares of oak and beech forests in Serbia [17].

Forest fragmentation

Fragmentation of forests is initiated when forest roads, electric power and water-supply installations, ski trails and ski lift corridors, penetrate into old growth or mature forest, dividing large surfaces into small elements, changing their habitat conditions [18]. Fragmentation is followed by habitat loss that seriously endangers forest wildlife. The changes of forest microclimate are noticeable at a distance of up to 60 m from fragment edges [19].

Altered radiation, wind, water, and nutrient regimes create new habitat conditions, inducing tree mortality in fragments and strongly influence forest dynamics and structure. An illustrative example of forest fragmentation is the destruction of 26 ha of native mature forest in the ski resort "Stara Planina" [20], when two fragments were created (Figure 2), endangering two local endemic plant species - *Campanula calycialata* (found only in the proximity of), and *Senecio pancici* (steno endemic of the Central Balkans). After the development of the ski resort, the buzzard (*Buteo rufinus*) disappeared from the area (IUCN Red list of threatened species, 2006), and populations of skylark (*Alauda arvensis*, IUCN Red list of threatened species, 2008) and Eurasian Woodcock (*Scolopax rusticola*, IUCN Red list of threatened species, 2008) have been significantly reduced [21, 22].

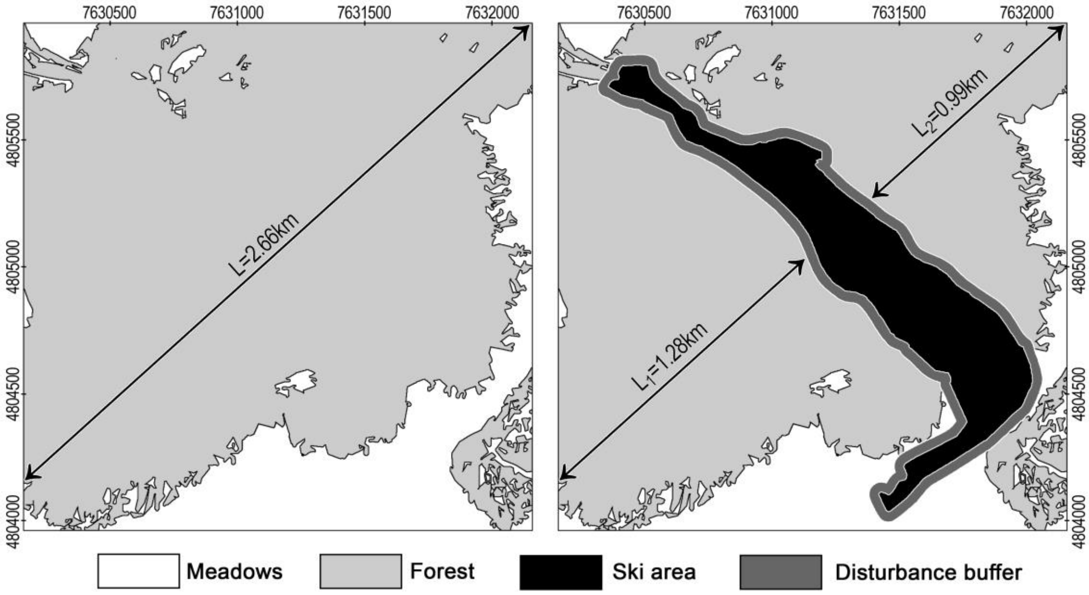


Figure 2. Forest fragmentation at the "Stara Planina" ski resort [18]

Illegal logging

According to the EU definition, "illegal logging and related trade occur when timber is harvested, transported, processed, bought or sold in violation of national or sub-national laws" [3]. Illegal logging in Serbia is strongly linked to numerous factors including unfavourable social and economic conditions; low awareness for the importance of forest protection; institutional inefficiencies, weak law enforcement; inefficient judicial and sanctioning systems [23]. Two types of illegal logging can be clearly distinguished in the Western Balkans: poverty-driven illegal logging and commercial illegal logging. Illegal logging carried out to fulfil the needs of poor local populations is negligible compared to the overall enterprise of illegal logging [23].

The estimated volumes of illegally cut wood in Serbian public forests are between 10.000 and 32.000 m^3 per year, while the total amount of illegally cut wood in private forests is estimated at about 500.000 m^3 [24]. Illegal logging is also very pronounced in southern Serbian municipalities (Vranje, Kuršumlija, Leskovac, Raška and Leposavić), near Kosovo and Metohija [25]. The total quantity of registered illegal logging in this part of Serbia is more than 200.000 m^3 for the period 2002 to 2008 [3].

Small hydro-power plants

In accordance with the National Renewable Energy Action Plan of the Republic of Serbia (http://www.mre.gov.rs/doc/efikasnost-izvori) around 90 Small Hydro-power Plants (SHPP) have been built in Serbia, of Derivation Type (SHPP-DT), with pipelines in length of 2–5 km. Additionally, 856 SHPP-DTs are planned for construction [26] in mountainous regions of Serbia, mainly in protected natural areas (National Parks, Nature Parks, Special Nature Reserves). Serbia is the least auspicious country in the Balkans when it comes to indigenous surface waters (annual specific runoff $q = 5{,}7\ l{\cdot}s^{-1}\ km^{-2}$) [27], which is why mass construction of SHPPs began on rivers considered to be hydrologically, but also ecologically most valuable. The implementation of this has led to the endangerment or even disappearance of endemic and protected fish species, fragmentation of the most valuable aquatic habitats, fragmentation of forests (due to the construction of access roads and derivative pipelines), endangered water supply of local communities and intensive erosion along access roads [28].

The problems identified as a result of construction of the existing SHPPs require urgent review of procedures for issuing licenses for both planned and already constructed facilities, with the imperative of prohibiting further construction in protected areas. All the planned SHPPs would provide only 2–3.5 % of the annual energy needs of Serbia, but that would mean total devastation of most of the quality watercourses in the mountain regions of Serbia [29].

For example, due to the small energy contribution and detrimental environmental consequences, the authorities in the US have removed more than 1,000 (SHPP-DT), in the period 1993–2017 [30]. Similar processes are taking place in France, Spain, Germany, and Sweden. Other ways of producing energy from renewable sources have far less negative effects on the environment, and if the current losses of the Public Enterprise "Electric Power Industry of Serbia" during the transmission of electricity, were reduced by only 2 % that would eliminate the need for derivative SHPP [29].

According to the Study of European organizations dealing with the protection of watercourses [31], eight SHPPs built in Albania, Croatia, and Macedonia in the period 2013–2015, were financed by the European Bank for Reconstruction and Development (EBRD) and the European Investment Bank (EIB). Drastic examples of violations of national legislation and environmental standards have been noticed, so the EBRD and the EIB reviewed its business policy for the year 2018, in terms of financing the construction of MHE [32]. Nevertheless, the construction of as many as 2.800 objects [33] has been planned in the Balkans, although this region is already one of the most endangered by current climate anomalies, which, among other things, leads to significantly reduced flow rates in low flow periods.

TORRENTIAL FLOODS, EROSION PROCESSES, AND FOREST ECOSYSTEMS

Torrential floods are the most frequent natural catastrophic events in the SEE region, causing loss of human lives and huge material damage, in both urban and rural areas [34]. In Serbia alone, torrential floods have caused death of more than 130 people in the last 64 years and material damage estimated at more than 10 billion € [34]. Representative examples are torrential floods that occurred in Serbia in May and September 2014 (more than 50 people died, direct material damage of over 2 billion dollars), in Bosnia and Herzegovina in May 2014 (27 people died) and in Macedonia in August 2016 (21 people died). The frequency of these events, their intensity and diffusion throughout the country make them a permanent threat with severe consequences to environmental, economic and social spheres [35]. The climate, along with the specific characteristics of the relief, distinctions of the soil and vegetation cover, severe erosion processes result in the frequent occurrence of torrential floods. Torrential (flash) flood represents a sudden appearance of maximal discharge in a torrent bed with a high concentration of sediment. In extreme cases, the two-phase fluid flows out from the torrent bed with enormous destructive energy. The two-phase fluid (water and sediment) can contain fractions (60 % of total volume) with different granulations ranging from clay particles to rock fragments, with diameters of up to 5.0 m and a total mass of over 200 tons [36].

The soil and vegetation cover directly affect the intensity of the surface runoff by creating "losses" of precipitation through the processes of interception, evaporation, transpiration, and infiltration [37, 38]. The eroded soil becomes compacted with an insufficient amount of nutrients and organic matter. The infiltration rates and water-storage capacity of the soil profile are reduced, which, in turn, increases the overland flow and erosion. The amount of surface runoff depends on the total precipitation, the type of land use, and the characteristics of the vegetation cover as well as on the air and water capacity of the soil [39, 40]. Clearcutting and the removal of forest vegetation influence the water balance by affecting evapotranspiration and possibly snow accumulation and melting. These activities increase the peak discharge by as much as 50 % in small basins and 100 % in large basins [41]. Timber harvesting has the potential to increase the total flow and lengthen the duration of larger flows while enabling sediment movement [42]. The risk of erosion processes, fast surface runoff, and torrential floods can be significantly decreased by land-use changes (afforestation of bare land, reclamation of degraded forests, meadows and pastures, siltfiltering strips, contour farming, and terracing) in order to reduce erosive material production and meliorate water infiltration and water storage capacity of the soil.

CONCLUDING REMARKS

Climate change and natural hazards cannot be prevented, but a better understanding of the processes and scientific methodologies for their prediction can help mitigate their impacts. Very often, the human factor contributes significantly to the effects of climate change and a range of disasters, with activities such as deforestation, mismanagement of forest and agricultural surfaces, man-induced forest fires, uncontrolled urbanization and the lack of erosion control and flood protection structures.

The observed data processing and model-based climate projections show that until the end of XXI century, climate warming in Serbia and SEE will cause an increase in the mean temperature of 2.5–5.0 °C, with a reduction of summer precipitation, an increased frequency of heavy precipitation, and significantly less snow precipitation, while the total annual values do not show significant changes [11].

The impacts of climate change associated with negative anthropogenic influence lead to the degradation of forests and huge soil surfaces which endanger biodiversity, economic activities, and health conditions in SEE countries. The derived results should raise public awareness and point to imperative action to apply mitigation and adaptation measures in the fields of water resources management, forestry, agriculture, nature protection, and biodiversity preservation. Wood processing industry practices and products must be raised in order to achieve higher ratio of final products when compared to raw wood, maximizing financial benefits and decreasing the volume of exports of semi-final products, which would provide a more rational utilization of the growing stock.

Forest management from the aspects of mitigation of climate change effects and natural hazards prevention should be complementary with other demands such as environmental protection, sustainable soil usage, drinking water supply, local economic development and sustained biodiversity. The restoration of eroded and deforested watersheds is one of the key activities in the process of mitigation and adaptation to the effects of climate change, as well as the reduction of disaster risk. It involves biotechnical works on slopes and technical works in the channel network, coordinated within a precisely defined administrative and spatial framework. Cooperation and overcoming of conflicts between the sectors of water resources management, forestry, agriculture, energetic, environmental protection and local economic development are indispensable at the following levels: policy, spatial planning, practice, investments and education. It is very important to connect these measures with the process of mitigation and adaptation to climate change in accordance with the platforms of UNFCC (United Nation Framework Convention on Climate Change) and UNCCD (United Nation Convention on Combat Desertification), inform and educate all stakeholders about the planned activities and provide subsidies for their implementation and media support.

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УЛОГАТА НА ШУМСКИТЕ ЕКОСИСТЕМИ ВО ПРОЦЕСОТ НА УБЛАЖУВАЊЕ И АДАПТАЦИЈА КОН ЕФЕКТИТЕ НА КЛИМАТСКИТЕ ПРОМЕНИ

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Шумските екосистеми обезбедуваат широк ранг на екосистемски услуги и имаат важна улога во одржувањето на животот на планетата Земја. Климатските промени во Североисточна Европа и прогнозите за периодот до 2070 година имаат големо влијание врз сегашните и идните планирања во управувањето со шумите и со водите поради забележаните трендови: зголемување на средногодишната температура на воздухот за 2,5–5,0 ºC до крајот на 21 век; редистрибуција на годишните врнежи, со многу повеќе врнежи во периодот пролет-лето, преку краткотрајни и интензивни врнежи; намалување на годишните врнежи и на влажноста на почвите за 10–20 %, со екстремни последици, како што се сушење и исчезнување на шумите во ридско-планинските региони. Деградацијата и губењето на шумите води кон зголемување и интензивирање на ерозијата на почвите, со зачестени буични поплави, калишта, лизгања на земјиштето и лавини. Стабилните шумски екосистеми се столбови на одржливиот развој и на репопулацијата, и може да обезбедат средства и ресурси за справување и за надминување на сиромаштијата во планинските подрачја на Југоисточна Европа.

Клучни зборови: шумски екосистеми; климатски промени; заштита од поплави; контрола на ерозија, планирање

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Original scientific paper

MOENCHIA ERECTA (L.) G. Gaertn., B. Mey & Scherb. AND CATAPODIUM MARINUM (L.) C.E. Hubb. TWO NEW SPECIES IN THE FLORA OF THE REPUBLIC OF MACEDONIA

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The paper deals with the two new species for the flora of the Republic of Macedonia - *Moenchia erecta* (L.) G. Gaertn., B. Mey & Scherb. and *Catapodium marinum* (L.) C.E. Hubb. and their distribution on the territory of the Republic of Macedonia.

Key words: *Moenchia erecta*; *Catapodium marinum*; flora; distribution; Republic of Macedonia

INTRODUCTION

The floristic and vegetation researches performed intensively in the Republic of Macedonia in the last period have led to new knowledge about the presence of new, hitherto unknown species for the territory. During our research of early spring thermophilic vegetation of the alliance *Romulion* (*Helianthemetalia*, *Helianthemetea*), which develops in the southern and southeastern parts of the discussed territory (Dojran, Strumica, Radoviš) and scrub vegetation in the zone of pseudomaquis (*Paliuretalia*, *Crataego-Prunetea*) (Gevgelija, Valandovo, Bogdanci, Dojran, Strumica, Demir Kapija) [1] we found two new species in the flora of the Republic of Macedonia - *Moenchia erecta* (*Caryophyllaceae*) and *Catapodium marinum* (*Poaceae*).

MATERIAL AND METHODS

The floristic investigation has been carried out according to the standard methods. For the purposes of determining the plant species, the most important floristic works concerning the flora of Europe [2, 3], Balkan Peninsula [4–7], Republic of Macedonia [8] and other regional floras, as well as some special papers and databases [9] dealing with taxonomy, nomenclature and chorology of the taxa studied were used. The herbarium material is deposed in the Herbarium of the Institute of Biology, Faculty of Natural Sciences and Mathematics in Skopje (MKNH).

RESULTS AND DISCUSSION

Moenchia erecta (L.) G. Gaertn., B. Mey & Scherb.

Moenchia erecta is a small annual plant with ascending basal branches. Flowers are tetramerous with 4 stamens and cylindrical capsule, usually slightly exceeding the sepal. It is widespread in most of Europe (mainly in the Mediterranean region, Atlantic Europe – West, Central and South

[#]Dedicated to academician Gjorgji Filipovski on the occasion of his 100th birthday

Europe, North, North-West Africa and the Middle East [3, 9], and secondarily in North America [10] (Figure 1).

It is a rare plant species in the Balkan Peninsula, only known from few localities in the territory of Greece [7], Bulgaria [6], Croatia [11] and Slovenia [12].

In Republic of Macedonia it was first discovered in the southeastern parts (Strumica-Novo Selo), near the border with Bulgaria (Figure 2). It develops in habitats with typical early spring thermophilic vegetation that belongs to the sub-Mediterranean ass. *Lago-Poetum bulbosae*, alliance *Romulion* (*Helianthemetalia*, *Helianthemetea*). In the elaborated territory, such vegetation is dominated by: *Aira elegantissima* Schur, *Alyssum desertorum* Stapf, *Achillea coarctata* Poir., *Galium divaricatum* Pourr. ex Lam., *Hypochoeris cretensis* (L.) Bory et Chaub., *Hypochoeris glabra* L., *Linaria pelisseriana* (L.) Mill., *Lotus angustissimus* L., *Myosotis ramosissima* Rochel, *Ornithopus compressus* L., *Plantago bellardii* All., *Poa bulbosa* L., *Psilurus incurvus* (Gouan) Schinz et Thell., *Romulea bulbocodium* (L.) Sebast. et Mauri, *Scleranthus verticillatus* Tausch, *Trifolium campestre* Schreb., *Trifolium scabrum* L., *Tuberaria guttata* (L.) Fourr., *Vulpia ciliata* Dumort and others.

In the northern and northeastern parts of Greece (Thassos, Kavala, Myrtofito, Askos, Nea Peramos), *M. erecta* appears in the population of the Mediterranean community - ass. *Romuleo graecae-Poetum bulbosae* [13]. It can be found on grazed places also elsewhere in the Mediterranean basin [14, 15] and it belongs to an element of Mediterranean heavily grazed dry grasslands [16].

Distribution in Republic of Macedonia:

Mk: Strumica-Novo Selo, on silicate bedrock 41.43231; 22.90296, 361 m., 16.5.2007 (leg. et det V. Matevski et A. Čarni) (MKNH)

Mk: Strumica-Novo Selo, on silicate bedrock 41.42425, 22.89463, 514 m., 16.5.2007 (leg. et det V. Matevski et A. Čarni) (MKNH)

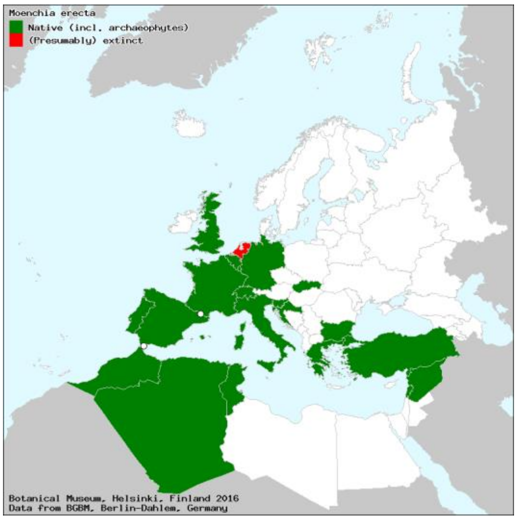

Figure 1. Map of distribution of *Moenchia erecta* (according the Euro+Med Plant Base)

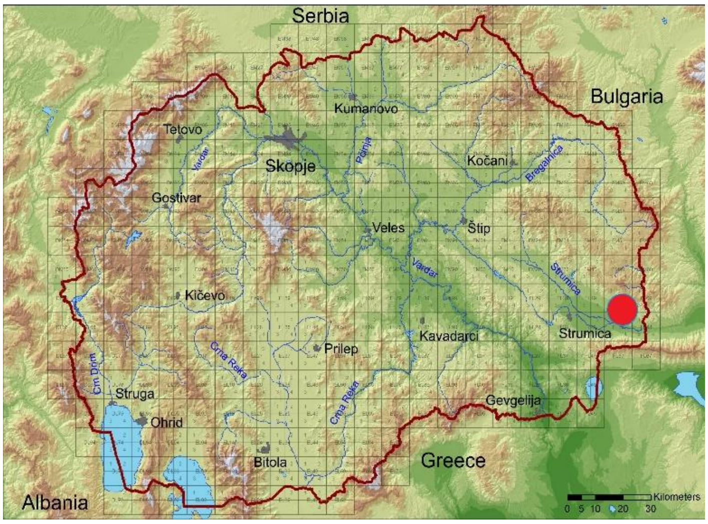

Figure 2. Distribution of *Moenchia erecta* in the Republic of Macedonia

Catapodium marinum (L.) C.E. Hubb.

Syn.: *Desmazeria marina* (L.) Druce, *Catapodium loliaceum* (Hudson) Link., *Desmazeria loliacea* (Hudson) Nyman; *Catapodium pauciflorum* (Merino) Brullo, *Sclerochloa loliacea* (Hudson) Woods.

The distribution range of *Catapodium marinum* covers dry open habitats near the sea in the South and West coasts of Europe, northwards to 59° N in Scotland (Orkney), North Africa and Middle East [2, 9] (Figure 3). This species can be found along the Adriatic sea [17–19] and also elsewhere along the coast of Balkan Peninsula [20]. Most often this species appears on coastal habitats, close to the sea: sand dunes, and also in trampled habitats [21].

According to the available literature data this species has not been known for the Republic of Macedonia. It was discovered in surrounding of the city of Strumica (Figure 4), in the zone of shrubby vegetation (pseudomaquis) dominated by the following woody and shrubby species - *Quercus coc-*

cifera L., *Carpinus orientalis* Mill., *Crataegus monogyna* Jacq., *Ligustrum vulgare* L., *Lonicera etrusca* Santi, *Pyrus amygdaliformis* Vill., *Quercus pubescens* Willd., *Rosa sempervirens* L. and others. In the herb (ground) layer of the pseudomaquis along with *Catapodium marinum* dominate *Alyssum minutum* Schltdl. ex DC, *Arabidopsis thaliana* (L.) Heynh., *Aristolochia pallida* Willd., *Asterolinon linum stellatum* (L.) Duby, *Cardamine hirsuta* L., *Carex distachya* Desf., *Cephalaria ambrosioides* (Sibth. et Sm.) Roem. et Schult., *Crepis pulchra* L., *Cystopteris fragilis* (L.) Bernh., *Dianthus pinifolius* Sm., *Draba muralis* L., *Filago gallica* L., *Lathyrus sphaericus* Retz., *Lupinus angustifolius* L., *Luzula forsteri* (Sm.) DC., *Medicago minima* (L.) L., *Scandix australis* L., *Sedum cepaea* L., *Silene italica* (L.) Pers., *Stipa bromoides* (L.) Doerfl., *Thymus sibthorpii* Benth., *Torilis arvensis* (Huds.) Link, *Trifolium angustifolium* L., *Trifolium arvense* L., *Trifolium dalmaticum* Vis., *Valerianella turgida* (Steven) Betcke, *Veronica arvensis* L., *Vicia hirsuta* (L.) Gray, *Vicia lathyroides* L., *Vicia villosa* Roth, *Viola kitaibeliana* Schult., *Vulpia myuros* (L.) C.C.Gmel. and others.

Ecological conditions in the reported locality were somehow different from that, reported by other authors. This area has been overpopulated already from the ancient times, there have been migrations of people (e.g. recent of "Syrian refugees") and the transhumance has been practiced for a long time [22]. So the species can move easily from the neighbouring coast in the pseudomaquis in the southern part of the Republic of Macedonia. But it is a question whether its occurrence here is stable or may be ephemeral.

Distribution in the Republic of Macedonia:

Mk: Strumica-Carevi Kuli, on silicate bedrock, 41.434333, 22.622861; SW, 518 m, 15.05.2011 (leg. et det V. Matevski et A. Čarni) (MKNH)

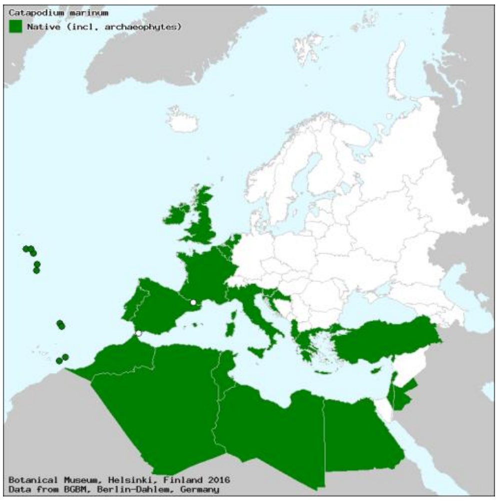

Figure 3. Map of distribution of *Catapodium marinum* (according the Euro+Med Plant Base)

Figure 4. Distribution of *Catapodium marinum* in the Republic of Macedonia

CONCLUSION

The work deals with the newly established populations of two new species of the flora of the Republic of Macedonia and their distribution on its territory - *Moenchia erecta* (L.) P. Gaertn. (Strumica-Novo Selo) and *Catapodium marinum* (L.) C. E. Hubb (Strumica-Carevi Kuli).

These and many other thermophilous species with Mediterranean distribution pattern (e.g. *Anthemis auriculata* Boiss., *Chaenorhinum rubrifolium* (DC.) Fourr., *Convolvulus elegantissimus* Mill., *Corynephorus divaricatus* (Pourr.) Breistr. *Dittrichia graveolens* (L.) Greuter, *Dittrichia viscosa* (L.) Greuter, *Galium setaceum* Lam., *Helianthemum aegyptiacum* (L.) Mill., *Hymenocarpos circinatus* (L.) Savi, *Silene galica* L., *Tolpis umbellata* Bertol, *Urtica pilulifera* L. and others) [23–31) that have been found in the Republic of Macedonia in the near past show the influence of global warming [32] on flora and vegetation in the region. We can consider plant species as a good indicator of changing climate. In this way we have to monitor the appearance of those species and predict the climatic changes that are foreseen.

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MOENCHIA ERECTA (L.) G. GAERTN., B. MEY & SCHERB. И CATAPODIUM MARINUM (L.) C.E. HUBB. ДВА НОВИ ВИДА ЗА ФЛОРАТА НА РЕПУБЛИКА МАКЕДОНИЈА

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Трудот се однесува на распространувањето на два нови, досега недоволно познати видови за флората на Република Македонија - *Moenchia erecta* (L.) G. Gaertn., B. Mey & Scherb. (Струмица-Ново Село) и *Catapodium marinum* (L.) C.E. Hubb. (Струмица-Цареви Кули).

Клучни зборови: *Moenchia erecta*; *Catapodium marinum*; флора; распространување; Република Македонија

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Original scientific paper

DYNAMIC OF LAND DEGRADATION NEUTRALITY BASELINE INDCATORS IN THE REPUBLIC OF MACEDONIA[#]

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Land degradation neutrality (LDN) is defined as a "state whereby the amount and quality of land resources necessary to support ecosystem functions and services and enhance food security remain stable or increase within specified temporal and spatial scales and ecosystems". The baseline is expressed as the initial (t_0) estimated value of each of the three indicators, used as proxies of land-based natural capital and the ecosystem services that flow from that land base: land cover/land use change, land productivity status and trends, soil organic carbon status and trends. The baseline of LDN was calculated with estimation of the average values across the 10 years baseline period of the following indicators: Land Cover/Land Cover change (LC/LCC), Land Productivity Dynamics (LPD) and Soil Organic Carbon (SOC). Three tier approaches for computation of the selected indicators were used: Tier 1: Global/regional Earth observation, geospatial information and modelling; Tier 2: National statistics (only for LC/LCC) and Tier 3: Field survey. Most significant changes in LC for the period 2000/2012 are in the categories of Forest land and Shrubs/grasslands. According the global data sets used for analysis of LPD, the total affected area with depletion of Land productivity for the period 2000/2010 is identified on a only 2.35 % of the country territory. The available global data sets gives a model SOC levels for the period 2000/2010. According these data, the total loss of SOC in our country is estimated on 3951 ***t***.

Key words: land degradation neutrality; land cover/use changes; land productivity; SOM

INTRODUCTION

Demands on global land resources are increasing as the world's population increases in number and affluence, yet the health and productivity of land is deteriorating [1]. Land degradation is a consistent loss of ecosystem functionality due to human and natural processes [2].

Land degradation is an interactive process involving multiple causal factors, among which climate variability, soil quality and land management play a significant role [3]. Land degradation is a global concern for sustainable development, conservation of biodiversity and mitigating and adapting to climate change. It refers to reduction or loss of the biological or economic productivity and complexity of land, reducing carbon storage in soil and vegetation, driving the loss of biodiversity and accelerating climate change [4].

Land degradation affects livelihoods, biodiversity and ecosystem services through reduction or loss of the biological or economic productivity and complexity of rain fed cropland, irrigated cropland, or range, pasture, forest and woodlands resulting from land uses or from a process or combination of processes arising from human activities [5].

Increased competition for land resources will increase social and political instability, exacerbating food insecurity, poverty, conflict and migration [6].

The concept of Land Degradation Neutrality (LDN) has been adopted as part of the 2030 Agenda for Sustainable Development and is enshrined in Target 15.3: "by 2030, combat desertification, and restore degraded land and soil, including land affected by desertification, drought and floods, and strive to achieve a land-degradation neutral world".

While Sustainable Development Goals SDG15, calls for the protection of terrestrial ecosys-

[#]Dedicated to academician Gjorgji Filipovski on the occasion of his 100th birthday

tems and the fight against land degradation in general terms, target 15.3 explicitly formulates the vision of a "land degradation neutral world" [7].

LDN is defined as a "state whereby the amount and quality of land resources necessary to support ecosystem functions and services and enhance food security remain stable or increase within specified temporal and spatial scales and ecosystems" [8].

The LDN conceptual framework focuses on the supporting processes required to deliver LDN, including biophysical and socio-economic aspects, and their interactions. Neutrality implies no net loss of the land-based natural capital relative to a reference state, or baseline [9].

LDN target setting is a complex process that includes numerous political and technical aspects. The concept of Land Degradation Neutrality (no net loss) is a maintenance or enhancement of the status of land based natural capital degradation in relation to a referent state (base line), hence the "base line" becomes a "target to be achieved" in order to maintain the neutrality of degradation processes. The LDN related to the "base line" maintenance is considered as a minimum target.

The accepted base line indicators are ***a) Land cover changes, b) Land productivity dynamics and c) Carbon stocks (bellow and above ground).*** These indicators are chosen to be used since they provide a good evaluation of the land based eco system services, these soil variables gives a good hint of soil quality and together can be used to monitor the quantity and quality of land-based natural capital.

In addition, the indicators address change in the system in different yet highly relevant ways: a) land cover provides a first indication of a reduction or increase in vegetation, habitat fragmentation and land conversion, b) land productivity captures relatively fast changes while c) SOC reflects slower changes that suggest trajectory and proximity to thresholds. Land degradation trends analysis is an important step in the process LDN, since it should not be an expression of the current status of LD, but a chronological assessment of land degradation processes and drivers, which is crucial for understanding of the current conditions of land degradation, revealing anomalies and identifying degraded areas. Such evidence based assessment provides a sound base for LDN target setting and identifying needs and opportunities of interventions [10].

Primarily, comparable and standardised national official data sources were used for calculation of "base line", identification of hot-spots and trends of land degradation

Main aim of this work was defining the LDN baseline indicators and their dynamic in the last 10 years in the Republic of Macedonia.

EXPERIMENTAL SECTION

The baseline is expressed as the initial (t_0) estimated value of each of the three indicators used as proxies of land-based natural capital and the ecosystem services that flow from that land base.

- Land Cover/Land Cover change,
- Land Productivity status and trends,
- Soil Organic Carbon status and trends

Land cover refers to the observed physical cover of the Earth’s surface, which describes the distribution of vegetation types, water bodies and human-made infrastructure. It also reflects the use of land resources (i.e., soil, water and biodiversity) for agriculture, forestry, human settlements and other purposes [11].

Land cover provides a first indication of changing vegetation cover, to some extent as proxy of the underlying use, and of land conversion and resulting habitat fragmentation. Land Cover can be considered as indicator for the sensitivity of land to degradaton related to socio-ecological dynamics of land management, especially: land abandonment and unsustainable use of rural and peri-urban areas [12].

Land productivity refers to the total above-ground net primary productivity (NPP) defined as the energy fixed by plants minus their respiration which translates into the rate of biomass accumulation that delivers a suite of ecosystem services. Land productivity captures relatively fast changes in land capability for bio production.

Soil organic carbon (SOC): carbon stock is the quantity of carbon in a pool (i.e., a system which has the capacity to accumulate or release carbon). Carbon pools are biomass (above-ground biomass and below-ground biomass), dead organic matter (dead wood and litter), and soil (soil organic matter). It is a summarizing parameter including all of the carbon forms of dissolved (DOC: Dissolved Organic Carbon) and total organic compounds (TOC: Total Organic Carbon) in soils [10].

The baseline LDN indicators were calculated with estimating of each of the following indicators, the average value across the 10 years baseline period.

There are 3 Tier approaches for computation of the selected indicators. The Tier approach, generally provides advice on estimation methods used at three levels of detail, from Tier 1 (the default method) to Tier 3 (the most detailed method). In the context of the LDN TSP, the following approach were used:

- Tier 1: Global/regional Earth observation, geospatial information and modelling;
- Tier 2: National statistics based on data acquired for administrative or natural reference units (e.g. watersheds) and national earth observation;

• Tier 3: Field surveys, assessments and ground measurements.

Such approach, allows to use methods consistent with national capacities, resources and data availability and facilitates comparability at global level.

For our work in the absence of national data generated from field surveys and ground measurements, the global graphical data sets were provided for the 3 indicators used in the process of the "base line" assessment as presented in the Table 1. Global data sets are generated from various referent sources.

Table 1. Default Tier 1 data provided by LDN TSP – Global Data Set

Indicator (metric)	Default Tier 1 data source
Land cover	ESA Climate Change Initiative Land Cover dataset : spatial resolution 300m; 3 epochs 2000, 2005 and 2010 (2015 available shortly)
Land productivity (net primary productivity)	JRC Land Productivity Dynamics dataset:15-year time series (1999 to 2013) of SPOT Vegetation NDVI; spatial resolution 1 km.
Carbon stocks above and below ground (SOC)	ISRIC SoilGrids250m (2016, in prep.)

Table 2. Description of LC categories

Value	Categories	Short description	ESA CCI-LC classes (codes)
1	Forests	Geographical areas dominated by natural tree plants with a cover of 15 % or more. This class also includes: - mosaic tree and shrub (> 50 %) / herbaceous cover - seasonally or permanently tree flooded with fresh water	Tree broadleaved evergreen, Tree broadleaved deciduous, Tree needle leaved evergreen, Tree needle leaved deciduous, Tree mixed leaf type, Mosaic tree, shrub / herbaceous cover, Tree flooded, fresh water (50, 60, 61, 62, 70, 71, 72, 80, 81, 82, 90, 100, 160)
2	Shrubs, grasslands and sparsely vegetated areas	Geographical areas dominated by: - natural shrubs; or - natural herbaceous plants; or - sparse natural vegetation with a cover of 15 % or less; This class also include: - mosaic natural vegetation (> 50 %) / crops - mosaic herbaceous cover (> 50 %) / tree and shrub	Mosaic natural vegetation / cropland, Mosaic herbaceous cover / tree, shrub, Scrublands, Grassland, Lichens and mosses, Sparse vegetation (40,110, 120, 121, 122, 130, 140, 150, 152, 153)
3	Cropland	Geographical areas dominated by: - herbaceous crops; or - woody crops; or - mixed herbaceous and woody crops; This class also include: - mosaic crops (50 %) / natural vegetation	Cropland rainfed, Herbaceous cover Tree or shrub cover Cropland, irrigated or post-flooding, Mosaic cropland / natural vegetation (10, 11, 12, 20, 30)
4	Wetlands and water bodies	Geographical areas dominated by: - shrub or herbaceous vegetation, aquatic or regularly flooded; or - mangroves or - water bodies (natural / artificial, standing / flowing, inland / sea)	Tree cover, flooded, saline water, Shrub or herbaceous cover, flooded, fresh/saline/brackish water Water bodies (170, 180, 210)
5	Artificial areas	Geographical areas dominated by artificial surfaces, including urban and associated areas (e.g. urban parks), transport infrastructures, industrial areas, burnt areas, waste deposits, extraction sites.	Urban areas (190)
6	Bare land and other areas	Geographical areas dominated by: - bare areas or - snow and glaciers	Bare areas, Permanent snow and ice (200, 201, 202, 220)

Global data sets used for all three indicators were in format different from the national standards; hence, the initial step in this research was to convert the digital data sets which enables its overlapping with other national data sets for the future in depth analysis.

As for the LC/LCC indicator, LC classes within ESA-CCI significantly differs from these used in CORINE LC dataset. In order to make both data sets comparable, the following approach of harmonization and reclassification was uses (Table 2).

The dynamics of LC/LCC has been analyzed over 10 years period with comparison of ESA-CCI data sets for year 2000 and year 2010, while for CORINE LC datasets were used for the period 2000–2012.

Land productivity refers to the biological productive capacity of the land, as source of all the food, fiber, and fuel that sustains humans [5].

The JRC's Land Productivity Dynamics (LPD) dataset is used as default source for land productivity data. The LPD dataset used, was derived from a 15-year time series (1999 to 2013) of SPOT Vegetation global NDVI observations composited in 10-day intervals at a spatial resolution of 1 km.

Global data set used during setting of the "base line" and estimation of SOM dynamic has been derived by the International Soil Reference and Information Centre (ISRIC).

All digital analyses were launched in a GIS environment using an appropriate software: ArcGIS 10.1 and QGis 3.1.

Finally, all results about land degradation hotspots, were checked and validated through on-field work, by recognition of the terrain and collecting relevant historical information from local people for the previously defined hotspots.

RESULTS AND DISCUSSION

Land Cover/Land Cover Changes

Global data recommended for validation of LC/LCC dynamics are originated from the European Space Agency-Climate Change Initiative for the periods 2000/2010 (Figure 1). In addition, it was recommended, if possible, to use national referent digital data sets. For this purpose, in our work the recommended global data set of LC (ESA-CCI) was compared with the existing data set of CORINE LC data base for the country.

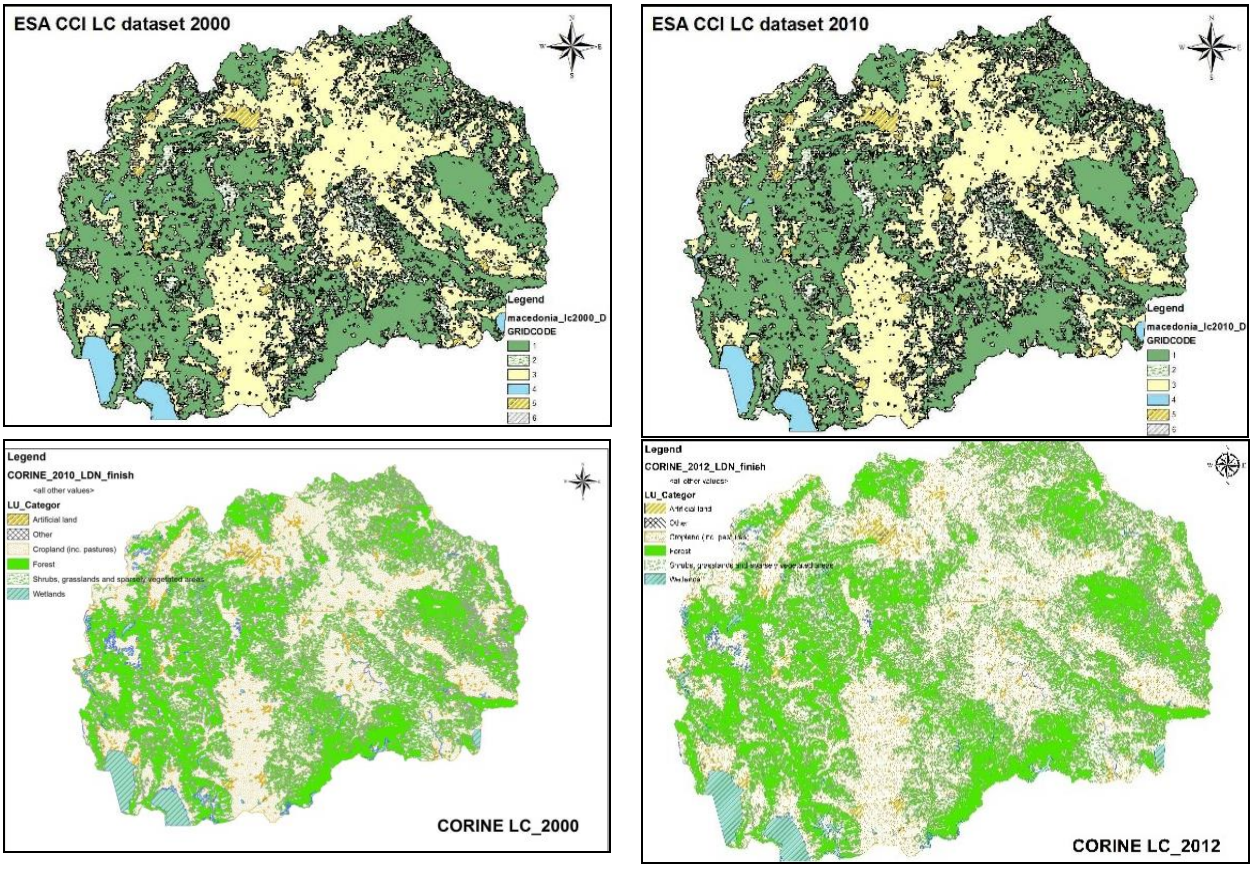


Figure 1. Land Cover by ESA CCI, 2000 and 2010

This data base was previously used in the country for many other analysis of LC and is concerned as the only existing referent data base of LC on a country level. The periods used for this comparison were 2000–2012. The classes of the LC in CORINE LCU on level 3, were grouped into 6 categories in a line with the IPCC Guidelines. Similar reclassification has been already made for the ESA-CCI data set as well.

For better comparison of the LC/LCC, vector files containing info for the spatial distribution of LC under each of the 6 categories, for each period for the both digital datasets were developed, as presented in (Figure 2). This procedure, enables calculation and comparison of the surface area under each of LC categories for both periods.

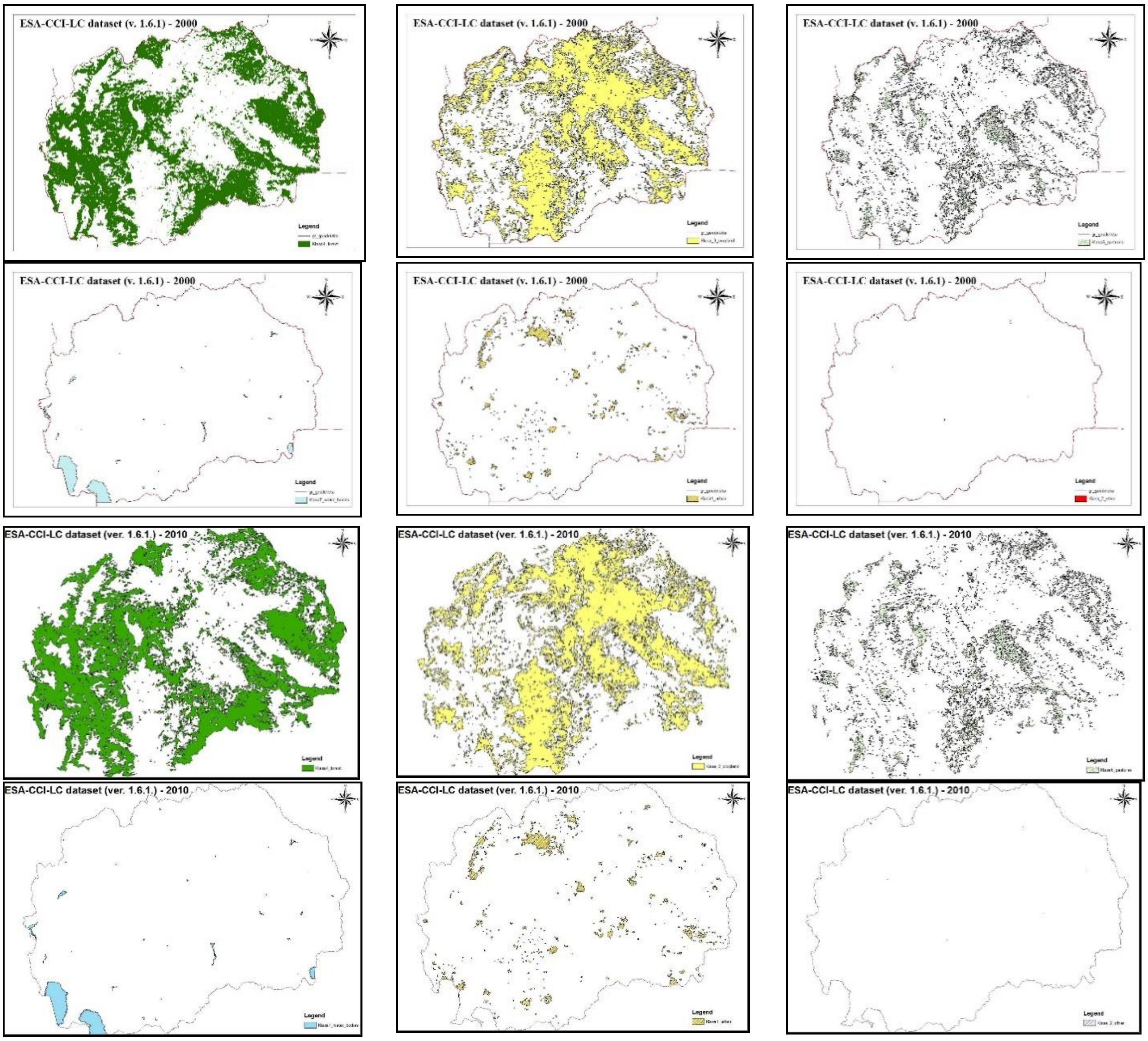
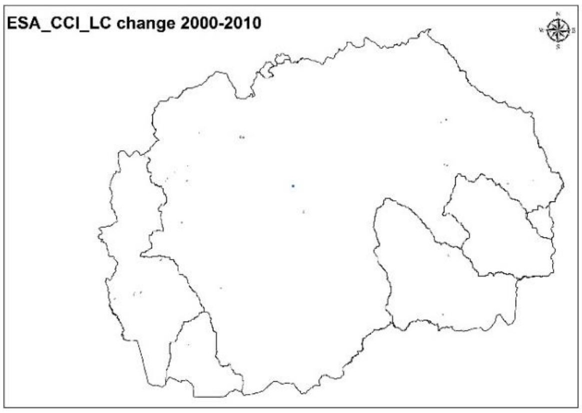


Figure 2. Separate ESA – LC categories of land use for the year 2010 and 2010

In the Figure 3 a land use change for both data sets are presented graphically, while the cumulative areas of land use change for each category are presented in Table 3.

Out of the presented data, a differences between the two datasets: ESA_CCI and CORINE LC in terms of LC change for the period 2000/2010 are significant. Most significant differences are notable among the first two categories forest and shrubs, grassland and sparsely vegetated areas. The ESA-CCI data base recognizes a total loss of 6, 5 sq. km, out of which 3, 9 sq. km are converted to shrubs, grassland and sparsely vegetated areas and 2, 9 to cropland. According this data base, there is no other land cover changes with the other 3 categories: wetland and water bodies, artificial areas and bare land and other areas.



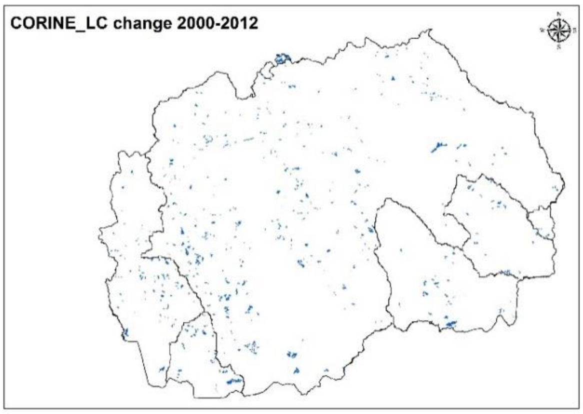


Figure 3. Land Cover change - differences ESIA-CCI and CORINE LC

Out of the data presented in Table 3 and 4, it can be noticed that according CORINE LC data base, the most significant changes in LC for the period 2000/2012 are in the categories of Forest and SG&Sva. Most probably the majority of reduced areas under forests are result of conversion to SH&Sva, in the process of interpretation of the satellite images for the period.

Table 3. Area under different categories of LC of CORINE Land Cover Data base

CLC categories	ESA-CCI, in km^2			CORINE Land cover in km^2		
	2000	2010	Net area change	2000	2010	Net area change
Forest (F)	11.159.00	11.152.00	-6.50	8.608.50	8.242.66	-365.83
Shrubs, grassland and sparsely vegetated areas (SG&Sva)	2.631.00	2.635.00	3.90	4.388.61	4.722.81	334.20
Cropland ©	10.345.00	10.347.00	2.6	11.256,61	11.228.94	-27.67
Wetland and water bodies (W&Wb)	497.00	497.00	0.00	723,11	698.30	-24.82
Artificial areas (Aa)	713.00	713.00	0.00	387,18	428.44	41.25
Bare land and other areas (Bl&Oa)	4.00	4.00	0.00	74,26	113.54	39.28
Total	25.349.00	25.349.00		25.438.27	25.434.69	

The reasons of this changes are result of forest fires in 2007 when almost 40 000 ha were burned. After fire, the land is bare and in the next period the self-restoration usually starts, firstly as a ground flora: grass and bushes and later in most cases forest species. For decoding and calculation of LC changes in 2010 aerial images from the period 2008/9 were used when significant land areas were affected with forest fires due to what in most cases forest areas were classified in the category of SG&Sva. There is also a notable increasing of the categories of bare-land (39, 28 km^2) and artificial land (41, 25 km^2) which is most probably result of urban expansion and conversion of fertile cropland and pastures. Of particular interest is the decreasing of the area classified as wetlands& water bodies. There are several reasons for this: errors which might appeared during the photointerpretation of satellite images, drought that cause decrease of water level and surface area of the Prespa Lake and variations of water level and surface area of the reservoirs due to the intensive usage of water for irrigation.

Changes in land cover may be characterized as positive or negative when contextualized with national or local information. Some critical transitions are generally considered as negative, for instance those:

- from natural or semi-natural land cover classes to cropland or settlements;
- from forest land to other land cover classes (i.e. deforestation), as well as those
- from natural or semi-natural land cover classes and cropland to settlements (i.e. urbanization).

Table 4. LC changes and its effects on land productivity (ha)

Land cover type	Area of LC changes	Converted to						LUC Hot Spots
		Forest	Shrubs	Cropland*	Wetland	Urban	Other	
Forest land	13.404.31	68.17	12.898.81^{a}		3.12^{a}	11.77^{a}	422.44^{a}	13.336.14
Shrubs	7.910.81	7.192.24^{b}	–	281.27^{a}	164.87^{a}	–	272.44^{a}	718.58
Cropland*	4.328.37	266.09^{b}	373.49^{b}	2780.13	21.35	27.24^{a}	860.07^{a}	–
cropland	*3.307.63*	*191.73*^{b}	*208.24*^{b}	*2368.7*^{b}	–	*11.49*	*527.46*	*538.96*
pastures	*1.020.73*	*74.36*^{b}	*165.24*^{a}	*411.42*^{a}	*21.35*^{a}	*15.75*^{a}	*332.61*^{a}	*946.37*
Wetland	347.95	91.39^{b}	–	–	247.23	9.33^{a}	–	9.33
Urban	5.67	–	–	–	5.67^{b}	–	–	–
Other	638.37	–	112.13^{b}	391.93^{b}	48.46^{b}	57.72^{a}	28.13	57.72
TOTAL CHANGE	26.635.49		13.064.05	692.69	189.34	106.07	1554.94	15.607.1^{a}

a - decline of land productivity (negative changes); b- improvement of land productivity (positive change)
**Sum of cropland and pastures*

Land Productivity Dynamics

Land productivity is an expression of the bioproductivityof all land components and their interaction, especially for regional assessments, not just those components related to human activities and direct use. Therefore, Land productivity is not to be confused with agricultural productivity [13].

Land productivity points to long-term changes in the health and productive capacity of the land and reflects the net effects of changes in ecosystem functioning on plant and biomass growth. Land productivity is also important for assessing changes in the carbon stocks of natural and managed systems, and thus their contribution to climate change mitigation efforts. LPD was performed on the base of the NDVI analysis for estimation of Net Plan Productivity. The Normalized Difference Vegetation Index (NDVI) so far is the most commonly used vegetation index. Simmilar analysis for estimation of total anyal biomass (TWB) and NPP for big areas or global level with usage of MODIS data set can be find in the work of Conijn at al. [14].

The normalized difference vegetation index (NDVI) is a simple numerical indicator that can be used to analyze remote sensing data and assess whether the target area contains live green vegetation [15]. NDVI is one of the simplest and most frequently used indices in plant studies [16].

The LPD dataset provides 5 qualitative classes of land productivity trends over the above mentioned time period. These qualitative classes do not directly correspond to a quantitative measure (e.g. t/ha of NPP or GPP) of lost or gained biomass productivity. The 5 classes are rather a qualitative combined measure of the intensity and persistence of negative or positive trends and changes of the photo-synthetically active vegetation cover over the observed period.

The JRC dataset's 1 km resolution is unlikely to be of appropriate scale to reflect human activities at a sub-national scale [17], especially in small scale landscape mosaics. Still, in a case of missing of national data sets, UNCCD suggests using the above-mentioned dataset and classification to determine the degree of land degradation.

As mentioned before, LPD data set provides 5 classes of land productivity (Table 5), among which the first 3 classes are considered to be an indication of potential land productivity decline, as an indicator of land degradation.

Table 5. Classes of Land Productivity Dynamics (LPD)

Value	Description	
1	Declining productivity	unacceptable
2	Early signs of decline	
3	Stable, but stressed	
4	Stable, not stressed	acceptable
5	Increasing productivity	

The Global data set for LPD was transformed into national projection for its further use with other re-projected data sets in the process of "base line" assessment (Figure 4). The LDN raster data set was converted into shape file. All classes were identified, integrated separated into separate files.

This was necessary, to identify the total area and spatial distribution of the first 3 classes which indicate decline or stress in terms of land productivity.

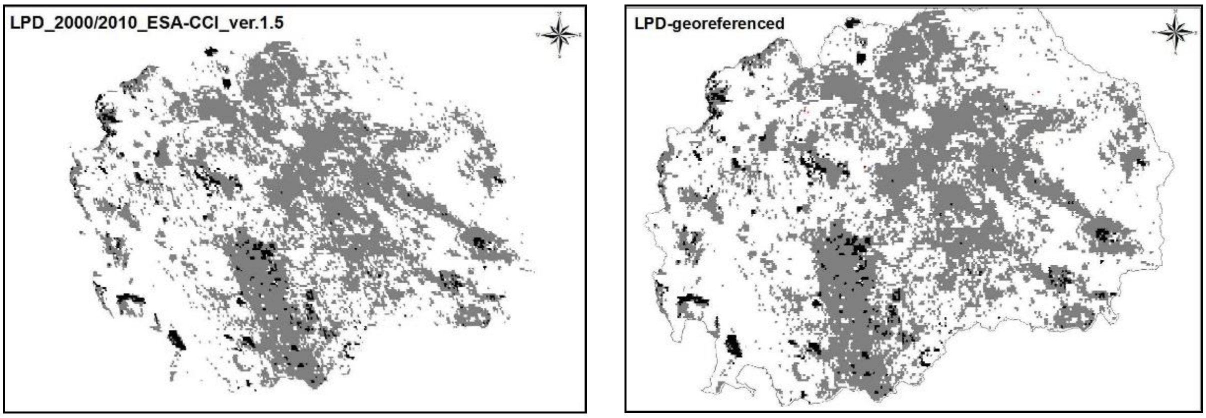


Figure 4. LPD data transformed in Macedonian geodetic system – an example dataset 2000

In Figure 5, are presented all 5 classes that present Land productivity dynamic (map on the left hand side) while on the other map are presented areas with unacceptable LPD classes' (1–3 class).

According to the calculations, the total area of LPD defined as unacceptable or only 2.35 % of the territory of the country and it seems as to be very small area, but in reality it is 58 500 ha with negative land productivity dynamic.

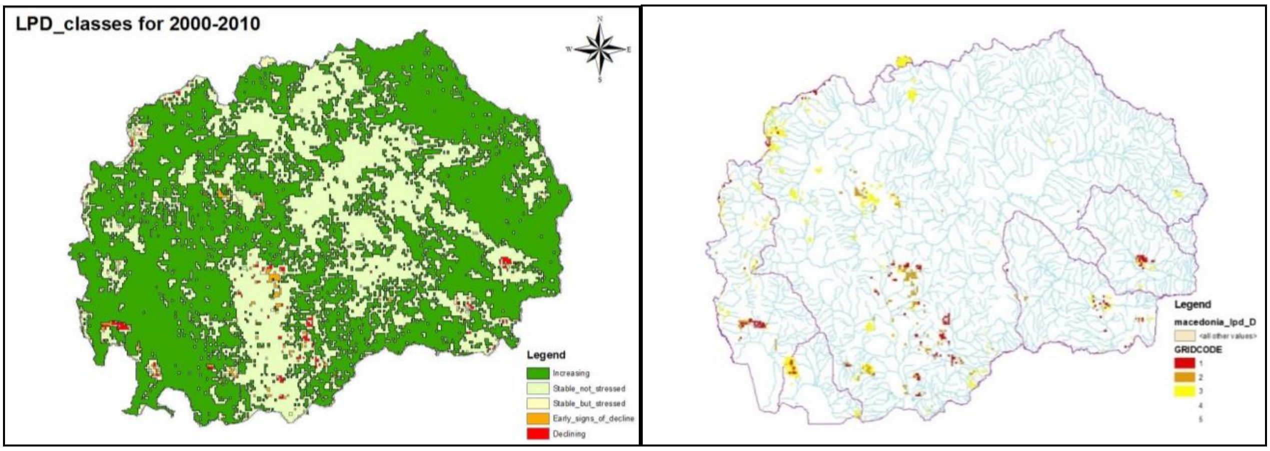


Figure 5. Land Productivity dynamics

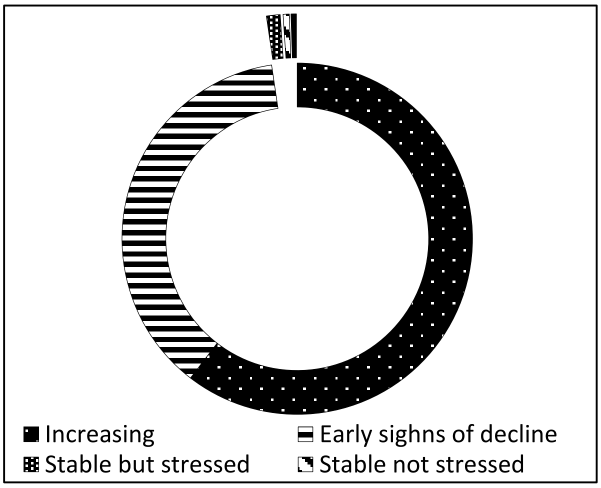


Figure 6. Distribution of the territory of the Republic of Macedonia per LPD classes – [km^2]

Dengiz [18] reports data for land productivity dynamics (LPD) of a degraded catchment located in sub-humid terrestrial ecosystem estimated via a land degradation assessment using three indicators: LC, land productivity, and SOC density. In more than 23 % of the catchments' area of approx. 3896 ha, land productivity is observed to decline while about 24 % shows early signs of decline level (Figure 6).

Soil Organic Carbon dynamic

Soils contain the largest dynamic reservoir of carbon on Earth. This makes soils a critical component of the global carbon cycle [19]. The factors controlling the rates andprocesses for SOC accumulation and lossinclude many factors, like: climate, topographic position, parent material, potential biota, time, and human activity;these are also thefactors that govern soil formation in general, hence the monitorign of SOC dynamuc is a very complex task.Yang Li-xia and Pan Jian-jun [20] noted that modelling of SOC is an one of the possible approaches in estimation of SOC dynamics, suggesting that future soil organic matter models should be developed toward based-process models, and not always empirical ones.

With a reference to the third indicator analysed in the process of the "base line" assessment, it should be noted that, two types of information are required:

1. the baseline SOC stocks (e.g. ton/ha) for the country in the year of interest (here 2000),and

2. corellation of changing of land use/cover conditions to changes in SOC stocks (aboveground and belowground-soil organic carbon SOC).

For the purposes of this study, modeling of the SOC content based on over 150,000 soil profiles collected over several decades by ISRIC, the depth of the soil layer to the parent substrate, the content of the skeleton, the apparent density, and other co-variables which are determined by means of remote sensing, and modeling of all realizations between these co-variables and the soil properties of the multi-index database for the soil has been modeled.In this way (although soil profiles have been monitored over the course of decades), the basic content of the SOC for 2000 has been set in a 250 m grid map.

To obtain an estimate of the change in SOC reserves in time period (2000–2010), suitable for setting LDN targets, a modified IPCC methodology is used that is used to produce National GHG inventories to predict the movements (changes) in SOC at the country level based on land use change / coverage [21].

The following dynamic trends (i.e. variables) were used to make a rough estimate of the change in SOC:

– the change in the soil cover/utilization associated with the ISRC assessment of the SOC content in 2000.

– The general bioclimatic zones (boreal, temperate, temperate continental, etc.) and the assumptions for change in the input of agricultural inputs with the change of soil cover/utilization, were considered as well.

On the base of these assumptions in change of land cover/land use change and inputs in different climatic zones, estimated quantities for each category of land cover was derived.

The general data set for the SOC was re-projected in a line with the national projection. The SOM raster file has been transformed from raster to shape file, and reclasified into 11 classes of SOM contents. Same procedure has been applied for both peridos 2000 and 2010 in order to idnetify the areas with decrease of SOM content in the surface layer (0–30 cm) in t/ha (Figure 7).

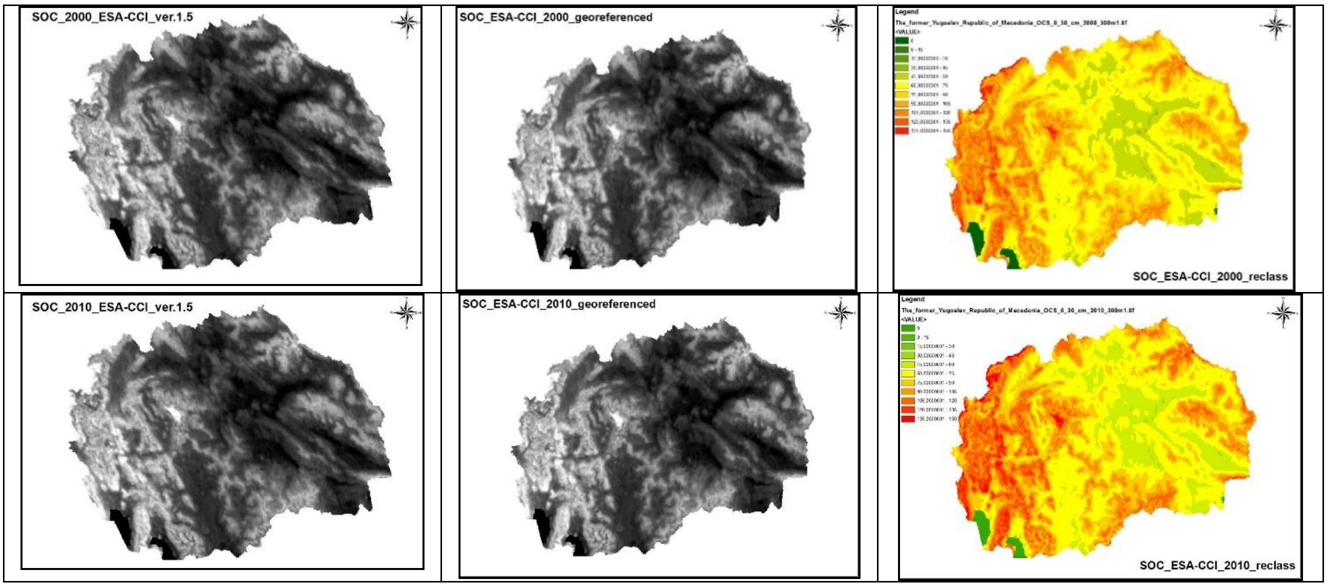


Figure 7. -SOM content classes spatial distribution for 2000 and 2010

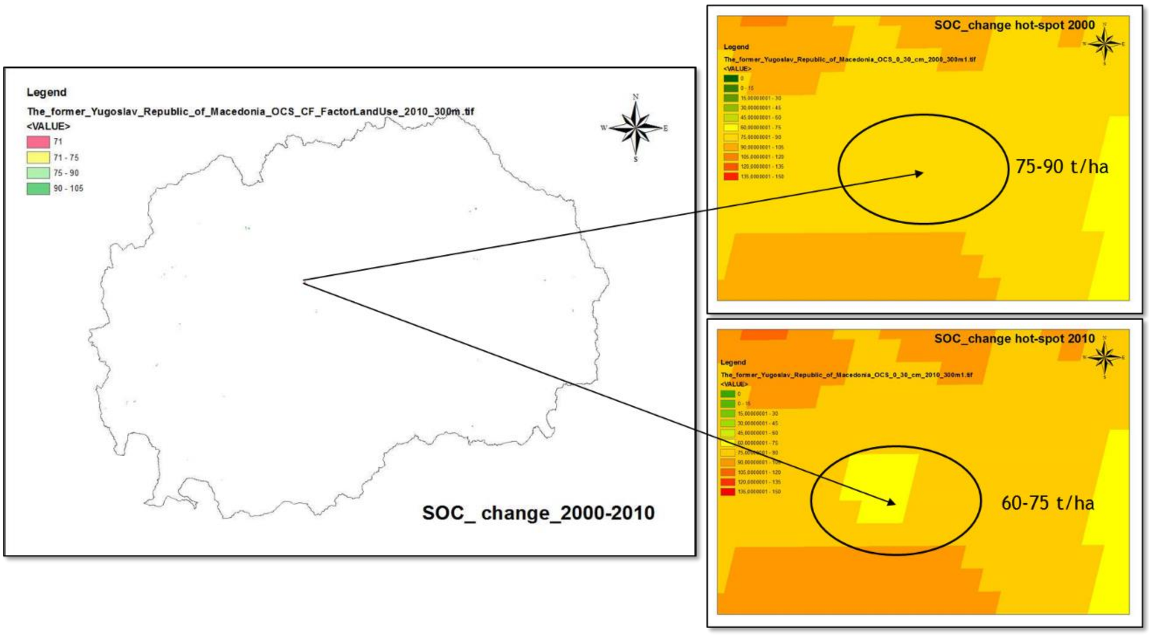


Figure 8. Area with SOM changes

The differences in soil organic matter are presented in Table 6 and Figure 8. SOC change is related and calculated on the base of land use change.

Out of the presented data it can be seen that conversion of forest to cropland (2.6 km^2) for the period 2000/2010 yields a total SOC decreasing of 3951 t.

Table 6. SOC change for the period 2000/2010

Conversion of LC classes	Net area change	Soil organic carbon 0 – 30 cm (2000–2010)				
	km^2	t/ha		total (t)		loss (t)
		2000	2010	2000	2010	2000/10
Forest to Cropland	2.6	86.6	71.4	22590	18639	–3951
Forest to Shrubs, grasslands and sparsely vegetated areas	3.9	89.2	89.2	34524	34524	0
Total	–6.5	–	–	57114	53163	
Total loss of SOC stock (country)						–3951

CUMULATIVE LAND DEGRADATION TRENDS

The three indicators used for setting the baseline (i.e. land cover, land productivity and carbon stocks above and below ground (metric: SOC)), complemented as needed by nationally relevant indicators, can also be used to assess trends. When setting the baseline, it is necessary to estimate for each indicator, the average value across the five-year baseline period. However a retrospective trend analysis requires an observation of the changes in the value of the indicators over a 10–15 year assessment period prior to the current condition (in our case 2000/2010).

As these indicators are complementary rather than additive and components of land condition, they should be analysed separately. However, land cover, being considered as an important indicator in itself, should also be used to stratify the other two indicators.

Degradation is generally considered to occur when:

- land productivity shows a significant negative trend; or
- SOC shows a significant negative trend; or
- negative land cover change occurs; or
- a negative change occurs in another nationally relevant indicator.

However, trends in the indicators need to be interpreted in the context of local conditions. Cumulative land degradation consists of area with negative trends in LPD (I –III class) and area with SOC decrease (Figure 9).

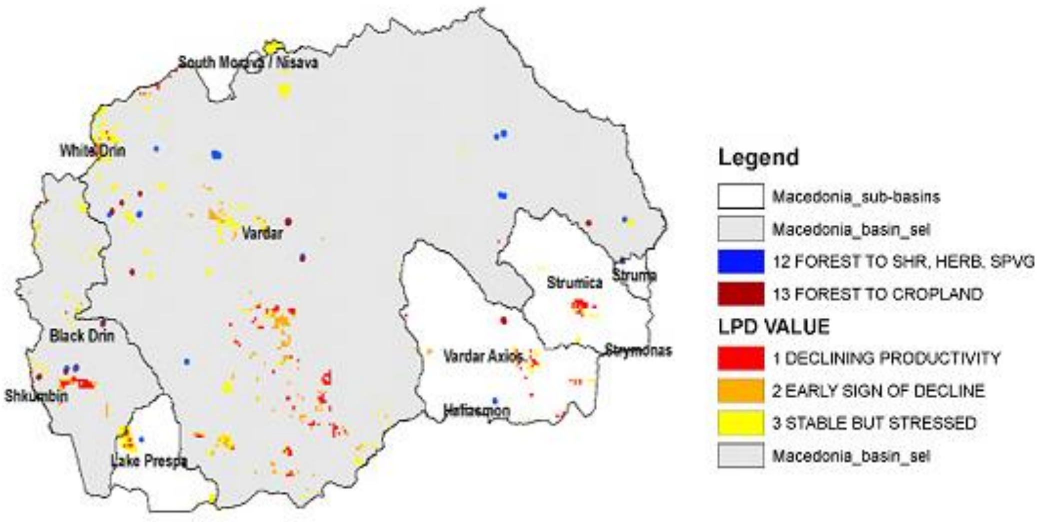


Figure 9. Cumulative Land degradation per watershed and priority watersheds

According to the ESA CCI data, the total degraded area is 588.6 sq. km (LPD – 585 sq. km and SOC loss – 2.6 sq. km). The area of degraded land per watershed according to the delineation by ESA CCI are presented in Table 7 (note: it is different than Macedonian delineation of watersheds). Total degraded area (negative status in dynamic of LPD +SOC) in the country cover 589 km^2 out of which 585 km^2 from LPD and 3.5 km^2 with SOC losses. More detail data about cumulative land degradation per watersheds in the country is presented in the following table.

Table 7. Cumulative land degradation per watersheds

Watersheds	Watershed area	LPD 1-3 area	SOC loss		Degraded area LPD+SOC
	km^2	km^2	t	km^2	km^2
Vardar	20.331.00	422.00	–2.979.00	2.00	424.00
Black Drim	2.782.00	124.00	–855.00	0.00	124.00
Struma/Strumica	1.699.00	25.00	–270.00	1.00	26.00
South Morava	40.00	15.00	0.00	0.00	15.00
Total	24.852.00	586.00	–4.104.00	3.00	589.00

CONCLUSIONS

Differences between two datasets for land cover/use changes: ESA_CCI and CORINE LC for the period 2000/2010 are significant.

Soil Organic Matter is estimated on the base of a global data and its dynamics over the period is limited to the land cover change.

Exhaustive and long term monitoring system of land degradation neutrality indicators dynamic should be established on a national level. Such system will enable implementing of Tier 2 and Tier 3 methodology for monitoring of LDN indicators.

The analyzes showed significant negative trend in dynamic of LDN indicators, due to what the country should adopt and implement "Land Degradation Neutrality Target setting program" for achieving the obligations aroused from the SDG 15.3.

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Global GIS/|RS Data Set received by UNCCD office

[1] ESA Climate Change Initiative Land Cover dataset: spatial resolution 300m; 3 epochs 2000, 2005 and 2010 (2015 available shortly)

[2] JRC Land Productivity Dynamics dataset: 15-year time series (1999 to 2013) of SPOT Vegetation NDVI: spatial resolution 1 km.

[3] ISRIC SoilGrids250m (2016, in prep.)

[4] LDN related tabular database

Other Global Data set

[1] EU – CORINE Land Cover/Use dataset (2000, 2006, 2012) https://land.copernicus.eu/pan-european/corine-land-cover

ДИНАМИКА НА ИНДИКАТОРИТЕ ЗА ОЦЕНКА НА СТАТУСОТ НА НЕУТРАЛНОСТА НА ДЕГРАДАЦИЈАТА НА ЗЕМЈИШТЕТО ВО РЕПУБЛИКА МАКЕДОНИЈА

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Неутралноста на деградацијата на земјиштето (НДЗ) е дефинирано како состојба при која количината и квалитетот на земјишните ресурси потребни за поддршка на екосистемските функции и услуги, како и подобрувањето на безбедноста на храната остануваат стабилни или се зголемуваат во рамките на одредени временски и просторни рамки и екосистеми. Основната состојба (baseline) е изразена како почетна (t0) проценета вредност на секоја од трите индикатори што се користат како референтни за процена на природниот капитал заснован врз земјишните ресурси, како и екосистемските услуги што произлегуваат од него, и тоа: земјишната покривка/промена во земјишата покривка, статусот и трендовите во однос на продуктивноста на земјиштето, како и статусот и трендовите во однос на содржината на органски јаглерод во почвата.

Основната линија на НДЗ е пресметана со процена на просечните вредности во текот на референтен период од 10 години за следниве индикатори: земјишна покривка/промена на земјишната покривка (LC/LCC), динамика на продуктивноста на земјиштето (LPD) и почвениот органски јаглерод (SOC). Беа користени три нивоа (Tier) за пресметување на избраните индикатори: Tier 1 ниво: користење глобално/регионално набљудување на Земјата, геопросторни информации и моделирање; Tier 2 ниво: користење национална статистика (само за LC/LCC) и Tier 3 ниво: теренско испитување. Најзначајни промени во однос на земјишната покривка за периодот 2000 – 2012 година се во категориите шуми и грмушки/пасишта. Според глобалните бази на податоци, што беа користени за анализа на продуктивноста на земјиштето, вкупната погодена област со намалување на продуктивноста на земјиштето за периодот 2000 – 2010 година е идентификувана на само 2.35 % од територијата на земјата. Достапната глобална бази на податоци содржи податоци добиени по пат на моделирање за содржината на почвен органски јаглерод (SOC) за периодот 2000 – 2010 година. Според овие податоци, вкупната загуба на СПЦ во нашата земја се проценува на 3951 t.

Клучни зборови: неутралност на деградација на земјиштето; промена на покровноста/искористувањето на земјиштето; продуктивност на земјиштето; почвена органска материја

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Original scientific paper

WATER USE EFFICIENCY AND PEPPER YIELD UNDER DIFFERENT IRRIGATION AND FERTILIZATION REGIME[#]

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The primary objective of this study was to determine water use efficiency (WUE) and pepper yield under different irrigation and fertilization regimes. For this purpose, a three-year field experiment was conducted with pepper, grown in a plastic house in the Skopje region. Four experimental treatments were applied in this study. Three of the treatments were drip fertigated (DF_1, DF_2, DF_3), while the last one was furrow irrigated with conventional application of fertilizer ($Ø_B$). The results obtained clearly showed that treatments DF_1, DF_2, and DF_3 resulted in significantly higher marketable and dry pepper yield in comparison to treatment $Ø_B$. Also, drip fertigation frequency at four and two days (DF_2 and DF_1) resulted in 9.6 % to 13.6 % higher marketable and 17.6 % to 20.1 % dry pepper yield when compared with drip fertigation scheduled by tensiometers (DF_3). Also, our results indicate that drip fertigation is an effective practice in achieving significantly higher WUE. Namely, WUE was 2.50, 2.47, 1.99 and 1.54 kg/m^3 for the treatments DF_1, DF_2, DF^3 and $Ø_B$, respectively.

Key words: furrow irrigation; conventional fertilization; drip fertigation; yield; water use efficiency

INTRODUCTION

Water scarcity and drought are the major factors constraining agricultural crop production in arid and semi-arid zones of the world. Innovations for saving water in irrigated agriculture and thereby improving water use efficiency are of paramount importance in water-scarce regions [1].

Worsened water availability conditions caused by the recent processes of climate warming evoke the attention of the scientists to the efficiency of the water use by crops [2]. A useful tool for successful yield and water management is the yield-water relationship [2, 3]. Development of water and fertilizer management technology that improve water use efficiency is the key to guaranteeing sustainable cultivation of facilities vegetable [4]. However, efficient use of water by irrigation is becoming increasingly important, and alternative water application method such as the dripping one may contribute substantially to the best use of water for agriculture and to improving the irrigation efficiency [5].

Pepper is one of the most important vegetable crops produced under irrigated agriculture [6]. According to Dorji *et al.* [7], pepper production is confined to the warm and semi-arid countries where water is often a limiting factor for production, necessitating the need to optimize water management. Furthermore, Tanaskovik [8] reported that pepper is among the most sensitive horticultural plants to drought stress. Such sensitivity has been noticed in several researches that studied the fresh and dry matter yield reduction affected by water stress [9–12]. Generally, the low pepper yield may be associated with water stress or inadequate soil nutrient [13, 14], which is a result of inadequate

[#]Dedicated to academician Gjorgji Filipovski on the occasion of his 100th birthday

water and soil nutrients procurement affected by irrigation and fertilization regime [15–17]. However, water shortage can be more detrimental to pepper than nutrient deficiency [18].

The pepper water requirements during the vegetation period are quite big compared to other crops, which is a result of the poorly developed root system [19] and large transpiring leaf surface [20, 21]. Water deficit during the period between flowering and fruit development reduces the final productivity of pepper [22, 23]. Therefore, in order to obtain high yields, pepper needs to be provided with adequate quantities of water throughout the vegetation period. In this relation, many authors have elaborated the topic as to how much attention should be paid to irrigation practice of pepper crop [9, 13, 16, 24–31].

Generally, the pepper producers in the Republic of Macedonia have used drip irrigation systems to increase the yield in recent years, but more research is still needed, related to the proper use of water and fertilizers to maximize pepper yield [17]. Also, there are limited results for water use efficiency under different irrigation and fertilization regimes. Therefore, the main objectives of this study were to compare irrigation and fertilization regimes in order to improve water use efficiency, with an aim not only to improve the pepper yield but also to increase the farmer's benefits and tenvironmental protection.

MATERIAL AND METHODS

The field experiment was conducted with pepper crop (*Capsicum annum L. var. Bela dolga*) pruned at two main shoots ("V" system) and grown in experimental plastic house nearby the Faculty of Agricultural Sciences and Food in Skopje, Republic of Macedonia (42° 00' N, 21° 27' E), during the period of May to October in 2005, 2006 and 2007. The soil type of experimental field is Fluvisol [32] with average field capacity of the 0–60 cm soil layer 30.31 %, at a permanent wilting point – 12.61 %, and soil bulk density – 1.52 g/cm^3. The average soil pH at 0 to 60 cm depth was 7.30, while soil electrical conductivity ECe was 2.31 dS/m. The soil 0–60 cm layers contained respectively 2.80 mg/100 g available forms of N, 13.2 mg/100 g available P_2O_5 and 22.5 mg/100g available K_2O.

Table 1. Chemical and physical characteristics of the 0–60 cm soil layer

Chemical characteristics	
Reaction (pH in water)	8.04
Electrical conductivity (ECe dS/m)	2.31
$CaCO_3$ %	3.54
Organic matter %	0.77
Available N mg/100 g soil	2.80
Available P_2O_5 mg/100 g soil	13.2
Available K_2O mg/100 g soil	22.5
Particle size of the soil layer	
Total sand in %	62.2
Silt in %	13.0
Clay in %	24.8
Water physical properties	
Permanent wilting point (soil moisture retention at 15 bars) in volume %	14.37
Field capacity (soil moisture retention at 0,33 bars) in volume %	34.05
Bulk density in g/cm^3	1.52

According to the literature data for the region [19], pepper planted in our conditions and yields up to 60 t/ha need the following amount of nutrients: 485 kg/ha N, 110 kg/ha P and 485 kg/ha K. The application of the fertilizer for the treatments was done in two portions. The first application of fertilizers was applied before transplanting of pepper, while the remaining amount of fertilizers was applied through the fertigation system for drip fertigation treatments (Table 2) and conventional fertilization for the control treatment (in two applications, one application at the flowering and second application at fruit formation). Namely, all investigated treatments have received the same amount of fertilizers, but with different methods and frequency of application.

Table 2. Type and amount of fertilizers used in drip fertigation treatments in kg/ha

Type of fertilizers	Amount of applied fertilizer	Period of application
15:15:15	318 kg ha^{-1}	before transplanting
0:52:34	375 kg ha^{-1}	drip fertigation during the vegetation
0:0:51+18S	802 kg ha^{-1}	drip fertigation during the vegetation
46:0:0	952 kg ha^{-1}	drip fertigation during the vegetation

*Remark: the same amounts and quantity of fertilizers were used for furrow irrigation treatment

The drip irrigation system was designed according to the objectives of the study. Polyethylene pipe with 32 mm diameter was used as the main line to supply irrigation water, while 20 mm for submain lines. Lateral lines were equipped with integrated compensating drippers with a discharge of 4 l/h each crop row. The spacing between the lateral drip pipes was 0.75 m, while the spacing between emitters was 0.33 m. The fertigation equipment used for drip fertigation treatments was Dosatron 16, with a plastic barrel as a reservoir for concentrated fertilizer. Electrical Conductivity of the irrigation nutrient solution throughout the cultivation season was between 0.5–0.7 dS/m. The source of water was of high quality (municipal water supply system for the city of Skopje). The water flow meter was installed for measuring the irrigation application rate.

The first irrigation application rate for all treatments in all three experimental years was based on the soil moisture deficit that would be needed to bring the 0–60 cm soil layer to field capacity. The irrigation program in all three years started immediately after the first irrigation application rate (around 20th May) and according to the experimental treatments designed for this study presented below. The last irrigation application rate was realized seven days before the last harvest (around 15th October). The irrigation scheme of the experiment (treatment DF_1, DF_2, and $Ø_B$) was scheduled according to the long-term average (LTA) daily evapotranspiration of pepper in the Skopje region (Figure 1). LTA crop evapotranspiration was calculated by using FAO software CROPWAT for open field and by using crop coefficient (K_c) and stage length adjusted for the local condition.

The irrigation scheme used in the experiment was designed according to a randomized block design for experimental purposes with four treatments, each treatment replicated three times. The experimental treatments were set up according to the daily evapotranspiration rate. The following experimental treatments were applied in this study: Drip fertigation according to daily evapotranspiration rate with application of water and fertilizer in every two days (DF_1); Drip fertigation according to daily evapotranspiration rate with application of water and fertilizer in every four days (DF_2); Drip fertigation scheduled with tensiometers (DF_3) with recommendations undertaken by Tekinel and Kanber [26]; Furrow irrigation according to daily evapotranspiration with application of water in every seven days and conventional fertilization ($Ø_B$). The daily evapotranspiration rate of DF_1 and DF_2 was decreased by 20 % (coverage coefficient) as a result of applied irrigation technique and regime, similarly to Xie *et al.* [33].

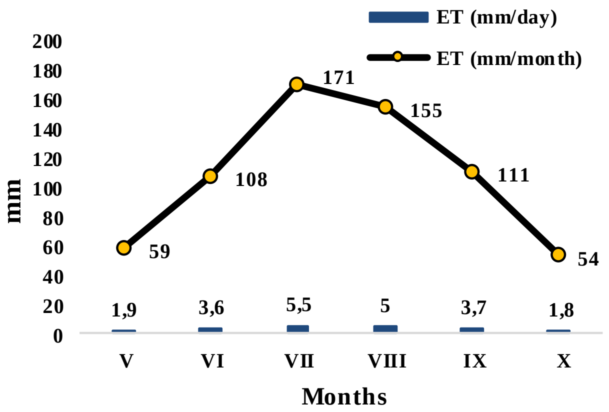

Figure 1. Long-term average daily and monthly evapotranspiration (mm) of pepper in Skopje region calculated by FAO software CROPWAT

Each plot (with a single replication) was designed with five crop rows and five plants in each row. The size of each plot (replication) was 6.6 m^2 (25 plants in 0.75 m of row spacing and with 0.35 m plant spacing in the row). The middle row was assumed for experimental purposes. The experimental plants were three in the middle of the experimental row and these plants were used for sampling and determination of WUE. The picking of fruits from the representative plants was carried out in the stage of technological maturity, part of the leaves, most often the older ones, were picked during the vegetation, the other part of the leaves and the entire stem were collected at the end of the vegetation. The procedure for laboratory preparation of the material was carried out according to the recommendations of IAEA [34]. The results for WUE were obtained as a ratio of the total biomass of dry matter and the seasonal water use by crop (evapotranspiration).

The data collected were subjected to analyses of variance using R 3.1.3 statistical software. LSD test at $P \leq 0.05$ was used to group the means per treatment when the F-test was significant.

RESULTS AND DISCUSSIONS

The meteorological conditions during the research

The optimal air temperature for growing pepper in a controlled environment is 20–30 °C during the day time and 18–20 °C during the night [35, 36]. Bosland and Votava [22], reported that best pepper yields can be obtained when the air temperature during day time is 18–32 °C, especially during the stage of fruit formation. According to Daşgan and Abak [37], maximum daytime temperatures inside the greenhouse depend on the outside air temperatures and vary from 20 °C to 34 °C. In our investigation, the average seasonal temperature in the experimental plastic house during 2005, 2006 and 2007 was 22.83 °C, 22.95 °C and 24.10 °C respectively (Figure 2).

For the normal growth of pepper and for high and quality yields, the optimal relative air humidity should range from 60 to 70 %. Gvozdenović *et al.* [38], reported that lower relative air humidity followed by high air temperature can affect flower and fruit falling. With the exception of October, the average relative air humidity during all three years of investigation was close to the recommended values for pepper production in the protected environment [39].

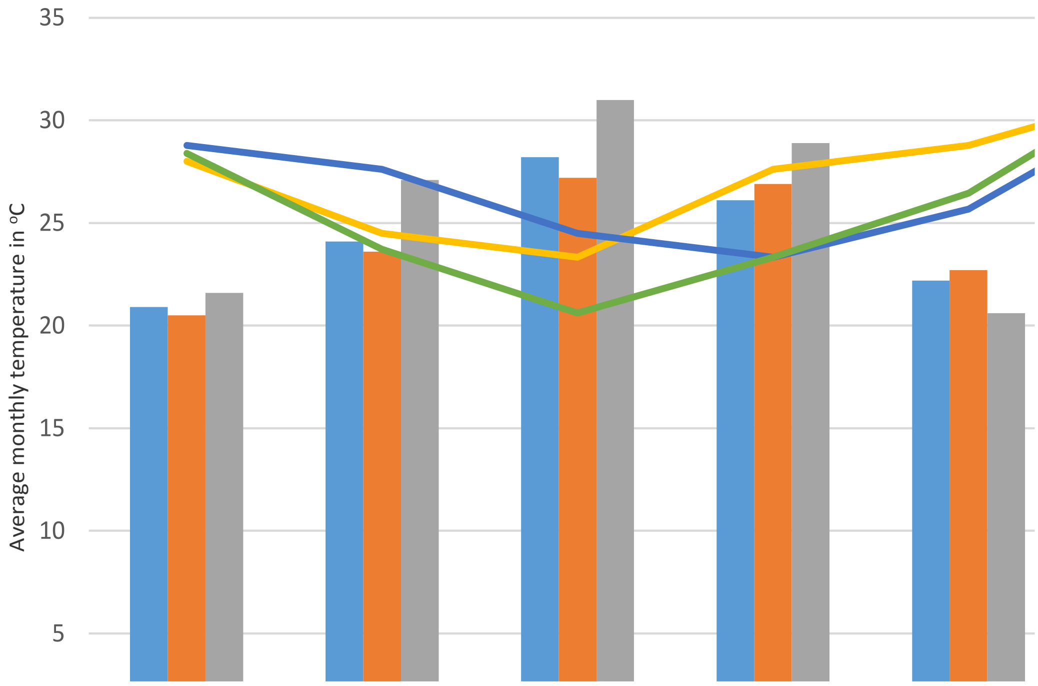

Figure 2. Monthly air temperature (°C) and monthly relative air humidity (%) in the experimental plastic house (by our measurements)

As was mentioned above, the field experiment was conducted in a controlled environment (plastic house), where precipitation does not have any influence on the crop water supply.

Potential evapotranspiration of pepper under different irrigation and fertigation regime

Potential evapotranspiration or crop water use (ETP) was determined monthly and seasonally by soil water balance method by using direct measurements over the soil layer 0–100 cm [40–42] and under permanent content of soil moisture and nutrients, as well as permanent agro-technical measures.

$$ETP_{month} = W_1 + I - W_2 \quad (1)$$

ETP_{month} in equation 1 presents the potential evapotranspiration (m^3/ha) total for each month, W_1 is active soil moisture content at the beginning of each month, I is irrigation water (mm) during the month and W_2 is active soil moisture content at the end of each month. As was mentioned above, our investigation was realized in an experimental plastic house, where precipitations (P) haven't influence on the soil water income. Also, as a result of the controlled irrigation practice of drip and furrow irrigation treatments applied in the study, there were no excess irrigation applications or runoff during the irrigation seasons. Therefore, surface runoff (RO) and deep percolation (DP) were assumed to be zero. Also, the subsurface water and water transported upward by a capillary rise (CR) haven't influence on water income in the root zone, and they were excluded from this estimation. The sum of monthly evapotranspiration present seasonally potential evapotranspiration or $ETP = ETP_{month\ 1} + ETP_{month\ 2} + \ldots + ETP_{month\ x}$ (where $ETP_{month\ 1}$, $ETP_{month\ 2}$, $ETP_{month\ x}$, present each individual month included in the investigation). The average results for the monthly and seasonal ETP totals are presented in Table 3.

The seasonal water use (ETP) varied from 4887.9 to 5881.4 m^3/ha in the different treatments. The highest water use was observed in $Ø_B$ treatment with 5881.4 m^3/ha, and the lowest was measured in DF_2 and DF_1, with 4840.1 and 4887.9 m^3/ha. DF_3 resulted in 5107.3 m^3/ha seasonally water use. The result for the average seasonal ETP total in our investigation was lower than that recommended by Doorenbos and Kassam [24], from 600 to 900 mm, which is connected with the proper and controlled irrigation and fertilization regime during all three years of investigation. On the other hand, the results for average the seasonal ETP in our investigation were similar to those observed in our previous investigations [17], and vary from 492 to 592 mm. Orgaz *et al.* [43], reported lower ET in three stems pruned pepper than ours, which was likely enough of different cultivation period and pruning system compared to our investigation.

The results for the average monthly and seasonal ETP in our investigation indicated small differences between the treatments DF_1 and DF_2, which is connected with the closer irrigation interval of these two treatments. Statistically, there is no significant difference in ETP. As a result of lower drip fertigation frequency, the treatment DF_3 showed 4.5 % to 5.5 % higher average seasonal ETP, compared to DF_2 and DF1, and the differences were statistically significant. Sezen *et al.* [16], reported lower evapotranspiration in drip irrigation treatment with moderate frequency from 6 to 10 days. Generally, the effect of drip fertigation on ETP is presented by the achieved results in treatments DF_3 in comparison with $Ø_B$. DF_3 showed from 14.4 % to 16.5 % lower average monthly ETP and about 15 % lower average seasonal ETP compared to $Ø_B$. The results are statistically significant at 0.05 level of probability. Higher ETP in treatment $Ø_B$ may be associated with continuous water stress and inadequate soil moisture and nutrient content, which also was reported in some other investigations [9, 17].

Table 3. Average (2005–2007) monthly and seasonal potential evapotranspiration (ETP in m^3/ha) of plastic-house grown pepper

Treatments	May	June	July	August	September	Seasonally
DF_1	275.3^a	1043.8^a	1627.7^a	1512.7^a	428.5^a	4887.9^a
DF_2	271.7^a	1028.9^a	1618.7^a	1495.8^a	425.0^a	4840.1^a
DF_3	282.4^a	1088.5^b	1717.1^b	1580.3^b	438.9^a	5107.3^b
$Ø_B$	328.9^b	1245.1^c	1985.4^c	1816.9^c	505.1^b	5881.4^c

[*]Values in rows followed by the same letter are not significantly different at the 0.05 probability level

Marketable pepper yield and fruit weight under different irrigation and fertilization regime

The influence of irrigation and fertigation regime on marketable pepper yield and fruit weight are shown in Table 4. From the data presented in Table 4, it can be concluded that the highest average pepper yield of 71.11 t/ha has been obtained in the treatment DF_1, followed by DF_2 with 68.40 t/ha or 2.71 t/ha less yield, and treatment DF_3 with 8.5 and 5.79 t/ha less yield when compared to DF_1 and DF_2. The lowest yield of 54.74 t/ha in our study was recorded in the control treatment ($Ø_B$). All three treatments with drip fertigation show statistically significant differences at 0.05 level of probability when compared to the control treatment $Ø_B$. The lowest pepper yield in treatment $Ø_B$ in our study is a result of continuous soil moisture stress during mass fructification and inadequate soil nutrient procurement affected by the applied irrigation and fertigation technique, what was the purpose of other our research [17]. Candido *et al.* [13] emphasized that water deficit and reduced fertilizer availability, especially of nitrogen, are very harmful to bell pepper during the reproductive phase. Furthermore, the low pepper yield in treatment $Ø_B$ in our study is associated with the results of several researches where soil moisture stress and limited irrigation caused decreases to yield and vegetative growth of pepper [3, 12, 18, 28, 44]. For high pepper yields, an adequate water supply [31] and relatively moist soils are required during the total growing period [19, 27]. Therefore, the positive effect of drip fertigation on yield in our research is due to the continuous intake of the readily available water and nutrients in the small volume of soil, from where they were actively extracted by the plant. If nutrients are applied outside the wetted soil volume they are generally not available for crop use [45]. A number of other investigators emphasize results with higher pepper yields, where drip irrigation or drip fertigation was applied in comparison with conventional irrigation and fertilizerapplication [9, 13, 15, 16, 29, 30].

Table 4. Average (2005–2007) results for marketable pepper yield and fruit weight

Treatment	Marketable pepper yield (t/ha)	Comparison with treatment $Ø_B$ in %	Average pepper fruit weight in g	Comparison with treatment $Ø_B$ in %
DF1	71.11[a]	129.9	73.15[a]	128.4
DF2	68.40[a]	125.0	69.18[b]	121.4
DF3	62.61[b]	114.4	63.42[c]	111.3
$Ø_B$	54.74[c]	100	56.99[d]	100.0

*Values in rows followed by the same letter are not significantly different at the 0.05 probability level

When we compared the drip fertigation treatments among themselves, it is clear that the high drip fertigation treatments DF_1 and DF_2 create a better environment for increasing of the yields in comparison with the low drip fertigation treatment DF_3. Namely, treatment DF_3 resulted in a 9.6 % to 13.6 % lower pepper yield in comparison to DF_2 and DF_1. According to Agele *et al.* [46], the trend to increase crop yields has led to frequent fertigation and therefore the time intervals between successive fertigation events have diminished to hours or even less. Bar Yosef [47] reported better pepper yields in treatment with drip fertigation 2 or 3 times a day (71 t/ha) compared to every day (68 t/ha) or every 2 day drip fertigation (66 t/ha). Also, various researches reported better yields in pepper and other crops by using high-frequency in comparison with low-frequency drip irrigation and fertigation [16, 48–52].

In the present study, we have documented that drip fertigation has an influence on the average pepper fruit weight too. The highest values of average pepper fruit weight were noted in treatments DF_1 and DF_2 with 73.15 g and 69.18 g, then comes the treatment DF_3 with 63.42 g and then comes the $Ø_B$ with the lowest fruit weight 56.99 g. All treatments under drip fertigation showed a statistically significant difference compared to the control treatment $Ø_B$. Also, statistically significant differences were noted among any of the drip fertigation treatments. Generally, the lower average pepper fruit weight in treatment $Ø_B$ compared to the drip fertigation treatments can be attributed to the irrigation and fertigation technique, while in DF_3 as a result on prolongated drip fertigation frequency proceeded with a pretty higher quantity of water and nutrients in comparison with DF_1 and DF_2. The water deficit imposed during the late flowering-early fruit set phase causes lower size, number, and weight of pepper fruits as well as yield losses [13]. Abayomi *et al.* [14], reported that the number and weights of marketable fruits decreased by low soil moisture and increased by the application of nitrogen fertilizer. Also, our results from the present investigation correspond with those of Tanaskovik *et al.* [51], where drip irrigated and fertigated tomato was compared with banded and furrow irrigation. Furthermore, a number of other researchers report better yield components in pepper and different vegetable crops especially when different irrigation and fertigation techniques were applied [26, 30, 53].

Dry matter pepper yield and water use efficiency under different irrigation and fertilization regime

The results for total dry matter pepper yield show the same pattern as a fresh fruit yield, which would once again indicate yield increase with the simultaneous application of water and nutrients through the drip irrigation system. The results obtained for dry matter pepper yield (D. M. yield) in drip fertigation treatments showed a statistically significant difference at 0.5 level of probability compared with the control treatment $Ø_B$. Similar results of D. M. yield in drip compared with furrow irrigated and drip fertigated compared with conventional irrigation and fertilization in pepper crop reported Antony and Singandhupe [9] and Tanaskovik *et al.* [17]. In this context, González-Dugo *et al.* [10] indicated that a continuous deficit of soil moisture affects the decrease of pepper D. M. yield.

Table 5. Average (2005-2007) results for dry matter pepper yield and WUE

Treatment	ETP m^3/ha	Dry matter pepper yield (t/ha)	WUE kg/m^3	Comparison with treatment $Ø_B$ in %
DF1	4887.9[a]	12.24[a]	2.50[a]	162.3
DF2	4840.1[a]	11.98[a]	2.47[a]	160.4
DF3	5107.3[b]	10.19[b]	1.99[b]	129.2
$Ø_B$	5881.4[c]	9.07[c]	1.54[c]	100.0

*Values in rows followed by the same letter are not significantly different at the 0.05 probability level

Also, in the present study, the drip fertigation frequency points to differences in the yield of total dry matter, i.e. the treatment DF_3 (average at seven days drip fertigation) has noted a yield lower by 2.05 t/ha in comparison to DF1, i.e. by 1.79 t/ha in comparison to DF2, and the differences were statistically significant at 0.05 level of probability. And many other authors [17, 50–52] have noted a higher dry matter yield individually by leaf, stem, fruit and totally in different vegetable crops in higher than in lower drip fertigation frequency.

The data obtained for water use efficiency (WUE) in our study are in relation to the previously mentioned results. From the data presented in Table 5, it can be concluded that treatments DF_1 and DF_2 with 2.50 and 2.47 kg/m^3, respectively, have shown the highest water use efficiency. As a result of lower irrigation frequency, the treatment DF_3 has shown 1.99 kg/m^3 WUE, or by 0.51 and 0.48 kg/m^3 lower produced dry matter yield compared to DF_1 and DF_2, and the differences were statistically significant. The differences between the drip fertigation treatments are a result of irrigation and fertigation frequencies. Sezen *et al.* [16] in their investigations with different irrigation regime in pepper crop, reported the highest yield and WUE in the treatment with drip irrigation frequency of 3 to 6 days, while in the drip irrigation treatment with irrigation frequency from 6 to 11 days and 9–15 days yield and water use efficiency decrease. Also, the results from our investigation correspond with those to Oğuzer *et al.* [25] were daily irrigated pepper show almost three times higher WUE in comparison with irrigation at every three days. Tanaskovik *et al.* [51] and Phene *et al.* [48], reported better WUE in high compared to low drip fertigated tomato crop. In this context, Bar-Tal *et al.* [54] indicated that high concentrations of nutrients used in prolongated fertigation lead to fluctuations from high or even excessive concentration immediately after irrigation in the rhizosphere to deficit levels as time proceeds. Therefore, high fertigation or irrigation frequency may represent a strategy to increase N uptake efficiency in many vegetable crops [55].

Furthermore, from the data obtained by WUE in our study, once again it is clear that the treatments under drip fertigation indicated the best results with a statistically significant difference in comparison with $Ø_B$. If our results are presented in comparative values, then WUE in the treatments DF_1 and DF_2 were almost 60 % higher in comparison with $Ø_B$. Also, the treatment DF_3 obtained more than 29 % higher WUE in comparison with treatment $Ø_B$. Our results correspond with several researches [9, 15, 16, 26], where different irrigation or fertigation techniques were evaluated over the pepper WUE. Also, a number of other researches with different vegetable crops reported higher WUE as a result of suitable drip irrigation and applying fertilizer's through the system in comparison with conventional irrigation and spreading of fertilizers on soil [4, 49, 51, 56]. Moreover, higher WUE in drip fertigation treatments compared with $Ø_B$ in the present study can be associated with higher nitrogen fertilizer use efficiency (NFUE), which was the purpose of our other research [17]. Similar results as ours are observed in drip fertigation pepper, tomato, cucumber, melon and eggplant by Halitligil et al. [15]. Yasuor et al. [57], reported that a higher concentration of nitrogen in irrigation water significantly influenced its uptake in the whole plant and among the plant's organs. According to Drechsel et al. [58], improvements in nutrient use efficiency should not be viewed only as a result of fertilizer management, because nutrient plant use is closely related with soil water stress and water management.

Stagnari and Pisante [59] and Ouzounidou *et al.* [60] indicated that nitrogen is one of the major potential environmental contaminants and, therefore, our results for water use efficiency are very important for the environmental protection from nitrogen pollution, especially in intensive agriculture, where water and nutrients are the most utilized resources for obtaining greater yields per unit area.

CONCLUSIONS

From the results in the present study, it can be concluded that the irrigation and fertilization techniques and drip fertigation frequencies are significantly important in order to obtain higher marketable yield and pepper fruit weight, as well as dry pepper yield. Furthermore, water use efficiency was significantly increased with the application of fertilizer through drip irrigation as compared to the furrow irrigation and spreading of fertilizer on the soil. Moreover, high-frequency drip fertigation are highly recommended for improving water use efficiency. Therefore, for similar conditions of growing pepper as ours, to achieve appropriate marketable yield, we recommended drip fertigation with high frequency (two or four days) in order to increase water use efficiency and to minimize the environmental impact from nitrogen pollution.

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ЕФИКАСНО КОРИСТЕЊЕ НА ВОДАТА И ПРИНОС НА ПИПЕРКАТА ПРИ РАЗЛИЧНИ РЕЖИМИ НА НАВОДНУВАЊЕ И ЃУБРЕЊЕ

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Главна цел на истражувањето беше да се утврди ефикасното користење на водата и приносот кај пиперката при различни режими на наводнување и ѓубрење. За оваа цел, извршивме тригодишни истражувања со пиперка одгледувана во пластеник во регионот на Скопско. Четири варијанти беа споредувани во истражувањето, од кои три со фертиригација (DF_1, DF_2, DF_3), додека четвртата варијанта беше наводнувана со бразди и класично ѓубрење ($Ø_B$). Добиените резултати од истражувањето покажуваат дека варијантите со фертиригација (капково наводнување и ѓубрење преку системот) покажуваат статистички значајно поголем принос на пиперка во свежа состојба, како и на сувата материја од целото растение во споредба со варијантата $Ø_B$. Исто така, фертиригација со интервал на четири и два дена (DF_2 и DF_1) покажува од 9.6 до 13.6 % поголем принос на свежа, односно од 17.6 до 20.1 % на сува материја од целото растение споредено со варијантата со интервал утврден преку тензиометри (DF_3). Понатаму, нашите резултати укажуваат дека ѓубрењето преку систем капка по капка е многу ефективна алатка за обезбедување поефикасно користење на водата од растенијата. Имено, од добиените резултати може да се види дека за потрошен кубен метар вода варијантите DF_1, DF_2, DF_3 и $Ø_B$ создале 2.50, 2.47, 1.99 и 1.54 принос на сува материја од целото растение.

Клучни зборови: наводнување со бразди; класично ѓубрење; фертиригација; принос; ефикасно користење на водата

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Review

A REVIEW TO THE GENESIS, EVOLUTION AND CLASSIFICATION OF THE SOILS FORMED ON LIMESTONES AND DOLOMITES IN THE REPUBLIC OF MACEDONIA[#]

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The soils formed on limestones and dolomites in different locations in the Republic of Macedonia have been examined. These soils differ in their genesis, evolution and properties from soils formed on other substrates and have a number of specificities, whereby all their properties largely depend on the parent material. They occupy much of the soil cover of the Republic of Macedonia. The field examinations were carried out according to the generally accepted method in our country [1, 2]. Most of them are under high mountainous pastures, some plots are under meadows and fields. They have great importance for the faster development of some industries in the country, forestry, tourism, as well as the agricultural development in the hilly and mountainous underdeveloped areas in our country.

Key words: soils formed on limestones and dolomites; genesis; evolution; classification

INTRODUCTION

The soils formed on limestones and dolomites occupy a large part of the soil cover of the Republic of Macedonia. Based on the pedological (soil) map of the Republic of Macedonia in scale 1:200.000 [3], these soils occupy around 12.45 % of the total area of the Republic of Macedonia or 2.571.300ha. In this area, Calcomelanosols /WRB-Rendzic Leptosol [4], covers around 220.000ha or 8.55 %, Calcocambisols /WRB-Chromic Leptic Luvisol on hard limestones [4], covers around 100.000ha or 3.88 %, but Terra Rossa /WRB-Rhodic Leptic Luvisol on hard limestones [4], rarely form continuous soil cover. These can be found on really small areas of karst relief, they have a concave shape and are characterized with mosaic and fragmented appearance, and cover around 260 ha or 1.00 % of the total area [5].

The soils formed on limestones and dolomites differ in their genesis, evolution and properties from soils formed on other substrates and have a number of specificities. All their properties (physical, physical-mechanical, chemical and biological) greatly depend on the parent material.

Calcomelanosols, and especially Terra Rossa and Brown soil on hard limestones and dolomites (Calcocambisols), are some of the insufficiently studied soil types in our country.

The motive for this research arose from the fact that they occupy much of the soil cover of the Republic of Macedonia and have great importance for the faster development of some industries in the country, forestry, tourism, as well as the agricultural development in the hilly and mountainous underdeveloped areas. The preservation of these soils in the Republic of Macedonia is especially important due to the higher extent of erosion, forest cutting, fires, excessive grazing, which made these researches even more significant.

In addition, the cartographic units with Terra Rossa areas were not distinguished on the pedological (soil) map of the Republic of Macedonia until these studies took place because did not exactly know their total area.

[#]Dedicated to academician Gjorgji Filipovski on the occasion of his 100th birthday

MATERIAL AND METHODS

The field examinations of soils formed on limestones and dolomites were carried out on various locations on the territory of the Republic of Macedonia (Figures 1 and 2). Following the field recognition, a total of 52 basic pedological profiles out which, 34 were calcomelanosols, 13 calcocambisols and 5 profiles of terra rossa were excavated (Figure 3, 4 and 5) were collected regarding the soil genesis conditions (parent material, relief, climate, vegetation and human factor). The field examinations were carried out according to the generally accepted method in our country [1, 2]. Detail facts and data about soil properties and methods were presented in [6].

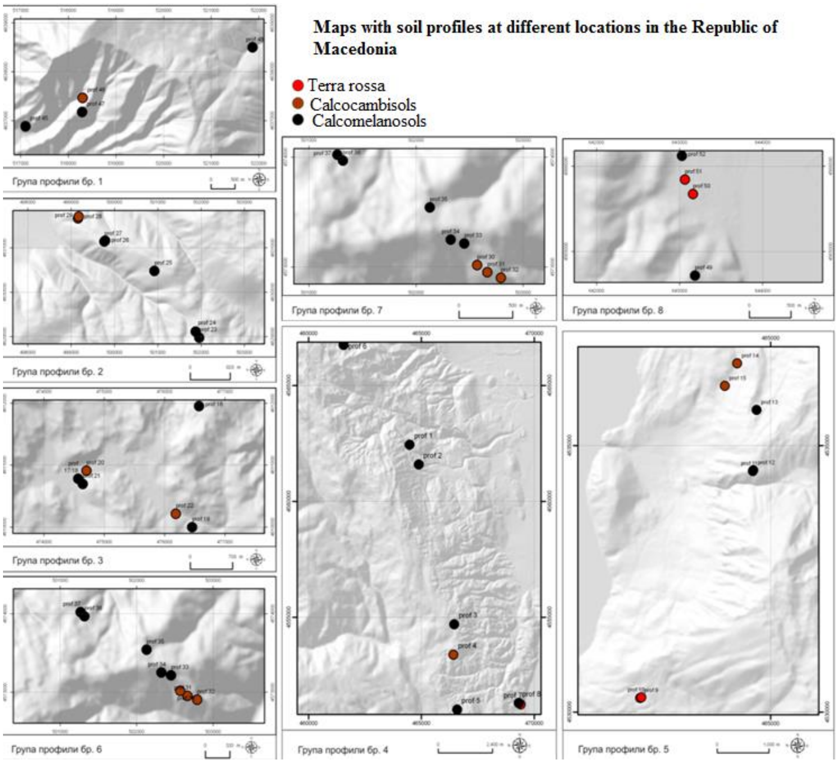

Figure 1. Map with soil profile at different locations in the Republic of Macedonia

Figures 2. Map with the altitude of the soil profile at different locations in the Republic of Macedonia

R

a) subtype
organogenic
Amo-R

b) subtype
organomineral
Amo-R

c) subtype
brownised
A-(B)rz-R

Figure 3. Calcomelanosols

Amo-(B)rz-R

Amo-(B)rz-R

Figure 4. Calcocambisols

Amo-(B)rz-R

Amo-(B)rz-R

Figure 5. Terra Rossa

RESULTS AND DISCUSSION

Geneza of the soils formed on limestones and dolomites

Calcomelanosols in their first stadium of development, appear in all climate-vegetation zones in our country, thus it can be said that the substrate is the main soil forming factor. However, the opinions on the soil forming factors in the literature differ. According to some authors cf. in [7], terra rossa are lithogenic soils, as they are formed in a similar way as calcomelanosols, on pure compact limestones and dolomites, and according to other authors, these are zonal soils as they appear only in the Mediterranean and modified Mediterranean climate. Third authors cf. in [7] combine these opinions and claim that these are lithogenic-climatogenic soils since the substrate is dominant soil forming factor for their formation, and the climate factor contributes for their preservation or evolution. Similar to calcomelanosols, calcocambisols can be treated for lithogenic soils, however, according to [7], these soils are not formed in some climate-vegetation zones of limestone - dolomite mountain ranges in our country, which speaks for the strong influence of other soil forming factors and points out to their zonal character.

Markoski, et. al., [6, 6a] described each of the soil forming factors and their significance in the formation of soils on limestones and dolomites in the Republic of Macedonia.

The following three processes take place in calcomelanosols: 1. Dissolving of $CaCO_3$ and $MgCO_3$ from limestone and dolomite and their leaching; 2. Accumulation of organic matter and formation of the humus horizon and 3. Formation of (B)rz horizon (only in brownised calcomelanosols). The third process is the most specific in the genesis of calcocambisols [7].

The first process takes place in all climate-vegetation zones, however, with different intensity. The limestone dissolving mostly depends on the mineralization and humification intensity, i.e. on the quantity of produced H_2CO_3 and humic acids, as well as on the temperature, the amount of rainfalls, vegetation etc. This process of the limestone dissolving has consequences and effects on the genesis and properties of calcomelanosols.

The second very important process in their genesis is the accumulation of organic matter. The humification creates humus which is important for the soil properties. The mollic humus-accumulative horizon is reach in organic matter (humus), it has a dark color and much better thermal properties. The organo-mineral complexes, the humates and coprogenic humus formation of stable crumb structure and have a special effect on the water-air regime in the soil. At the same time, the accumulation of humus increases the absorption capacity of these soils.

The third process appears in the brownised calcomelanosols and calcocambisols that form the cambic horizon (B)rz, and it is marked as degradation, clay-forming process and brownization. Opinions for this process are given by Filipovski [8], as well as by Ćirić and Pavićević [9, 10] who claim that the brownization process leads to dehumization and release of clay from the clay-humus complexes, without changing its mineralogical and chemical composition, and [10] points out that it is not clear whether clay decomposition is carried out in this process as well. In addition, Filipovski commented Spirovski [11] and Filipovski [12] who claim that chemical weathering through hydrolysis takes place in this process, at the same time forming clay (argillisation) and releasing iron oxides, and Laatsch [13] has determined that in this process, with the chemical weathering of the secondary minerals releases iron sesquioxides that give the soil brown and reddish-brown color. This brownization process occurs in conditions when the calcomelanosols form solum with depth from 30 to 40 cm even in conditions with fewer temperature variations. The intensity of the brownization process grows in the case of higher temperatures. New humus is no longer accumulated in the lower part of the solum at the brownised calcomelanosols and calcocambisols, which is located under the depth of the biological accumulation. When the solum will reach a depth of 30 to 40cm, the humidity in its lower part will become higher, the temperature will become more constant and the conditions for microbiological processes for humus mineralization will become more favorable. With the decreasing of the content of humus, the crumb aggregates decompose, the clay is released, the mass becomes more compacted, and nut, polyhedral structure. New quantities of clay can be obtained with the deepening of the (B)rz horizon and thus, (limestone dissolution- decarbonization) accompanied by a release of the clay silicate residium from it, a process that runs quite slowly.

According to [8], the brownisation starts from the bottom up, i.e. from the limestone up, and can take place in two phases whereby in the first phase only the color begins to change (the humus is lost), it becomes brown, while in the second phase, the other properties, especially physical properties of the soil begin to change (the structure is changed, i.e it becomes less loose, the non-capillary porosity decreases and the aeration and water permeability decreases). The chemical properties also change the content of humus and nutrients decreases, the acidity of the reaction increases, and the base saturation percentage decreases. This process can explain the increased content of clay in the horizon (B), which in these soils is marked as (B)rz, as it is formed with the release of the residuum from the limestone. In the first phases (B)rz is shallow, even shallower than in the Amo horizon at the subtype brownised calcomelanosols and in the later phases, it goes deeper and becomes more dominant, as in the calcocambisols, and becomes one of the diagnostic signs of this soil type.

Clay eluviation can occur in the genesis of the calcocambisols, a process characterized by soil subtype: Luvic. This process contributes for a larger textural differentiation of the horizons, and initial formation of the horizon E. Information on the genesis of calcomelanosols and calcocambisols can be found in the papers of [7, 14–29].

There are various opinions for the genesis of terra rossa. All of them refer to the origin of terra rossa and the relation between terra rossa and the parent material, whereby some of the opinions are even opposed. Most of the theories and opinions are presented by [8]. There is a so called residual theory regarding the genesis of terra rossa. It has been present for a longer time and it is a result of several years of studies carried out by some Croatian geologist Tućan and Marić cf. in [7] who studied the Croatian karst. This theory is accepted by some soil scientists [30]. According to this theory, terra rossa are mainly lithogenic soils as there are no significant differences between the residium and the mineral part of the soil. This opinion is also shared by the authors as they have been comparing the chemical and mineral composition of the residium and terra rossa. According to the residual theory, during the genesis of terra rossa, the residuum does not change significantly, which means that the terra rossa represents release residuum obtained from the limestone dissolution. This dissolution takes place in various climate conditions, which means that the Mediterranean climate is not a prerequisite for the formation of terra rossa. The genesis of terra rossa takes place in the presence of pure limestone, with a small content of residium, with red color and close ratio of SiO_2:R_2O_3, whereby this residium originates from terra rossa which material was integrated in the limestones during the formation. In the later process of decarbonization, the residuum releases from the limestone and creates the mineral part of the soil. This process of releasing residuum is really slow, takes place for a long time with biochemical dissolution at various climate conditions.

According to the other theory cf. in [7], the silicate residium of the limestone is not identical to terra rossa. It is released with the dissolution of the limestone dissolves and as such, it represents a substrate which, with the rubification process, forms into terra rossa. The rubification process that took place in the past, but also takes place currently, especially in the Mediterranean and Subtropical areas, characterized with various pronounced characteristics, and especially dry and hot summers and dry and hot soil climate.

The processes that form terra rossa and some other ferralitic soils, Duchaufour, cf. by Filipovski [7] are called ferrallitisation, and the formation of terra rossa - rubification.

The author [31] has noted that in very warm and humid Mediterranean areas, such as Lebanon, the release of the residium and rubification occurs quickly and recent terra rossa is formed. Pavićević, [32] also considers that in the karst of the Adriatic Sea, where there are exceptionally high amounts of rainfall, the rubification is a modern process and that terra rossa is formed directly or with rubification of other soils. The same author divides terra rossa in the karst of the Adriatic coast into two groups: primary, formed with direct rubification of the residium and secondary, formed with rubification of other soil types.

Our research of the mineral composition of fractions (sand, silt) of the total soil, the geological substrate and the unsoluble remains in terra rossa, have indicated that the largest portion of minerals in the soil is the same as in unsoluble remains, but we must not disregard the fact that there is increased content of quartz in the sand fraction and the formation of vermiculite whose presence was not noted in the unsoluble remains [6].

Evolution of the soils formed on limestones and dolomites

The evolution of calcomelanosols has been studied by several authors in our country. Using the knowledge from our additional research from then until today, Filipovski, [8] has concluded that the evolution of calcomelanosols has taken place in three directions: a) forming of calcocambisols (organogenic → organomineral/haplic → brownized calcomelanosol); b) forming of terra rossa (organogenic → organomineral/haplic → rubified calcomelanosol); and c) forming of calcomelanosol with mor or tangel-humus (organogenic → organomineral/haplic → calcomelanosol with mor humus with organic O horizon). Whereby, the same author states that the evolution of the calcomelanosols can stop in the initial phase and it can be permanent (for example, during the phase of organogenic calcomelanosol). With the evolution of calcomelanosols, there is growth in the percentage of coverage of the ground with soil, the depth of the profile is increased, and this reduces the effect of the limestone over the soil processes and properties. Also, the author continues to state, the evolution significantly changes the other soil properties: structure, water-air properties, humus contents, as well as the morphological properties of the profile. Evolution is also influenced by the depth of the profile, relief, climate-vegetation conditions, nature of the substrate, erosion etc.

The first, organogenic phase is formed as an initial phase (A-R) in conditions when the accumulation of humus, due to any reason (poor residium, extreme permeability of the substrate, unfavorable climate conditions) occurs more intensively that the dissolving of limestone and formation of clay. Organogenic calcomelanosols are characterized by a very shallow Amo horizon (around 10 cm) which lies directly on top of the hard limestone and dolomite. They contain high amounts of humus, over 15 % in our region. Due to the dry soil climate conditions, microbiological processes in organogenic calcomelanosols have a weak intensity, and humification mainly occurs under the influence of the fauna.

In the second organomineral/haplic phase, calcomelanosols reach their full maturity and maximal biological activity. The organomineral/haplic calcomelanosol has a deeper profile. The Amo horizon amounts to about 30cm, it contains less humus, has a crumby structure, and a well developed humus-clay complex. A limestone skeleton can be present in the humus horizon. The organomineral/haplic calcomelanosol is a more frequent subtype than the previous subtype and it dominates the zone of high-mountain pastures.

The third phase, when these is brownization of calcomelanosol occurs with deepening of the profile. The brownized calcomelanosol represents a transitional phase towards calcocambisols. It is formed from the previous subtype with the initial appearance of the cambic horizon (B)rz which has lower depth than the humus-accumulative Amo horizon. The increase of the clay content in this cambic (B)rz horizon is mostly residual clay, left after the dissolution of $CaCO_3$.

Filipovski [8] has also described the evolution of calcomelanosols up to the formation of rubified/rhodic luvic calcomelanosols. Rubified/rhodic luvic calcomelanosols is a transitional phase leading to terra rossa. In this phase there is the initial formation of red cambic (B)rz horizon which has a smaller depth than the humus-accumulative horizon. In our conditions, it can be found in the lowest zones of Galichica, immediately next to Ohrid Lake, where the impact of the modified Mediterranean climate can be felt, with the respective vegetation and limestones with red residium.

Certain authors, such as [15, 33] describe the evolution of calcomelanosols towards cinnamonic forest soils/Chromic Luvisol on saprolite (WRB). In addition to calcomelanosols, terra rossa is mentioned as a previous stadium of calcocambisols.

In the case of calcocambisols, depending on the processes present in the soils, similar to the previous type, they can evolve into three directions: lesivation (illimerization), rubification, humusation and transformation into terra fusca.

In our region, illimerization is the most common case of evolution of calcocambisols, whereby there is the following evolution sequence: typical calcocambisol → illimerized/luvic calcocambisol. Illimerization according to [7] is usually present when the solum of these soils reaches a depth of around 50 to 60cm. Such is the case in level fields and in negative forms of the karst relief. In these relief forms, there is little surface running-off of water and it leaches the bases more intensively, there is weak acidification, as well as peptization and eluviation of clay. After this process reaches a certain level, under the A horizon there is an initial formation of the eluvial E horizon, and the clay is then transferred mechanically, without any changes to its chemical and mineral composition.

The rubification of calcocambisols has been described by [32, 34], cf. by Filipovski [7]. It is present in the lowest zone of the oak region, where these soils are present in complexes with terra rossa. The devastation of the forest and tillage on these soils contribute to the reduction of humus, for bigger heating and drying of the soil, which are key conditions for the hydrated sesquioxides to transform into nonhydrarted (hematite) which are red in color.

In addition, Ćirić [9] cf. by Filipovski [7] describes the third direction, humification of calcocambisols in the higher zones where these soils are present. This evolution occurs with the devastation of forests and the increase of surfaces with grass vegetation, where under its influence, after the erosion of the A horizon in the remainder of the solum ((B)rz horizon) the A horizon is formed again. These humificated calcocambisols do not differ from the brownized calcomelanosols.

The evolution of terra rossa researched by several authors: [12, 34, 35], by certain authors from the former Yugoslavian Republics: [29, 32, 37–39], as well as by others: [31, 40–43]. In all of the research by these authors, three directions of the evolution of terra rossa have been pointed out: 1. Brownization, 2. Illimerization and 3. Progradation (humification).

Brownization, according to [7], is present in terra rossa which after the withdrawal of the Mediterranean climate, has remained in conditions with higher moisture and lower temperatures. This is even more intensified if the Mediterranean climate is additionally weakened or the environmental conditions change (forest, deeper solum, cooler and wetter expositions). With all of these processes, the top part of the solum is brownized, where under the influence of more humid and cooler conditions the rubification is incomplete and slow. The author has pointed out that there is a partial regression of rubification with the formation of more hydrated sesquioxides (goethite) and with the appearance of brown or more often red-brown color (brownized terra rossa).

Illimerization is present in climates that are even more humid, at higher altitudes, in negative forms of karst relief with stronger surface humidification and deeper solum. In this terra rossa the processes of acidification and peptization of colloids and their leaching are stronger. The author clarifies that these processes strengthen the texture differentiation with clear signs of leaching the clay from the A horizon into the Bt horizon and with the appearance of the initial formation of the E horizon (luvic terra rossa).

The third direction of evolution is progradation (humification) which consists of an accumulation of a higher quantity of humus into the already formed terra rossa (most often under the influence of grass vegetation). The dark humus horizon differs from the one in rhodic luvic calcomelanosols because it contains less humus and has a crumb structure (humic terra rossa) [7].

Classification of the soils formed on limestones and dolomites

The studied soils formed on limestone and dolomite have been classified according to the classification of Škorić, [24], Table 1.

Table 1. Classification of the soils formed on limestones and dolomites according to Škorić, [24]

Calcomelanosol		
Subtypes	Variety	Form
Organogenic (profile N^0 6,11,12,13,17,21, 24)	Lithic	- with mollic horizon
Organomineral (typic) (profile N^0 1,2,5,8,19,23,25,26,34,35,37,39,40 41,42,43,44,45,47,48,49,52)	Lithic	- with mollic horizon
Cambic (profile N^0 3, 16,18, 33, 36)		- with mollic horizon
Brown soil on hard limestones and dolomites (Calcocambisol)		
Haplic (typic)	medium deep (35-50cm) (profile N^0 22, 28, 30, 31, 46) deep (> 50cm) (profile N^0 4, 14, 15, 20, 27, 29, 32)	Clay (profile N^0 4,14,15,20,22,27,29,38,46) Loamy (profile N^0 28,30,31,32)
Terra Rossa		
Haplic (typic)	1. shallow (to 40cm) (profile N^0 50) 2. medium deep (40 – 70cm) (profile N^0 7, 10, 51) 3. deep (> 70cm) (profile N^0 9)	Clay

We have determined almost all types and subtypes of soils formed on limestone and dolomites: soil type - Calcomelanosol with subtypes: organogenic, organomineral (typic) and cambic, variety: lithic and form: with the mollic horizon. Calcocambisol, subtype Haplic (typic), variety: medium deep and deep and forms: clay and loamy. Soil type - Terra Rossa, subtype Haplic (typic), variety: shallow, medium deep and deep and form: clay.

In calcomelanosols, the division into subtypes is based on the evolution principle. The division into varieties is based on the nature of the substrate, and the division into forms is based on the nature of the humus horizon.

In calcocambisols and terra rossa, the division into subtypes is based on the evolution principle. In these two soil types, the division into varieties is based on the profile depth, and the division into forms is based on the mechanical composition.

According to WRB (World Reference Base for Soil Resources) [4], Calcomelanosol is classified as Rendzic Leptosol (lithic, molic), and according to the FAO Soil Classification, [41] it is designated as Rendzic Leptosol.

Brown soil on hard limestones and dolomites according to the WRB classification represents Chromic Leptic Luvisol on hard limestones (skeletic, humic), and according to the FAO Classification: Chromic Luvisol on hard limestones.

According to the World Reference Base for Soil Resources, Terra Rossa is classified as WRB Rhodic Leptic on hard limestones, and according to the FAO Classification it falls within Ferric Luvisol on hard limestones.

According to the proposed classification of Filipovski, [44], calcomelanosols fall within the major group of Molisols, while calcocambisols and terra rossa fall within the major group of Cambisols.

CONCLUSION

The key processes in whose genesis are: the dissolving of $CaCO_3$ and $MgCO_3$ from limestone and dolomite and their leaching; accumulation of organic matter and the formation of humus horizon and formation of horizon (B)rz (only in brownized calcomelanosols). The third process is the most specific in the genesis of calcocambisols and terra rossa.

The evolution of the soils formed on limestones and dolomites happens in three directions: calcomelanosol appears as a first phase and goes towards: the formation of calcocambisols (organogenic → organomineral → chromic luvic); the formation of terra rossa (organogenic → organomineral → rhodic luvic); and the formation of calcomelanosol with (mor) or tangel humus (organogenic → organomineral → calcomelanosol with mor humus with O organic horizon.

In our research, we have determined the following soil types and subtypes formed upon limestones and dolomites: soil type - Calcomelanosol with the subtypes: Organogenic, Organomineral/Haplic and Cambic, variety: lithic and form: with mollic horizon; Calcocambisol with subtype: Haplic (typic), variety: medium deep and deep and forms: clay and loamy and Terra Rossa with subtype: Haplic (typic), variety: shallow, medium deep and deep and form: clay.

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ГЕНЕЗА, ЕВОЛУЦИЈА И КЛАСИФИКАЦИЈА НА ПОЧВИТЕ ОБРАЗУВАНИ ВРЗ ВАРОВНИЦИ И ДОЛОМИТИ ВО РЕПУБЛИКА МАКЕДОНИЈА

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Испитувани се почвите образувани врз варовници и доломити на различни локации во Република Македонија. Овие почви по својата генеза и еволуција и по своите својства се разликуваат од почвите образувани врз другите супстрати и имаат редица специфичности, при што сите својства во најголема мера зависат од матичниот супстрат. Овие почви заземаат голем дел од почвениот покривач на Република Македонија. Теренските истражувања се извршени според општо прифатениот метод во нашата земја [1, 2]. Поголем дел од нив се под високопланински пасишта, некои парцели се под ливади и ниви. Тие имаат големо значење за побрзиот развој на шумарството, туризмот како и за развојот на земјоделството во ридско-планинските недоволно развиени подрачја во нашата земја.

Клучни зборови: почви образувани врз варовници и доломити, генеза, еволуција, класификација

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Original scientific paper

DISTRIBUTION OF CHEMICAL ELEMENTS IN SOIL FROM CRN DRIM RIVER BASIN, REPUBLIC OF MACEDONIA[#]

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The aim of this study was to investigate the distribution of chemical elements in topsoil and subsoil, focusing on the identification of natural and anthropogenic element sources in the area of the Crn Drim River Basin, Republic of Macedonia. For that purpose, by using sampling network of 5 × 5 km, 124 soil samples from 62 locations (topsoil and bottom soil) were collected. In total 60 elements were analysed, from which 18 elements (Ag, Al, B, Ba, Ca, Cr, Cu, Fe, K, Li, Mg, Mn, Na, Ni, P, Pb, V и Zn) were analysed by inductively coupled plasma - atomic emission spectrometry (ICP-AES) and an additional 42 elements were analysed by ICP - mass spectrometry (ICP-MS). Multivariate statistical analysis was applied to the obtained data. Factor analysis applied to the ICP-AES results produced four geogenic factors: F1 (Ba and K); F2 (Ag, Cd, Cu, Ni, Pb and Zn), F3 (Cr, Fe, Na, Ni and V) and F4 (Al, Ca, Mg and Mn). Data obtained from the distribution maps and data analysis on soil samples, indicate the natural occurrence of the analysed elements as well as low concentrations of heavy metals in the studied area.

Key words: soil; Crn Drim River Basin; Republic of Macedonia; multivariate statistics; geochemical mapping

INTRODUCTION

Pollution with heavy metals is a global problem initiated by progress in world technology and the human exploitation of natural resources; this has become a subject of many studies. The regional contamination of soil occurs mainly in industrial regions and within large settlement centres, where factories, traffic and municipal waste are the most important sources of trace metals [1]. The level of environmental pollution depends on the proper control of anthropogenic activities; these factors indicate a global problem of environmental pollution [2].

Heavy metals occur as natural constituents of the Earth's crust, and are persistent environmental contaminants since they cannot be degraded or destroyed. Some heavy metals have bio-importance as trace elements, but the biotoxic effects of many on human biochemistry are of great concern. Hence, there is a need for the proper understanding of the conditions, such as concentrations and oxidation states, which make them harmful, and how biotoxicity occurs [3]. The major causes of emission are anthropogenic sources, specifically mining operations, where, in some cases, even long after mining activities have ceased, the emitted metals continue to persist in the environment [4–6].

The soil cover of the Republic of Macedonia is very heterogeneous, with great changes over small distances. Almost all of the relief forms, geological formations, climatic influences, plant associations and soils that appear in Europe (with the exception of podzols) are represented. More than 30 soil types are found in Macedonia [7–9]. According to Filipovski [10] negative degradation of soils in Macedonia started a long time ago. In recent years, results suggest that the Republic of Macedonia has the same problem of pollution by heavy metals, and the most important emission sources are mines,

[#]Dedicated to academician Gjorgji Filipovski on the occasion of his 100^{th} birthday drainage systems and smelters near the towns of Veles, Tetovo, Kavadarci and Probištip [11–21].

The goal of the present study was to investigate the spatial distribution of about 60 chemical elements in soil from the Crn Drim River Basin, in the Republic of Macedonia. For this purpose, applying a sampling network of 5 × 5 km, 124 soil samples from 62 locations (topsoil and bottom soil) were collected. The soil samples were analysed by inductively coupled plasma - atomic emission spectrometry (ICP-AES) for macro-elements (Ag, Al, B, Ba, Ca, Cr, Cu, Fe, K, Li, Mg, Mn, Na, Ni, P, Pb, V и Zn) and inductively coupled plasma - mass spectrometry (ICP-MS) for trace elements (As, Be, Bi, Br, Cd, Ce, Co, Cs, Dy, Er, Eu, Ga, Gd, Ge, Hf, Ho, I, In, La, Lu, Mo, Nb, Nd, Pd, Pr, Pt, Rb, Sb, Sc, Sm, Sn, Sr, Ta, Tb, Te, Ti, Tl, Tm, W, Y, Yb и Zr).

STUDY AREA

The investigated area is located in the southwestern part of Macedonia and covers the basin of the Crn Drim River (Figures 1 and 2). This river passes through two valleys: Ohrid-Struga and the Debar-Radika River basin. Crn Drim flows from the Ohrid Lake in the town of Struga. First it flows through Struga Field to the village of Tašmarunište, where it enters into the Drimkolska Gorge and immediately in the artificial Globočica Lake. After the Globočica dam, a short river flow is again formed to re-enter the nearby Debar Lake. It leaves it at Debar Lake dam and continues 12 km as a border river and then enters into Albania. The Crn Drim River Basin covers an area of 3,350 km^2. The area receives an average of 933 mm of precipitation per year [22, 23].

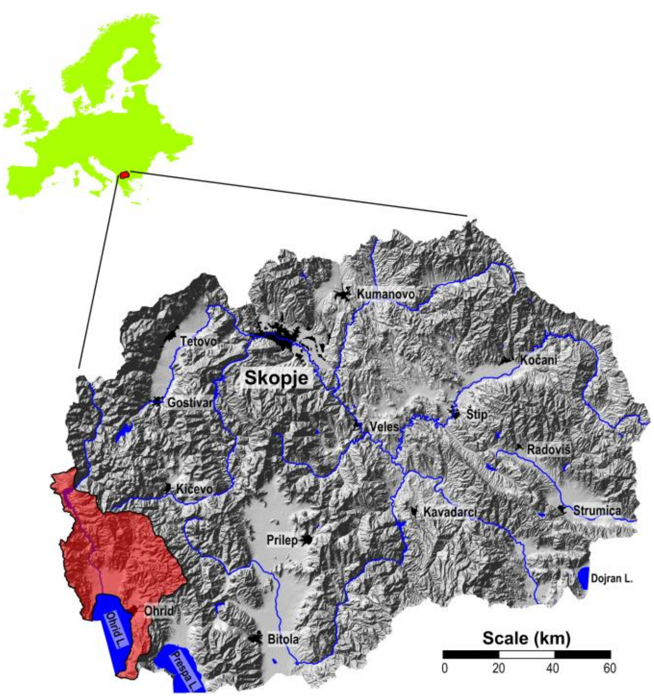

Figure 1. The investigated area on the map of the Republic of Macedonia

Figure 2. Topographic map of the investigated area

In the far southwest of the Republic of Macedonia, the Ohrid-Struga valley stretches between the Mts. of Jablanica, Belička and Mokra in the west; Mts. Galičica, Petrina, Plaćenska and Ilinska in the east; Stogovo and its branch Karaorman to the north and the hilly region of Gora to the south. It is characterised by a changed Mediterranean climate and winds coming from the west and north. The last valley is the Debarca valley, located to the north of the Ohrid valley [24].

The largest part of the Crn Drim River Basin is tectonically separated as part of the West-Macedonian zone with properties formed during the Hercynian and Alpine orogeny. During the Hercynian orogeny, Paleozoic metamorphism was formed in synclines and anticlines, while the Alpine orogeny was characterised by intense metamorphism. Later in this orogeny, Tertiary tectonic trenches were formed. Triassic sediments were formed during the Alpine orogeny, in huge structures orientated mostly in the north-south and northwest-southeast directions [25–28].

The area of Debar and low flow of the Radika River (Debar zone) is in the Cukali-Krasta zone [25–28]. The Cukali-Krasta zone is composed of Upper Cretaceous (i.e. Turonian) conglomerates: sandstones, claystones and limestones with olistostromes. In this zone, evaporites and minor Paleogene sediments are present. The boundary with the West-Macedonian zone is marked by the Stogovo nappe, after which the Paleozoic, Triassic and Jurassic complex occurs as a bundled mass; it has an allochthonous length of at least 7–10 km through the Upper Cretaceous sediments and evaporites of the Cukali-Krasta zone. This zone of the Debar area essentially represents a tectonic half-window. The diapiric structure of Dešat Mountain is very important in the Cukali-Krasta zone; it is composed of anhydrite and gypsum, characterised by partial but noticeable diapiric, internal folding and brecciation, with the development of tectonic breccias – mylonites at the contacts with the adjacent rock masses.

The geological structure of the investigated area is dominated by alluvial creations and semi-sedimentary sediments, distributed in the plains (Figure 3). This area is located in the West-Macedonian geotectonic zone, within the Ohrid Neogene Basin. In the bases of the Neogene and Quaternary sediments lies the Triassic rocks, while on the surface of the terrain are the lake and swamp sediments that are deposited in the Quaternary period; here they have the greatest distribution [25–28].

The creation of this graben structure is related to the end of the lower and early middle Pliocene: that is, the period when the expansion of the orogenic phase began with the manifestation of intense differentiated vertical movements. As a result of such processes, in the beginning, the old fault structures were reactivated and later on, they came to be a sink in the space (i. e. its transformation into Pliocene lake basins) [25, 29].

The Pliocene sediments in this area are found in the southern part, as well as in the northwest part. The Galičica Mountain is a dominant relief appearance located between Ohrid Lake to the west and Prespa Lake to the east. According to its structural characteristics, Galičica Mountain is a typical horst that has been elevated by the dominant neotectonic interblock faults.

The maximum vertical movement in the western part of Mt. Galičica was accomplished via the system of scalable faults. Due to the massiveness of limestones and the intensive radial tectonics, with which the mountain is cut into several blocks, the dials cannot be noticed. In the lower parts, the synclinal structure is constructed of Triassic conglomerates that lie over the Paleozoic metamorphites [25–28].

The area of Ohrid is characterised by Paleozoic, Triassic, Jurassic, Neocene and Quaternary formations. The Paleozoic formations consist of a thick complex of metamorphic and magmatic rocks. Based on fossil remains, this complex is divided over the Cambrian, Ordovician and Devonian periods. The Cambrian and Ordovian sections are composed of phyllite schists, and the Devonian is characterised by phylitic shales, metaconglomerates, carbon shales and marble limestones. Through the Paleozoic metamorphism, granodiorites and syenites were intertwined. The Triassic formations lie transgressive over the Paleozoic complex. In some localities (Mt. Jablanica), the Triassic sediments are overlapped with conglomerates composed of diabase, gabbro, Triassic limestone and, in the final boundaries, serpentinites and shales. Neocene sediments have the character of fresh water, and with their microflora are assumed to have formed during the Middle Pliocene period. There are also sediments of the new Pliocene. Quaternary sediments are widespread and consist of glacial, morene, and fluvioglacial sediments, Terra Rosa, travertine, breccias, thallus and alluvial deposits [29].

EXPERIMENTAL

Sampling

Samples of natural surface soils in the Crn Drim River Basin, in the Republic of Macedonia, were collected according to the European guidelines for soil pollution studies [30], and also according to our experience [12, 13, 20, 31]. The study area (3350 km^2) was covered by a sampling grid of 5 × 5 km (Figure 4). Altogether 124 soil samples were collected from 62 locations, with the collection of topsoil (0–5 cm) and subsoil (20–30 cm) samples. The possible organic horizon was excluded. One sample represents the composite material collected at the central sample point itself, and at least four points within a radius of 10 m around it towards the north, east, south and west. The mass of the composite sample was about 1 kg.

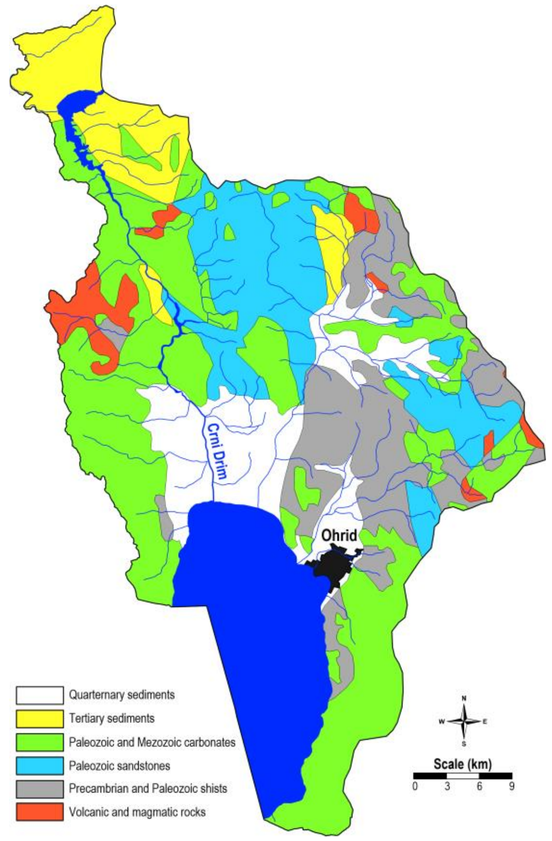

Figure 3. General geological map of the Crn Drim River Basin

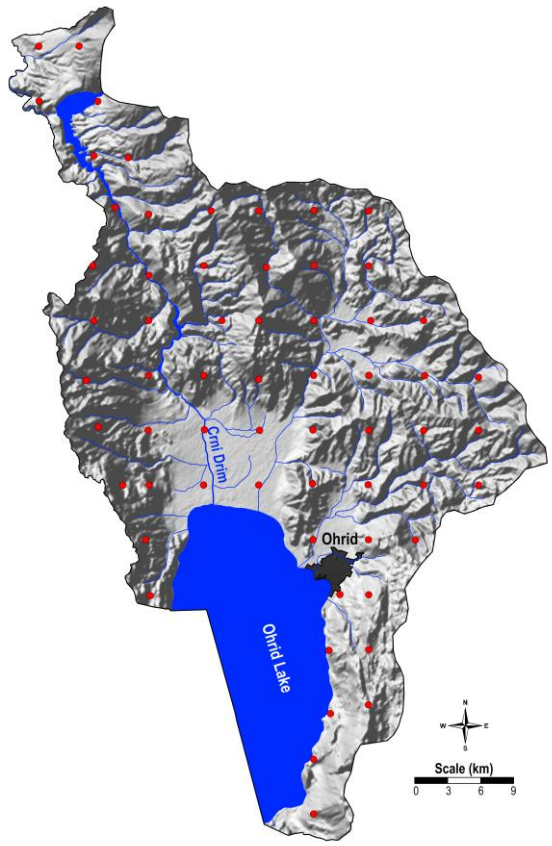

Figure 4. Soil sampling locations in the Crn Drim River Basin

Sample preparation

The soil samples were air dried indoors at room temperature for about two weeks. They were then gently crushed, cleaned of extraneous material and sifted through a plastic sieve with 2 mm mesh [30]. The sifted mass was quartered and milled in an agate mill to produce an analytical grain size below 0.125 mm.

For the digestion of soil samples, open wet digestion with a mixture of acids was applied. The digestion was carried out in this order: the precisely measured mass of dust samples (0.25 g) was placed in Teflon vessels. After this, 5 ml of concentrated HNO_3 was added, until brown vapours left the vessels. Nitric acid is a very suitable oxidant for the digestion of organic matter in samples. For the total digestion of inorganic components, 5–10 ml HF was added. When the digest became a clear solution, 2 ml of $HClO_4$ was added for the total digestion of organic matter. After cooling the vessels for 15 min, 2 ml of HCl and 5 ml of water were added for the total dissolution of metal ions. Finally, the vessels were cooled and digests were quantitatively transferred to 50 ml calibrated flasks [20].

Instrumentation

All samples were analysed by ICP-AES (Varian, model 715-ES) for the elements with higher contents according to the instrumental conditions presented by Balabanova et al. [14]. Trace elements were analysed by ICP-MS measurements on a SCIEX Perkin Elmer Elan DRC II (Canada) inductively coupled plasma mass spectrometer (with quadruple and single detector setup) under the instrumental conditions presented earlier [16]. The quality control of the applied techniques was performed using the standard addition method, and the recovery for the investigated elements ranged from 98.2 % to 100.8 %.

Data processing

Data analysis and the production of maps were performed on a PC using Paradox (ver. 9), Statistica (ver. 6.1), AutoDesk Fig. (ver. 2008) and Surfer (ver. 8.09) software. All field observations, analytical data and measurements were introduced into the data matrix. Parametric and nonparametric statistical methods were used for data analysis [20]. Based on the results of the normality tests and visual inspection of the distribution histograms, for all elements, logarithms of the element content were used to acquire normal distributions. Basic statistics for all 60 elements in the topsoil and bottom soil are given in Tables 1 and 2.

Multivariate R-mode factor analysis [20] was used to reveal associations of the chemical elements that had been determined by ICP-AES. From numerous variables, the factor analysis (FA) derives a smaller number of new, synthetic variables. Factor analysis was performed on variables standardised to a mean of zero and one unit of standard deviation [32]. As a measure of similarity between variables, the product-moment correlation coefficient (r) was applied. For orthogonal rotation, the varimax method was used.

The universal kriging method with linear variogram interpolation was applied for the construction of the areal distribution maps of the 18 elements determined by ICP-AES and the factor scores (F1–F4) for topsoil (0–5 cm) and subsoil (20–30 cm) samples. Seven classes of the following percentile values were selected: 0–10, 10–25, 25–40, 40–60, 60–75, 75–90 and 90–100.

RESULTS AND DISCUSSION

ICP-AES was applied for the analysis of 18 macro-elements (Ag, Al, B, Ba, Ca, Cr, Cu, Fe, K, Li, Mg, Mn, Na, Ni, P, Pb, V и Zn) while the additional 48 elements (As, Be, Bi, Br, Cd, Ce, Co, Cs, Dy, Er, Eu, Ga, Gd, Ge, Hf, Ho, I, In, La, Lu, Mo, Nb, Nd, Pd, Pr, Pt, Rb, Sb, Sc, Sm, Sn, Sr, Ta, Tb, Te, Ti, Tl, Tm, W, Y, Yb и Zr) were analysed by inductively coupled plasma – mass spectrometry (ICP-MS).

Descriptive statistics of the measurements for topsoil and bottom soil samples from 62 locations (124 soil samples total) are presented in Tables 1 and 2. Values for Al, Ca, Fe, K, Mg, Na and Ti are in %, values for I, Lu, In, Te and Tm are in μg/kg, and the values for the remaining elements are in mg/kg. In Tables 1 and 2, the following statistical parameters are given: X – arithmetic average; X(BC) – arithmetic average after Box-Cox method; Md – median; min – minimum; max – maximum; P_{10} – 10th percentile; P_{90} – 90th percentile; P_{25} – 25th percentile; P_{75} – 75th percentile; S – standard deviation; Sx – standard error; CV – coefficient of variation; A – skewness; E – kurtosis; BC – Box-Cox transformed values.

The order of the distribution of concentrations of the major elements Al, Ca, Fe, K, Mg, Na and Ti were in the following ranges: 0.42–6.5% Al; 0.09–4.7 % Ca; 2.2–6.7 % Fe; 0.16–2.4 % K; 0.21–7.2 % Mg, and 0.027–0.68 % Na and 0.10–0.84 % Ti. The contents of major elements are most frequently a result of the dominant geological formations of the area: Quaternary sediments, Precambrian and Paleozoic schists, Paleozoic sandstones and Paleozoic and Mesozoic carbonates.

Table 1. Descriprive statistics for the content of analyzed elements in top-soil samples the Crn Drim River Basin

Element	N	Unit	X	X(BC)	Md	Min	Max	P_{10}	P_{90}	P_{25}	P_{75}	S	Sx	CV	A	E	A(BC)	E(BC)
Ag	62	mg/kg	0.78	0.76	0.75	0.48	1.2	0.58	1.0	0.65	0.87	0.17	0.022	21.9	0.66	0.05	0.24	-0.44
Al	62	%	2.1	1.8	1.7	0.44	6.5	0.91	3.8	1.2	2.8	1.2	0.16	60.1	1.35	1.99	0.12	-0.38
As	62	mg/kg	27	16	16	4.7	270	7.1	46	11	28	38	4.8	141	4.99	29.43	-0.10	-0.25
B	62	mg/kg	58	55	54	26	114	37	84	43	71	19	2.4	32.3	0.71	0.27	-0.06	-0.37
Ba	62	mg/kg	310	270	250	65	940	150	570	180	390	190	24	60.9	1.39	1.80	0.31	-0.08
Be	54	mg/kg	2.3	2.2	2.3	0.072	4.9	0.51	3.8	1.6	2.9	1.1	0.15	49.2	0.20	0.09	-0.21	0.11
Bi	54	mg/kg	0.23	0.18	0.18	0.005	0.83	0.050	0.49	0.10	0.32	0.18	0.025	79.5	1.30	1.66	-0.05	-0.13
Br	54	mg/kg	3.2	2.7	2.9	0.005	6.9	0.87	6.0	1.6	4.7	1.9	0.26	59.6	0.23	-1.03	-0.99	1.20
Ca	62	%	0.78	0.55	0.56	0.11	4.6	0.26	1.5	0.39	0.76	0.78	0.099	101	3.04	10.93	-0.06	0.65
Cd	62	mg/kg	0.64	0.30	0.30	0.005	3.4	0.035	2.1	0.15	0.62	0.86	0.11	133	1.90	2.60	-0.20	0.06
Ce	54	mg/kg	20	16	16	1.3	58	5.0	46	7.0	27	15	2.0	73.9	0.80	-0.16	-0.31	-0.54
Co	57	mg/kg	17	14	13	1.0	76	6.9	28	10	19	14	1.8	81.2	2.96	10.19	0.31	2.73
Cr	62	mg/kg	120	85	87	50	1000	59	180	69	110	130	17	112	5.81	39.14	0.08	-0.43
Cs	54	mg/kg	3.5	3.1	3.1	0.24	11	0.95	6.6	2.1	4.5	2.4	0.33	68.2	1.27	1.48	0.39	0.09
Cu	62	mg/kg	34	31	30	8.0	125	19	47	23	41	17	2.1	50.2	2.81	13.48	0.31	2.28
Dy	54	mg/kg	1.6	1.1	1.5	0.037	6.0	0.23	2.9	0.53	2.1	1.4	0.18	85.9	1.48	2.40	-0.28	-0.29
Er	54	mg/kg	0.81	0.56	0.71	0.016	3.5	0.11	1.5	0.21	1.1	0.72	0.098	89.2	1.56	3.03	-0.28	-0.41
Eu	54	mg/kg	0.53	0.40	0.40	0.051	1.7	0.10	1.1	0.23	0.74	0.42	0.057	78.7	1.14	0.84	-0.20	-0.72
Fe	62	%	3.8	3.7	3.6	2.2	6.6	2.8	5.2	3.3	4.5	0.91	0.12	23.8	0.78	0.29	0.01	-0.23
Ga	54	mg/kg	13	12	12	3.5	37	5.7	21	8.7	15	6.1	0.83	47.1	1.41	3.52	0.26	0.71
Gd	54	mg/kg	2.2	1.6	1.9	0.077	7.6	0.42	4.0	0.75	3.0	1.8	0.25	82.9	1.40	1.91	-0.28	-0.21
Ge	54	mg/kg	0.36	0.22	0.20	0.070	2.4	0.099	0.81	0.14	0.41	0.43	0.058	118	3.05	10.94	0.22	-0.61
Hf	54	mg/kg	1.1	0.90	1.0	0.065	3.4	0.26	1.9	0.47	1.5	0.74	0.10	68.8	1.03	1.54	-0.22	-0.39
Ho	54	mg/kg	0.30	0.21	0.26	0.005	1.2	0.045	0.56	0.085	0.39	0.26	0.036	88.1	1.52	2.72	-0.30	-0.29
I	54	µg/kg	55	23	22	5.0	250	5.0	140	5.0	98	64	8.8	116	1.38	1.19	0.03	-1.57
In	54	µg/kg	38	34	36	5.0	111	15	64	21	48	21	2.9	56.2	1.18	2.12	0.07	0.35
K	62	%	1.4	1.4	1.3	0.33	2.4	0.77	2.1	1.1	1.7	0.50	0.063	35.9	0.12	-0.65	0.06	-0.62
La	54	mg/kg	12	8.4	9.8	0.59	57	2.5	26	4.0	14	11	1.5	94.4	2.24	6.38	-0.11	0.14
Li	62	mg/kg	32	31	30	12	62	19	46	25	39	11	1.4	35.2	0.42	-0.14	0.08	-0.31
Lu	54	µg/kg	120	88	110	5.0	460	18	230	43	160	94	13	80.2	1.31	2.33	-0.25	-0.47
Mg	62	%	0.92	0.67	0.64	0.22	7.2	0.35	1.5	0.47	1.0	0.96	0.12	105	4.92	30.68	0.01	0.19
Mn	62	mg/kg	820	730	820	61	3700	320	1200	510	1000	510	65	62.0	3.00	16.23	-0.01	2.35
Mo	54	mg/kg	0.71	0.24	0.43	0.005	3.0	0.005	1.9	0.005	1.1	0.81	0.11	115	1.25	0.72	-0.33	-1.42
Na	62	%	0.16	0.13	0.12	0.029	0.67	0.061	0.29	0.089	0.20	0.12	0.015	70.6	2.10	6.05	0.14	-0.08
Nb	54	mg/kg	61	19	19	3.0	950	7.9	140	12	34	150	20	237	4.87	27.05	-0.27	0.73
Nd	54	mg/kg	9.4	7.5	8.3	0.54	29	2.1	19	3.4	13	7.0	0.96	74.8	1.18	1.25	-0.25	-0.24
Ni	62	mg/kg	92	63	61	12	1000	32	140	42	98	130	17	142	5.82	38.78	0.03	1.27
P	62	mg/kg	810	720	730	250	2600	430	1300	530	950	420	54	52.1	2.00	5.75	0.01	0.43
Pb	62	mg/kg	32	32	31	14	62	21	44	26	39	9.3	1.2	28.7	0.50	0.73	0.32	0.46
Pd	54	mg/kg	0.51	0.41	0.41	0.050	1.7	0.11	1.0	0.26	0.72	0.38	0.052	75.6	1.38	1.86	-0.14	-0.06
Pr	54	mg/kg	2.4	1.9	2.2	0.14	7.0	0.57	4.8	0.91	3.4	1.7	0.24	72.5	1.08	0.99	-0.26	-0.27
Pt	54	mg/kg	0.31	0.24	0.30	0.005	1.0	0.063	0.68	0.098	0.48	0.26	0.035	82.5	0.90	0.18	-0.08	-0.88
Rb	54	mg/kg	52	47	46	3.5	148	14	100	24	68	33	4.6	64.2	1.01	0.67	0.24	-0.26
Sb	54	mg/kg	1.5	0.57	0.64	0.074	45	0.20	1.3	0.48	0.87	6.0	0.82	398	7.30	53.50	-0.32	3.57
Sc	54	mg/kg	6.3	5.1	5.5	1.1	33	2.0	10	3.5	8.1	4.9	0.67	78.2	3.33	16.65	0.03	0.26
Sm	54	mg/kg	1.9	1.5	1.7	0.10	6.1	0.38	3.8	0.69	2.6	1.5	0.20	78.0	1.28	1.51	-0.23	-0.26

Table 1 (continuation)

Sn	54	mg/kg	17	11	10	0.30	141	2.2	36	5.8	24	21	2.9	124	3.89	20.61	-0.19	0.60
Sr	54	mg/kg	28	25	27	0.88	79	9.6	46	17	39	17	2.3	58.8	0.88	0.97	-0.47	0.70
Ta	54	mg/kg	1.0	0.62	0.75	0.050	7.6	0.16	2.0	0.36	1.2	1.2	0.16	117	3.59	16.66	-0.80	1.08
Tb	54	mg/kg	0.29	0.22	0.26	0.005	1.0	0.051	0.53	0.10	0.41	0.25	0.034	83.9	1.43	2.13	-0.32	-0.05
Te	54	µg/kg	27	11	5.0	5.0	200	5.0	64	5.0	40	38	5.2	144	2.92	10.00	0.40	-1.54
Ti	54	%	0.32	0.29	0.29	0.10	0.84	0.18	0.49	0.23	0.36	0.14	0.019	44.2	1.45	3.18	0.16	0.46
Tl	54	mg/kg	0.46	0.36	0.38	0.050	1.5	0.050	0.90	0.17	0.71	0.35	0.047	76.4	0.84	0.22	-0.18	-0.91
Tm	54	µg/kg	110	82	100	5.0	480	16	220	33	150	100	14	87.5	1.50	2.82	-0.18	-0.63
V	62	mg/kg	110	99	98	65	410	71	150	87	120	48	6.2	44.0	4.21	24.67	0.00	-0.09
W	54	mg/kg	1.4	1.1	1.1	0.064	4.8	0.20	2.8	0.61	2.1	1.1	0.14	74.1	0.97	0.88	-0.19	-0.55
Y	54	mg/kg	7.2	5.3	4.9	0.22	29	1.6	12	2.8	11	6.1	0.83	84.8	1.63	3.01	-0.24	0.06
Yb	54	mg/kg	0.73	0.52	0.66	0.018	3.1	0.11	1.4	0.22	0.99	0.63	0.085	86.4	1.48	2.82	-0.25	-0.49
Zn	62	mg/kg	140	130	130	58	290	90	210	110	170	52	6.5	36.1	1.05	1.03	-0.20	0.34
Zr	54	mg/kg	58	53	56	7.1	144	21	95	37	78	30	4.1	51.7	0.66	0.42	-0.25	-0.17

N – Number of samples; X – mean; X(BC) – mean of Box-Cox transformed values; Md – median; Min – minimum; Max – maximum; P_{10} – 10th percentile; P_{25} – 25th percentile; P_{75} – 75th percentile; P_{90} – 90th percentile; S – standard deviation; S_x – standard deviation of transformed values; CV – coefficient of variation, A – skewness; E – kurtosis; BC – Box-Cox transformed values

Table 2. Descriprive statistics for the content of analyzed elements in sub-soil samples from the Crn Drim River Basin

Element	n	Unit	X	X(BC)	Md	Min	Max	P_{10}	P_{90}	P_{25}	P_{75}	S	Sx	CV	A	E	A(BC)	E(BC)
Ag	62	mg/kg	0.82	0.80	0.80	0.44	1.2	0.59	1.1	0.68	0.93	0.18	0.022	21.5	0.20	-0.51	-0.24	-0.29
Al	62	%	2.4	2.0	1.9	0.42	5.9	0.83	4.4	1.4	3.2	1.4	0.17	58.0	0.89	0.17	-0.15	-0.58
As	62	mg/kg	27	16	16	5.5	280	8.2	50	11	31	39	5.0	143	5.00	30.39	0.20	-0.39
B	62	mg/kg	60	56	59	25	140	38	87	45	67	21	2.7	35.5	1.43	3.51	0.04	0.60
Ba	62	mg/kg	310	260	240	28	980	90	580	150	390	210	26	67.2	1.19	1.27	-0.13	-0.11
Be	58	mg/kg	2.3	2.3	2.1	0.005	5.3	0.84	3.9	1.8	3.1	1.2	0.16	50.7	0.36	0.20	-0.08	0.20
Bi	58	mg/kg	0.20	0.16	0.17	0.005	0.78	0.048	0.40	0.10	0.24	0.15	0.020	77.9	1.58	3.03	0.00	0.42
Br	58	mg/kg	3.9	3.0	2.7	0.005	20	0.76	8.1	1.8	4.5	4.2	0.55	106	2.52	6.87	0.54	1.38
Ca	62	%	1.0	0.56	0.54	0.095	4.7	0.21	2.7	0.31	1.0	1.2	0.15	117	1.98	3.10	0.02	-0.28
Cd	62	mg/kg	0.83	0.34	0.29	0.005	7.3	0.052	2.1	0.13	0.94	1.3	0.17	160	2.92	9.90	0.14	-0.07
Ce	58	mg/kg	21	15	14	0.37	105	2.5	55	7.9	29	22	2.8	102	1.97	4.32	0.15	-0.05
Co	59	mg/kg	16	14	14	1.9	56	7.0	29	9.9	22	9.5	1.2	58.5	1.51	3.93	-0.26	0.74
Cr	62	mg/kg	120	86	86	49	910	59	180	69	110	120	15	102	5.03	30.75	0.23	-0.43
Cs	58	mg/kg	3.2	2.9	3.2	0.069	8.9	0.84	5.5	1.9	4.1	1.9	0.25	58.4	0.71	0.75	-0.45	0.53
Cu	62	mg/kg	35	33	34	11	75	21	50	25	44	13	1.7	37.9	0.56	0.34	-0.30	-0.05
Dy	58	mg/kg	1.6	1.1	1.1	0.091	6.7	0.23	4.7	0.60	2.1	1.6	0.21	99.4	1.78	2.62	0.21	-0.24
Er	58	mg/kg	0.84	0.57	0.52	0.046	3.8	0.11	2.3	0.30	1.0	0.86	0.11	103	1.81	2.77	0.22	-0.24
Eu	58	mg/kg	0.52	0.37	0.35	0.025	2.2	0.10	1.2	0.18	0.65	0.49	0.065	94.5	1.73	2.64	0.13	-0.19
Fe	62	%	4.0	3.9	3.9	2.4	6.7	3.0	5.3	3.3	4.7	0.91	0.12	22.6	0.74	0.24	0.07	-0.51
Ga	58	mg/kg	13	12	13	2.8	30	6.7	20	9.5	16	5.2	0.69	40.1	0.76	1.40	-0.25	0.72
Gd	58	mg/kg	2.3	1.6	1.5	0.11	9.6	0.31	5.1	0.70	2.8	2.3	0.30	98.6	1.79	2.75	0.19	-0.28
Ge	58	mg/kg	0.37	0.23	0.20	0.075	1.5	0.096	1.1	0.15	0.48	0.35	0.047	96.2	1.80	2.64	0.03	-1.03
Hf	58	mg/kg	1.1	0.92	0.94	0.071	3.0	0.31	2.7	0.43	1.6	0.82	0.11	73.8	0.84	-0.31	0.04	-0.79
Ho	58	mg/kg	0.31	0.21	0.21	0.018	1.4	0.041	0.88	0.12	0.37	0.32	0.041	102	1.79	2.63	0.25	-0.26
I	58	µg/kg	110	36	42	5.0	1500	5.0	290	14	95	230	30	209	4.84	27.93	0.03	-0.66

Table 2 (continuation)

In	58	µg/kg	37	34	36	5.0	96	15	59	25	47	18	2.4	49.1	0.88	1.26	-0.06	0.19
K	62	%	1.4	1.4	1.5	0.16	2.4	0.73	2.1	1.0	1.9	0.51	0.064	35.9	-0.13	-0.55	-0.21	-0.45
La	58	mg/kg	12	7.8	6.8	0.39	60	1.4	30	3.5	17	13	1.7	105	1.66	2.71	0.06	-0.50
Li	62	mg/kg	34	33	33	7.4	67	19	51	26	39	12	1.5	35.1	0.43	0.53	-0.09	0.51
Lu	58	µg/kg	120	88	79	5.0	520	18	340	46	150	110	15	93.8	1.67	2.50	0.15	-0.14
Mg	62	%	0.91	0.67	0.69	0.21	5.8	0.30	1.7	0.44	1.1	0.84	0.11	91.5	3.66	18.66	0.01	-0.36
Mn	62	mg/kg	820	720	770	87	4500	350	1300	530	1000	600	76	73.0	3.92	23.58	0.24	3.00
Mo	58	mg/kg	0.68	0.21	0.44	0.005	7.7	0.005	1.4	0.005	0.80	1.2	0.16	175	4.24	22.22	-0.09	-1.08
Na	62	%	0.16	0.12	0.12	0.027	0.68	0.051	0.29	0.071	0.20	0.12	0.015	75.8	1.98	5.64	-0.04	-0.35
Nb	58	mg/kg	79	22	20	3.3	1300	10	150	13	37	210	27	261	4.66	23.90	0.33	0.73
Nd	58	mg/kg	9.5	7.1	6.8	0.39	39	1.4	22	3.6	13	8.7	1.1	91.2	1.61	2.37	0.13	-0.30
Ni	62	mg/kg	100	64	68	12	1200	31	160	43	99	150	20	154	6.03	41.27	-0.14	1.08
P	62	mg/kg	750	650	650	250	2700	320	1300	500	890	430	54	57.0	1.96	6.03	0.06	-0.21
Pb	62	mg/kg	30	30	29	5.0	50	19	43	23	37	9.0	1.1	29.8	-0.01	-0.08	-0.23	0.34
Pd	58	mg/kg	0.45	0.34	0.36	0.050	2.0	0.050	0.95	0.15	0.61	0.39	0.052	88.1	1.80	4.25	0.07	-0.41
Pr	58	mg/kg	2.4	1.8	1.7	0.098	9.9	0.35	5.6	0.98	3.3	2.2	0.29	90.0	1.60	2.47	0.13	-0.28
Pt	58	mg/kg	0.28	0.22	0.28	0.005	1.1	0.053	0.52	0.10	0.44	0.23	0.030	80.7	1.41	3.11	-0.12	-0.30
Rb	58	mg/kg	45	41	40	0.95	135	12	79	28	57	26	3.4	57.9	0.87	1.53	-0.36	0.65
Sb	58	mg/kg	1.1	0.51	0.59	0.067	26	0.17	1.1	0.37	0.82	3.4	0.45	310	7.33	54.95	-0.02	2.69
Sc	58	mg/kg	6.3	5.2	5.1	1.2	25	2.4	13	3.5	8.1	4.1	0.54	66.0	1.90	5.70	-0.02	-0.15
Sm	58	mg/kg	2.0	1.4	1.3	0.050	7.8	0.32	4.4	0.67	2.6	1.8	0.24	93.6	1.65	2.36	0.12	-0.22
Sn	58	mg/kg	15	9.5	8.5	0.67	107	2.5	42	3.9	19	18	2.3	118	2.88	11.57	0.19	-0.14
Sr	58	mg/kg	27	23	21	2.9	107	8.8	51	13	36	20	2.7	75.2	1.75	3.85	0.41	0.25
Ta	58	mg/kg	3.2	0.71	0.82	0.050	131	0.22	1.8	0.42	1.2	17	2.3	535	7.58	57.62	0.60	4.49
Tb	58	mg/kg	0.30	0.22	0.22	0.017	1.2	0.043	0.76	0.11	0.40	0.30	0.039	98.1	1.78	2.64	0.26	-0.26
Te	58	µg/kg	36	14	18	5.0	290	5.0	95	5.0	46	49	6.5	138	2.97	11.77	0.04	-1.64
Ti	58	%	0.31	0.29	0.29	0.11	0.74	0.18	0.44	0.23	0.37	0.11	0.014	34.9	1.12	3.54	-0.24	0.85
Tl	58	mg/kg	0.47	0.36	0.40	0.050	1.5	0.050	0.96	0.16	0.70	0.38	0.050	80.4	0.95	0.35	-0.03	-1.01
Tm	58	µg/kg	120	81	75	5.0	540	16	320	46	150	120	16	101	1.79	2.81	0.09	-0.08
V	62	mg/kg	120	110	110	65	390	81	170	90	130	49	6.2	42.1	3.37	15.88	0.07	0.21
W	58	mg/kg	1.4	1.1	1.1	0.060	5.5	0.32	3.2	0.54	2.1	1.1	0.15	80.7	1.32	1.87	0.06	-0.40
Y	58	mg/kg	8.0	5.4	4.6	0.33	33	1.5	20	2.4	12	7.9	1.0	99.4	1.61	2.14	0.13	-0.45
Yb	58	mg/kg	0.76	0.53	0.47	0.036	3.4	0.098	2.1	0.30	0.94	0.75	0.099	99.4	1.77	2.74	0.17	-0.21
Zn	62	mg/kg	140	130	130	68	350	94	210	110	170	52	6.5	36.3	1.58	3.59	0.24	0.18
Zr	58	mg/kg	62	55	51	11	157	22	120	35	97	36	4.7	58.2	0.63	-0.61	0.06	-0.90

N – Number of samples; X – mean; X(BC) – mean of Box-Cox transformed values; Md – median; Min – minimum; Max – maximum; P_{10} – 10th percentile; P_{25} – 25th percentile; P_{75} – 75th percentile; P_{90} – 90th percentile; S – standard deviation; S_x – standard deviation of transformed values; CV – coefficient of variation, A – skewness; E – kurtosis; BC – Box-Cox transformed values

Table 3. The ratios of the element average content in topsoil (TS) and subsoil (SS) samples from the Crn Drim River Basin

Element	Topsoil	Subsoil	Ratio (TS/SS)	T (test)	Sign	F (ratio)	Sign	R (TS/SS)	Sign
Ag	0.76	0.80	0.95	-1.35	NS	1.07	NS	0.45	*
Al	17900	20100	0.89	-1.09	NS	1.11	NS	0.51	*
As	16.23	16.44	0.99	-0.10	NS	1.08	NS	0.30	*
B	54.8	56.3	0.97	-0.46	NS	1.09	NS	0.52	*
Ba	274	256	1.07	0.60	NS	1.44	NS	0.86	*
Be	2.18	2.25	0.97	-0.31	NS	1.11	NS	0.58	*
Bi	0.18	0.16	1.14	0.79	NS	1.24	NS	0.25	NS
Br	2.69	2.96	0.91	-0.56	NS	1.72	NS	0.23	NS
Ca	54799	5560	0.99	-0.10	NS	1.71	NS	0.79	*
Cd	0.30	0.34	0.88	-0.47	NS	1.13	NS	0.64	*
Ce	15.52	14.82	1.05	0.25	NS	1.39	NS	0.40	*
Co	14.23	14.15	1.01	0.04	NS	1.26	NS	0.54	*
Cr	85.0	86.2	0.99	-0.20	NS	1.05	NS	0.90	*
Cs	3.14	2.89	1.09	0.63	NS	1.15	NS	0.48	*
Cu	30.95	33.05	0.94	-0.86	NS	1.22	NS	0.76	*
Dy	1.13	1.14	1.00	-0.02	NS	1.00	NS	0.40	*
Er	0.56	0.57	0.99	-0.07	NS	1.03	NS	0.43	*
Eu	0.40	0.37	1.07	0.37	NS	1.08	NS	0.31	*
Fe	36932	38931	0.95	-1.32	NS	1.15	NS	0.87	*
Ga	12.11	12.32	0.98	-0.21	NS	1.20	NS	0.21	NS
Gd	1.64	1.60	1.03	0.14	NS	1.08	NS	0.36	*
Ge	0.22	0.23	0.96	-0.27	NS	1.10	NS	0.00	NS
Hf	0.90	0.92	0.98	-0.12	NS	1.10	NS	0.20	NS
Ho	0.21	0.21	0.98	-0.08	NS	1.04	NS	0.43	*
I	0.02	0.04	0.63	-1.72	NS	1.00	NS	0.35	*
In	0.03	0.03	0.99	-0.08	NS	1.27	NS	0.08	NS
K	13792	14033	0.98	-0.27	NS	1.04	NS	0.91	*
La	8.40	7.75	1.08	0.40	NS	1.34	NS	0.46	*
Li	31.18	32.91	0.95	-0.83	NS	1.09	NS	0.93	*
Lu	0.09	0.09	1.00	0.00	NS	1.07	NS	0.33	*
Mg	6722	6701	1.00	0.03	NS	1.07	NS	0.88	*
Mn	732	715.6	1.02	0.20	NS	1.18	NS	0.93	*
Mo	0.24	0.21	1.18	0.42	NS	1.02	NS	0.21	NS
Na	1328	1205	1.10	0.82	NS	1.31	NS	0.91	*
Nb	19.4	22.1	0.88	-0.69	NS	1.28	NS	0.62	*
Nd	7.48	7.07	1.06	0.33	NS	1.24	NS	0.36	*
Ni	62.6	64.2	0.97	-0.20	NS	1.15	NS	0.93	*
P	720	648	1.11	1.20	NS	1.24	NS	0.90	*
Pb	32.24	30.01	1.07	1.35	NS	1.00	NS	0.73	*
Pd	0.41	0.34	1.21	1.13	NS	1.17	NS	0.24	NS
Pr	1.94	1.81	1.07	0.39	NS	1.28	NS	0.36	*
Pt	0.24	0.22	1.09	0.46	NS	1.21	NS	0.02	NS
Rb	46.83	40.59	1.15	1.14	NS	1.21	NS	0.42	*
Sb	0.57	0.51	1.11	0.67	NS	1.05	NS	0.66	*
Sc	5.09	5.20	0.98	-0.17	NS	1.12	NS	0.28	NS
Sm	1.47	1.42	1.04	0.22	NS	1.20	NS	0.35	*
Sn	10.75	9.48	1.13	0.59	NS	1.13	NS	0.17	NS
Sr	25.03	22.97	1.09	0.64	NS	1.14	NS	0.55	*
Ta	0.62	0.71	0.88	-0.65	NS	1.01	NS	0.45	*
Tb	0.22	0.22	1.01	0.03	NS	1.01	NS	0.37	*

Table 3 (continuation)

Te	0.01	0.01	0.79	-1.22	NS	1.07	NS	0.66	*
Ti	2921	2906	1.01	0.07	NS	1.43	NS	0.22	NS
Tl	0.36	0.36	0.99	-0.07	NS	1.06	NS	0.18	NS
Tm	0.08	0.08	1.01	0.03	NS	1.06	NS	0.42	*
V	99.1	105	0.94	-1.26	NS	1.16	NS	0.90	*
W	1.14	1.11	1.03	0.16	NS	1.02	NS	0.26	NS
Y	5.34	5.38	0.99	-0.04	NS	1.26	NS	0.61	*
Yb	0.52	0.53	0.98	-0.09	NS	1.00	NS	0.40	*
Zn	132.8	132.6	1.00	0.03	NS	1.16	NS	0.65	*
Zr	52.82	55.22	0.96	-0.40	NS	1.25	NS	0.51	*

NS – non-significant; * – significant

In order to determine the dependence of the average contents (Box Cox) of the analysed elements between the topsoil and the subsoil, the ratio of the contents was calculated (Table 3). The elements distribution should not vary significantly between the topsoil (0–5 cm) and the subsoil (20–30 cm), except if certain destructive anthropogenic or natural processes contribute to variation in the concentration. For almost all elements, insignificant differences were noted for their content in the topsoil versus subsoil. Thus, this relation varied from 0.88 for Cd and Ta to 1.18 for Mo, which shows an absence of a significant influence of possible soil pollution from anthropogenic activities. It should be noted that the significant difference in iodine content (ration of 0.63) is due to iodine dynamics in soils, by its movement beyond the topsoil during rainfall or drainage events; it appears to be effectively retained in the deeper soil horizons by the substantial adsorption capacity provided by relatively small amounts of humus [33].

A comparative analysis conducted based on the contents of the analysed elements in topsoils from the Crn Drim River Basin region and soil from Macedonia [20] and Europe [29] is given in Table 4. For the comparative analysis, median values were used as a more stable parameter, as well as the range of the content for each element. The median content of Al (1.7 %) and Fe (3.6 %) was higher than the median for the soil from the whole territory of Macedonia (1.3 % and 3.5 %, respectively), while the contents of the other macro-elements (Ca, Fe, K, Li, Mg, Na and Ti) were lower in relation to the Macedonian soil. The median values for some of the trace elements were lower (Ba, Bi, Ce, Co, La, Mo, Rb, Sb, Sc, Tl, W and Y), higher for some elements (As, Be, Nb, Ni, P, Sn, Sr, Ta and V) and very similar for other elements (Cd, Cr, Cu, Hf, Li, Mn, Pb) in soil samples from Crn Drim River Basin compared with those from Macedonian soil, which shows that their distribution corresponds to the lithogenic origin of the rocks. Comparing the median values of soil from Crn Drim River Basin with the European soil (Table 4), the content of Al and Na was much lower in relation to the data published by Salminen et al. [30], while for the other macro-elements the values did not show significant variations. The distribution of the remaining chemical elements corresponded to the lithogenic origin of the rocks in the separate subregions of the area (Figure 3). The only major difference was in the content of Cu and Zn, which were more than two times higher in topsoil from the Crn Drim River Basin than in the European soil. It is important to note that, except in the case of Ba, the median value for all the elements included in The New Dutchlist, such as As, Cd, Co, Cr, Cu, Pb, Mo, Ni and Zn (http://www.contaminatedland.co.uk), were mostly below the target values.

Because of the great number of variables, data reduction was performed using factor analysis; this was performed only for the elements analysed by ICP-AES. A matrix of correlation coefficients was produced based on previously standardised and Box-Cox transformed values for element contents in the samples of topsoil and subsoil (Table 5). In the factor analysis, 62 samples of topsoil (0–5 cm) and 62 samples of subsoil (20–30 cm) and the analysis of 19 chemical elements were considered. From the R-mode factor analysis, three chemical elements (B, Li and P) were eliminated from further analysis because they had low shares of communality or low tendencies to form independent factors. Table 5 shows the loadings of values for each individual element on each factor, showing four geochemical associations. The total communality of the factors was 69.8 % (Table 5).

Based on the results of the factor analysis (Table 5) and the trends shown on the geochemical maps, four natural geochemical associations in the soil have been defined: Factor 1 (Ba, K, Ni), Factor 2 (Ag, Cd, Cu, Pb, Zn), Factor 3 (Cr, Fe, Na, Ni, V) and Factor 4 (Al, Ca, Mg, Mn).

Table 4. Comparison of the median, minimal and maximal values of the content of the analysed elements in top-soil from the Crn Drim River Basin with soil from Macedonia and Europe

Element	Unit	Dutchlist		Crn Drim River Basin		Macedonia [20]		Europe [30]	
		Target	Action	Md	Min–Max	Md	Min–Max	Md	Min–Max
Ag	mg/kg			0.75	0.48-1.2	-	-	0.27	0.01-3.15
Al	%			1.7	0.44-6.5	1.3	0.05-35	5.8	0.70-14.1
As	mg/kg	29	55	16	4.7-270	10	1.0-720	12	0.32-562
B	mg/kg			54	26-114	-	-	-	-
Ba	mg/kg	200	625	250	65-940	430	6-2900	375	30-1870
Be	mg/kg			2.3	0.072-4.9	2.0	<1.0–8.0	<2.0	<2.0-18.7
Bi	mg/kg			0.18	0.005-0.83	0.30	<0.1-15	<0.5	<0.5-9.57
Br	mg/kg			2.9	0.005-6.9	-	-	-	-
Ca	%			0.56	0.11-4.6	1.3	0.05-35	0.66	0.019-34.3
Cd	mg/kg	0.8	12	0.30	0.005-3.4	0.30	0.01-110	0.92	0.03-14
Ce	mg/kg			16	1.3-58	56	1.0–180	48.2	1.04-379
Co	mg/kg	20	240	13	1.0-76	17	0.50–150	8.0	<1.0-191
Cr	mg/kg	100	380	87	50-1000	88	5.0-2700	60	<3-6230
Cs	mg/kg			3.1	0.24-11	-	-	2.71	<0.5-69
Cu	mg/kg	36	190	30	8.0-125	28	1.6-270	13	0.81-256
Dy	mg/kg			1.5	0.037-6.9	-	-	3.42	0.18-45
Er	mg/kg			0.71	0.016-3.5	-	-	1.98	0.12-26
Eu	mg/kg			0.40	0.051-1.7	-	-	0.77	0.05-7.0
Fe	%			3.6	2.2-6.6	3.5	0.03-12	1.34	0.049-10.6
Ga	mg/kg			12	3.5-37	-	-	13.5	0.54-34
Gd	mg/kg			1.9	0.077-7.6	-	-	3.85	0.20-36
Ge	mg/kg			0.20	0.070-2.4	-	-	-	-
Hf	mg/kg			1.0	0.065-3.4	1.0	<0.10–6.6	5.55	<0.2-21
Ho	mg/kg			0.26	0.005-1.2	-	-	0.72	0.03-9.2
I	mg/kg			22	5.0-250	-	-	3.94	<2-71
In	mg/kg			0.036	0.005-0.11	-	-	0.05	<0.01-0.41
K	%			1.3	0.33-2.4	1.9	0.02-5.3	1.59	0.022–5.1
La	mg/kg			9.8	0.59-57	25	0.60–88	23	1.10-143
Li	mg/kg			30	12-62	26	1.8-210	-	-
Lu	mg/kg			0.11	0.005-0.46	-	-	0.30	<0.02-3.21
Mg	%			0.64	0.22-7.2	0.94	0.12-13	0.47	<0.006–15
Mn	mg/kg			820	61-3700	900	17-10000	510	31-6070
Mo	mg/kg	10	200	0.43	0.005-3.0	0.90	<0.10–51	0.61	<0.10-21
Na	%			0.12	0.029-0.67	1.3	0.007-3.7	0.6	0.03-3.34
Nb	mg/kg			19	3.0-950	11	0.30–2000	9.68	0.45-134
Nd	mg/kg			8.3	0.54-29	-	-	21	1.14-132
Ni	mg/kg	35	210	61	12-1000	46	2.1-2500	18	<2-2690
P	mg/kg			730	250-2600	620	110-3900	960	82-9900
Pb	mg/kg	85	530	31	14-62	32	1.2-10000	23	5.3-970
Pd	mg/kg			0.41	0.050-1.7	-	-	-	-
Pr	mg/kg			2.2	0.14-7.0	-	-	5.6	0.29-31.6
Pt	mg/kg			0.30	0.005-1.0	-	-	-	-
Rb	mg/kg			46	3.5-148	86	0.70–390	-	-
Sb	mg/kg			0.64	0.074-45	0.80	<0.10–630	0.60	0.02-31
Sc	mg/kg			5.5	1.1-33	12	<1.0–39	8.21	<0.50-54
Sm	mg/kg			1.7	0.10-6.1	-	-	3.96	0.23-30
Sn	mg/kg			10	0.30-141	2.6	<0.10–680	3.00	<2.0-106
Sr	mg/kg			27	0.88-79	140	21-1400	89	8-3120
Ta	mg/kg			0.75	0.050-7.6	0.70	<0.10–30	0.68	<0.05-6.8
Tb	mg/kg			0.26	0.005-1.0	-	-	0.60	0.03-7.0
Te	mg/kg			0.005	0.005-0.20	-	-	0.03	<0.02-0.93
Ti	%			0.29	0.10-0.84	0.34	0.004–1.2	0.34	0.012-3.27
Tl	mg/kg			0.38	0.050-1.5	0.70	<0.50–16	0.66	0.05-24
Tm	mg/kg			0.10	0.005-0.48	-	-	0.30	0.05-4.03
V	mg/kg			98	65-410	89	1.0-470	60	2.7-537
W	mg/kg			1.1	0.064-4.8	1.3	0.20–18	<5.0	<5.0-14
Y	mg/kg			4.9	0.22-29	18	0.30–110	21	<3.0-267
Yb	mg/kg			0.66	0.018-3.1	-	-	1.99	0.09-25
Zn	mg/kg			130	58-290	83	8.0-10000	52	<3-2900
Zr	mg/kg	140	720	56	7.1-144	35	0.80–210	231	5.0-1060

Md – median; Min – minimum; Max – Maximum

Table 5. Matrix of dominant rotated factor loadings (n = 124, 16 selected elements)

Element	F1	F2	F3	F4	Comm
Ba	**0.82**	0.17	0.05	-0.22	75.5
K	**0.86**	-0.13	-0.02	-0.07	75.7
Ag	-0.08	**0.67**	0.21	0.20	54.0
Cd	-0.34	**0.71**	-0.01	0.01	62.4
Cu	-0.14	**0.55**	0.30	0.45	58.5
Pb	0.33	**0.67**	-0.25	0.00	62.1
Zn	0.16	**0.79**	0.34	0.17	80.0
Cr	-0.39	-0.02	**0.82**	0.12	82.9
Fe	-0.09	0.20	**0.72**	0.38	70.2
Na	0.15	-0.17	**0.60**	0.38	56.0
Ni	**-0.60**	0.17	**-0.62**	0.31	87.2
V	0.24	0.28	**0.77**	0.02	73.0
Al	0.09	0.12	0.22	**0.80**	71.0
Ca	-0.28	0.34	-0.06	**0.72**	72.2
Mg	-0.19	-0.12	0.29	**0.84**	84.1
Mn	-0.27	0.18	0.19	**0.62**	52.4
Prp. Totl.	15.6	16.6	19.1	18.6	69.8
Eigen Val	5.52	2.42	1.90	1.33	
Expl. Var,	2.50	2.65	3.05	2.97	

F1, F2, F3, F4 – Factor loadings; Com – Communality (%); Var – Variance (%)

Factor 1 (Ba, K, Ni) is a lithogenic and geogenic association. The spatial distribution of the scores of this factor is given in Figure 5, both for topsoil and bottom soil samples. It is obvious that the highest values for Ba and K content were in areas occupied by the Precambrian and Paleozoic schists, and Paleozoic sandstones. From Tables 1 and 2, it can be determined that the Ba content in the topsoil ranged from 65 to 940 mg/kg, while in the bottom soil its values were from 28 to 980 mg/kg. The median in the surface layer was 250 mg/kg, and in the subsoil was 240 mg/kg. The highest contents of this element were observed in soil samples from the Precambrian and Paleozoic schists, represented in the central part of the area; that is, on the border between the municipalities of Ohrid and Struga. The high Ba content was also found in the soils from the Paleozoic sandstones, represented in the Gorna Debarca area, which is primarily characterised by hilly and mountainous relief. Potassium content ranged from 0.33 % to 2.4 % in the topsoil and from 0.16 to 2.4 % in the subsoil, with median values of 1.3 % and 1.5 %, respectively. According to the distribution map, its representation extends to the Precambrian and Paleozoic schists, Paleozoic sandstones, and Paleozoic and Mesozoic carbonates. The correlation for Ni in this Factor is negative and its spatial distribution was much different than that of the other elements (Figure 6); it is obvious that its content was the lowest in the previously mentioned areas and highest in the areas occupied by Paleozoic and Mesozoic carbonates (Mts. Galičica and Jablanica) and by Tertiary sediments (Figures 3 and 6). Nickel content ranged from 12 to 1000 mg/kg and from 12 to 1200 mg/kg in top- and subsoils, with median values of 61 mg/kg and 65 mg/kg, respectively.

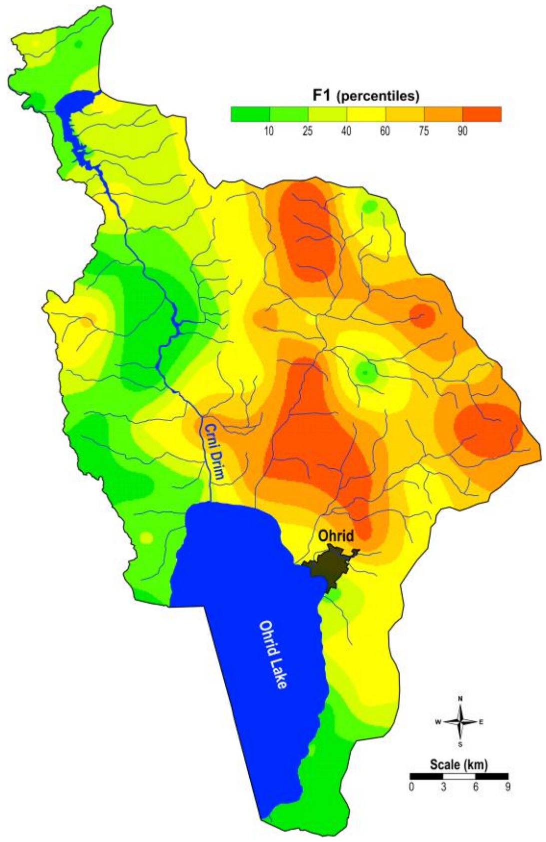

Figure 5. Spatial distribution of factor scores of F1 (Ba, K, Ni) in the Crn Drim River Basin

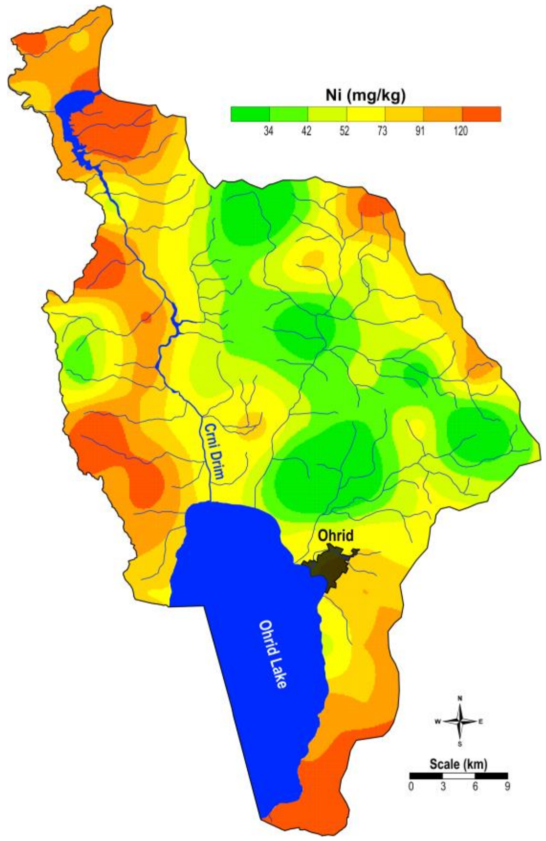

Figure 6. Spatial distribution of nickel in the Crn Drim River Basin

Factor 2 (Ag, Cd, Cu, Pb, Zn) represents the geogenic association. The spatial distributions of the factor scores of this factor for topsoil and bottom soil are shown in Figure 7. The origins of these elements are mostly related to the Paleozoic and Mesozoic carbonates. The highest contents these elements were in the areas of Mts. Galičica and Jablanica.

The content of silver ranged from 0.48 to 1.2 mg/kg in both top- and subsoil, with very close median values of 0.75 mg/kg and 0.80 mg/kg, respectively. From the similarity of these values, it can be concluded that there is no contamination of the surface layer of the soil from anthropogenic sources. The highest contents for silver were found in the Palaeozoic and Mesozoic carbonates, that are noticeable over Mount Galičica and around the city of Ohrid, and in the northeastern part of Gorna Debarca, where many types of rocks are present: Tertiary sediments, Precambrian and Paleozoic schists and magmatic rocks. A similar distribution was also observed for Cd and Cu. The median value for Cd was 0.30 mg/kg in the topsoil, with a range of 0.005 to 3.4 mg/kg, and 0.29 mg/kg in the subsoil soil with a range of 0.005 to 7.3 mg/kg. The median value for Cu in the topsoil was 30 mg/kg, which is significantly higher compared to the median of the surface layer at the Europe (13 mg/kg) and Macedonia (16 mg/kg) levels. The same applies to the median in the surface layer with a value of 34 mg/kg. The minimum and maximum values ranges were 8–125 mg/kg and 11–75 mg/kg, respectively. The spatial distributions of the content of Pb and Zn (Figures 8 and 9) were similar to the other elements from Factor 2 (i.e. the areas occupied by the Paleozoic and Mesozoic carbonates, as well as by Paleozoic sandstones in the northern and eastern part of the basin). According to the data presented in Table 4, the median value for Pb was higher in relation to the median for European and Macedonian soils, both in the topsoil and in the subsoil. In the study area, it was 31 mg/kg (range: 14–62 mg/kg) and 29 mg/kg (range: 5–50 mg/kg), whereas the values for European and for Macedonian soil were 10 and 17.2 mg/kg, and 17 and 14 mg/kg, respectively. The last element in this factor was zinc, whose spatial distribution is given in Figure 9. The median value for Zn was the same for top- and subsoil samples (130 mg/kg), and it was higher than in the sampled than in the European and Macedonian soil (Table 4) These findings for some parts (the town of Ohrid and its surroundings) of the investigated region could be also explained by anthropogenic influence of the urban and industrial activities [34].

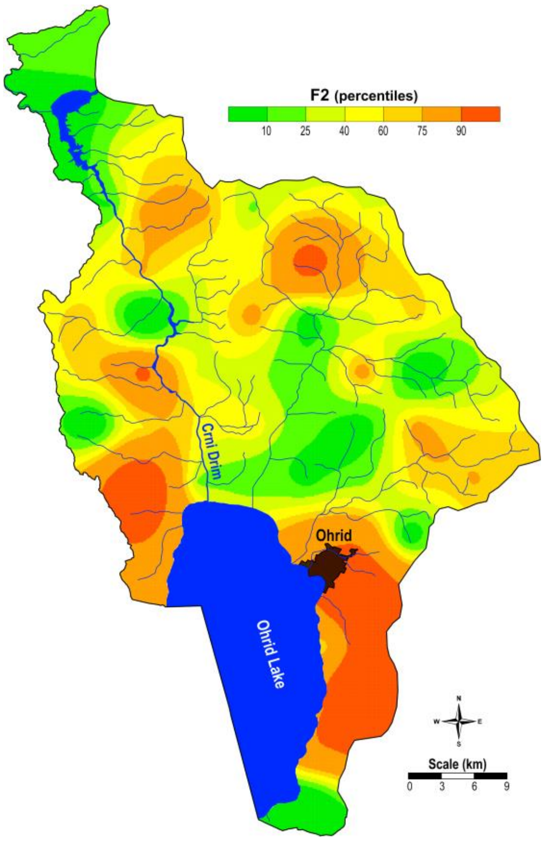

Figure 7. Spatial distribution of factor scores of F2 (Ag, Cd, Cu, Pb, Zn) in the Crn Drim River Basin

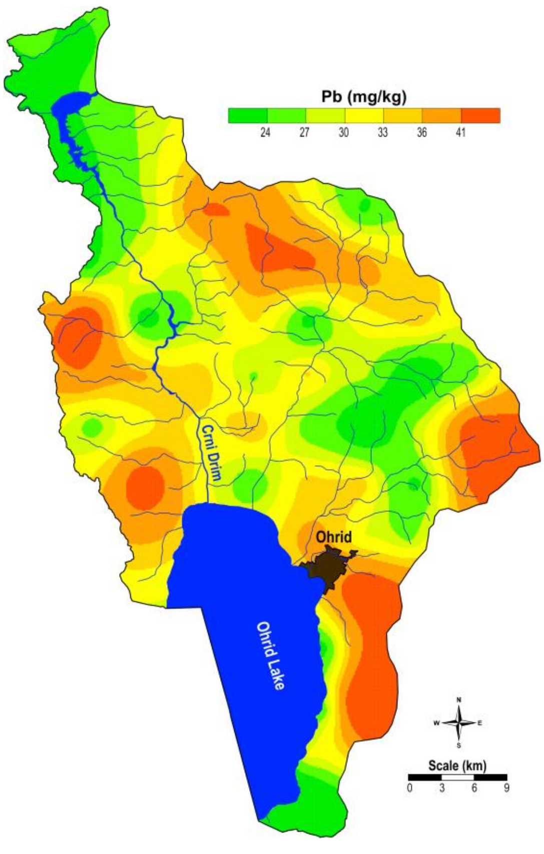

Figure 8. Spatial distribution of lead in the Crn Drim River Basin

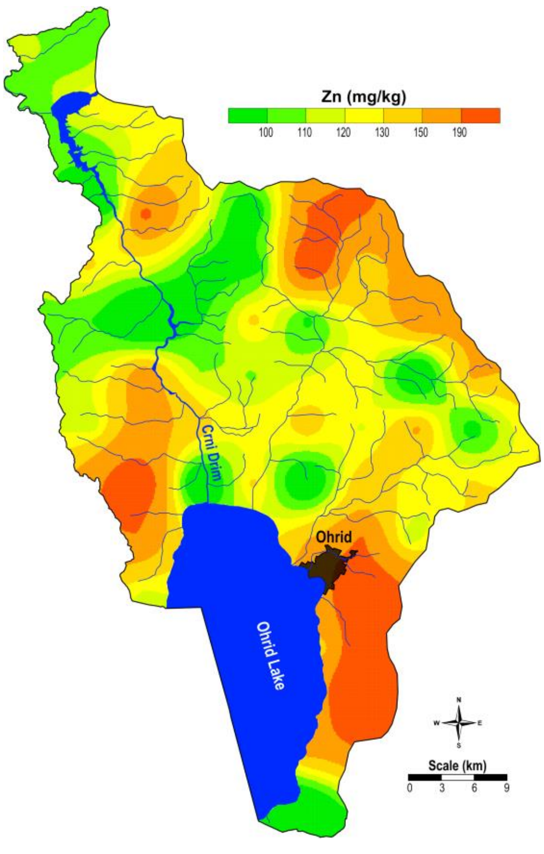

Figure 9. Spatial distribution of zinc in the Crn Drim River Basin

Factor 3 (Cr, Fe, Na, Ni, V) is a natural factor that depends on the underlying soil lithology and the spatial distribution of the factor scores. Figure 10 shows that the sources of these elements are mainly natural phenomena such as the erosion of rocks and soil chemical processes. Higher content of these elements was located in areas of Tertiary sediments in the area of Debar, while lower contents were found in the areas of Paleozoic and Mesozoic carbonates on the Galičica and Jakupica Mountains, and of Quaternary sediments in the Ohrid-Struga Valley. Typical examples of this association of elements are chromium and nickel (Figures 11 and 12). The highest values for Cr and Ni were obtained in soils around the Debar Lake and Center Župa and near the village of Slivovo). The content of Cr ranged from 50 to 1000 mg/kg and from 49 to 910 mg/kg, in top- and subsoil, with median values of 87 mg/kg and 86 mg/kg, respectively. Corresponding values for Ni content were: a range of 12 to 1000 mg/kg in both layers, and medians of 61 mg/kg and 68 mg/kg.

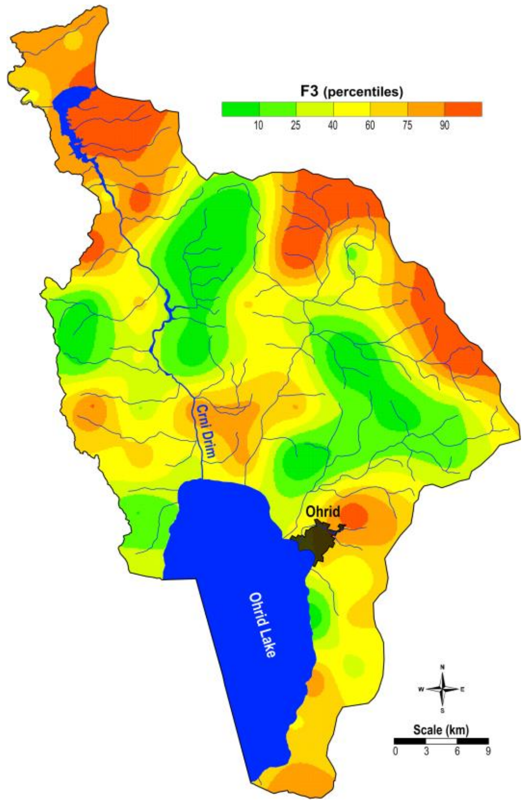

Figure 10. Spatial distribution of factor scores of F3 (Cr, Fe, Na, Ni, V) in the Crn Drim River Basin

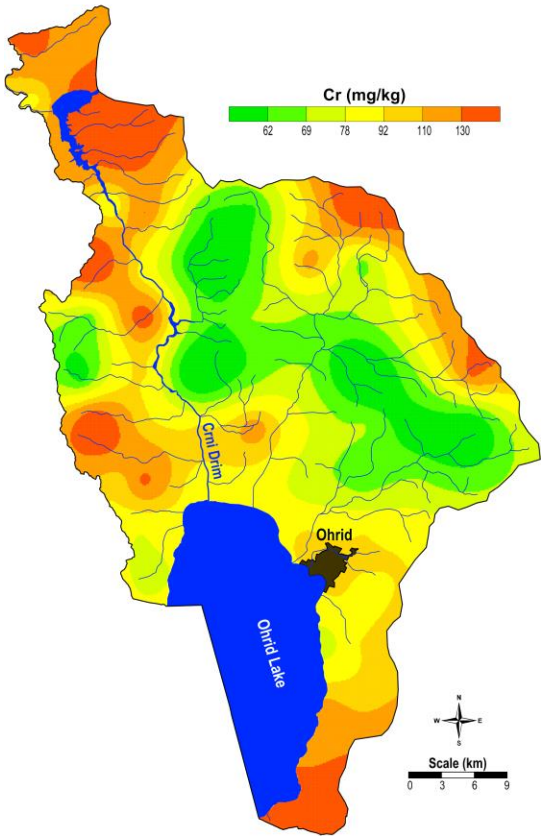

Figure 11. Spatial distribution of chromium in the Crn Drim River Basin

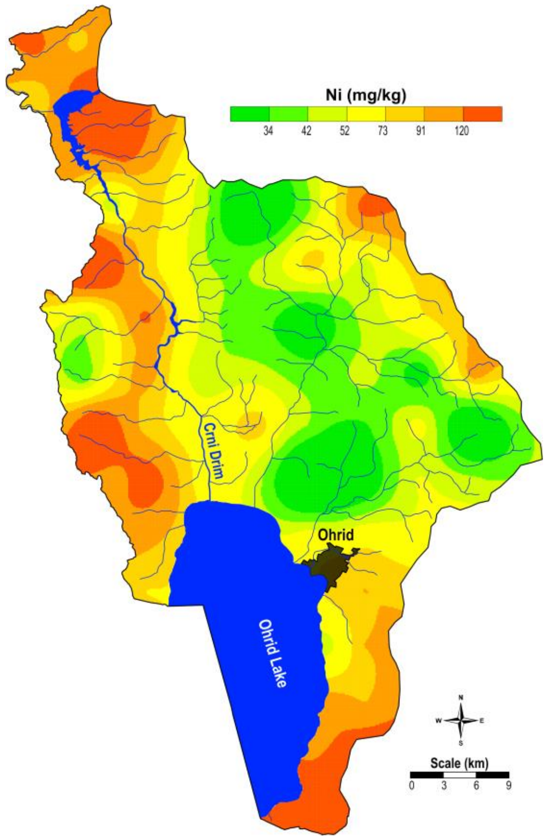

Figure 12. Spatial distribution of nickel in the Crn Drim River Basin

Factor 4 includes Al, Ca, Mg and Mn. The highest contents were found in the areas of Paleozoic and Mesozoic carbonates present on the Galičica and Jakupica Mountains, and on the eastern part of the basin, as well as in the areas of volcanic and magmatic rock in the western part of the area (Figure 13). This distribution was related to areas with carbonate rocks; which is very characteristic of the spatial distribution of Ca and Mg (Figures 14 and 15). The median content for Mg was 0.64 % and 0.69 % for top- and subsoil, respectively, with a range of 0.22 % to 7.2 % in the surface layer and 0.21 % to 5.8 in the sub-layer. The median value for Ca was slightly smaller; 0.56 % and 0.54 % respectively, for the two layers. High value of Ca and Mg occured in several places: in the middle part of Galičica Mountain, but also near the village of Konjari, where the soil is predominantly over the Paleozoic and Mesozoic carbonates, near the village of Lukovo, an area dominated by magmatic rocks, southwest of the city of Struga, near the village of Radožda, located on the surface of the Paleozoic and Mesozoic carbonates, and in Upper Debarca, where Precambrian and Mesozoic schists, magmatic rocks and Paleozoic and Mesozoic carbonates are dominant.

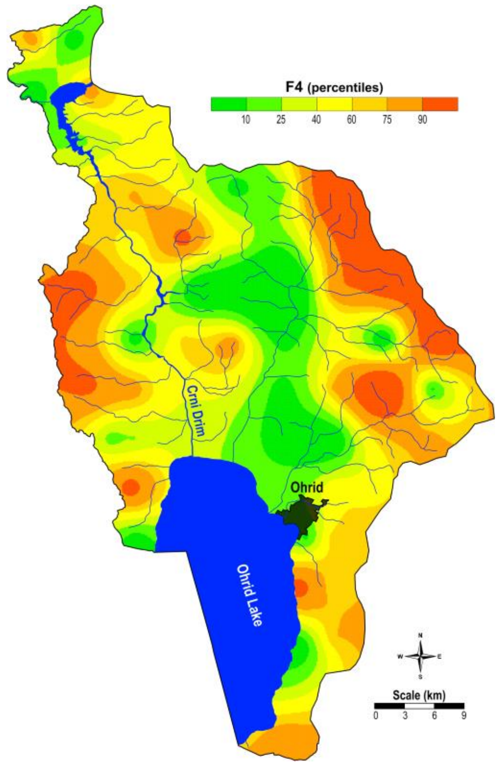

Figure 13. Spatial distribution of factor scores of F4 (Al, Ca, Mg and Mn) in the Crn Drim River Basin

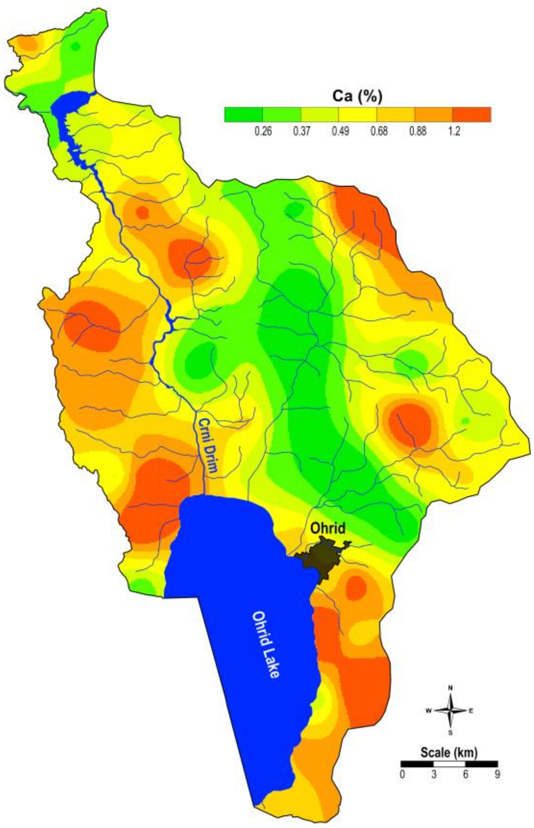

Figure 14. Spatial distribution of calcium in the Crn Drim River Basin

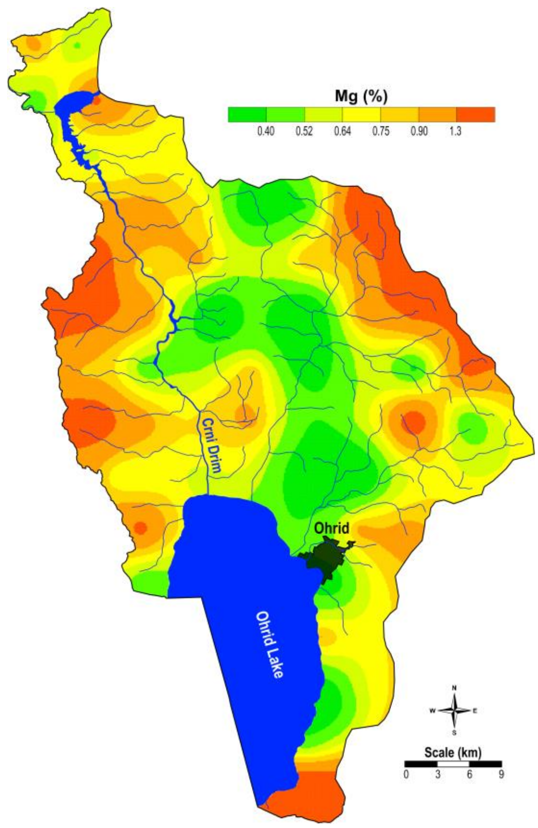

Figure 15. Spatial distribution of magnesium in the Crn Drim River Basin

Bivariate statistics were also applied to the rare-earth elements (REE) determined by ICP-MS. The matrix of correlation coefficients is given in Table 6, where the correlation for the content of the following 14 rare elements is represented: Ce, Dy, Er, Eu, Gd, Ho, La, Lu, Nd, Pr, Sm, Tb, Tm and Yb. It is obvious that the correlation coefficients for all of the REE were very high (from 0.75 to 1.0). The map of their spatial distribution is presented in Figure 16. It can be noted that the highest values existed in the areas dominated by the Paleozoic and Mesozoic carbonates (in the vicinity of Velestovo and Konsko, as well as on the part of the Galičica Mountain, but also in the Struga area near the villages of Oktisi and Vevčani). There are also high values for their content in the region of the Precambrian and Paleozoic schists in Debarca, occupied by Precambrian and Paleozoic schists.

Table 6. Matrix of correlation coefficients for the rare-earth elements (n = 124)

Element	Ce	Dy	Er	Eu	Gd	Ho	La	Lu	Nd	Pr	Sm	Tb	Tm	Yb
Ce	1.00													
Dy	0.81	1.00												
Er	0.75	0.99	1.00											
Eu	0.90	0.92	0.88	1.00										
Gd	0.91	0.97	0.94	0.97	1.00									
Ho	0.77	1.00	1.00	0.89	0.95	1.00								
La	0.93	0.83	0.79	0.86	0.90	0.80	1.00							
Lu	0.81	0.98	0.98	0.92	0.96	0.98	0.82	1.00						
Nd	0.96	0.91	0.86	0.96	0.98	0.87	0.95	0.90	1.00					
Pr	0.97	0.89	0.84	0.95	0.96	0.85	0.95	0.88	1.00	1.00				
Sm	0.95	0.94	0.89	0.97	0.99	0.90	0.92	0.93	0.99	0.99	1.00			
Tb	0.87	0.99	0.97	0.95	0.99	0.98	0.87	0.97	0.95	0.93	0.97	1.00		
Tm	0.76	0.99	1.00	0.88	0.94	0.99	0.78	0.98	0.86	0.84	0.89	0.97	1.00	
Yb	0.77	0.99	1.00	0.89	0.95	0.99	0.79	0.99	0.87	0.85	0.90	0.97	1.00	1.00

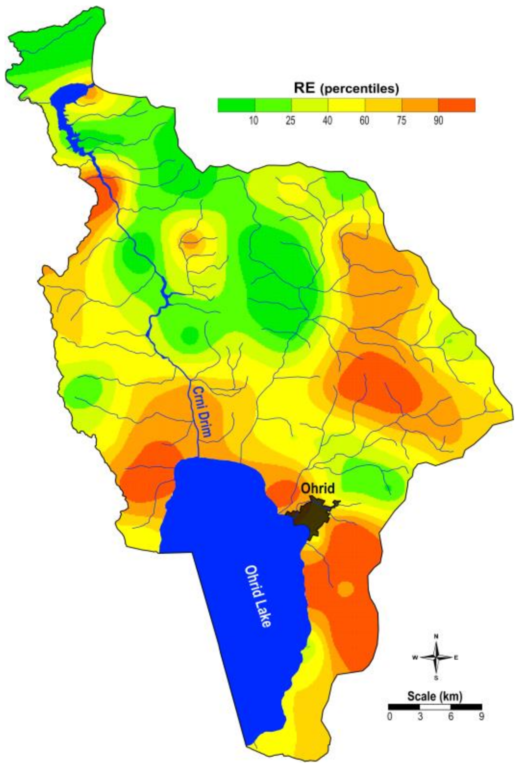

Figure 16. Spatial distribution of rare-earth elements in the Crn Drim River Basin

CONCLUSION

The study on the distribution of sixty elements in soil from 62 locations in the Crn Drim River Basin, Republic of Macedonia, was performed. Factor analysis with the multivariate R-method was applied in order to show the associations between chemical elements. Four factors were obtained from applying factor analysis to the first group of the elements analysed by ICP-AES: Factor 1 (Ba and K), Factor 2 (Ag, Cd, Cu, Ni, Pb and Zn), Factor 3 (Cr, Fe, Na, Ni and V) and Factor 4 (Al, Ca, Mg and Mn). Data obtained from the distribution maps of the factors and individual elements, as well as data analysis on soil samples, indicate the natural occurrence of the analysed elements as well as low concentrations of heavy metals in the studied area.

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ДИСТРИБУЦИЈА НА ХЕМИСКИ ЕЛЕМЕНТИ ВО ПОЧВИТЕ ОД СЛИВОТ НА РЕКАТА ЦРН ДРИМ, РЕПУБЛИКА МАКЕДОНИЈА

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Целта на истражувањето е утврдување на дистрибуцијата на хемиските елементи во површинските и потповршинските почви од регионот на сливот на реката Црн Дрим, Република Македонија, со посебно внимание на природното и антропогеното потекло на елементите. За таа цел, со мрежа за земање на примероци од 5 × 5 km, земени се вкупно 124 примероци почва од 62 локации (површински и потповршински). Анализирани се вкупно 60 елементи, од кои 18 елементи (Ag, Al, B, Ba, Ca, Cr, Cu, Fe, K, Li, Mg, Mn, Na, Ni, P, Pb, V и Zn) се анализирани со примена на атомската емисиона спектрометрија со индуктивно спрегната плазма (ICP-AES) а останатите 42 елементи со примена на масената спектрометрија со индуктивно спрегната плазма (ICP-MS). Добиените резултати се обработени со мултивариатната статистичка метода. Факторната анализа на податоците добиени со ICP-AES дава четити геогени фактори: F1 (Ba и K); F2 (Ag, Cd, Cu, Ni, Pb и Zn), F3 (Cr, Fe, Na, Ni и V) и F4 (Al, Ca, Mg и Mn). Податоците од анализата на примероците и од картите на дистрибуција покажуваат поврзаност со литогенезата на испитуваните елементи и со релативно ниски содржини на тешките метали во испитуваното подрачје.

Клучни зборови: почви; слив на реката Црн Дрим; Република Македонија; мултиваријатна статистика; геохемиско мапирање

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Original scientific paper

PHYTOPHTHORA CACTORUM (LEBERT & COHN) J. SCHRÖT AS CAUSAL AGENT OF DIEBACK OF CHESTNUT AND APPLE TREES IN MACEDONIA[#]

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From 2013–2017, 11 chestnut populations and 16 apple orchards/plantations in Macedonia were examined for health; soil, root and bark samples were collected from trees expressing symptoms regarded as *Phytophthora* specific. Using leaf baits of *Prunus laurocerasus* and selective V8 Agar (PARPNH), 19 pure *Phytophthora* sp. cultures were isolated and identified as *P. cactorum* by ITS sequencing. Sixteen isolates were from apple trees and 3 from chestnut trees. Phylogenetic analyses suggested slight distance between *P. cactorum* isolates originating from chestnut trees compared to those from apple orchards. Assessment of pathogenicity using chestnuts twigs showed no differences between *P. cactorum* isolates from the two tree host species.

Key words: *Malus* spp.; *Castanea sativa*; pathogenicity; phylogenetic analysis

INTRODUCTION

The genus *Phytophthora* was first reported in 1845, when *Botrytis infestans*, fully described in 1876 as *Phytophthora infestans* (Mont) De Bary was identified as the causal agent of potato blight, the main factor causing yield losses during the infamous Great Irish Famine (1844–1886). The disease was responsible for the death of approximately 1–1.5 million people and sparked massive emigration from Ireland because of the lack of food available to ordinary people [1]. Soon after these events, in 1870 *Peronospora cactorum* (Levert and Cohn) J. Schröt was first described as the cause of rot on the cacti *Cereus giganteus* and *Melocactus nigrotomentosus* in the Czech Republic (Lebert and Cohn, 1870, cited in [2]). This fungus-like organism (FLO) was later transferred to the genus *Phytophthora*.

Phytophthora cactorum is a generalist plant pathogen with a worldwide distribution. It causes a variety of symptoms on many plant hosts: damping-off of seedlings, fruit rot, leaf and stem rot, collar and crown rot, stem canker and root rot [3]. Numerous plant diseases have been attributed to this oomycete, and it has been recorded on over 200 plant species, causing disease on 150 genera (e.g. including *Fagus* spp., *Juglans regia*, *Malus*, *Castanea sativa*), in 60 plant families (Tucker, 1993; Nienhous, 1960; cited in [2]). *P. cactorum* causes necrosis on inoculated plants of *Quercus robur* [4], on apple, rhododendron and strawberry, with genetically different isolates expressing different host specificity [5], and is also one of the *Phytophthora* spp. complex responsible for ink disease of chestnut trees [6]. The only accessible relevant data on *Phytophthora* species detected in Macedonia is the paper published by the European and Mediterranean Plant Protection Organization (EPPO) for presence of dying off symptoms caused by *P. cryptogea*, dating from 1985 [7].

[#]Dedicated to academician Gjorgji Filipovski on the occasion of his 100th birthday

The morphological characteristics used for detection of *Phytophthora* spp., such as dimensions and shapes of zoosporangia and oogonia, may be highly variable and often overlap between species, making identification to the species level difficult [8, 9]. Leonian [10] stated that *P. cactorum* is a species easily identified by morphological characteristics, while later, isozyme analysis and mtDNA studies showed a high level of similarity between isolates originating from different geographical locations [11, 12].

In the last 15–20 years there has been an increase in the number of newly described *Phytophthora* species [13–16], but keys available for morphological identification are not in accord with the natural division to species level *sensu stricto* [17]. Molecular methods applied to *Phytophthora* species isolates, therefore, are a necessary tool for accurate identification to the species level.

In this study, we assessed chestnut populations and apple orchards in the Republic of Macedonia for symptoms of *Phytophthora* sp. infections. Bark and roots from symptomatic trees, plus samples of surrounding soils were collected for isolation of *Phytophthora* spp. and the pathogenicity of *P. cactorum* strains isolated during the study was assessed.

MATERIALS AND METHODS

Collection of samples. Between 2013 and 2017, we assessed 27 sites for presence of symptoms on apple and chestnut trees (Table 1). Soil samples were collected from four sides of symptomatic trees after removal of the soil surface organic layer using methods described previously [18–20]. The four soil samples from a single tree, each from a pit of ca 25 × 25 × 25 cm, were mixed in sterile plastic bags, and stored at room temperature (24 °C ± 4 °C) until processed. Bark samples, taken from trunk lesions and rotten tissue (mostly from the collar area), or root fragments, were collected using a knife or axe previously surface sterilized in 70 % ethanol.

Table 1. List of sites assessed for presence of disease symptoms characteristic for *Phytophthora* infection

N_0	Site	GPS coordinates	Host ~age	Collected material	Symptomatic (S) / asymptomatic (A)	Type of soil [37]
1	„Agroplod“ Resen Apple orchard	Lat: 41.090597 Lon: 21.019831	*Malus domestica* ~15	Soil Roots	S	Fluvisol
2	v. Perovo Resen Apple orchard	Lat: 41.016807 Lon: 20.990369	*Malus domestica* ~15	Soil Roots Bark	S	Gleysol
3	v. Gorna Bela Crkva Resen Apple orchard	Lat: 41.051997 Lon: 21.021626	*Malus domestica* ~10	Soil Roots Bark	S	Fluvisol
4	v. Grncari Resen Apple orchard	Lat: 41.010382 Lon: 21.052023	*Malus domestica* ~15	Soil Roots Bark	S	Fluvisol
5	v. Brajcino Resen Apple orchard	Lat: 40.898478 Lon: 21.152175	*Malus domestica* ~15	Soil Roots Bark	S	Fluvisol
6	v. Carev Dvor Resen Apple orchard	Lat: 41.036188 Lon: 21.004805	*Malus domestica* ~15	Soil Roots Bark	S	Fluvisol
7	v. Ezerani Resen Apple orchard	Lat: 41.024585 Lon: 21.025962	*Malus domestica* ~15	Soil Roots Bark	S	Fluvisol
8	v. Pretor Resen Apple orchard	Lat: 40.988544 Lon: 21.055793	*Malus domestica* ~15	Soil Roots Bark	S	Fluvisol
9	v. Stenkovec Resen Apple orchard	Lat: 41.55523 Lon: 20.613661	*Malus domestica ~15*	Soil Roots Bark	S	Dystric Cambisol

Table 1 (continuation)

10	v. Gradsko Gradsko Apple orchard	/	*Malus domestica* *~5*	Soil Roots Bark	S	Humic Calcaric Regosol +Regosol
11	v. Sopotsko Resen Apple orchard	/	*Malus domestica* *~15*	Soil Roots Bark	S	/
12	v. Jankovec Resen Apple orchard	/	*Malus domestica* *~15*	Soil Roots Bark	S	/
13	v. Bolno Resen Apple orchard	/	*Malus domestica* */*	Soil Roots Bark	S	/
14	v. Gorno Dupeni Resen Apple orchard	/	*Malus domestica* *~15*	Soil Roots Bark	S	/
15	v. Dolna Bela Crkva Resen Apple orchard	/	*Malus domestica* *~15*	Soil Roots Bark	S	/
16	v. Mislesevo Struga Apple orchard	Lon: 41.178572 Lat: 20.705224	*Malus* sp. ~10	Soil Roots	S	Fluvisol
17	v. Skudrinje Debar	Lon: 41.559646 Lat: 20.602625	*Castanea sativa* ~50	Soil Roots	S	Rendzic Leptosol
18	v. Osoj Kicevo	Lon: 41.530615 Lat: 20.934237	*Castanea sativa*	Soil Roots	S	Rendzic Leptosol
19	v. Kaliste Struga	Lon: 41.166303 Lat: 20.650994	*Castanea sativa* ~60	Soil Roots	S	Rendzic Leptosol
20	v. Recane Gostivar	Lon: 41.745676 Lat: 20.825748	*Castanea sativa* */*	Soil Roots	S	Cambisol
21	v. Kale Tetovo	Lon: 42.019510 Lat: 20.958687	*Castanea sativa* ~15	Soil Roots	S	Cambisol
22	v. Vrutok Gostivar	Lon: 41.763703 Lat: 20.825986	*Castanea sativa* ~50	Soil Roots	S	Cambisol
23	v. Trebenista Ohrid	Lon: 41.196587 Lat: 20.772027	*Castanea sativa* ~50	Soil Roots	S	Rendzic Leptosol and Chromic Leptic Luvisol on hard limestones
24	a. “Strazha” Kicevo	Lon: 41.695773 Lat: 20.844772	*Castanea sativa* ~40	Soil Roots	S	Chromic Leptic Luvisol on hard limestones
25	v. Knezino Kicevo	Lon: 41.517146 Lat: 20.919102	*Quercus pubescens* ~30	Soil Roots	S	Chromic Luvisol on saprolite
26	v. Smolari Strumica	Lon: 41.370692 Lat: 22.902385	*Castanea sativa* ~40	Soil Roots	S	Cambisol
27	v. Vratnica Tetovo	Lon: 42.145672 Lat: 21.113922	*Castanea sativa* ~60	Soil Roots	S	Cambisol + Um-brisol

Isolations. The baiting method was applied to all soil and bark samples, using fully open young plant leaves of *Prunus laurocerasus* as bait. Soil, 250–300 g per sample, with root fragments, was placed in plastic containers and flooded with sterile distilled water, to a depth of approx. 1 cm above the soil level, and bait leaves floated on the water surface. Containers were incubated in the dark at room temperature (24 °C ± 4 °C) and leaves observed daily for discolored lesions. When observed, small fragments (10–20 mm^2) were cut from the lesions and placed on selective PARPNH V8 agar (200 ml V8 juice/l, pimaricin 10 mg/l, ampicillin 200 mg/l, rifampicin 10 mg/l, pentachloronitrobenzene (PCNB) 25 mg/l, nystatin 50 mg/l and hymexazol 50 mg/l) described in Jung *et al.* [4], and incubated at room temperature in the dark. Cultures with morphology similar to *Phytophthora* were sub-cultured to fresh PDA, V8 agar or malt extract agar (MEA).

Morphological identification. Morphological characteristics of isolates were recorded after two weeks of growth in the dark on PDA, V8 agar or MEA, at room temperature (24 °C ± 4 °C). To induce production of sexual and vegetative fruiting bodies, plugs (ca. 1 cm^2) of young cultures were placed in non-sterile soil extract solution (NSSES) [2]. After 24 hours in NSSES, plugs were washed in sterile distilled water and observed under microscope [20]. Morphological structures were measured, and the identification key of Erwin & Ribeiro [2] used to identify isolates based on morphology. All structures were photographed.

Growth rate. All isolates were subjected to growth-rate trials according to the protocol described in [21]. Agar plugs (2 mm^2) were subcultured from culture margins to Petri plates containing ca. 20 ml V8 agar amended with 0.2 % $CaCO_3$ with 4 replicates per sample and incubated at 24°C ± 4°C. Growth was measured in 2 perpendicular directions after 6 days of incubation.

DNA isolation and amplification. DNA was isolated from cultures grown in the dark on PDA at room temperature (24 °C ± 4 °C). Surface mycelium was gently collected with a spatula, lyophilized and ground. DNA was extracted from 50–100 mg of lyophilized tissue per sample, using the Plant-fungi DNA isolation kit (PureLink™ Plant, Total DNA Purification Kit) following the manufacturers' instructions. Extracted DNA was subject to PCR using ITS 4 [22] and ITS 6 [23] universal *Phytophthora* primers, with the following amplification conditions: initial denaturation at 95 °C for 3 min.; 35 cycles of denaturation (95 °C for 30 sec.), annealing (55 °C for 30 sec.), and extension (72°C for 50 sec.); and a final extension at 72 °C for 10 minutes. Amplicons were subjected to electrophoresis on 1 % agarose gel, 1 × TBE at 120 V for 90 minutes, stained with SYBR® Safe DNA gel stain and observed under UV light. All samples with visible DNA bands ranging from 800 to 1000 bp were sequenced (Macrogen, The Netherlands) utilizing both ITS 4 and ITS 6 universal *Phytophthora* primers. Sequences were analyzed using DNA Dynamo and compared against accessions in the online *Phytophthora* database (http://www.phytophthoradb.org/; [24]). Sequences were aligned using MEGA 7, and the ClustalW Multiple alignment tool, as implemented in MEGA 7 [25]. Phylogenetic trees were constructed using the maximum likelihood method implemented in MEGA 7, with 1000 bootstrap replicates. In addition to sequences obtained in this research, several sequences available on http://www.phytophthoradb.org/ were utilized to compare our sequences with other available *Phytophthora* spp. sequences.

Pathogenicity test. For the pathogenicity test, material from dormant one year old chestnut shoots taken from a single coppice was used [26]. The chestnut shoots (length 10–15 cm; width 5–15 mm) were inoculated by removing a small piece of bark and insertion of agar plugs (ca 3 × 3 mm) extracted from a fresh culture of *P. cactorum*. Inoculation points were covered with sterile moist cotton plugs and secured with Parafilm. Two isolates were used for inoculations; one isolated from a chestnut, the other one from an apple tree. Forty replicate inoculations were made per isolate, 20 were on 5–10 mm diam. shoots, 20 on 10–15 mm diam. shoots. Inoculated shoots were placed on sterile moist filter papers in 15 cm diam. glass Petri dishes, with 10 replicate shoots per Petri dish, and incubated in dark for 7 days at room temperature (24 °C ± 4 °C; Figure 1), after which lesion lengths were measured. Ten random samples were taken for re-isolation on selective PARPNH medium to prove that the *Phytophthora* isolates caused the lesions.

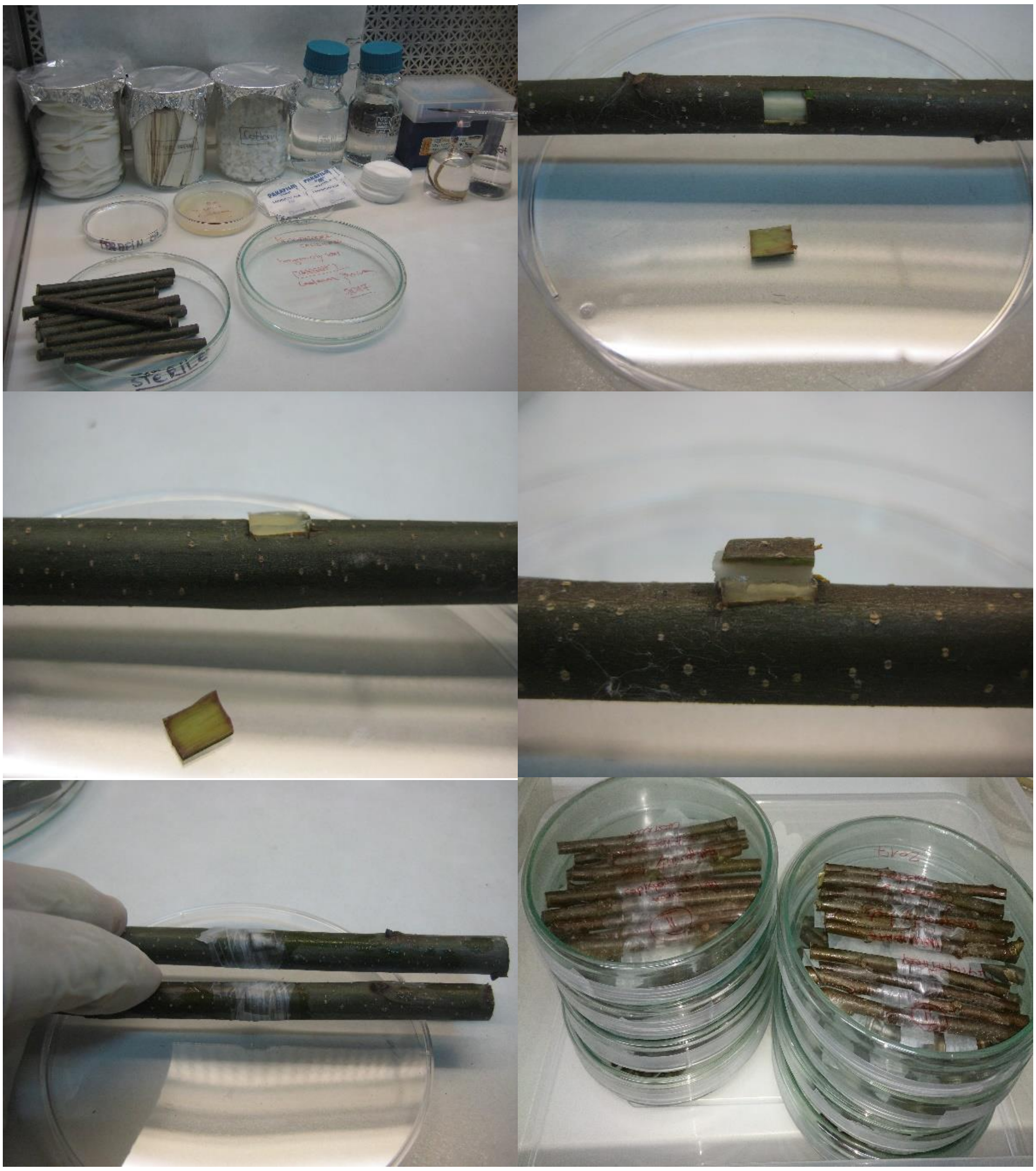

Figure 1. Inoculation of chestnut twigs for pathogenicity tests

RESULTS AND DISCUSSION

Eighty-one soil, root and/or bark samples were collected from apple trees which exhibited disease symptoms characteristic of *Phytophthora* infection in 16 apple orchards. In addition, 54 soil, root and/or bark samples were collected from symptomatic chestnut trees from 11 sites. Of these, fifty cultures with morphologies resembling *Phytophthora* spp. were obtained on selective media. Twenty-one isolates were identified as *P. cactorum* by culture morphology and microscopic features. Of these 19 isolates, 16 were from apple trees, and 3 from chestnut trees. All isolates were with coralloid culture morphology (Figure 2) and an average daily growth rate of 6.5 mm when incubated at room temperature (24 °C ± 4 °C) in the dark on V8 agar. Oogonia measured 29 × 27 μm on average, whereas oospores measured 21 × 21 μm on average. Antheridia were 13 × 11 μm. The mean zoosporangia dimensions were 45 × 35 μm; chlamydospores were rare but measured 22 × 21 μm on average (Figure 3).

All *Phytophthora* spp. isolates obtained from apple and chestnut trees in Macedonia clustered together on the same branch of the phylogenetic tree as *P. cactorum*, *P. hedraiandra* and *P. pseudotsugae*. While the aforementioned species are highly similar and poorly resolved between themselves, the whole branch is highly supported with a bootstrap value of 91 (Figure 4).

Figure 2. Characteristic coralloid morphology of P. cactorum on (left to right) PDA, V8 Agar and MEA

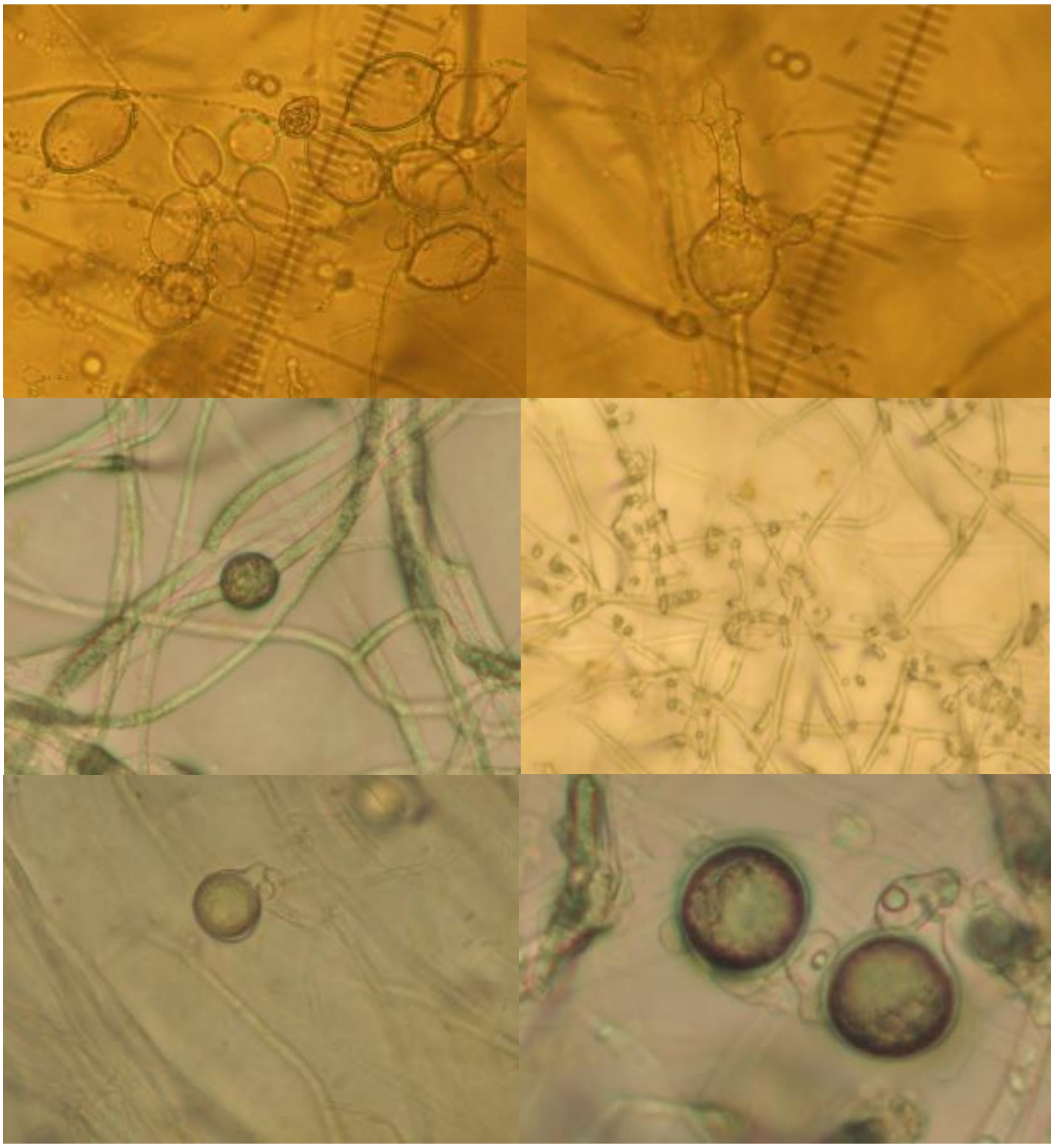

Figure 3. Reproductive structures of *P. cactorum*: typical formation of zoosporangia in groups (upper left); characteristic oospore proliferation in sporangium (upper right), chlamydospore (middle left), hyphal swellings (middle right), oospore (down left) and oogonia with paragenic antheridium (down right).

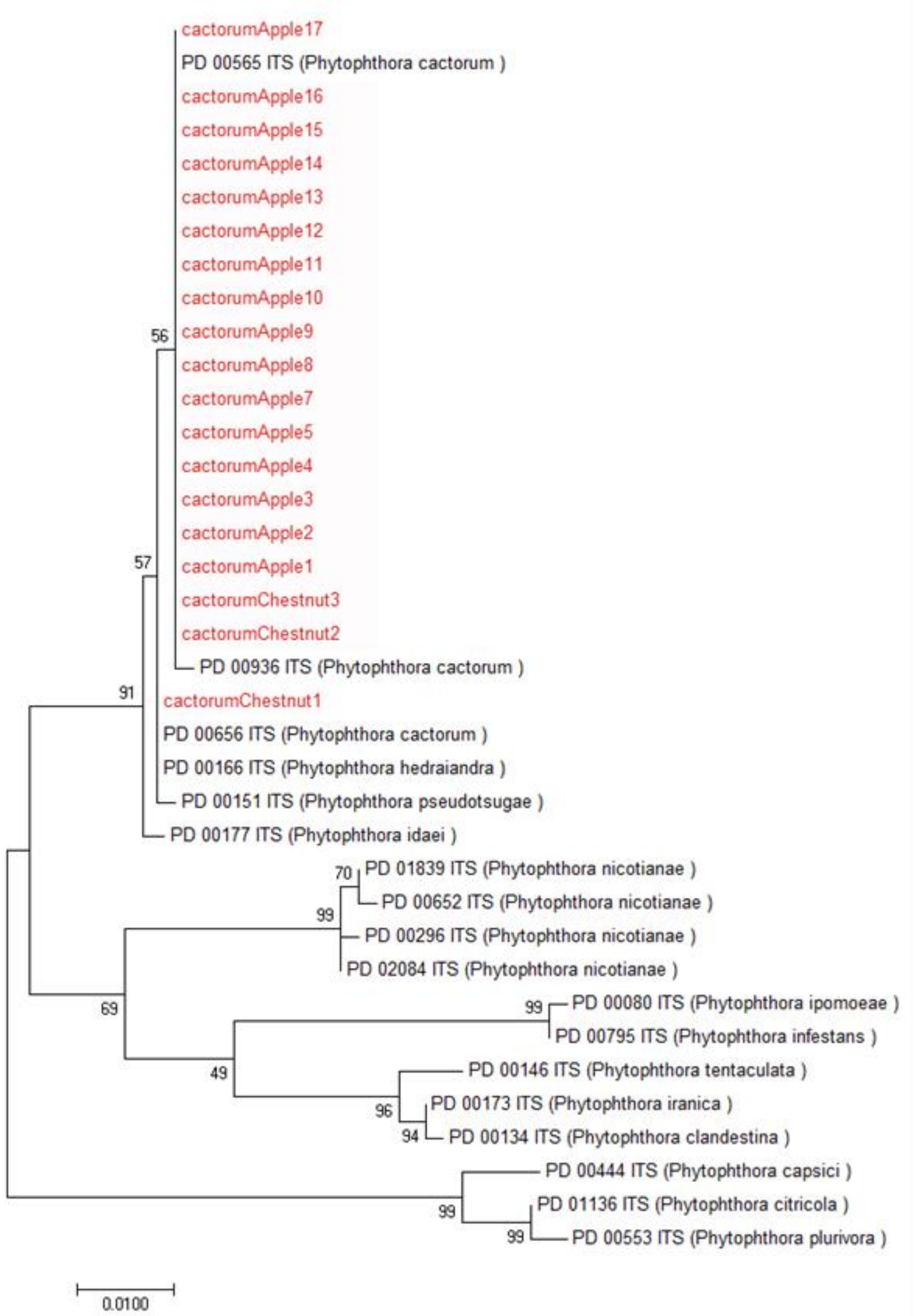

Figure 4. Phylogenetic tree constructed using MEGA7, using maximum likelihood method and Tamura-Nei substitution model. Bootstrap values were obtained after 1000 pseudereplicates. Isolates characterized in this study are in red, while the ITS sequences, publicly available at http://www.phytophthoradb.org are in black.

Nevertheless, most sequences from Macedonia were highly similar, indicating a single *Phytophthora* sp. was responsible for the infections in both apple orchards and chestnut forests. No differences in morphologies of cultures and the dimensions of the reproductive structures were observed between the isolates of *P. cactorum* originating from the two different host plant species. The pathogenicity tests also showed no difference between the length of the lesions on the chestnut twigs induced by the isolates originating from the two different host plant species. Lesion lengths ranged from 22 mm to 59 mm on the 5–10 mm diam. shoots, and between 30 mm and 59 mm on shoots 10–15 mm in diam. (Table 2; Figure 5, 6).

Table 2. Lengths of the lesions on chestnut twigs, induced by inoculation of *P. cactorum* isolates originating from the 2 plant host species

Number	**Shoot diameter (mm)**	**Dimensions of emerged lesions according to *Phytophthora* isolates (mm)**	
		P. cactorum (chestnut)	*P. cactorum* (apple)
1	5–10	49	57
2		32	49
3		34	41
4		39	47
5		38	40
6		51	29
7		31	34
8		47	47
9		41	51
10		32	39
11		34	42
12		39	46
13		30	49
14		47	50
15		50	40
16		32	59
17		52	36
18		33	32
19		41	22
20		49	31
1	10–15	0	39
2		37	35
3		31	44
4		41	49
5		38	33
6		38	39
7		30	33
8		33	49
9		42	38
10		35	47
11		36	53
12		41	30
13		39	39
14		51	59
15		51	55
16		34	41
17		36	41
18		47	40
19		33	31
20		42	35

These results further support the conclusion that *Phytophthora* isolates from Macedonia had similar growth rates and pathogenicity on chestnut, and were most likely *P. cactorum*, or at least within this species complex.

Regarding other countries in the region, *P. cactorum* has been reported as pathogen on peach, almond, apple and strawberry [27, 28] as well as from cherry [29, 30], all in Greece. Regarding pathogenicity, isolates originating from peach and almond trees were more aggressive than apple and strawberry isolates [31]. In Bulgaria, *P. cactorum* has been reported on American ginseng [32], and on apple and cherry [33]. The pathogenicity of *P. cactorum* has been assessed on young apple trees and apple fruits [33]. In Serbia *P. cactorum* has been reported on maple [34], in the soils of young hybrid poplar stands [35], on sycamore, walnut, common hawthorn, sessile oak, Hungarian oak, common alder, European wild pear and apple [36]. Having in mind these findings and the generally accepted view of *P. cactorum* as a generalist pathogen, we would expect that this plant pathogen is present on numerous other plant hosts in Macedonia. Further research is needed in order to gain important data on plant hosts, as well as diversity and pathogenicity of *P. cactorum* in the country.

Figure 5. Lesions emerged after inoculation of chestnut twigs with *P. cactorum*

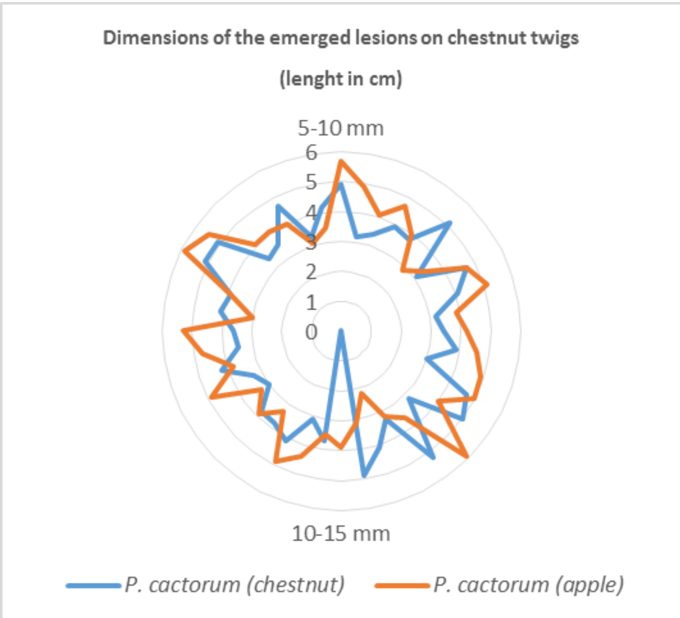

Figure 6. Dimensions of the emerged lesions on chestnut twigs

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SEE-ERA.NET PLUS Joint Research Project "Diversity and invading *Phytophthora* spp. plant pathogens in agro and forest ecosystems in Southeast Europe". Multilateral project (Bulgaria, Macedonia, Greece, Serbia and Romania), 2010-2012.

COST (Cost Action FP0801: Established and Emerging Phytophthora: Increasing Threats to Woodland and Forest Ecosystems.)

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PHYTOPHTHORA CACTORUM (LEBERT & COHN) J. SCHRÖT, ПРИЧИНИТЕЛ НА СУШЕЊЕ НА КОСТЕНОВИ И ЈАБОЛКОВИ ДРВЈА ВО МАКЕДОНИЈА

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Во периодот од 2013–2017 г., во Република Македонија беше истражувана здравствената состојба на 11 костенови популации и 16 јаболкови овоштарници/насади. Од нив беа колектирани почвени, коренови и примероци од кора од стебла кои покажуваа симптоми кои се сметаат типични за *Phytophthora*. Користејќи ливчиња од *Prunus laurocerasus* како мамки и селективна подлога V8 Агар (PARPNH), изолиравме 19 чисти култури на *Phytophthora* sp. кои беа идентификувани како *P. cactorum* преку секвенционирање на ITS регионот. Шестнаесет изолати потекнуваа од јаболкници, а 3 беа од костенови стебла. Филогенетските анализи покажаа мала разлика меѓу изолатите на *P. cactorum* кои потекнуваат од костенови стебла споредено со оние од јаболкови насади. Од проценката на патогеноста со користење на костенови гранчиња не се покажаа разлики меѓу изолатите на *P. cactorum* кои потекнуваа од различни видови растенија-домаќини.

Клучни зборови: *Malus* spp.; *Castanea sativa;* патогеност; филогенетски анализи

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FARM RESPONSE TO CLIMATE CHANGE: EXPLORATORY ANALYSIS OF MACEDONIAN AGRICULTURE USING THE RICARDIAN MODELING APPROACH

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Agriculture is one of most vulnerable sectors in the country, with the imminent intensification of global warming effects. In this paper, we attempt to assess the adaptation of Macedonian crop farmers to the impact of climate change. An alternative specification of the Ricardian model is adopted by using a composite aridity index to capture the response of farm returns to temperatures and precipitations. The econometric results indicate the significance of winter and summer season weather-related variables and confirm the non-linearity of the climatic function in relation to the farmers' economic results and adaptation capacity. The farm returns are highly sensitive to different climate change scenarios and tend to decrease unless adequate adaptation and mitigation measures take place, both at micro and macro levels.

Key words: Ricardian modeling approach; climate change; crop farms; Macedonian agriculture; aridity index

INTRODUCTION

Global warming and climate change are at this point a recognized threat and a top priority on policy makers' agendas (Angelini *et al*. [1]). Climate change will influence all spheres of living to a certain extent, but unquestionably, it will have a deep effect on agricultural systems through higher temperatures, greater crop water demand, more variable rainfalls, and weather extremes (Sutton *et al.* [2]).

Agriculture is particularly important for the Macedonian economy as a major contributor to the national gross domestic product (around 10%, or 15% with the food industry) and as a major employment and social absorber. Indeed, agriculture is a direct or indirect generator of income and livelihood in rural areas; it employs roughly 20% of the population (442 thousand engaged persons or 243 thousand full-time equivalents, SSO [3]).

The country is classified in the Continental South agro-climatic zone in Europe, where it is expected that climate change brings potential changes in the precipitation pattern consisting of increased rainfall in winter and decreased water availability in summer (Iglesias *et al.* [4]). Although Macedonia is a small landlocked country "comparable to a single grid-cell of current global climate models that are used to simulate the future climate change in a large scale", there is great variance in elevation and high heterogeneity in climate conditions (Bergant [5]). Three major types of climate can be distinguished (Aladzajkov [6]): i) moderate Continental climate, ii) modified Mediterranean climate and iii) Mountain climate. The annual temperature cycle is divided into a warm summer and relatively cold winter connected with transitional seasons of spring and autumn. Another important characteristic of the Macedonian climate is the uneven spatial distribution of precipitations throughout the country, by seasons and years. Usually there are periods of droughts, followed by high intensity rainfalls, which contribute to soil erosion and land degradation (MEPP [7]).

[#]Dedicated to academician Gjorgji Filipovski on the occasion of his 100th birthday

Climate change projections foresee a severe impact over the next 30 years that could lead farmers losing up to half of certain crops' yields (rainfed maize, apple, grapes, vegetables) under the medium impact scenario, unless adaptation measures are implemented (Sutton *et al.* [8]). Similarly to the previous finding, other sources (Bergant [5], MEPP [7], MEPP [9]) estimate in the period between 2025 and 2100 a continuous increase in temperature, especially in the summer, and a decline in precipitations in all seasons and at annual level, most emphasized or even absent in the months of July and August. Additionally, substantial water shortages are projected, especially for the Crna River basin, which will affect the water availability for irrigation purposes.

The impacts of climate change and identified areas where adaptation may be necessary were the focus of few studies (Callaway *et al.* [10], Sutton *et al.* [2] and [8], MEPP [9]). They conclude that climate change will have an impact on the reduction of yields in most crops and additionally assess that water resource management implications of the forecast change in climate could be severe, with increased water shortages especially during the summer season. Adaptation is pointed out as the key remedy for addressing climate change effects; "without adaptation, the climate change damages may grow to become approximately the same or bigger than current net income - jeopardizing the economic sustainability of farming in some areas" (Callaway *et al.*, p. 16 [10]). With these challenges in mind, the aim of this article is to assess the impact of climate change and farmers' adaptation in the Macedonian context using a Ricardian model approach.

METHOD

This section presents the Ricardian modelling approach as it has been used in the literature and applied in the United States, Europe or other continents (Mendelsohn and Massetti [11]). As explained further down, the typical Ricardian model specification had to be adapted to this work by considering alternative variables representing climate change. This latter aspect is captured using a measure which in the fields of meteorology and geography is known as the "aridity index".

Traditional Ricardian model

Hertel and Rosch [12] identify three categories of models that are adequate in assessing the impact of climate change on agriculture: i) crop growth simulations, ii) statistical studies and iii) hedonic (Ricardian) models. The crop growth simulations use extensive data, and provide highly detailed output, but as a result of that are not applicable on a large area. The statistical methods which analyze the relationship linking climate variables such as temperature and rainfall, and crop yields, have modest data requirements and can be applied on a wide level, but do not consider adaptation, hence they may give results that are extreme, i.e. which are either too optimistic or too pessimistic. The 'Ricardian' approach overcomes this issue with land values as the key variable to explain. It has a moderate requirement for data, accounts for regional level changes, and takes account of farmers' adaptation to the new conditions. It is convenient to use in developing countries, which usually do not have long strains of historical data (Mendelsohn *et al.* [13]; Mendelsohn and Massetti [11]).

Mendelsohn *et al.* [13] developed the "Ricardian approach" based on David Ricardo's theory that rent of land is equal to the economic advantage obtained by its most productive use, relative to the advantage obtained by using marginal land for the same purpose (Ricardo [14]). This approach examines "the impact of climate on farm revenue, while including adaptations that farmers would make in response to the changing economic and environmental conditions", by directly measuring farm prices or revenues, hence accounting for the direct impacts of climate change on yields of different crops, substitution of inputs, introduction of diverse activities, and other potential adaptations to different climatic conditions (Mendelsohn *et al.* [13]).

The Ricardian approach is an economic cross-sectional model, with geographic areas as units of observation. The method itself consists of regression analysis of statistical relationships between economic indicators and climate variables; the end-result measures the degree of influence of each factor (climatic and other control variables) on land values. Farmland prices are the first choice as a dependent variable, given that data are readily available and as such were used in a number of studies in the U.S. and Europe (Mendelsohn *et al.* [13], Chatzopoulos and Lippert [15], Van Passel *et al.* [16]). However, such indicator is not applicable in many developing or transition countries, due to the lack of data on agricultural farm values and poorly functioning land markets. Instead, the dependent variable used in most studies across the world (but mainly dealing with developing countries) is the net revenue of farms (often expressed on a per hectare basis). This latter approach has been applied in studies of climate change impact on agriculture in Africa (Kurukulasuriya *et al.* [17], Seo and Mendelsohn [18]), South America (Seo and Mendelsohn [19]), and China (Wang *et al.* [20], Chen *et al.* [21]).

Generally speaking, the explanatory variables based on the Ricardian model approach could be grouped into few categories: i) climatic, ii) geographical, iii) geophysical/edaphic and iv) socio-economic variables. Apart from the compulsory presence of temperature and precipitation indicators in an empirical Ricardian model, a combination of other variables is used in the various studies, depending on their availability and relevance. This includes soil attributes (quality, salinity, pH, erosion), altitude, latitude, irrigation, distance from city, population density, labor, etc. Irrigation is also taken into account in some of the studies.

The following formulation of the Ricardian model has been adopted in most of the studies applying this approach so far:

$$GR_k = \alpha + \sum_i f_i(T_{ik}) + \sum_i h_i(P_{ik}) + \sum_j m_j G_{jk} + \varepsilon_k \quad (1)$$

In expression (1), GR_k is the (unit) gross return (measured in general on a per hectare basis) of the unit of observation k (most likely a farm), $f\,(T_{ik})$ and $h\,(P_{ik})$ are assumed to be quadratic functions of temperatures and precipitations, subscript i refers to seasons, G is a vector of all other control j variables (farm elevation, irrigation, agro-climatic regions, etc.), α and m_j are parameters and ε is the error term.

However, in model (1), the explanatory variables, temperature and rainfall, are more likely to be defined at a macro (region) level, while the dependent variable is defined at a micro (*i.e* farm) level. There is a potential issue in regressing land rent, observed at micro level, and aggregate variables such as temperatures and rainfall, defined at macro level (region or station proximity), that can lead to difficulties in obtaining robust estimates. If this latter problem is not taken into consideration, it could lead to a spurious regression in estimating the effect of aggregate variables (temperatures and rainfall) on micro units (farms) (Moulton [22]). More specifically, the standard errors of the estimated coefficients could exhibit a downward bias that increases with the average group size, the intraclass correlation of the disturbances and the intraclass correlations of the regressors (*ibid*).

Another problem that could emerge in the traditional Ricardian model could be that interactions or more complicated nonlinearities between temperatures and rainfall could occur. This problem has been recently evidenced by Fezzi and Bateman [23] in the case of the United Kingdom. Climatologists and geographers have been aware of this problem and for this reason they suggest that so-called aridity indices should be used. To our knowledge, the idea of specifying a Ricardian model using aridity indices has not been explored in the relevant literature and it is one of the objectives of this work to attempt to estimate a Ricardian model where temperatures and rainfall are replaced by an aridity index.

Ricardian model based on the use of aridity index

The effects of climate through temperature and precipitation on agricultural rents tend to be highly non-linear and vary considerably by season (Mendelsohn *et al.* [13]; Kurukulasuriya *et al.* [17]). In order to capture this issue in our study, instead of using second order polynomial forms linking directly the dependent variable to temperatures and precipitations, we introduce the de Martonne (aridity) indicator, implicitly assuming a different (and unconventional) nonlinear function within which precipitations and temperatures interact.

The de Martonne aridity index (*DMI*), a modification of Lang's rain factor index, is a "relatively simple approach to the problem of allowing for weather influence upon crops in agricultural production analysis" (Oury, p. 270 [24]). This index allows to determine the climatic zone and as such is used in several recent studies linking the aridity index to crop yield (Cukaliev *et al.* [25], Lungu *et al.* [26]). The de Martonne index is computed based on the following formulation:

$$DMI_i = \frac{12P_i}{T_i + 10} \quad (2)$$

where P_i = monthly rainfall for month i (mm), T_i = average monthly temperature for month i (°C). Low aridity index indicates low degree of moisture, i.e. presence of higher temperatures and lower rainfall. Climatic conditions expressed through DMI values can be classified as extremely dry (<5), dry (5-15), semi-dry (15-20), mildly wet (20-30), wet (30-60) and very humid over 60 (Lungu *et al.* [26]).

We regress the gross return per ha over the de Martonne index and other control variables:

$$GR_k = \alpha + \sum_i l_i(DMI_{ik}) + \sum_j m_j G_{jk} + \varepsilon_k \quad (3)$$

where $l_i\,(DMI_i)$ is a quadratic function of the aridity index in month or season i (DMI_i) and where β_1 and β_2 are parameters:

$$l_i(DMI_i) = \beta_{1i}\ DMI_i + 0.5\beta_{2i}(DMI_i)^2 \quad (4)$$

Replacing the DMI_is and $l_i(DMI_i)$ functions by their respective expressions (2) and (4) in the Ricardian model specification (3) leads to a complex nonlinear relationship between the dependent variable and the temperatures and rainfall. This will serve as the basis to estimate the Ricardian model in the Macedonian context.

DATA

The data used in this study are obtained from several sources. For the farm level variables we use the annual Farm Monitoring Survey (FMS) of the National Extension Agency. The empirical application of the Ricardian model is based on 439 observations from 2011. The following farm types producing the respective crops are considered: cereals, fodder and industrial crops (Specialized field crop farms); orchards and vineyards (Perennial crops farms), mixed crop and mixed crop/livestock farms (Mixed farms) and vegetable farms. The FMS source also provides general farm data such as location (village and region) and utilized agricultural area (UAA). Basic economic results such as farm income, specific costs and gross margin are also derived from the FMS survey. The land market in the country is insufficiently developed to allow the use of land values. The use of gross margin as a proxy for the dependent variable instead of net income is justified on the grounds that there is insufficient data with regard to the fixed costs in the FMS survey.

The National Hydro-Meteorological Service gathers climatic data for the territory of Macedonia, such as temperature expressed in Celsius degrees and precipitation measured at monthly sums in millimeters. The variables with meteorological data are obtained from the eight meteorological stations regularly reported by the State Statistical Office, namely: Skopje, Bitola, Prilep, Shtip, Kriva Palanka, Ohrid, Demir Kapija and Berovo (SSO [27]). Farm data are linked with the nearest corresponding meteorological station. In our study, the climatic variables are calculated on a three-month season basis (winter, spring, summer and autumn).

Farm elevations are determined based on the altitude above sea level of the farm village. The soil attributes are extracted from the Macedonian Soil Information System (Filipovski [28], MASIS [29]), following the farm village location and dominant properties (pH, humus, clay, silt, lime, soil capability).

RESULTS AND DISCUSSION

We begin this section by providing a brief overview of the main characteristics of the farm sample. Then we present the specification of the Ricardian model assessing the relationship between the farm returns and the key climatic and control variables, followed by impact analysis scenarios and underlining the limitations.

Characteristics of the sample

An overview of the variables with descriptive statistics is given in Table 1. The average per hectare farm gross return in 2011 is 124 thousand MKD, ranging from 3 to 815 thousand MKD/ha. Looking at different farm types, expectedly, lowest per hectare margins are met at field crop farms and mixed farms (53 and 94 thousand MKD, respectively), followed by perennial crops (176 thousand MKD) and vegetable farms (183 thousand MKD).

The mean seasonal temperature ranges from 2.4 °C in the winter period to 22.1°C in the summer, in all seasons being lowest in Berovo and highest in Demir Kapija. The lowest annual rainfall is recorded by the Stip meteorological station and highest by the Ohrid station. The calculated De Martonne aridity index has peak values in winter, but pointing out to semi-arid conditions and high vulnerability in the remaining seasons. The values in 2011 for all seasons are lower than those reported for the eight meteorological stations for the period of 1971–2000 by Cukaliev *et al.* [25], especially with regard to the spring and autumn season (with 1971–2000 spring DMI equal to 29 and autumn DMI equal to 32.1, respectively).

In our sample, most farms are within the Mediterranean and Continental zones (only seven farms are located on altitude over 1.000 m above sea level). In terms of irrigation, only 12 % of the land is reported to have irrigation related costs, as a proxy to this farm practice. In this respect, it is an interesting finding that when cross-analyzed, farms located in areas with lowest De Martonne index apply irrigation most frequently (for instance, in regions with lowest aridity index of 5.0, 50 % of the land is irrigated).

In Table 1, we also report the major soil properties of the land in a farm village (in absence of exact farm land coordinates) and the calculated soil capability index that ranges from 31 to 58 in the sample.

Table 1. Descriptive statistics (n = 439)

Variable	Mean	St. Dev	Minimum	Maximum
Gross return (MKD/ha)	123.972	119.325	3.457	814.834
Temperature (winter) (°C)	2.4	1.0	0.7	3.7
Temperature (spring) (°C)	10.9	1.7	8.2	13.3
Temperature (summer) (°C)	22.1	2.3	18.5	25.4
Temperature (autumn) (°C)	11.5	1.8	8.1	13.5
Precipitation (winter) (mm)	135.8	20.3	105.8	160.6
Precipitation (spring) (mm)	104.1	20.9	77.9	144.5
Precipitation (summer) (mm)	94.5	48.1	44.4	169.2
Precipitation (autumn) (mm)	102.9	17.7	82.2	126.6
De Martonne index (winter)	44.0	7.3	32.2	52.6
De Martonne index (spring)	20.2	4.3	13.8	28.7
De Martonne index (summer)	12.2	6.9	5.0	23.7
De Martonne index (autumn)	19.3	4.4	14.7	28.0
Elevation (m)	494	266	41	1223
UAA per farm (ha)	4.5	9.2	0.2	120.7
Irrigated UAA per farm (ha)	0.6	1.8	0.0	26.9
Distance to town (km)	10.4	6.9	0.0	43.0
pH value	6.9	0.7	5.3	8.3
Humus (%)	2.7	1.1	0.0	8.0
$CaCO_3$ (%)	3.9	4.9	0.0	42.0
Clay (%)	12.9	6.8	3.0	36.0
Sand (%)	60.9	8.3	41.0	83.0
Silt (%)	26.3	6.9	12.0	54.0
Favorability (soil capability index)	50.9	4.7	31.0	58.0

Ricardian model specification of Macedonian farmers' adaptation to climate change

The empirical implementation of the modified Ricardian model used in this work leads us to select an estimated model specification as presented in Table 2. The dependent variable in the model is the unit farm return (gross margin per ha) expressed in a logarithmic form. Initially, we specify regressions with climatic variables (aridity indices), along number of control variables such as irrigation, elevation, distance to town, latitudinal data and the extracted farm proximate soil properties. However, these estimated model specifications exhibit a low explanatory power, but also reveal poor and unstable statistical significance of numerous control variables, which stem from a strong multicollinearity among these control variables. Hence, we reduce the presented model specification to the core climatic variables and the farm type dummy variables. The model is estimated with the Ordinary Least Squares estimation method. Despite a low explanatory power as shown by the value of adjusted R^2 equal to 0.275, an F-statistical test of zero slopes rejects the null hypothesis of no impact on the dependent variables of the selected climatic (aridity indices) and other control (farm type) variables.

The estimated model aims to capture the farm type effects by dummy variables (mixed crop farms as the reference type), since the impact of climate change on farm revenue reflects not only yields variations but also crop substituting (Seo and Mendelsohn [19]). The econometric results indicate that the gross margin for mixed farm group is on average not significantly different from the reference mixed crop farm. The specialized field crops farm estimated coefficient is significant, but interestingly, with negative effect, suggesting that this strategy to focus on field crops and not diversify into other types of production does not contribute to higher returns to the farmer. Some adaptation measures, such as adjustment of sowing dates and cultivation depth, as well as irrigation, are proposed as beneficial in avoiding or lessening the negative effects of climate change in field crops farming (MEPP [9]). The specialized vegetable farms and perennial farm types (orchards and vineyards) dummy variables are statistically significant and positively related to the unit farm gross returns, thus showing that it is more profitable to grow vegetables, fruit and grapes relative to a mixed farm.

Table 2. Econometric results

Explanatory variables	**Estimated coefficient**	**Standard error**	**t-statistic**	**P-value**
Intercept	3.12182	1.94451	1.60545	0.109
Mixed farm	-0.129461	0.113492	-1.14071	0.255
Specialized field crop farm	-0.591234	0.142103	-4.16061	0.000
Specialized vegetable farm	0.518671	0.125188	4.14314	0.000
Specialized perennial crop farm	0.488594	0.111704	4.37401	0.000
De Martonne index (DMIwinter)	0.378100	0.097005	3.89773	0.000
De Martonne index (DMIsummer)	0.093282	0.040130	2.32449	0.021
De Martonne index (DMIautumn)	-0.026423	0.016737	-1.57869	0.115
0.5 × DMIwinter × DMIwinter	-0.008517	0.002319	-3.67193	0.000
0.5 × DMIsummer × DMIsummer	-0.008552	0.002886	-3.03269	0.003
Adjusted R^2 : 0.275224				
F statistic(zero slopes): 19.4805				0.000

Global warming will cause switch in production structure; some studies imply changes in South American agriculture from cereal production towards fruit and vegetables that succeed in warmer locations (Seo and Mendelsohn [18]), other switch to maize and wheat instead of vegetables in warmer conditions such as expected in China (Wang *et al.*[20]). Vegetable, fruit and grape systems are more intensive than cereals and other field productions. Production under plastic tunnels is characteristic for early vegetables in Macedonia, as it enables hedging from the outdoor conditions and producing in a protective environment. Fruit and grape production is generally very sensitive to certain weather circumstances (such as spring frosts, hail, extreme high temperatures and uneven rainfall distribution) and typically with high production variations throughout the years due to these climatic factors. Investments in ultraviolet and hail protective nets and more sophisticated irrigation techniques could mitigate many of the effects of global warming. Climate change causes flooding and torrential rainfall in the low altitude Mediterranean zone, and the main issue in the Continental zone is the water availability (Sutton *et al.* [8]), hence it confirms the positive effect of irrigation. Enhancing some rainfed agricultural systems, such as organic farming (where soil qualities are improved and water use is more efficient), is also seen as part of the mitigation strategy (MEPP [9]).

The climatic variables (measured by de Martonne indices) for the winter and summer seasons are statistically significant, indicating that climate change has an impact on Macedonian farms. In both cases, higher value of the index is associated with an increase in the farm gross margin, albeit with a much stronger estimated coefficient for the winter period and with quite low value for the summer period. Although the estimated coefficient associated with the autumn DMI is not statistically significant at a 10 % level but close to it (p-value equal to 0.115), this climatic variable is kept in the estimated model because it shows that season is characterized by a drier climate pattern which results in slowing down crop growth.

All the estimated coefficients associated with the quadratic climatic variable terms are statistically different from zero, which confirms the non-linear relationship between aridity indices and unit gross return. This finding is consistent with the literature (Mendelsohn *et al.* [13], Kurukulasuriya *et al.* [17]). We include winter and summer aridity indices, as the extreme seasons with highest and lowest De Martonne values. The squared terms of both the winter and summer aridity indices are negative, implying that their relationship with the farm gross return is inverted-U shaped. This relationship is difficult to interpret, since climate sensitivity of crops varies according to their vegetation phase, but nevertheless points out to hill-shaped functions as the usual response in crop production (Van Passel *et al.* [16]). Overall, these concave-relationship curves suggest the best adaptation of farmers to be within the mean index values, not the extremes. In winter, too much humidity can cause pests, too little is also not beneficial.

Climate scenario effects on farm returns

In Table 3, we examine the scale of the global warming effect on the unit farm gross margin. The estimated Ricardian model (Table 2) is used to derive projected changes in the farm returns under different future climatic conditions. We use MEPP [9] predicted projections that provide five different precipitation and temperature change scenarios for the years of 2025 and 2050, hence obtaining the absolute changes in the de Martonne index. The marked negative percentage changes in gross margin per ha resulting from the predicted changes in precipitations and temperatures are pointing to pronounced adverse climate change effect across all scenarios, similar to findings in comparative studies (for instance, Van Passel *et al.* [16] estimate farm land value losses of −5 to −9% per °C at farms in Southern Europe). In our study, farm returns shrunk as the scenarios aggravate and the time period gets longer (5.6 % decrease at the 2025 lowest impact scenario, 23.1 % decrease at the 2025 lowest impact scenario, 28.8 % decrease at 2025 medium impact scenario, etc.). The estimations for the highest impact scenarios are overinflated, but nevertheless this exercise emphasizes the pressing need for farm-level and government-level measures, which will have to take place.

Table 3. Change in climate variables and farm gross margin per ha in different scenarios

		2025					2050				
		low	medium low	medium	medium high	high	Low	medium low	medium	medium high	High
Precipitations (mm)	Winter	-1	-1	-3	-4	-5	-3	-4	-6	-8	-10
	Summer	-4	-6	-13	-20	-25	-12	-15	-25	-38	-48
	Autumn	-1	-1	-2	-4	-5	.5	-7	-9	-11	-14
Temperatures (°C)	Winter	0.5	0.7	0.8	0.9	1.1	0.8	1	1.5	1.9	2.4
	Summer	1.2	1.6	1.7	1.9	2.4	1.5	2.1	3.0	3.8	4.8
	Autumn	0.7	1.0	1.1	1.2	1.5	1.0	1.3	1.9	2.4	3.0
De Martonne index	Winter	-2.5	-3.1	.5.1	-6.3	-7.6	-5.1	-6.5	-9.4	-12	-14.5
	Summer	-1.8	-2.5	-5.0	-7.4	-9.2	-4.6	-5.7	-9.2	-13.4	-16.5
	Autumn	-1.1	-1.3	-1.9	-3.0	-3.7	-3.4	-4.6	-6.0	-7.2	-8.9
	Farm gross margin/ha	**-5.7%**	**-9.1%**	**-28.8%**	**-48.7%**	**-71.2%**	**-23.1%**	**-35.1%**	**-81.4%**	**-151.1%**	**-222.8%**

Limitations of the Ricardian approach in the Macedonian context

The theoretical and methodological framework underlying the Ricardian modelling approach to the impact of climatic change to agriculture is suitable in the Macedonian context, considering the predicted climate-induced changes hindering agricultural development. Instead of the more traditional approach of using specific crops yields, this approach uses the value of the farmland or net rent and estimates how it is affected by the climate in different regions. One of the basic assumptions of the Ricardian approach is that every farmer tends to maximize profits by adapting the production to the changing environment. Further assumption is that there is no change in real crop prices in response to climate change, which may be considered as a disadvantage of the model (Cline [30]). Critical comments on this model focus, on one hand, on the exclusion of the adaptation adjustment costs (Hertel and Rosch [12]), while Quiggin and Horowitz [31], on the other hand, challenge the comparative static nature of the empirical results. Taking into careful consideration these limitations, yet the Ricardian (hedonic) model is viewed as the best suited approach in most widely received economic studies, since the strength of this approach is that it accounts, to a large extent, for behavioral responses (Schlenker and Roberts [32]).

The most notable limitations of the present study are of empirical nature, namely the available type and quality of data, and hence the need to use different types of proxies in order to assess factors important in the adopted modeling framework. Although we were able to acquire micro-level farm data containing the basic economic indicators, still many essential variables were difficult to obtain. For instance, irrigation could be assessed only through water costs, while in reality some farmers would irrigate, but either not report or not recognize a certain expenditure as an irrigation related cost. Nevertheless, not including irrigation as a variable in the specification does not necessarily mean bias in the model. Schlenker and Roberts [32] argue that irrigation critically influences predicted climate impacts, but Seo and Mendelsohn [18] suggest that although their results show that irrigation lessens the damages of the climate change, there are no conclusive results indicating that not including irrigation in an empirical Ricardian model will yield a significant bias. Vanschoenwinkel and Van Passel [33] suggest farm irrigation response to climate change to be significantly different, depending on how irrigation is defined. The soil variables are not significant regressors – one explanation could be that since we do not have information on the exact location of the farm land plots, we have taken into account the dominant village soil type and properties, but still it does not seem to be influencing the farm gross margin. Latitudinal data are also insignificant, as the country is small and stretches across a small space. Distance to town is also insignificant, although it is expected that an important factor inflating farm land value can be proximity to urban centers due to non-agricultural pressure (Chatzopoulos and Lippert [15]), but also that farm returns can often be higher due to market vicinity, more marketing options and higher prices. Some of these issues may be overcome by conducting a tailor-made survey, or supplementing the annual farm accounting survey with several focused control variables through an accompanying questionnaire.

CONCLUSIONS

The Ricardian approach is a widely applied and popular analytical model when assessing the impact of climate change on agriculture. It estimates climate-induced changes in farm returns and captures the first-round adaptations by farmers as approximation of the economic value of climate change on agriculture (Mendelsohn *et al.* [13]). Taking into consideration the particularities of the Macedonian conditions, and the availability and reliability of data, this approach has been modified for the purpose of this study. The adapted specification combines temperature and precipitation, as key explanatory variables, into a single index (de Martonne aridity index), and uses it as such in the model regression.

Recent studies have raised the issue on climate change, reporting the predictions on the nature and scale of the impact (Sutton *et al.* [2] and [8], Bergant [5], MEPP [7], Callaway *et al*. [10], MEPP [9]). There is improved awareness of this issue, but still it is not highly positioned in the policy framework. These studies have stressed the need for adaptation and proposed concrete courses of action in order to mitigate the effect. This study captures the adaptations with the current farming systems, as a response to the changing climate. In this respect, we attempt to add to the efforts to increase the understanding of the impact of climate change on Macedonian agriculture and its sensitivity, as the study discloses that climate change has influence on farm returns.

Climate change will affect the choice of crops and influence the production structure, moving towards systems that are more efficient in using the available resources, especially water and soils. Traditional and innovative adaptation measures must take place in a timely manner in order to prevent and handle the expected weather climate change effects; irrigation, as the key responding strategy to the inadequate rainfall during vegetation period, combined with different supplementary adjustments such as introducing heat-resistant varieties, protective netting, increase in vegetable production under protected areas, advanced plastic or glass tunnels etc.

It is important to close this paper by stressing the fact that the empirical results presented herein are exploratory and further in-depth investigation must be conducted. The empirical analysis can be further refined by examining more closely the characteristics of the non-linear response of unit farm returns of crop farms to precipitations and temperature.

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ДОХОДОТ НА ФАРМИТЕ И КЛИМАТСКИТЕ ПРОМЕНИ: АНАЛИЗА НА МАКЕДОНСКОТО ЗЕМЈОДЕЛСТВО СО КОРИСТЕЊЕ НА РИКАРДИСКИОТ ПРИСТАП НА МОДЕЛИРАЊЕ

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Земјоделството е еден од најранливите сектори во земјата со оглед на интензивирањето на ефектите на глобалното затоплување. Во овој труд се обидуваме да ја процениме адаптацијата на македонските производители под влијанието на климатските промени. Воведуваме алтернативна спецификација на Рикардискиот модел преку вклучување композитен ариден индекс за да се опфати реакцијата на доходот на фармите во однос на температурите и врнежите. Економетриските резултати укажуваат на значајност на променливите поврзани со зимските и летните сезони и ја потврдуваат нелинеарноста на климатската функција во однос на економскиот резултат на фармерите и капацитетот за адаптација. Доходот на фармите е високо чувствителен на различни сценарија за климатски промени и ќе се намалува доколку не се преземат соодветни мерки за приспособување и ублажување, на микро и на макро ниво.

Клучни зборови: Рикардиски пристап на моделирање; климатски промени; растителни фарми; македонско земјоделство; ариден индекс

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Original scientific paper

LANDSLIDES SUSCEPTIBILITY ZONATION OF THE TERRITORY OF NORTH MACEDONIA USING ANALYTICAL HIERARCHY PROCESS APPROACH

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Landslides are natural disasters that have an impact in many areas around the world including the territory of the Republic of Macedonia. In this country, about 300 large landslides are registered, most of which cause serious damage to the infrastructure almost every year. In that sense, the mapping of sites that are susceptible to landslides is essential for the management of these areas. This is a crucial step to prevent landslides in places where this could be expected or to minimize its damages. Therefore, a heuristic approach of Analytical Hierarchy Process (AHP) combined with Geographic Information System (GIS) and Remote Sensing (RS) is used in this work for the assessment of potential landslide areas in the Republic of Macedonia. In the procedure, 6 triggering factors indicating a strong influence on the landslide activity are selected, including lithology, slope angle, land cover, terrain curvature, distance from rivers and distance from roads. Through the procedure, expert-based weight of these factors is made. The LS model is produced with the summing up of the factor layers in the form of harmonized raster grids. Finally, the values of the grid model are classified according to the quantiles and natural breaks scheme. The produced maps show acceptable results confirmed by validation methods and ROC analysis, indicating that about 40% of the country area is under high and very high landslide susceptibility. This approach can be further improved if combined with statistical methods in the form of a hybrid model.

Keywords: Landslide susceptibility; landslide hazard zonation; AHP; ROC; AUC

INTRODUCTION

With large areas of erodible crystalline rocks (gneiss, mica-schists, other schists), sandstones, lacustrine and fluvial deposits, steep slopes (39.5 % of the area above 15°), semi-arid climate and sparse vegetation, landslides are very common in North Macedonia. Frequent storms with heavy or prolonged rains contribute to excess runoff and hillslope instability. Landslides, slumps, and soil creep are especially often on the valley sides, where Neogene lacustrine sands and sandstones are superimposed over inclined impermeable clay and schist layers. In more compact weathered rocks (igneous, limestone, marble), rockfalls, rockslides, debris flows, and other gravitational processes occur. In addition to the natural factors, increased human impact (road-cuts and heavy constructions on steep terrain) significantly contribute to the activation of landslides resulting in economic damages and even casualties [1, 2].

To reduce the risk from the landslides, identification and mapping of the landslide-prone area is a very important task. This information is often described in the form of landslide susceptibility zonation (LSZ) [3–9]. According to Brabb [10], landslide susceptibility (LS) is the likelihood of a landslide to occur in an area on the basis of local terrain conditions. It is the degree to which a terrain can be affected by slope movements, i.e., an estimate of "where" landslides are likely to occur. According to van Westen et al. [11], a landslide susceptibility analysis (LSA) involves essentially four main phases: (a) the production of a landslide inventory map, (b) the assessment of event – controlling factors that influence the landslide manifestation, (c) the appli-

[#]Dedicated to academician Gjorgji Filipovski on the occasion of his 100[th] birthday

cation of appropriate methods for determining the weights of each factor and (d) the compilation of the landslide susceptibility map using a GIS procedure. In most cases, the complexity of the causative and triggering factors, their unknown interrelationship and the lack of knowledge, make the LSA a very demanding task [12]. However, with the help of GIS, it is possible to integrate spatial data of different layers to determine the influence of the causative factors on landslide occurrence [13–17].

Besides the high frequency and yearly damages of up to several million euro, in the Republic of Macedonia, only a few small-scale studies of GIS and RS based landslide area assessments were made with different success. Thus, Milevski et al. [18] use SAGA GIS-based cluster classification of landslide-related factors for susceptibility zonation of Gevgelija-Valandovo basin, and later, frequency-ratio model was implemented in landslide hazard zonation of Pehčevo Municipality [19, 20], Vlaina Mountain [21] and index-based method in landslide susceptibility of the Kriva River catchment [22]. Meanwhile, Peševski [23] made a very detailed landslide inventory of the Polog-Reka (NW) area as a basis for landslide hazard zonation (LHZ).

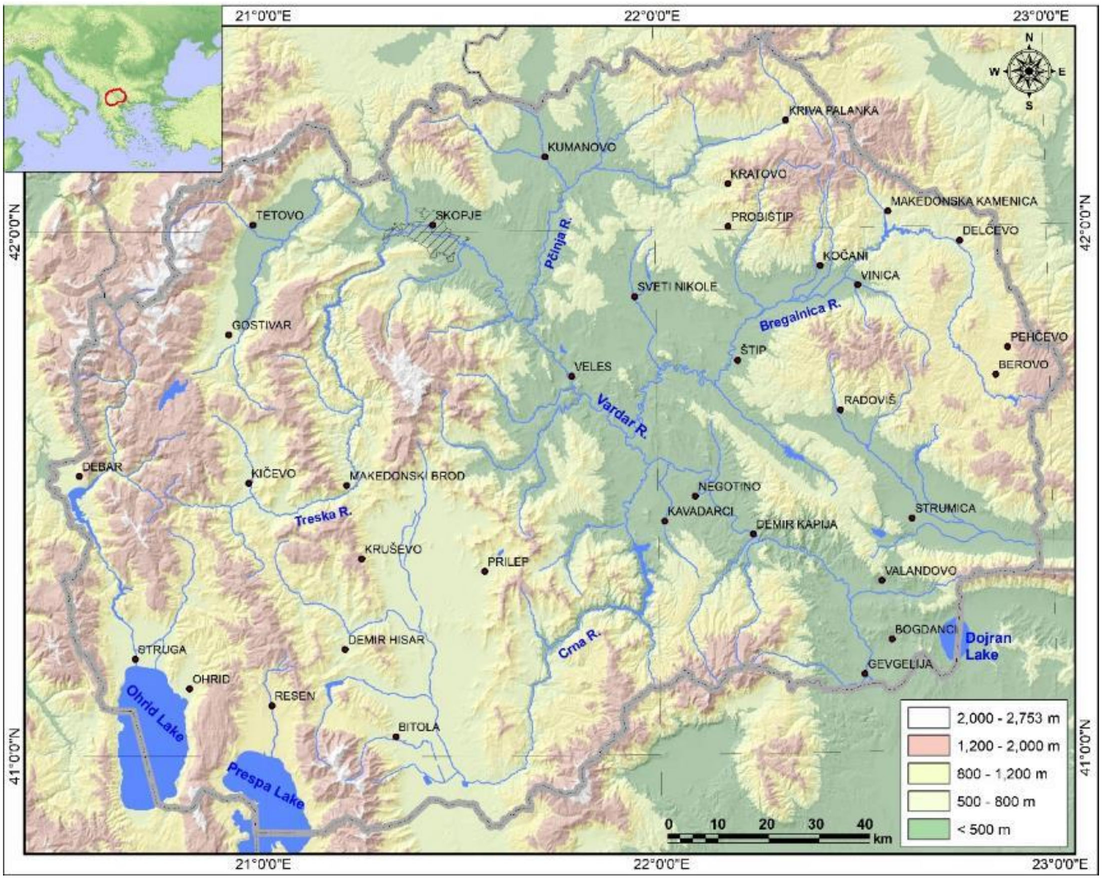

Figure 1. Geographic location of North Macedonia

Currently, Macedonia is without detailed (national-scale) landslides inventory and landslide susceptibility zonation whichis necessary for any land use planning purpose. Thus, the aim of this paper is to make an attempt to determine areas or zones in the country susceptible to landslides. That is made with an analytical hierarchy process (AHP) implemented through geographical information system (GIS) and remote sensing (RS). The advantage is the cost-saving and large-area identification of hazard zones. Therefore, it can be used in hazard zoning of the disaster management authorities [24].

METHODOLOGY

Modeling and mapping of landslide-prone areas on a regional scale is a very complex task, because of many natural and anthropogenic factors related to landslide processes. The first step in this regard is the selection of the most suitable method for landslide susceptibility assessment. Keeping in mind the large extent of the area and the small landslide inventory, heuristic approach with the Analytical Hierarchy Process (AHP) is selected as a method in this paper.

The AHP is one of the most popular Multi-Criteria Decision-Making (MCDM) tools for formulating and analyzing decisions [25, 26] and it consists of three main operations, including hierarchy construction, priority analysis, and consistency verification [27]. Recently, this approach is widely used in the GIS-based assessment of landslide susceptibility [28, 29]. Within the approach, comparison of the contributions of different landslide triggering factors is estimated, where the weight of each criterion is determined by expert-based pair-wise comparison matrix as described by Saaty and Vargas [30].

The implementation of AHP methodology in the assessment of landslide susceptibility firstly requires the finding of interdependencies between the most important influential attributes. It is highly recommended to normalize the values of input attributes and classify them into a specific number of classes. In our case, a 5-class range was used, meaning that 1 is the least likely, while 5 is highly likely to trigger landslide occurrence. Reclassified and ranged attributes, with their weights, give the final impact on the susceptibility model. Thus, a proper selection of most influencing factors or triggers is a very important step in this process.

There is a lort of researches worldwide about the selection of most important landslide triggering factors. According to Crozier [4], depending on the characteristics of the study area, at least three triggering factors have to be included in GIS analysis including topography, lithology and land use. Donati and Turrini [31] indicate that the most common landslide triggering factors are: lithological units, tectonic features, slope angle, proximity to (road and drainage) networks, land cover and rainfall distribution. In the preliminary LS mapping on the national level in Slovenia, Komac and Zorn [32] used 6 factors as a most relevant: lithology, surface inclination, surface curvature, land use, maximum 24-hour precipitation, and surface aspect. Thus, the proper selection is of greater importance than the number itself. Based on the previous knowledge and experience, and keeping in mind data availability, in this work 6 landslide triggering factors were considered: slope, lithology, land use, plan curvature (convexity), distance from streams and distance from roads. When the aspect is analyzed, a weak correlation with landslide distribution is shown, and because of that, aspects as a factor are excluded in the modeling. Actually, numerous other studies are controversial about aspects-landslides correlation [33-36]. The similar is with precipitations which do not have significant spatial differences (in average 500 to 800 mm per year) and there is no accurate data about the heavy rain distribution. In the entire procedure, SAGA GIS v.7 software is used, where all of the factors were converted to raster grids with 20-m resolution. For the purpose of the study, each factor is divided into proprietary classes according to its range, distribution and structure. The data for slope and curvature were calculated from the 20 m digital elevation model (DEM) of the entire country, based on the combined freely available 20-m ALOS and 30-m SRTM DEM. Slope values are classified into 5 classes (0-5°, 5-10°, 10-30°, 30-45°, and more than 45°). In a similar way, according to the values, terrain (profile) curvature is split into 5 classes: highly convex, convex, flat, concave and highly concave. The lithology grid was prepared from a 1:100,000 scale digitalized geological map of the country with 78 lithological units: from Precambrian gneiss and mica-schist through Mesozoic limestone to Cenozoic sediments of marine, lacustrine and riverine origin. These lithological units are reclassified according to the erodibility and engineering-geological features into 5 classes: from clastic sediments and tuffs to very resistant rocks (marble, limestone, quartzite etc.). Land use layer was prepared according to CORINE (CLC2012) general classification hierarchy. Distances from the streams were derived using DEM-based drainage network tool, while the distance from the roads was prepared from the latest (2018) freely available OSM (Open Street Map) road network in vector format. According to the relevant research experience and consulted bibliography, 5 buffer zones for roads (on 50 m steps) and streams (on 100 m steps) were created and rasterized.

In our study, previously selected factors are weighted according to the AHP matrix by the combination of the experts opinion, the field experience of the authors, as well as the results of landslide susceptibility assessment (LSA) from the former researches on smaller (test) areas in the country [18-23]. For the ranking of factor classes, two approaches are used: expert opinion in combination with statistical analysis of the landslide frequency for that class.

One of the basic requirements for AHP-based landslide susceptibility modeling is to have sufficient landslide inventory as a basis for the validation of the model accuracy. However, in Macedonia, detailed inventory is not prepared on the national level yet. For that reason, considering the available time, we prepare inventory based on the landslide records from the field trips and our previous works, then different kinds of maps (especially geological one), landslide records with remote-sensing of satellite imagery, reports from the media etc. The final landslide dataset consists of 270 landslides as the validation dataset used during the verification of the results produced from the model.

RESULTS

To acquire factor weights in AHP, each factor is rated against every other factor by assigning a relative dominant value between 1 and 9 to the intersecting cell. When the factor on the vertical axis is more important than the factor on the horizontal axis, this value varies between 1 (equally important) and 9 (very important). Conversely, the value varies between the reciprocals 1/2 (0.5) and 1/9 (0.11). Since we have used 6 parameters, the comparison matrix has 36 boxes (Table 1). The matrix-based weight of the factors, as well as the consistency ratio (CR) of the matrix, is calculated with the AHP Excel template [37]. According to the prepared landslide inventory, own experience and relevant publications, most of the landslides in the Republic of Macedonia occur on moderate slopes (10–30°) and on terrain composed by clastic sediments (Neogene lacustrine deposits, colluvium sediments) and schists (mica-schists, green-schists etc.). Also, a significant number of landslides occur in terrains with weak vegetation (pastures, grasslands, bare and erodible rocks), but also in the cultivated land on steep terrains and in urban areas. The statistically substantial number of landslides are located on the distance up to 100–200 m from the streams and up to 50 m from the roads, mostly as a large roadside rock falls. Based on these facts, the AHP matrix in Table 1 and the class ranks in Table 2 are prepared.

Table 1. AHP comparison matrix for the selected factors

Factor	Slope	Lithology	Land cov.	Conv.	Roads	Streams	Weight
Slope	1	3	3	4	3	4	0.378
Lithology	0.33	1	1	3	3	4	0.212
Vegetation	0.33	1	1	1	2	3	0.154
Convergence	0.25	0.33	1	1	1	2	0.104
Roads	0.33	0.33	0.5	1	1	1	0.086
Streams	0.25	0.25	0.33	0.5	1	1	0.066

Consistency ratio (CR) which shows how consistent is the hierarchy of the factors in the AHP matrix is a very important parameter. Saaty [25] suggest that the CR must be less than 0.1 to accept the computed weights otherworld the ratings should be re-evaluated. CR for the matrix in Table 1 is 0.035 indicating the acceptable consistency of the comparison matrix.

The factor class ranking (R) is made in a range of 1 (insignificant influence) to 5 (highest influence for that factor). Thus, it is found that the highest number of recorded landslides (86) is present in the slope class of 10–30° and that class is ranked with the value 5. Contrary, in the slope class of 0-5° only 3 landslides are registered so that the slope class is ranked with 1. A similar procedure is taken for all other factors. However, some expert-based evaluation is made when the statistical results are problematic. That is the case with road buffers wherein the first buffer (0–50 m) statistically very large number of landslides is found (135). Our explanation is that most of the recorded landslides with field surveys (for this study) were visible from the roads. For that reason, a weighting of the factor proximity to roads was lower on the matrix scale (but the < 50 m road buffer is with a value of 5).

Finally, the weight of each factor is multiplied by its rankings R (based on the qualitative and expert rankings [38]), then multiplied by 5 and rounded to the final value (Table 2).

The final map (Figure 2) is calculated by summing up the values of each grid cell of all of the 6 digital layers. The values of the resulting model are in the range from 2.6 (areas with the lowest potential for landslides) to 26 (areas with the greatest potential for landslides or already under landslides).

However, the LS map with continuous values provides an only general view of the landslide-prone areas. For better differentiation and landslide susceptibility zoning, the classification of these values must be done. In that sense, using GIS-based natural breaks and quantile classification, we try to classify LS values into five classes of very low, low, medium, high and very high landslides susceptibility zones. Both classifications are performed in SAGA GIS software and their results are compared to ROC curve validation.

Table 2. The weight values of factors used for AHP model

Factor	Rank	R*w*5	Value	Factor	Rank	R*w*5	Value
Slopes w = 0.378				Cultivated lands	3	3.1	3
0-5°	1	1.9	2	Urban areas	3	3.1	3
5-10°	3	5.7	6	Transitional forests	2	1.5	2
10-30°	5	9.5	10	Dense forests	1	0.8	1
30-45°	4	7.6	8	Water bodies	0	0.0	0
>45°	2	3.8	4	**Convexity w = 0.104**			
Lithology w = 0.212				Concave	5	2.6	3
Clastic sediments	5	5.3	5	Highly concave	4	2.1	2
Schists	4	4.2	4	Flat	3	1.6	1.5
Gneiss	3	3.2	3	Convex	2	1.0	1
Flysch	3	3.2	3	Highly convex	1	0.5	0.5
Granitic rocks, andesite	2	2.1	2	**Roads w = 0.086**			
Quartzite, amphibolite	1	1.1	1	0-50 m	5	2.1	2
Limestone, marble	1	1.1	1	>50 m	1	0.4	0
Land Cover w = 0.154				**Streams w = 0.066**			
Bare rocks	4	3.9	4	0-100 m	5	1.6	2
Pastures	4	3.1	4	>100 m	1	0.3	0

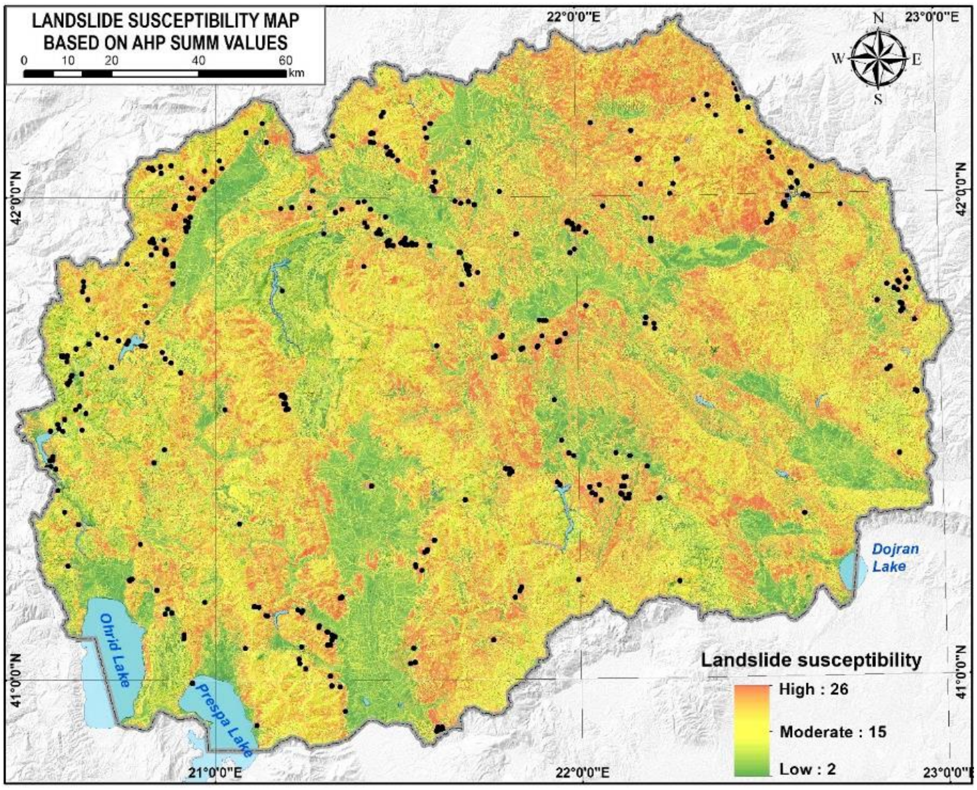

Figure 2. Unclassified AHP-based landslide susceptibility map of North Macedonia

Natural breaks (or Jenks) algorithm performing classification by grouping similar values while maximizing the differences between classes. It gives good results when the histogram shows evident breaks, and for this reason [39]. During this classification method, a problem appears with too small areas of very low and very high susceptibility zones. For that reason, natural breaks (jenks) method is updated with the histogram specific breaks (with the following ranges: 2-12, 12-14, 14-16, 16-18 and 18-26 for the very high LS zone) and the result is shown in Figure 3.

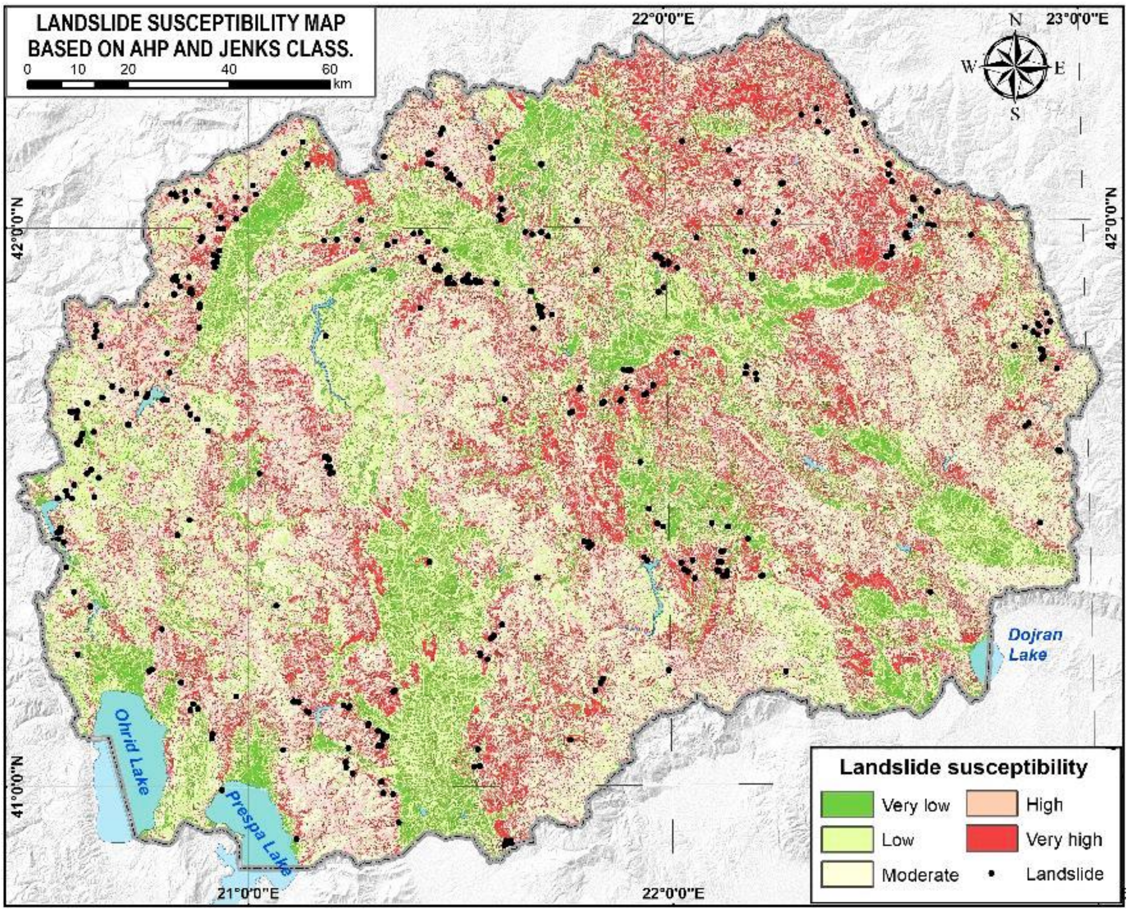

Figure 3. AHP-based landslide susceptibility map of North Macedonia according to the natural breaks (jenks) classification

The second method, i.e. quartile classification is well suited to linearly distributed data assigning the same number of data values to each class. There are no empty classes or classes with too few or too many values [40]. The map prepared with quantile classification (Figure 4) is with a slightly more dominant high and very high landslide susceptibility zone. That is even more evident from the map crops which cover the Skopje basin (Figure 6). Evidently, there is a more significant difference in very high landslide susceptibility area which is confirmed with validation tables. However, the generally small difference is only a result of the class breaks threshold and not related to the AHP procedure itself.

In order to choose the more accurate map of both implemented classifications, the validation technique was used to compare known landslide location data with the landslide susceptibility zonation map. That is made with validation data and ROC curve derived AUC (Area Under Curve).

Both GIS-based classifications (quantiles and natural breaks) shows the acceptable accuracy of the implemented model because more than 70 % of the landslides in the inventory are in the class of high (H) and very high (VH) landslide susceptibility (Table 3). However, natural breaks classification here is superior because only 18 landslides fall in the class of low and very low susceptibility vs 31 landslides in quantile classification. Also, within natural breaks classification, 203 landslides (75 %) fall in the zone of high and very high susceptibility vs only 193 landslides (71.6 %) in quantile classification. However, the number of landslides (in %) compared with the area (in %) of high and very high susceptibility class, show an equal ratio for both classifications i.e. 3.61. From the other side, the same ratio for the areas with low and very low susceptibility class is 0.39 for natural breaks and 0.57 for quantiles which favors natural breaks. Taken that the ratio tends to be as close to 0 for very low LS class, and increase well above 1 for very high LS class, then natural breaks classification shows slightly better overall accuracy. Thus, according to the AHP map prepared with natural breaks classification, 93.4 % of the landslides fall within very high, high and moderate landslide susceptibility zones (covering 66.6 % of the country area).

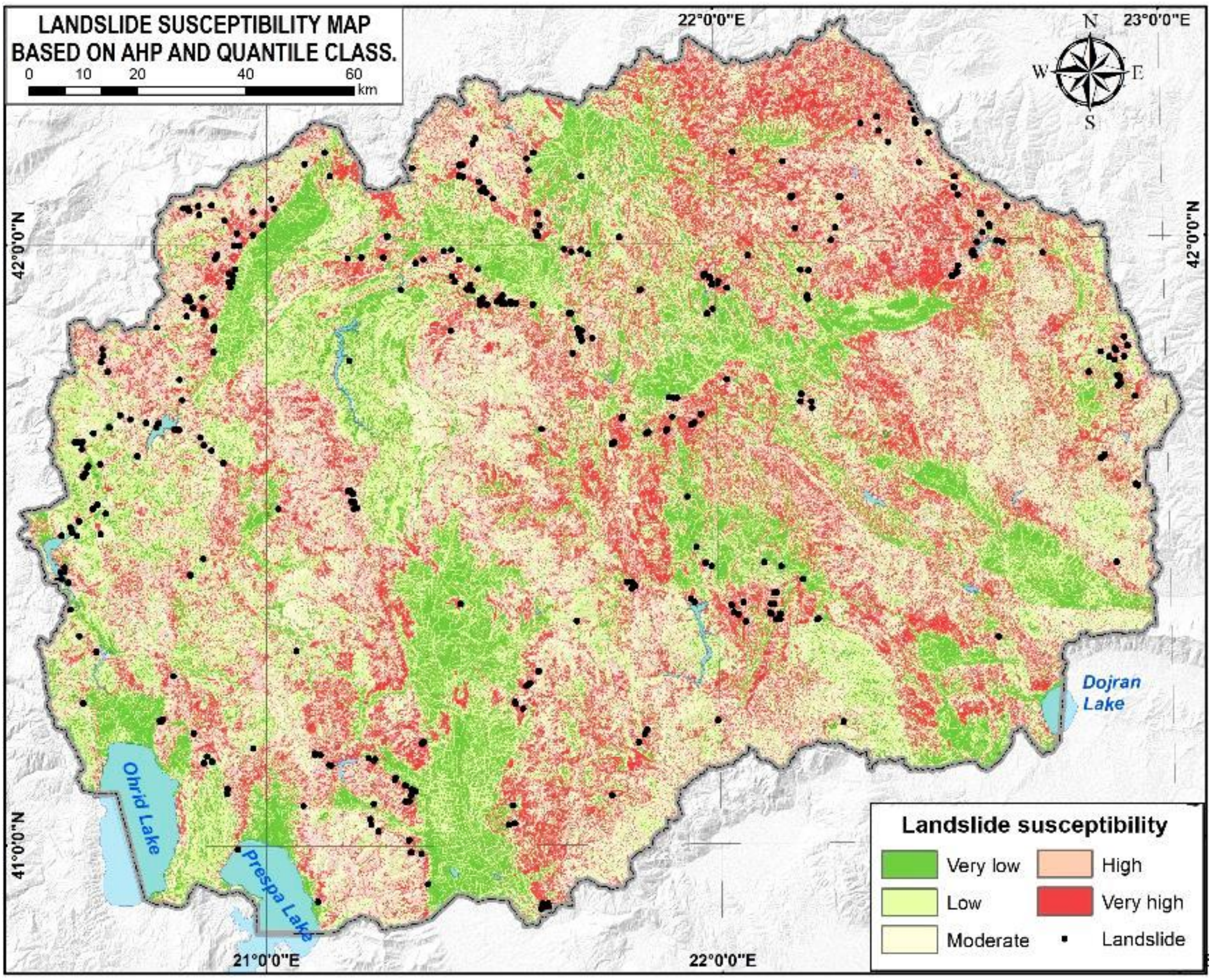

Figure 4. AHP-based landslide susceptibility map of North Macedonia according to the quantile classification

Table 3. Data for AHP-based LSZ according to natural breaks and quantile classification

	Natural breaks (jenks) classification					Quantile classification				
LS class	Area km^2	Area %	Lds.N	Lds.%	Ratio	Area km^2	Area %	Lds.N	Lds.%	Ratio
very low	3882.1	15.1	7	2.6	0.17	5142.6	20.0	11	4.0	0.20
low	4697.7	18.3	11	3.9	0.22	5091.2	19.8	20	7.2	0.37
moderate	6190.1	24.1	50	18.4	0.77	5271.2	20.5	46	17.1	0.83
high	6227.9	24.2	98	36.2	1.49	4962.6	19.3	101	37.5	1.94
very high	4715.2	18.3	105	38.8	2.12	5245.5	20.4	92	34.1	1.67
Total	25713.0	100.0	270	100		25713.0	100.0	270	100.0	

An alternative way to the above statistics is the receiver operating characteristic (ROC) value and the area under the ROC curve (AUC). This method has been widely used as a measure of performance of a predictive rule. ROC plots the different accuracy values obtained against the whole range of possible threshold values of the functions, and the AUC serves as a global accuracy statistic for the model, regardless of a specific discriminate threshold. This curve is obtained by plotting all combinations of sensitivities and proportions of false negatives (1-specificity) which may be obtained by varying the decision threshold. The range of values of the ROC curve area is 0.5–1 for a good-fit, while values below 0.5 represent a random fit [41]. In our case, for better assessment of the model, except the recorded "true-positive" landslides (value 1) in the validation dataset, 540 "false-positive" landslides (value 0) are also selected as random points sampling from DEM (using SAGA GIS). According to our results, with non-random spatial sampling (i.e. on flat areas, highly convex areas etc.), AUC is inadequately high compared with random sampling (excluding the areas of already confirmed-recorded landslides).

The ROC curve and AUC in this study are calculated in SPSS-statistical software (trial version) and presented in Figure 5. It is interesting that both AHP-based maps have almost the same AUC with the very slight advantage of the natural breaks classification (0.780 vs 0.776). Thus, for both, there is nearly 78 % agreement with the landslide locations which is a reasonable result at this scale.

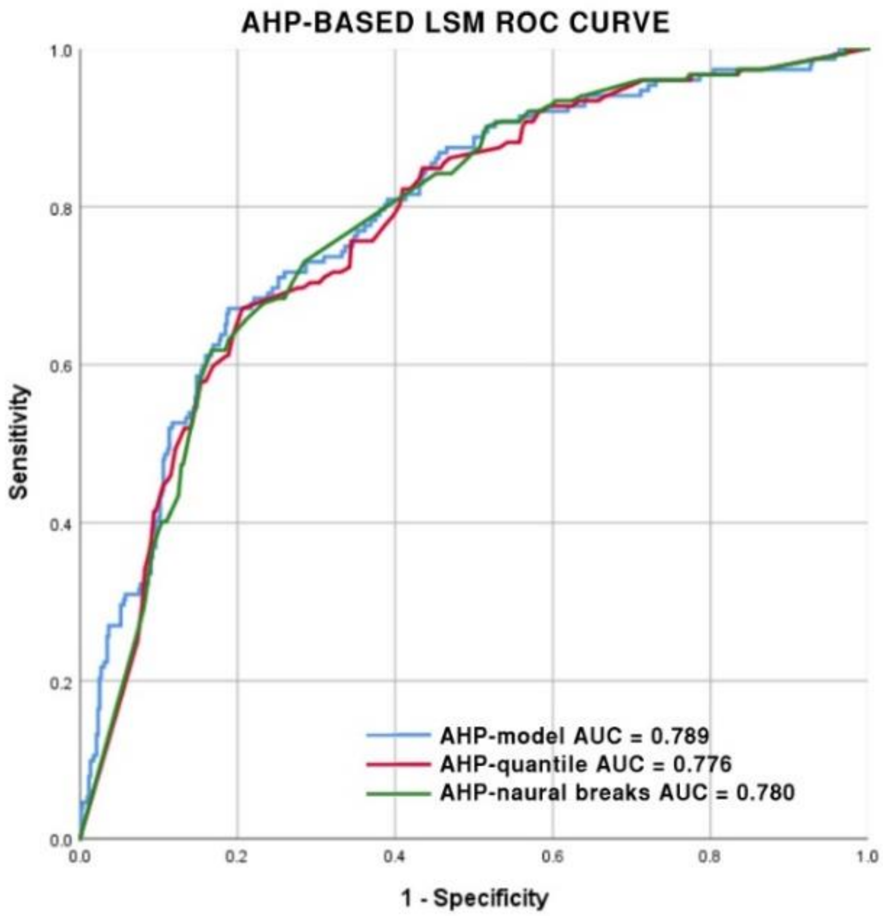

Figure 5. ROC curve and AUC for the AHP-based LS maps produced in this study

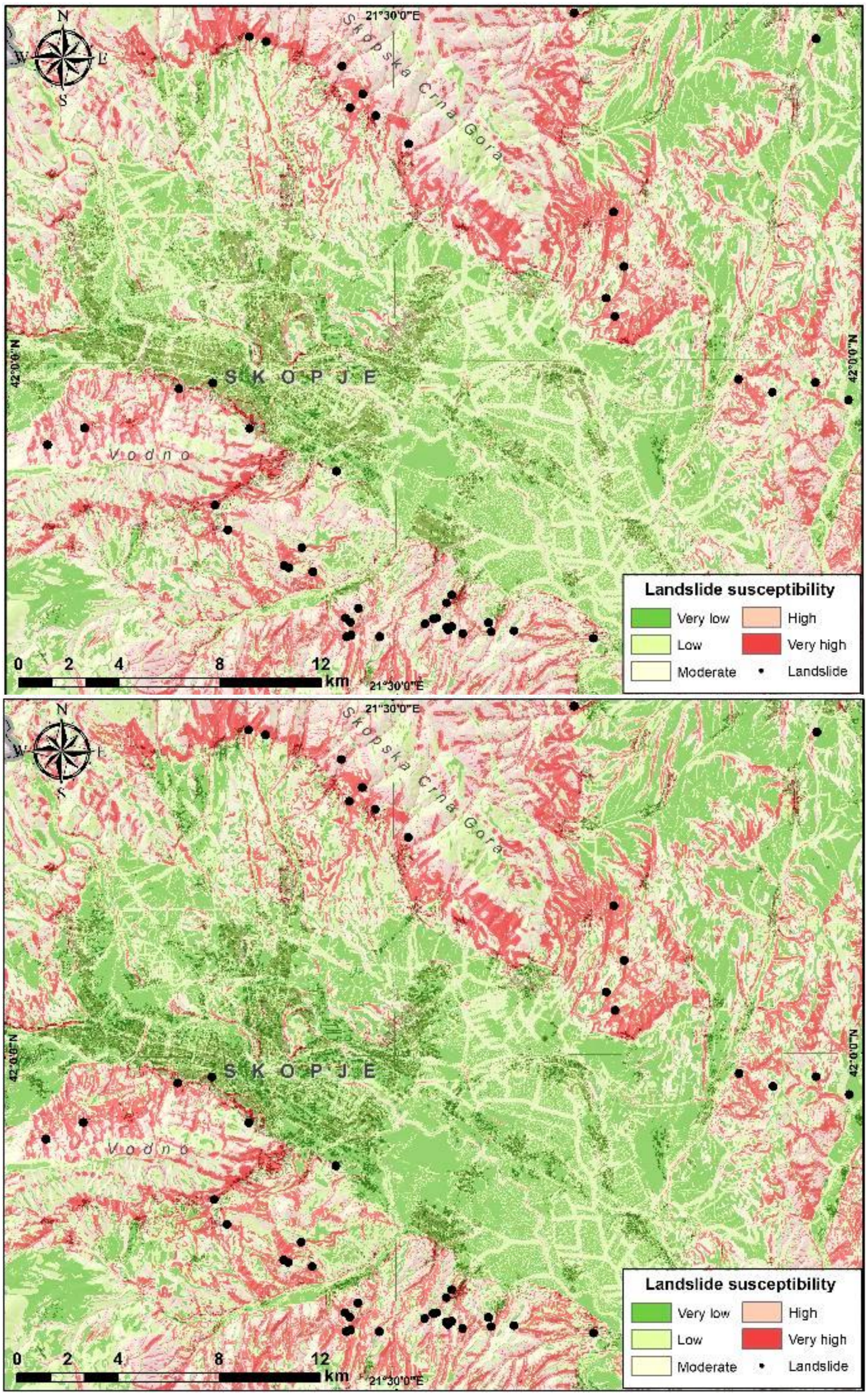

Figure 6. Part of the AHP landslide susceptibility map in the area of Skopje Basin according to the natural –break (up) and quantile (bottom) classification

CONCLUSIONS

LSA is a crucial step to prevent landslides in places where this could be expected or to minimize its damages. At the regional scale, statistical methods like frequency ratio are generally considered the most appropriate for LS mapping because they are objective, reproducible and easily updatable [33]. However, for the implementation of these methods, sufficient landslide inventory is needed. Without that, a semi-quantitative approach can be used as in this paper where Analytical Hierarchy Process (AHP) in a GIS environment is applied. Within the procedure, six factors are selected, analyzed and weighted according to the expert judgment and statistical rankings from the few case studies through the country. Among the factors, slope, lithology, plan curvature, land use, distance from streams and distance from roads are used as the most influencing. The final model is prepared as a sum of weighted grid cells values for each of the 6 factors - layers. With further quantile and natural breaks classification, 5 landslide susceptibility classes are defined and represented on the map. Even with very limited landslide inventory, statistically, there is about 78% agreement (AUC value) between the maps (models) and 270 landslide locations, which is an acceptable result taking into consideration the scale of analysis. It is interesting that both classifications show very similar AUC in slightly favor of natural breaks (0.78) and indicate that about 40% of the country area is under high and very high landslide susceptibility. Regionally, most of the area with high and very high landslide susceptibility in Macedonia is extended over hilly terrains and in mountain foots, on the side of valley bottoms in gorges, and on the sides of depressions and basins which are usually covered with Neogene lacustrine sediments (Fig. 2, 3 and 4). Thus, according to the maps, the areas in the central part of the country (Tikveš depression), the north-east part on the hillslopes of Osogovo and Bilino mountains and upper Bregalnica catchment, on the edges of Skopje Basin (Fig. 6), and the foothills of Šara Mountain are among the most susceptible to landslides. On the contrary, larger plains in the country and terrains built by solid rocks (limestone, marble, andesite etc.), especially in the western part, show low landslide susceptibility. However, the field studies found that even there the occurrence of (smaller) landslides is not totally excluded (near channels, roads, constructions, and other sites with substantial anthropogenic activities).

The LS approach implemented in this work can be further improved in combination with statistical methods if larger and more reliable landslide inventory database is prepared [42] and if other triggering factors (TWI, SPI etc.) are evaluated.

The ultimate goal of producing an accurate LS map that willcover the entire country is not only to indicate endangered areas but to take actions and activities toward prevention and decreasing of the hazard risk itself. If applied properly, such maps are suited for minimizing or avoiding future risks and damages [43]. Nevertheless, in Macedonia, national funds are primarily used for recovery from damages by landslides, and much less for prevention and especially in producing quality mass-movement susceptibility models and maps. In that sense, this model is the first attempt on the country level hoping that further improvement will be made soon.

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ЗОНИРАЊЕ НА ПОДЛОЖНОСТ ОД СВЛЕЧИШТА НА ТЕРИТОРИЈАТА НА РЕПУБЛИКА МАКЕДОНИЈА, СО ПРИМЕНА НА AHP (ANALYTICAL HIERARCHY PROCESS APPROACH) ПРИСТАП

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Свлечиштата се природни непогоди кои имаат големо негативно влијание во многу подрачја низ светот, вклучувајќи ја и Република Македонија. Овде се регистрирани бројни фосилни и рецентни свлечишта, а при поинтензивни врнежи или топење на снег, често се активираат нови. Тие предизвикуваат значителни материјални штети, а понекогаш и човечки жртви (како што било со свлечиштето на ридот Градот во Кавадарци во 1956 година). Во таа смисла, моделирањето и зонирањето на подрачјата подложни на појава на свлечишта е од особено значење, особено при планирање на користење на просторот. Од неодамна, за оваа намена се користат современи ГИС-пристапи, главно за помали територии, а во последно време и за регионален до државен опфат. Во таа смисла, овој труд е прв обид да се изработи модел на зони со различен степен на подложност на свлечишта. Притоа, користен е аналитичко-хиерархискиот пристап (AHP) кој се базира на рангирање на значењето на факторите што влијаат на појавата на свлечишта. Во постапката се избрани 6 фактори, и тоа: наклони на теренот, литологишки состав, покровност и користење на земјиштето, тип на наклон (конкавен или конвексен), близина до реки и близина до патишта. Рангирањето е изведено со помош на експертски оцени за значењето на наведените фактори изнесени во досегашната релевантна библиографија, како и на статистичка анализа на локацијата на регистрираните (270) свлечишта во однос на секој од дадените фактори. Всушност, во рамките на секој фактор одделно се издвоени класи на кои според горенаведениот принцип им е доделена различна „тежина“. Со собирање на сите „тежински“ вредности за факторите и класите во рамките на нив, преку растерски леери во софтверскиот пакет SAGA GIS е добиен модел на подложност на свлечишта за целата територија на државата. Вредностите од овој модел, кои се движат помеѓу 2.5 и 26, се поделени во 5 зони: од зона со најмала (или без) подложност на свлечишта, до зона со многу голема подложност (веројатност) за појава на свлечишта. Моделот е проверен детално со т.н. функција на ROC-крива, при што е добиен солиден резултат од 0.78 или 78 % точност. Понатаму останува овој приод да се дополни со методот на статистичка веројатност или фреквенција за добиениот резултат да биде уште подобар. За такво нешто, пак, неопходна е подетална датабаза на свлечишта во државата.

Клучни зборови: подложност на свлечишта; зонирање; AHP; ROC;AUC

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Original scientific paper

EFFECT OF NATURAL AMORPHOUS SILICA - MULTIMINERAL FERTILIZER FLORAL MICROSIL ON SOME MORPHOLOGICAL AND YIELD COMPONENTS IN RICE (*ORYZA SATIVA* L.)

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The effect of natural multimineral fertilizer Floral microsil (FM) (50 % bio-available amorphous SiO_2 + macronutrients and trace elements) was investigated on some morphological and productive properties in rice at the environmental conditions of Republic of Macedonia, on cultivar San Andrea. Two treatments were studied: control (standard fertilization) with 450 kg/ha complex mineral fertilizers NPK (16:16:16) as basic fertilizer + two splits with Urea 46 % N (200 + 100 kg/ha), and FM treatment: 20 kg/ha FM before sowing, seed treatment with 20 kg/ha FM + three splits of FM + Urea (30 + 100; 20 + 60 and 20 + 60 kg/ha respectively). The field trials were set up in Zade design during 2014 and 2015. Results were analyzed with ANOVA and LSD test.

The FM treatment significantly affected plant and stem height (2014), producing shorter plant (103.02 cm) and stem (87.47 cm) compared to the control (111.81 cm and 95.91 cm). Significantly lower biological (20958.34 kg/ha) and straw yield (10769.67 kg/ha) were determined in the FM treatment compared to the control (24852.00 kg/ha and 15101.34 kg/ha). The FM treatment significantly increased the 1000 grains weight (39.97 g against 38.28 g control average). The paddy and white rice yield (9839.99 kg/ha; 5856.75 kg/ha) in FM treatment were statistically on par with the control (9368.60 kg/ha and 5907.91 kg/ha), as well as the panicle length, number of productive and non-productive tillers per m^2, the head rice yield (whole grains and broken grains) and the hectoliter weight.

The application of FM significantly increased the nitrogen use efficiency estimated thru the partial factor productivity (97.24 kg paddy rice/kg N and 57.88 kg white rice/kg N), as compared to the control average (44.61 kg paddy rice/kg N and 28.14 kg white rice/kg N). Therefore, paddy and white rice yield statistically on par with the standard fertilization were produced with a lower amount of applied nitrogen fertilizer. These findings are of ecological significance for the rice production in the Republic of Macedonia.

Key words: fertilizer; morphological; partial factor productivity; productive; rice; silica

INTRODUCTION

High and stable yield along with good crop quality is of main importance for farmers in plant agriculture, including rice production. The implementation of adequate fertilization that allows balanced crop nutrition with the required nutrients is essential in achieving high yield and quality products in rice production. The optimal nutritional balance in rice for production of 1 t of paddy is achieved by uptake of around 14.7 kg N, 2.6 kg P and 14.5 kg K [1], or 14.8 kg N, 3.8 kg P and 15.0 kg K [2].

The improvement of rice production technology in the Republic of Macedonia is a continuous process. As fertilization is an important part of rice production, over the years different types of fertilizers and fertilization techniques have been investigated. This process is ongoing, depending on the availability of new fertilizers. A number of studies have shown that basic rice fertilization before sowing with nitrogen or NPK fertilizers is necessary for obtaining good yield results [3–7]. The study of foliar application with NPK fertilizers with trace elements - Kristalon™ Special [8] and Lactofol O [9]

[#]Dedicated to academician Gjorgji Filipovski on the occasion of his 100[th] birthday

showed a positive effect of this type of fertilizers on rice yield. Calcium-based foliar fertilizers Megagreen and Herbagreen generally showed no significant effect in rice production [10, 11].

The standard rice production technology in the Republic of Macedonia includes basic crop fertilization and supplemental fertilization. The largest amount of the fertilizer in the field (around 2/3 of N, and completely P and K) is applied with the basic fertilization prior to seeding, usually with application of 400 to 600 kg/ha complex mineral fertilizers (NPK: 15-15-15, 16-16-16, 17-17-17, 20-13-15). The rest amount of N is applied with the supplemental fertilization (second split application) during vegetation in the tillering stage by using 150 to 250 kg/ha nitrogen fertilizers such as urea, ammonium nitrate or CAN [12, 13]. Fertilizers containing other nutrients, including silica and other trace elements are not used, as N, P, K, S and Zn are the nutrients generally considered critical for the rice crop [14–18].

The aim of this study was to evaluate the effect of Floral microsil fertilizer (50 % SiO_2 + macronutrients and trace elements) on some important morphological and yield properties in rice. Although silicon is not considered an essential element for rice nutrition, it has a positive effect on s the rice plant as it supports healthy growth and development [1, 19–21]. A number of studies point to the positive effect of silica fertilizers in rice production, such as resistance to lodging, increased uptake of nutrients (N, P, K), increased yield components, yield and resistance to diseases [22–31].

Other elements present in Floral microsil, such as calcium, magnesium, iron, boron, copper and manganese are not considered critical for the growth and yield of the rice crop, as their deficit in irrigated paddy fields is generally considered a rare case [32–37]. The essential elements for rice present in the fertilizer are potassium, sulfur and phosphorus.

The results obtained from this study are important in understanding the effect of silica from silica-based fertilizers on the rice crop in the environmental conditions of the Republic of Macedonia.

MATERIAL AND METHOD

Material

Floral microsil (FM) is a natural multimineral fertilizer. By chemical composition, FM contains: silica (Si) – the main component of the fertilizer, as amorphous SiO_2 50 %, aluminum (Al) 18.9 %, potassium (K) 7.8 %, magnesium (Mg) 4.2 %, calcium (Ca) 3.6 %, iron (Fe) 3.2 %, sulfur (S) 2 %, sodium (Na) 1.2 %, titanium (Ti) 0.5 %, phosphorus (P) 0.1 %, strontium (Sr) 0.1 %, barium (Ba) 969 ppm, fluorine (F) 500 ppm, copper (Cu) 327 ppm, vanadium (V) 156 ppm, zirconium (Zr) 144 ppm, manganese (Mn) 119 ppm, zinc (Zn) 78 ppm, cerium (Ce) 68 ppm, rubidium (Rb) 42 ppm, chlorine (Cl) 40 ppm, nickel (Ni) 30 ppm, gallium Ga 17 ppm, lithium (Li) 17 ppm, boron (B) 15 ppm and molybdenum (Mo) 13 ppm. In water, the amorphous silica forms a colloid solution of monosilicic acid H_4SiO_4 or $Si(OH)_4$ which is bioavailable to the plant roots. A concentration of 1400 ppm monosilicic acid is present in 2.5 g of fertilizer dissolved in 1 l water. This fertilizer is not available on the market, as it is still in the phase of evaluation. Cultivar San Andrea was used in this experiment.

Method

The field trials were set up in Zade design (trial with plot arrangement in long stripes developed by Adolf Zade) during 2014 and 2015, under typical rice producing conditions of the Republic of Macedonia. Two treatments of Floral microsil (FM) treatment and control were studied. The size of each application was 1000 m^2. The standard rice production technology was applied in both treatments. The only difference between the treatments was the fertilization. The overview of the types and quantities of applied fertilizers in each treatments and time of application, along with the quantity of applied nutrients from fertilizers is shown in Table 1.

At the end of vegetation, prior to harvest, the plant height, stem height and panicle length were measured in field conditions on a total of 30 plants in each treatment (10 random plants per replication). Prior to harvest, average sample (bundle of whole plants – above ground biomass from 1 m^2 crop area) was taken from each replication in order to assess the number of productive and non-productive tillers (sterile tillers, unripe panicles and weedy rice panicles) per m^2, the biological yield (straw + paddy), straw yield and paddy rice yield. In laboratory conditions were determined the hygroscopic grain moisture at harvest, the 1000 grains weight and hectoliter weight of paddy rice, and the head rice yield. In order to determine the head rice yield, paddy rice samples of 100 g from each replication were milled on a laboratory milling machine during 1.40 min. The white rice yield was estimated on the basis of obtained paddy rice yield and head rice results. Results were analyzed by ANOVA and LSD test at 0.05 and 0.01 levels of probability.

The partial factor productivity from applied nitrogen was calculated according to Cassman *et al.* [38], as a ratio of the grain yield to the applied N:

PFP = Y/N_r, where Y is grain yield (kg/ha) and N_r is the amount of applied N (kg /ha). Partial factor productivity was calculated for both paddy and white rice yield per 1 kg nitrogen from applied fertilizers.

The effect of FM fertilizer was studied on Italian rice cultivar San Andrea, which was at the period of the trial the most prevalent variety in cultivation in the Republic of Macedonia. This cultivar is a line from the cultivar Rizzoto, with a plant height of 107 to 116 cm, vegetation length of 150 to 160 day, head rice yield of 61 to 66.5 %, 1000 paddy grains weight of 35 to 37 g, and paddy yield of 6480 to 8710 kg/ha [39, 40].

Table 1. Quantities and time of application of the used fertilizers in the study

Control (standard rice production technology)		
Time of application	Fertilizer type and quantity (kg/ha)	Nutrients kg/ha
Basic: before sowing	NPK 16:16:16 (450)	72 (N); 72 (P); 72 (K)
1st split: active tillering	Urea 46 N (200)	92 (N)
2nd split: end of tillering	Urea 46 N (100)	46 (N)
Total quantity of applied fertilizers: 750 kg/ha (450 NPK + 300 Urea 46 N) Total active nutrients from fertilizers: 210 (N) + 72 (P) + 72 (K)		
Floral treatment		
Time of application	Fertilizer type and quantity kg/ha	Nutrients kg/ha
Before sawing	FM (20)	10 (Si); 1.56 (K); 0.4 (S); 0.02 (P)+ trace elements
Seed treatment	FM (20)	10 (Si); 1.56 (K); 0.4 (S); 0.02 (P)+ trace elements
1st split: early tillering	FM + Urea 46 N (30 + 100)	15 (Si); 2.34 (K); 0.6 (S); 0.03 (P); trace elements + 46 (N)
2nd split: active tillering	FM + Urea 46 N (20 + 60)	10 (Si); 1.56 (K); 0.4 (S); 0.02 (P); trace elements + 27.6 (N)
3rd split: end of tillering	FM + Urea 46 N (20 + 60)	10 (Si); 1.56 (K); 0.4 (S); 0.02 (P); trace elements + 27.6 (N)
Total quantity of applied fertilizers: 330 kg/ha (220 Urea 46 N + 110 FM) Total active nutrients from fertilizers: 101.2 (N) + 55 (Si) + 8.58 (K)+ 2.2 (S)+ 0.11 (P) + trace elements		

Weather and soil conditions

The field trials were set up in the Rice experimental station of the Institute of Agriculture Skopje, in the Sredorek area of Kochani. The trial site is located within the main rice-producing region that belongs to the temperate continental sub-mediterranean region of the Republic of Macedonia [41] and represents typical rice producing conditions of the country. The temperatures and precipitation sums during rice vegetation in the trial years 2014 and 2015, along with long-term average data for the 1998–2013 period are presented in Table 2 (data obtained from the meteorological station at the Institute of Agriculture Skopje – Rice research station in Kochani).

From previous surveys [42] the soil in the Sredorek area where the field trial was set up is classified as alluvial. pH (reaction) of the soil solution has been determined with a glass electrode in water suspension and in 1MKCI suspension [43]. The content of $CaCO_3$ was determined using Scheiblers calcimeter [43]. Easily available forms of P_2O_5 and K_2O were determinate by the Al method [44]. The major soil characteristics are given in Table 3.

Table 2. Average temperatures and precipitation sums for 2014 and 2015, along with 1998 – 2013 averages

	Months							Average	
	IV	V	VI	VII	VIII	IX	X	Yearly average	During vegetation
Year	Mean monthly temperatures (°C)								
2014	12.4	16.8	20.8	23.2	23.8	18.3	13.8	13.8	18.4
2015	11.4	18.9	21.0	26.3	25.5	21.6	13.9	13.9	19.8
AVG 1998- 2013	13.9	18.7	22.8	25.5	25.2	20.0	14.8	14.1	20.1
Mean monthly maximum temperature (°C)									
2014	18.0	23.0	28.1	30.9	31.8	25.0	20.7	20.1	25.4
2015	18.3	25.9	28.2	34.1	33.2	28.3	20.2	20.4	26.9
AVG 1998- 2013	19.4	24.1	28.7	31.6	31.6	26.3	20.4	19.5	26.0
Mean monthly minimum temperature (°C)									
2014	7.4	10.8	14.0	16.5	16.6	13.4	8.7	8.5	12.5
2015	5.2	12.5	14.1	17.9	17.5	14.8	9.3	7.8	13.0
AVG 1998- 2013	5.8	10.3	13.4	15.2	15.2	10.8	6.8	6.4	11.1
Monthly precipitation (mm)								Precipitation sum (mm)	
2014	121.0	92.0	116.0	65.0	31.0	89.0	37.0	794.0	551.0
2015	31.0	32.0	62.0	2.0	32.0	59.0	127.0	605.0	345.0
AVG 1998- 2013	39.7	49.1	59.3	27.9	33.0	41.8	58.5	493.9	309.3

Table 3. Some chemical characteristics of the soil in Sredorek area

Soil depth (cm)	$CaCO_3$ (%)	PH		Easy available mg/100 g soil	
		H_2O	N KCl	P_2O_5	K_2O
0 – 20	0	5.60	4.70	23.61	13.30
20 – 40	0	6.00	5.30	7.48	12.95

RESULTS AND DISCUSSION

The results obtained in this study are presented in Tables 4 to 11. FM treatment resulted in lower average plant height (103.02 cm) and stem height (87.47 cm) as compared to the control (Table 4). Similar results were reported by Hekimhan *et al*. [28]. Statistically significant differences were obtained in 2014. On the other hand, the differences in 2015 were non-significant. In the control, the cultivar San Andrea had an average plant height of 111.81 cm and an average stem height of 95.91 cm. This plant height value corresponds to the range of 107 cm to 116 cm reported for this cultivar in the country of origin [39, 40].

Shorter panicle in FM treatment was observed in both years, with significant differences.

The lower values for the plant height, stem height and panicle length in the FM treatment can be attributed to the lower nitrogen rate as compared to the control. Nitrogen level plays an important role in increasing rice plant height [45]. According to Dastan *et al.* [25], while plant height, stem length and panicle length increased by increasing the nitrogen fertilizer, their values decreased by silicon application.

While lodging occurred in the control in both years, resistance to lodging was evident in the FM treatment, as lodging was not observed. These resultsare in accordance with the reported effect of silica on rice resistance to lodging [31]. Silicon is distributed to tissues involved in maintaining rigidity of the plant to prevent lodging, specifically the leaf sheath, the outermost part of the stem and the leaf blade midrib [23]. According to Dastan *et al*. [25], the silicon application increased resistance to lodging because of a decrease in plant height, stem, panicle, 3rd and 4th internodes length, which decreased the bending moment of the 3rd internode. The effect of silica on rice stalk rigidity was greater at lower doses of applied nitrogen [22].

During the tillering stage (monitored at early and active tillering), the rice plants are grown in the FM treatment developed longer roots compared to control, as evident in Figures 1 and 2. These observations are in accordance with Jawahar *et al.* [46], who reported that silica fertilizer (Silixol) significantly increased the root length and volume in rice. Similarly, Adhikari *et al.* [47] reported enhanced length, volume and dry matter weight of root in rice seedlings with the application of silica nanoparticles.

Table 4. Effect of Floral microsil fertilizer on plant height, stem height and panicle length (cm) in rice cultivar San Andrea

	Floral	SD	CV	min	max	Control	SD	CV	min	max
Plant height										
2014	103.97*	6.16	5.94	94	115	118.85	8.57	7.21	105	133
2015	102.07	5.33	5.22	92	111	104.77	4.12	3.93	96	111
Average	**103.02**					**111.81**				
* the result for the Floral microsil treatment significantly differs from the control ($p< 0.05$) LSD (2014): 9.26 ($\alpha_{0.05}$), 21.37 ($\alpha_{0.01}$); LSD (2015): 10.42 ($\alpha_{0.05}$), 24.03 ($\alpha_{0.01}$)										
Stem height										
	Floral	SD	CV	min	max	Control	SD	CV	min	max
2014	87.67*	5.96	6.80	78	99	102.52	8.92	8.70	88	118
2015	87.27	4.83	5.53	79	96	89.30	4.00	4.48	81	97
Average	**87.47**					**95.91**				
* the result for the Floral microsil treatment significantly differs from the control ($p< 0.05$) LSD (2014): 9.81 ($\alpha_{0.05}$), 22.62 ($\alpha_{0.01}$); LSD (2015): 9.82 ($\alpha_{0.05}$), 24.64 ($\alpha_{0.01}$)										
Panicle length										
	Floral	SD	CV	min	max	Control	SD	CV	min	max
2014	16.30	1.65	10.21	13	21	16.33	2.31	14.15	12	23
2015	14.80*	1.32	8.92	13	18	15.47	1.37	8.86	13	18
Average	**15.55**					**15.90**				
* the result for the Floral microsil treatment significantly differs from the control ($p< 0.05$) LSD (2014): 1.32 ($\alpha_{0.05}$), 3.03 ($\alpha_{0.01}$); LSD (2015): 0.63 ($\alpha_{0.05}$), 1.44 ($\alpha_{0.01}$)										

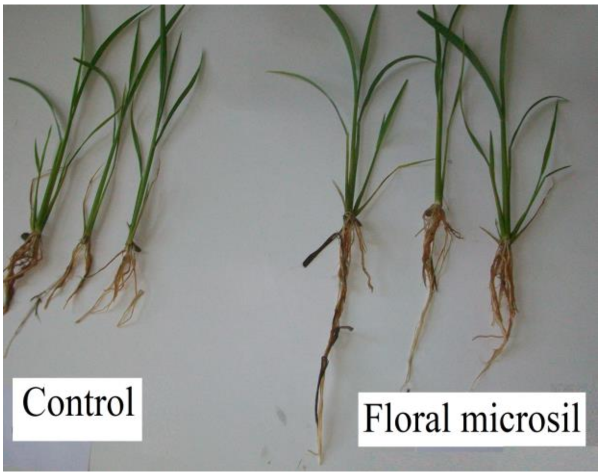

Figure 1. Root development in rice at early tillering stage: Control- plants grown with standard fertilization; Floral microsil- plants grown with Floral microsil fertilizer

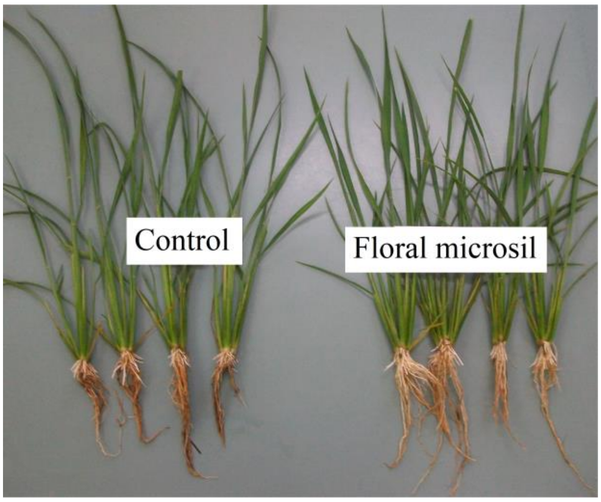

Figure 2. Root development in rice at active tillering: Control- plants grown with standard fertilization; Floral microsil- plants grown with Floral microsil fertilizer

Table 5 presents the results for the number of productive and non-productive tillers per m^2. In the FM treatment, a higher average number of productive and non-productive tillers per m^2 (412.50 and 4.00 accordingly) were produced as compared to the control (381.50 and 1.17 respectively). The differences were non-significant.

Table 5. Effect on Floral microsil fertilizer on the number of productive and non-productive tillers per m^2 in rice cultivar San Andrea

	No. productive tillers/m^2			**No. non-productive tillers/ m^2**		
	2014	2015	**Average**	2014	2015	**Average**
Floral	420.33	404.66	**412.50**	6.33	1.66	**4.00**
SD	111.38	94.55		4.16	1.91	
Control	430.33	332.66	**381.50**	0.33	2.00	**1.17**
SD	63.34	42.52		0.58	4.00	
Ftest	p > 0.05	p > 0.05		p > 0.05	p > 0.05	
$LSD_{0.05}$	224.46	215.16		8.96	8.37	
$LSD_{0.01}$	517.72	394.96		20.66	15.36	

The biological yield (straw + paddy), straw yield and paddy rice yield at 14 % grain moisture are presented in Table 6. The FM treatment resulted in significant differences in the biological and straw yield, while the paddy rice yield was statistically on par with the control values.

In the FM treatment, significantly lower biological and straw yield was produced in both years, with an average of 20958.34 kg/ha and 10769.67 kg/ha accordingly, as compared to the control (biological yield- 24852.00 kg/ha; straw yield 15101.34 kg/ha). The average paddy rice yield at 14 % grain moisture was higher in the FM treatment (9839.99 kg/ha) as compared to the control (9368.60 kg/ha). The differences were non-significant.

The decrease in biological yield in the FM treatment in both years was mainly due to the decrease in straw yield as compared to the control. The significantly lower straw yield can be attributed to the lower N rate applied. According to Pramanik and Bera [45], nitrogen application increased the straw yield significantly with an increase in levels up to 200 kg/ha.

The average hygroscopic grain moisture in paddy rice at harvest ranged from 17.43 % in the FM treatment to 17.92 % in the control (Table 7). Significant differences were found in 2015.

Table 6. Effect of Floral fertilizer on the biological yield (straw + paddy), straw yield and paddy rice yield at 14 % grain moisture in rice cultivar San Andrea (kg/ha)

	Floral	**SD**	**Control**	**SD**	**F test**	**$LSD_{0.05}$**	**$LSD_{0.01}$**
			Biological yield				
2014	20016.67	1164.40	23116.67	236.29	p≤0.05	2602.63	6003.05
2015	21900.00	1195.83	26587.33	1553.16	p≤0.05	2932.49	5382.99
Average	**20958.34**		**24852.00**				
			Straw yield				
2014	9466.67	557.52	12650.00	259.81	p≤0.05	1868.77	4310.37
2015	12072.67	1384.59	17552.67	1437.99	p≤0.01	1084.76	1991.23
Average	**10769.67**		**15101.34**				
			Paddy rice yield at 14 % grain moisture				
2014	10152.30	721.61	10054.87	275.41	p>0.05	1961.43	4524.09
2015	9527.67	837.17	8682.33	603.61	p>0.05	2263.14	4154.30
Average	**9839.99**		**9368.60**				

Table 7. Effect of Floral fertilizer on hygroscopic grain moisture at harvest in rice cultivar San Andrea (%)

	Floral	**SD**	**Control**	**SD**	**Ftest**	**$LSD_{0.05}$**	**$LSD_{0.01}$**
2014	17.80	0.26	17.93	0.06	p>0.05	0.80	1.84
2015	17.05	0.10	17.90	0.08	p≤0.01	0.21	0.38
Average	**17.43**		**17.92**				

The application of FM had a significant effect on the 1000 grains weight, but not on the hectoliter weight (Table 8). Significantly higher 1000 grains weight was obtained in both years in Floral with an average value of 39.97 g, as compared to the control (38.28 g). Significantly increased 1000 grains weight due to silica application was also reported by Hekimhan *et al.* [28], Pati *et al.* [29] and Cuong *et al.* [30].

Significant differences were not determined for the hectoliter weight, which ranged from 51.69 kg/hl in FM to 51.35 kg/hl in the control.

Table 8. Effect of Floral microsil fertilizer on 1000 grains weight (g) and hectolitre mass of paddy (kg/hl) in rice cultivar San Andrea

	Floral	SD	Control	SD	Ftest	$LSD_{0.05}$	$LSD_{0.01}$
			1000 grains weight				
2014	39.20	1.44	37.33	2.00	$p \leq 0.05$	1.60	3.68
2015	40.73	0.96	39.23	0.50	$p \leq 0.05$	0.92	1.69
Average	**39.97**		**38.28**				
			Hectolitre mass				
2014	51.50	0.50	51.33	0.29	$p > 0.05$	0.72	1.65
2015	51.87	0.48	51.37	0.25	$p > 0.05$	0.65	1.19
Average	**51.69**		**51.35**				

The head rice yield in the FM treatment was statistically on par with the control values. Insignificantly higher values were found in the control for the whole grains (Table 9). The FM had average values for the total milled rice, whole grains and broken grains of 69.32 %, 59.80 % and 9.52 % accordingly as compared to 70.18 %, 63.53 % and 6.65 % in the control.

The head rice yield (whole grains) in both the control and the FM treatment was higher in 2015 as compared to 2014. Accordingly, the broken grains percentage was higher in 2014. This variation of the head rice yield can be explained by the environmental factors that prevailed during the study, as 2014 was a cooler and wetter year during rice vegetation and grain filling period compared to 2015.

Table 9. Effect of fertilizer Floral microsil on the head rice yield in cultivar San Andrea (%)

	Floral	SD	Control	SD	F test	$LSD_{0.05}$	$LSD_{0.01}$
			Whole grains				
2014	53.87	2.40	58.03	2.53	$p > 0.05$	7.25	16.73
2015	65.73	2.37	69.03	0.97	$p > 0.05$	4.77	8.75
Average	**59.80**		**63.53**				
			Broken grains				
2014	12.13	2.76	10.00	1.85	$p > 0.05$	9.82	22.65
2015	6.90	2.17	3.30	0.87	$p > 0.05$	4.52	8.31
Average	**9.52**		**6.65**				
			Total milled rice				
2014	66.00	0.46	68.03	1.27	$p > 0.05$	3.07	7.07
2015	72.63	0.53	72.33	0.29	$p > 0.05$	0.84	1.53
Average	**69.32**		**70.18**				

The results for the white rice yield are shown in Table 10. The white rice yield in FM treatment in both years was statistically in par compared to the yield obtained in the control, with the average yield difference of only -0.87 %. The FM treatment yielded 5856.75 kg/ha average white rice, while the control 5907.91 kg/ha. The results show that the application of FM in combination with a lower amount of nitrogen yielded white rice yield that is statistically on par with the standard fertilization method.

Table 10. Effect of Floral fertilizer on white rice yield in rice cultivar San Andrea

	Floral	SD	Control	SD	F test	$LSD_{0.05}$	$LSD_{0.01}$
2014	5457.70	166.89	5824.64	511.26	p>0.05	1636.51	3774.67
2015	6255.80	508.38	5991.17	339.05	p>0.05	1275.81	2341.92
Average	**5856.75**		**5907.91**				

The partial factor productivity from applied nutrients is a useful measure of nitrogen use efficiency because it provides an integrative index that quantifies total economic output relative to the utilization of all nutrient resources in the system, including indigenous soil nutrients and nutrients from applied inputs [38]. According to Pati *et al.* [29] and Cuong *et al.* [30], Si application significantly increased the uptake of nutrients (N, P, K), and increased the yield and yield components. This was also evident in the trial, as the FM treatment significantly increased the nitrogen use efficiency estimated thru the partial factor productivity from applied nitrogen. In FM treatment average partial productivity of 97.24 kg, paddy rice/kg N and 57.88 kg white rice/kg N was obtained as compared to the control (average values of 44.61 kg paddy rice/kg N and 28.14 kg white rice/kg N). Therefore, a significantly higher quantity of paddy and white rice per 1 kg applied nitrogen was produced in the FM treatment.

Table 11. Effect of Floral microsil application on partial factor productivity of applied nitrogen in rice cultivar San Andrea

	Floral	SD	Control	SD	F test	$LSD_{0.05}$	$LSD_{0.01}$
Partial factor productivity from applied nitrogen (paddy rice)							
2014	100.32	7.13	47.88	1.31	$p \leq 0.01$	18.23	42.04
2015	94.15	8.27	41.34	2.87	$p \leq 0.01$	17.56	32.23
Average	**97.24**		**44.61**				
Partial factor productivity from applied nitrogen (white rice)							
2014	53.93	1.65	27.74	2.43	$p \leq 0.01$	9.77	22.53
2015	61.82	5.02	28.53	1.61	$p \leq 0.01$	10.13	18.59
Average	**57.88**		**28.14**				

The application of Floral microsil fertilizer significantly increased the nitrogen use efficiency estimated thru the partial factor productivity. Therefore, paddy and white rice yield statistically on par with the standard fertilization were produced with a lower amount of applied nitrogen fertilizer. These findings are of ecological significance, as they suggest that the application of plant bio-available silica in Macedonian rice production could reduce the use of mineral fertilizers prevalent in the standard fertilization.

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ВЛИЈАНИЕТО НА ПРИРОДНОТО МУЛТИМИНЕРАЛНО ЃУБРИВО СО АМОРФЕН СИЛИЦИУМ FLORAL MICROSIL ВРЗ ОДРЕДЕНИ МОРФОЛОШКИ И ПРИНОСНИ СВОЈСТВА КАЈ ОРИЗОТ (*ORYZA SATIVA* L.)

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Влијанието на природното мултиминерално ѓубриво Floral microsil (FM) (50 % биодостапен аморфен SiO_2 + макронутриенти и елементи во траги) врз некои морфолошки и продуктивни својства на оризот беше испитано во агроеколошките услови на Република Македонија кај сортата San Andrea. Беа испитани две варијанти: контрола (стандарден начин на ѓубрење) со 450 kg NPK (16:16:16) како основно ѓубриво + две прихранувања со Urea 46 % N (200 + 100 kg/ha), и FM варијанта: 20 kg/ha FM пред сеидба, третман на семе со 20 kg/ha FM + три прихранувања со FM + Urea (30 + 100; 20 + 60 и 20 + 60 kg/ha соодветно). Полските опити

беа поставени според Zade-методот во текот на 2014 и 2015 година. Резултатите беа анализирани со ANOVA и LSD-тест.

Третманот со FM значајно влијаеше на висината на растението и стеблото (2014), резултирајќи со пониско растение (103.02 cm) и стебло (87.47 cm) во споредба со контролата (111.81 cm и 95.91 cm). Значително понизок биолошки принос (20958.34 kg/ha) и принос на слама (10769.67 kg/ha) беа добиени кај FM-варијантата во споредба со контролата (24852.00 kg/ha и 15101.34 kg/ha). Третманот со FM значајно ја зголеми масата на 1.000 зрна (39.97 g наспроти 38.28 g просек во контролата). Разликите во приносот на арпа и бел ориз (9839.99 kg/ha; 5856.75 kg/ha) во FM-варијантата беа статистички на исто ниво со контролата (9368.60 kg/ha и 5907.91 kg/ha), како и должината на метличката, бројот на продуктивни и непродуктивни братимки на m^2, рандманот (цели зрна и кршени зрна) и хектолитарската маса.

Апликацијата на FM значајно ја зголеми искористеноста на азотот, одредена преку односот на количината на добиен земјоделски производ (приносот) и количината на употребено ѓубриво на единица површина – partial factor productivity (97.24 kg арпа/kg N и 57.88 kg бел ориз/kg N), во споредба со контролата (44.61 kg арпа/kg N и 28.14 kg бел ориз/kg N). Според тоа, при апликација на ѓубривото Floral microsil во комбинација со помала количина азотно ѓубриво се постигна принос на арпа и бел ориз сличен со стандардниот начин на ѓубрење. Овие резултати се од еколошко значење за оризопроизводството на Република Македонија.

Клучни зборови: ѓубриво; морфолошки; partial factor productivity; продуктивни ориз; силициум

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Short communication

CHARACTERIZATION AND QUANTIFICATION OF PROTEINS IN WHEY OBTAINED AS A BY-PRODUCT FROM WHITE CHEESE AND YELLOW CHEESE PRODUCTION[#]

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After the cheese production process, the whey, obtained as a by-product, is not valorised and remains in the waste water which is usually disposed of in natural watercourses. The aim of the study was to analyse the profile of whey proteins, as well as, to quantify the amount of those fractions. 12.5 % SDS-PAGE was used. The total amount of proteins in whey from cow white cheese was 0.73 % ± 0.15, while in cow kashkaval whey was 0.91 % ± 0.08. In whey from white cheese, the relative protein percentages were: lactoglobulin 67.29 % ± 4.99, lactalbumin 20.64 % ± 2.02 and other fractions related to bovine serum albumin with 12.07 % ± 3.05. In whey from yellow cheese, the proteins percentages were: lactoglobulin 52.62 % ± 1.21, lactalbumin 17.62 % ± 1.26 and other fractions related to bovine serum albumin with 29.74 %, respectively. Predominantly, β-lactoglobulin was present in the analysed samples. The valorisation of the waste whey obtained in the white cheese production, and development of new product also contributes in the environment protection.

Key words: whey proteins; protein profile; by-product

INTRODUCTION

Whey is a by-product in cheese manufacturing process, in general defined as the serum or watery part of milk that remains after the separation of the curd that forms as a result of the milk coagulation by acid or proteolytic enzymes. The whey composition depends on the type milk and cheese or the method of casein precitipation that the manufacturer has applied [1].

The whey protein fractions contains about 50 % β-Lg, 25 % α-La and 25 % other protein fractions, including immunoglobulins. There are wide variations in composition depending on the milk supply, and the process involved in the production of the whey. Whey is classified into three groups: sweet whey (pH typically 5.8–6.6), medium acid whey (pH typically 5.0–5.8) and acid whey (pH > 5.0). In general, the whey obtained from rennet-coagulated cheese develops low levels of acidity, whereas the whey from fresh acid cheeses, such as Ricotta or Cottage cheese, yields medium acid or acid whey. The whey from caseins produced by acid is classed as high acid whey, whereas whey from rennet casein is sweet whey [2].

Whey proteins are well known for their high nutritional value and versatile functional properties in food products. The worldwide production estimation of whey indicate that about 700.000 tons of whey proteins are available as valuable food ingredients. The nutritional and functional characteristics of whey proteins are related to the structure

[#]Dedicated to academician Gjorgji Filipovski on the occasion of his 100[th] birthday

and biological functions of these proteins [3]. Whey protein products, such as whey protein concentrate or whey protein isolate are widely used in the food industry due to the high functional and nutritive properties. Also, these products represent the best way for the utilization of whey proteins [4].

Another option for whey utilization is whey cheese production. Worldwide, the whey cheese types are manufactured according to traditional procedures by denaturation of whey proteins. Ricotta is the most important, and well-known, whey cheese in the world. The Macedonian type of whey cheese recognised as urda is produced from whey originating from kashkaval production [5].

The aim of this study was to compare protein profiles of different types of whey in relation to develop possible technology for the whey cheese obtained from white cheese. The knowledge of the protein profile of the whey derived from white and yellow cheese production will contribute in the development of procedures for valorization of the waste whey from white cheese production process.

EXPERIMENTAL SECTION

The samples of the whey obtained at the white brined cow cheese and yellow hard cow cheese production were analysed. White cheese production process is a vat technology with pasteurized milk at 79 °C, whereas yellow cheese technology is a tank process with pasteurised milk at 72 °C. Due to the different types of technologies, vats vs. tank, the yields of the final product were different. The yield obtained at white brine cheese production was 5.5 L milk/kg product, while at yellow hard cheese 9.8 L milk/kg product. The pH value of cheese whey and yellow cheese whey was 5.89 and 6.37, respectively. The total number of analysed samples was 6 in 4 repetitions.

Electrophoretic analyses were done using sodium dodecyl sulphate polyacrylamide gel electrophoresis (SDS-PAGE). The samples were analysed using 12.5 % T resolving gels and were previously treated with equal amount of reducing buffer (8 M urea/2 M thiourea, 75 mM DTT, 50 mM Tris, 3 % SDS, and 0.004 % bromophenol blue, pH 6.8) [6].

The gel used for electrophoresis was divided into an upper 3 % T stacking gel pH 6.8. The stacking gel has a role to deposit the proteins at the top of the resolving gel as a narrow band. SDS-PAGE was performed according to Laemmli method [7]. Briefly, samples were loaded onto a 12 cm × 10 cm × 1 mm polyacrylamide running gel consisting of a 12.5 % resolving gel [30:0.8, acrylamide/ (N,N′-methylene bis-acrylamide)] and a 3 % stacking gel containing 1 % SDS. Milk protein standards containing bovine casein (ap. 22 kDa), lactalbumin (ap. 14.5 kDa) and lactoglobulin (ap. 18 kDa) and bovine serum albumin (ap. 66,5 kDa) prepared as mixture in concentration of 20 mg/ml. Electrophoretic separation was carried out at a constant voltage of 10 V/cm^{1}. Gels were stained with Coomassie Brilliant Blue G-250 and distained with 10% acetic acid. The analysis of the gels was done with Phoretix software (Nonlinear Dynamics New Castle on Tyne, UK) [8].

<u>Photometric quantification of total proteins</u> was performed in order to determine the residues of proteins in waste water after the cheese-making process using Bradford method [9].

RESULTS AND DISCUSSION

Utilization of the remaining proteins in whey waste water after the cheese-making process was the topic of this study with two objectives. The first one was to protect the natural water streams from pollution, and the second was to recycle the valuable remaining compounds to develop a new by-product. For such purposes were estimated the profile of the protein residues in whey waste water and their quantity.

The method of choice for protein profiling was SDS-PAGE. The type of electrophoresis used was of the denaturing type because it used dithiothreitol (DTT) that reduces all the disulphide bonds, while the sodium dodecyl sulphate bonds to all the protein regions, breaking all the non-covalent bonds and gives the proteins a negative charge. The optimization of conditions for SDS-PAGE electrophoresis on milk proteins from whey waste was done changing the voltage, duration and amount of applied sample. We found that the most conclusive results are reached using 12,5 % SDS-PAGE (Figure 1).

To confirm reproducibility of the electropherograms, two gels were prepared with 2 different sample concentrations, a stock and 1:1 dilution of the stock which were run under the same conditions (Figure 2).

The results showed that in all samples β-lactoglobulin was present in the highest concentration, followed by α-lactalbumin and ending with fractions with the similar molecular weight as bovine serum albumin. Densitometric quantification of each fraction confirmed the visual observation. (Figure 3).

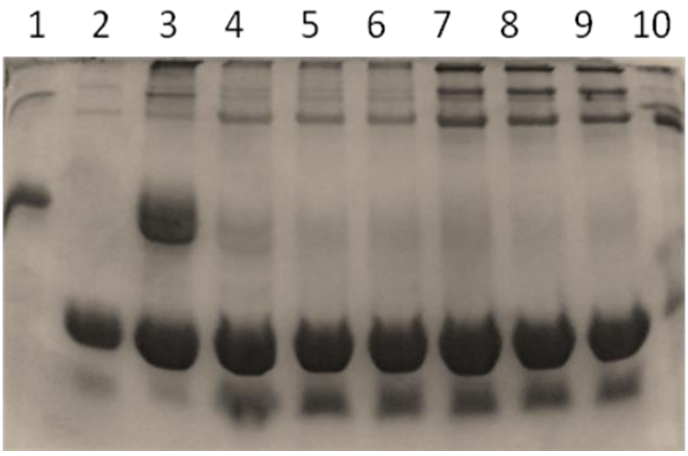


Figure 1. 12,5 % SDS-PAGE on milk proteins: #1 casein (standard), #2 lactoglobulin (standard), #3 milk protein mix (casein, lactoglobulin, bovine serum albumin - standards), #4–6 three whey samples after production of cow white brine cow cheese, #7–9 three whey samples after production of yellow hard cheese, #10 BSA (standard)

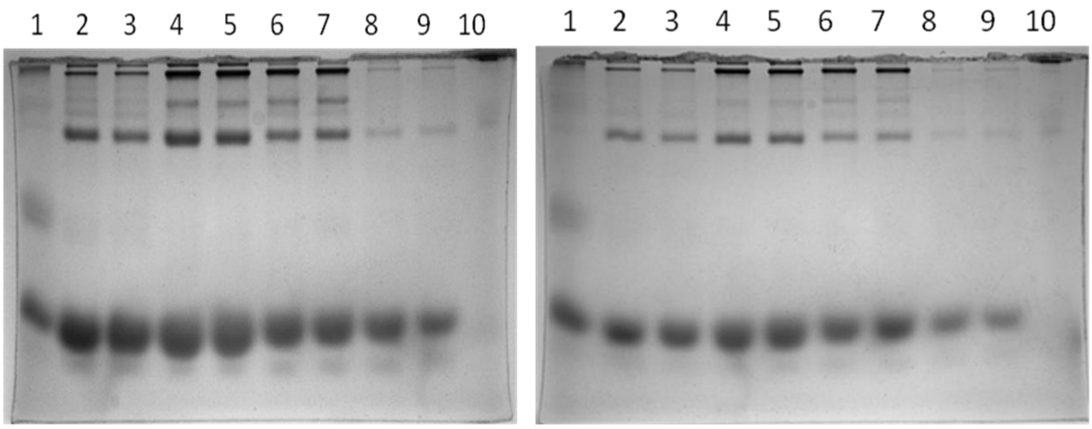


Figure 2. SDS-PAGE electroforegrams of the same samples with different dilutions. #1mix (casein, β-lactoglobulin, α-lactoalbumin ,BSA) #2–3 whey from sheep white cheese ; #4-5 whey from sheep yellow cheese; #6–7 whey from mixed sheep-cow yellow cheese; #8–9 whey from mixed sheep-cow white cheese; #10 BSA standard. A) Undiluted samples. B) Diluted samples 2×

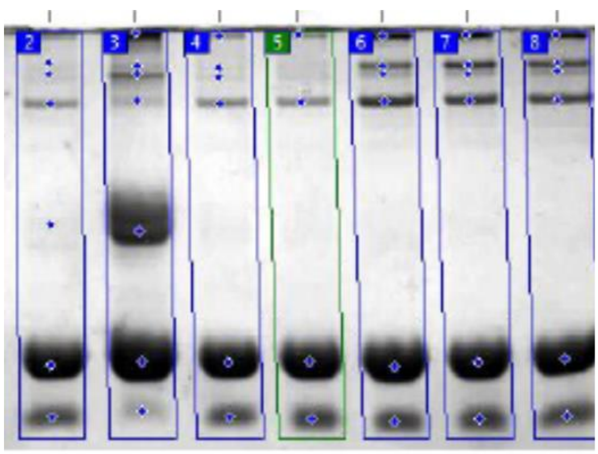
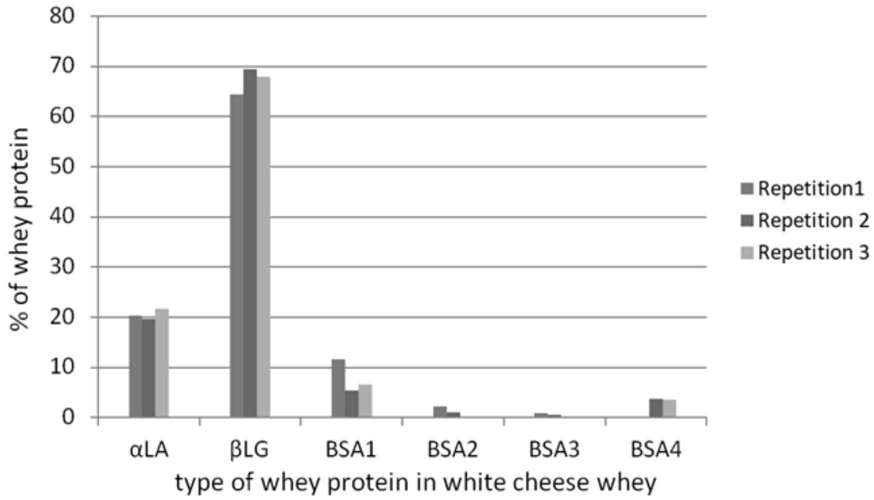


Figure 3. Phoretix analysis of 12.5 % SDS-PAGE on separate fraction in protein profile: #2,4,5 Waste whey from white cheese; #6-8 Waste whey from yellow cheese; #3 Milk protein standard.

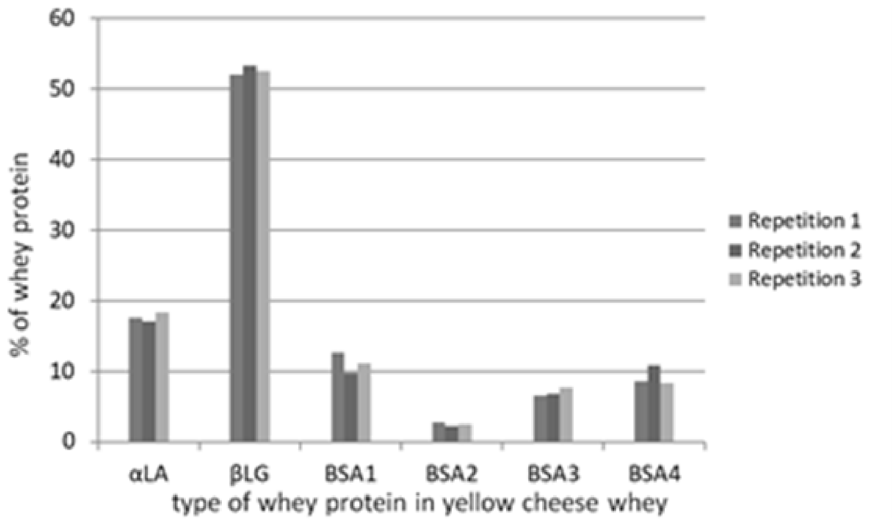
Numerical data on percentage participation of each fraction are shown in Graph 1 and 2. Because we didn't have precise distinction between the fractions with molecular weight close to BSA, we labeled those fractions a BSA 1, 2, 3 and 4.

After cheese processing, the total amount of proteins in the whey waste water from white cheese was 0.71 % ± 0.15, while it was 0.91 % ± 0.8 in the waste water after yellow cheese production (Graph. 3).

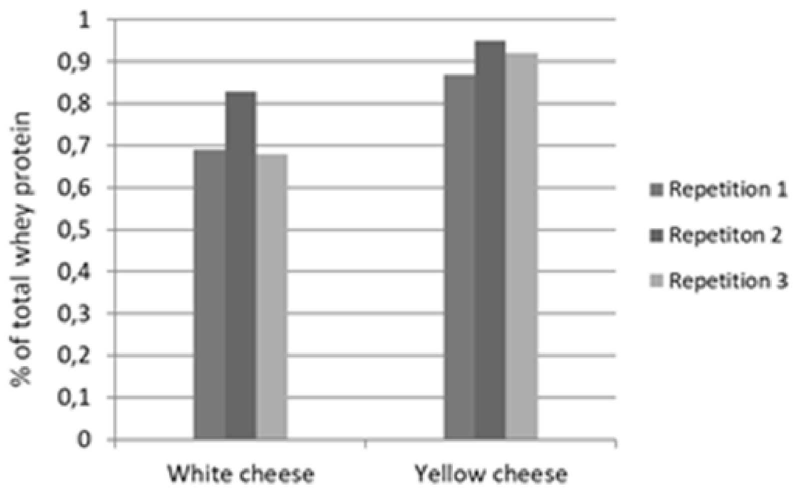
The results showed that the quantity and composition of proteins in whey waste water after the production of white and yellow cheese are stable and is a good basis for recycling of those proteins in development of new products. Future product development should be turned in the direction of valorisation of the white cheese whey waste for whey cheese production. Knowledge of whey composition and adjustments of the process parameters in whey cheese technology could allow manufacturing of whey cheese to realize maximal yield. Also, white cheese whey could be the basic raw material for the production of traditional lactose free whey cheese [10, 11]. Usage of waste whey in some products will contribute in improvement of physicochemical parameters (COD, BOD, pH) of waste water and environmental protection [12].



Graph 1. Percentage of each fraction in whey waste water after white cheese making process in three repetitions



Graph 2. Percentage of each fraction in whey waste water after yellow cheese making process in three repetitions



Graph 3. The amount of total protein in whey waste water after white and yellow cheese making process

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КАРАКТЕРИЗАЦИЈА И КВАНТИФИКАЦИЈА НА ПРОТЕИНИТЕ ВО СУРУТКА КАКО НУСПРОИЗВОД ОД ПРОИЗВОДСТВОТО НА СИРЕЊЕ И КАШКАВАЛ

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Сурутката добиена како нус-производ од производството на бело сирење, не се валоризира во индустријата за млечни производи и директно оди како отпадна вода. Целта на ова истражување беше да се утврди протеинискиот профил на сурутката, а воедно и да се квантифицира количеството на одделни фракции. 12,5 % SDS-PAGE беше корисен како стандард за електрофоретската техника. Вкупното количество на протеини во сурутка од бело кравјо саламурено сирење е 0,73 % ± 0,15, додека во сурутка од кравји кашкавал е 0,91±0,08. Кај сурутката од белото сирење, одделните фракции се застапени со следниве проценти: 67,29 % ± 4,99 лактоглобулин, 20,64 % ± 2,02 лактоалбумин и 12,06 % ± 3,05 говедски серум албумини. Во сурутката од кашкавал, суруткините протеини се присутни со следниве проценти: 52,62% ± 1,21 лактоглобулин, 17,62 ± 1,26 лактоалбумин, и 29,74 % говедски серум албумини. Во анализираните примероци на сурутка е утврдено дека доминира β-лактоглобулинот. Валоризацијата на отпадната сурутка од производство на бело сирење во развој на нов производ придонесува во заштитата на животната средина.

Клучни зборови: суруткини протеини; протеински профил; нус-производ