Eurasian Journal of Soil Science

2021

Volume : 10
Issue : 3
Page : 179 - 268

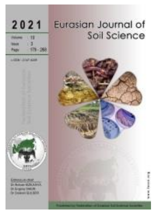
e-ISSN : 2147-4249

Federation of Eurasian Soil Science Societies

Editor(s)-in-chief
Dr.Rıdvan KIZILKAYA
Dr.Evgeny SHEIN
Dr.Coskun GULSER

www.fesss.org

Published by Federation of Eurasian Soil Science Societies



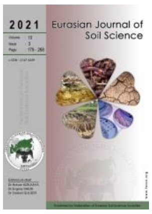
EURASIAN JOURNAL OF SOIL SCIENCE

(Peer Reviewed Open Access Journal)

Published by Federation of Eurasian Soil Science Societies

ABOUT THIS JOURNAL: Eurasian Journal of Soil Science is the official English language journal of the Federation of Eurasian Soil Science Societies. Eurasian Journal of Soil Science peer-reviewed open access journal that publishes research articles, critical reviews of basic and applied soil science in all related to soil and plant studies and general environmental soil science.

ABSTRACTING AND INDEXING: SCOPUS, CABI, FAO-Agris, EBSCOhost, ProQuest, DOAJ, OAJI, TR Dizin, TURKISH Journalpark, CrossRef, CiteFactor, CAS, etc.



EURASIAN JOURNAL OF SOIL SCIENCE

(Peer Reviewed Open Access Journal)

Published by Federation of Eurasian Soil Science Societies

YEAR: 2021 VOLUME : 10 ISSUE : 3 PAGE : 179 – 268

CONTENTS

Eurasian Journal of Soil Science 2021, 10(3), 179- 190

Eurasian Journal of Soil Science

Journal homepage : http://ejss.fesss.org

Laboratory assessment of soil respiration rates under the impact of ornithogenic factor in Antarctic region

Ekaterina Chebykina (Maksimova)*, Ivan Alekseev, Evgeny Abakumov

Department of Applied Ecology, Faculty of Biology, Saint-Petersburg State University, Saint-Petersburg, Russia

Article Info

Received : 07.10.2020
Accepted : 15.01.2021
Available online : 25.01.2021

Author(s)

E. Chebykina *
I. Alekseev
E. Abakumov

* Corresponding author

Abstract

SOM stabilization rates were estimated in the soils of Antarctic region in case of influence of ornithogenic factor. Soils in large penguin clusters, near nests of *Stercorarius sp.*, as well as soils located in geochemically subordinate positions (also often are visited by birds) were found to be characterized by an increased content of carbon and nitrogen with a rather narrow ratio of C/N. The pH values decreased in ornithogenic soils due to the organic acids that produced plants (mosses, *Deschampsia antarctica*) inhabit these soils and the decomposition products of the organic matter guano. The amount of CO_2, in general, released over the entire experiment period is quite large for both ornithogenic and non-ornithogenic soils. CO_2 emission rates were the highest in ornithogenic soils. Ornithogenic soils of the studied area are characterized by the most stabilized organic matter. Thus, the avifauna favors and increases the rate of the mineralization process by several times. An acceleration in the organic matter mineralization rate leads to an increase in nutrients amount available to plants, as in the case of the studied soils. The quality of initial SOM is of a great importance in post-ornithogenic environments. Therefore, further researches of CO_2 emissions rates are needed to characterize post-ornithogenic dynamics and develop an approach to model this process.

Keywords: Antarctic region, CO_2 emission, mineralization rate, ornithogenic factor, soil respiration.

Introduction

Soil organic matter (SOM) mineralization and CO_2 emissions from soil significantly influence on a global carbon cycle and ecosystem stability. For this reason, great attention has been paid to this topic already (Debasish-Sasha et al., 2014; Bruun et al., 2015; Muñoz-Rojas et al., 2015; Novara et al., 2015).

Soils of Arctic and Antarctic regions contain maximum SOM stocks within the whole pedosphere, therefore, they are of a great importance in global carbon circulation and stabilization (Schuur et al., 2015; Parras-Alcántara et al., 2015; Peng et al., 2015). At the same time, SOM stocks in the Antarctic region are underestimated along with the Arctic region. It is due to the data lack for many areas of this continent, due to the high content of stones in the soils and the carbon content high variability in the fine earth (Abakumov, 2010; Yu et al., 2012; Abakumov and Mukhametova, 2014; Wasak and Drewnik, 2015; Abakumov et al., 2016). Antarctic soils are different in their morphology, chemistry, texture and mineralogical composition (Abakumov et al., 2018; Dmitrakova and Abakumov, 2019) as well microbiome structure (Alekseev et al., 2020). Particularly, Antarctic soils have a low content of soil TOC but it is different in various areas and soils. Soil TOC content has a wide range: from minimum levels (close to 0%) in a humic regolith soils (Campbell and Claridge, 1987; Ugolini and Bockheim, 2008; Bockheim, 2013) to 3-4% in soils under mosses, lichens, and cereals (Simas et al., 2008; Abakumov, 2010), or in some areas formed under guano it reaches up to 30-40% of organic matter (Simas et al., 2007b).

: https://doi.org/10.18393/ejss.868088
: http://ejss.fesss.org/10.18393/ejss.868088
Publisher : Federation of Eurasian Soil Science Societies
e-ISSN : 2147-4249

Ornithogenic soils are a special type of soil formation that is characteristic primarily for ecosystems of the Southern Hemisphere (Abakumov, 2010), although these soils are regularly found in the northern polar biome (Ivanov and Avessalomova, 2012). Ornithochoria was shown (Parnikoza et al., 2016) to be quite important in plant remnants redistribution in the Antarctic region because a significant number of variably composed organic material are transported by birds within inland landscapes. Previously, a specificity in morphological structure of ornithogenic soils was established (Abakumov, 2014b), features of soils micromorphological and mineralogical composition under bird colonies were revealed (Abakumov, 2014a), and features of ornithogenic soils geography of the Northern and Southern hemispheres were shown (Abakumov, 2010; Abakumov and Lupachev, 2011/2012; Ivanov, 2013; Pereira et al., 2013), classification aspects were clarified (Parnikoza et al., 2015), and a development of soils in post-ornithogenic succession was described (Pereira et al., 2013; Abakumov, 2014b; Abakumov, 2018; Alekseev and Abakumov, 2018). However, further researches characterized SOM composition, its structural compounds and their distribution in Antarctic ornithogenic soils are needed as published data on this topic are rare.

Huge organic matter pools nowadays are affected to microbial degradation (Schuur et al., 2015) and other environmental risks (IPCC, 2007; Rein, 2013, Tsibart et al., 2014; Zaccone et al., 2014) due to global climate changes and subsequent upon it permafrost degradation. Polar environments SOM is a source of vulnerable carbon that is quite sensitive to remobilization because of increasing temperatures (Schuur et al. 2015; Ejarque and Abakumov, 2016).

Field and laboratory experiments (Zhao et al., 2012) are usually used for an evaluation of organic carbon mass emission loss. Possible mineralization losses from ornithogenic and non-ornithogenic soils can be assessed by controlled laboratory experiments. These methods are necessary for analysis of an apparent stability of SOM and its' mineralization losses and for prediction the possible stability and losses of organic carbon in soils of polar environments. At the same time, data obtained in controlled laboratory experiment and from field experiments (e.g., closed chambers method) are not comparable between each other. Nevertheless, data obtained in unified conditions can be used for further simulation modeling of SOM transformation.

The aim of this study is to investigate the soil organic matter mineralization (carbon mineralization rates and CO_2 emissions) in Antarctic soils of different origin by means laboratory incubation.

Material and Methods

Study sites

Soils subjected to a significant ornithogenic influence and non-subjected, were studied in terms of soil properties and CO_2 emission intensity: plots in large penguin clusters, near nests of *Stercorarius* sp., as well as plots located in geochemically subordinate positions (also often are visited by birds) and accumulating nutrients as a result of redistribution in the relief. The studies were carried out on King George Island (Fildes Peninsula) and on the specially protected natural area (SPNA) of Ardley Island (South Shetland Islands). A location of the sites is shown in Figure 1.

Figure 1. Location of study sites. Green circles – ornithogenic substrates, red circles – non-ornithogenic substrates.

King George Island is the largest island of South Shetland Islands archipelago (Figure 1). A relief of a southeastern part of the island is strongly dissected, has a number of bays. Most of the island is covered by a glacier. Numerous hills are composed of volcanic rocks (strongly eroded). According to eco-climatic zoning, King George Island refers to the Antarctic Peninsula in a part that is located north of the isotherm of average annual temperatures of -1°C. The island is located in the natural zone of Maritime Antarctica (Terauds et al., 2012). Soil formation is largely possible only at the tops of the hills and remnants, and also in the coastal parts characterized by a milder climate. Basalts, tuffs and andesites are parent materials, periglacial plots are covered by some fluvioglacial materials and moraines, while coastal areas are occupied by maritime sands and gravels. Mosses, lichens, algae are typical for most of the island's habitats. In some parts of the island, two species of vascular plants occur – *Colobanthus quitensis* and *Deschampsia antarctica*. Seabirds, penguins and seals are abundant in habitats of the coastal island, and play a crucial role in soil development (Michel et al. 2006; Simas et al. 2007a).

Ardley Island is located on a south-west coast of King George Island, 500 m east of the Fildes Peninsula coast in Maxwell (Fildes) Bay. Mean annual air temperature (MAAT) at King George and Ardley Island is about -2.3°C; mean annual wind speed is 9.3 m/s; annual precipitation – 729 mm. The area is represented mainly by andesite-basalt lavas and tuffs belonging to the Tertiary. Several elevated terraces-beaches are also described. Due to high biodiversity of Ardley Island it is designated as Antarctic Special Protected Area (ASPA). A wide variety of seabirds arrive in the area during the breeding period (11 species) or molting. Ardley Island is also characterized by a highly developed and noticeable flora, including several species of vascular plants, lichens and mosses. The most common lichens at studied plots are *Usnea* gen. and *Himantormia lugubris*, as well as *Xanthoria* sp., *Rinodina* sp., *Placopsis* sp., *Buellia* sp., *Haematomma* sp., and *Caloplaca* sp., which occupied mostly the higher parts of Ardley Island.

Soil identification was carried out using the "Classification and Diagnostics of Soils of Russia" (2004) (Shishov and Tonkonogov, 2004) and the World Reference Base for Soil Resources (FAO 2015) (WRB, 2015). Both classification schemes can be applied to the soils of Antarctica, but are clearly insufficient to describe the entire diversity of soils in the region. The studied ornithogenic soils are distinguished by a specific morphological structure of the soil profile, which is often represented by the following set of soil horizons: peat horizon - organic dark gray or dark-brown horizon and median horizon. Characteristic of studied soil and their horizons are given in Table 1.

Table 1. Characteristic of studied plots and soils.

Plot	Depth, cm	Description	Soil horizons description
		Ornithogenic soils	
Bel 12	0-2	The coast of Maxwell Bay, sand spit leading to Ardley island. The plot on the coast, covered by moss vegetation (20x30 m). Soil name (WRB/RSCS): Histic Lithic Cryosol/Peat Lithozem underlain by permafrost	Peat horizon. Brownish color of plant debris. Low decomposition degree.
Bel 12	2-12		Brownish-grey horizon. The abundance of rounded boulders. Sandy loam.
Bel 14	0-2	Fildes Strait southwest coast. A vast (150x8 m) area covered with moss vegetation and reaching along the coast. Soil name (WRB/RSCS): Histic Spodic Cryosol/Peat Cryoturbated Podbur underlain by permafrost	Peat horizon. Brownish color of plant debris. Low decomposition degree.
Bel 14	2-15		Dark grey horizon. The abundance of rounded boulders (5-20 cm). Sandy loam.
Bel 16	*Deschampsia antarctica*	CHN (Chinese Antarctic Program) monitoring site on top of a rocky highwall on the shore of the Drake Strait at the Biologists Bay. *Deschampsia antarctica* grows by curtains, moss cover grows sporadically. Fine detrital material is on the surface. Soil name (WRB/RSCS): Grey-Humus Lithic Cryosol/Grey-Humus Lithozem underlain by permafrost	Grey-humus horizon. Taupe. Medium-textured loam. Inclusion of rotted rock.
Bel 17	0-2	Surroundings of Bellingshausen Station, King George Island. Wet valley between rocky highwall. Waterlogging. A projective cover of moss cover is about 50 percent. Soil name (WRB/RSCS): Histic Stagnic Cryosol/Peat Gleyic Lithozem underlain by permafrost	Taupe horizon. Medium-textured loam. Lumpy and clumpy.
Bel 17	2-7		Gley horizon with redoxymorphism signs. Glaucescent-gray with stripes of redoxymorphic material (mainly in the upper part of the horizon). Medium-textured loam. Lumpy structure.

Table 1. continue

Plot	Depth, cm	Description	Soil horizons description
		Ornithogenic soils	
Bel 23	0-1	A mild hillslope in the central part of Ardley Island. A penguin nesting site is on a nearby rocky highwall. The surface is covered by alga *Prasiola crispa*. Soil name (WRB/RSCS): Post-ornithogenic Grey-humus Lithosol/Post-ornithogenic grey-humus Lithozem	Ornithogenic horizon. Grayish-glaucescent. Ornithogenic soil processing.
Bel 23	1-23		Glaucescent-gray horizon. Less ornithogenic soil processing. Redoxymorphic signs appear in the lower part of the horizon.
Bel 24	Freshbar	The top of a weathered rocky highwall near lighthouses on the east coast of Ardley Island. The place of active life of the penguin colony. The surface is completely covered by guano layer. Soil name (WRB/RSCS): Turbic Ornithosol/Cryoturbated Ornithogenic soil	
Bel 25	0-1	East coast of Ardley Island. The surface is covered by moss vegetation (projective cover is about 70%). Feathers of penguins and other birds are on the surface. Soil name (WRB/RSCS): Post-ornithogenic Grey-humus Lithosol/Post-ornithogenic grey-humus Lithozem	Peat horizon. Brownish color of plant debris. Low decomposition degree.
Bel 25	1-4		Dark grey-brown horizon. Traces of humus accumulation and accumulation of minerals subjected to ornithogenic impact. Sandy loam.
Bel 25	4-30		Transition horizon to the parent rock. Dun color. Sandy loam. Inclusions of medium rounded rocky material.
		Non-ornithogenic soils	
Bel 5	0-2	Small plot covered by mossy vegetation. Covers the surface of fine-grained material. Soil name (WRB/RSCS): Histic Spodic Cryosol/Peat Cryoturbated Podbur underlain by permafrost	Peat horizon. Brownish color of plant debris. Low decomposition degree.
Bel 5	2-16		Brown horizon. Sandy loam. Inclusions of small boulders.
Bel 26	0-1	Bellingshausen Station. Top of a flat hill. Moss-lichen cover. There are a lot of detrital material on the surface (40-50 cm). Soil name (WRB/RSCS): Histic Spodic Cryosol/Peat Cryoturbated Podbur underlain by permafrost	Peat horizon. Brownish color of plant debris. Low decomposition degree.
Bel 26	1-6		Light brown-gray horizon. Sandy loam. Clarified lens as a sign of a podzolic (eluvial) process.
Bel 26	6-27		Brown coffee color. Bfe horizon. Sandy loam.
Bel 27	0-5	Bellingshausen Station. The area between residential buildings and diesel power plant. Waterlogging. According to the drilling station, the permafrost is at a depth of 4 meters. Soil name (WRB/RSCS): Hyperskeletic Turbic Technosol/Cryoturbated Technozem underlain by permafrost	

Active layer thickness and dynamics in the studied area have been previously investigated. Permafrost table depths for the area of this study have been previously evaluated by vertical electrical resistivity sounding (Alekseev and Abakumov, 2020b). It was found that permafrost table lies at the depths of We found that permafrost table depth ranged between 89 and 100 cm in the area of our study.

Laboratory analyses

All chemical and biological parameters, described in the paper, were measured in soil fine earth, sieved through a 2-mm sieve. Standard soil analyzes (pH, C and N content) were performed according to conventional methods: C-H-N analyzer (Varie EL MAX, Elementar, Germany) were used for carbon and nitrogen content determination and pH was measured in solution – soil to water – with ratio of 1 : 25 (Vorobyova, 2006). A controlled laboratory incubation was carried out during the mineralization experiment. The experiment was carried out in five replicates for each soil horizon (collected from polypedones with an area of 2x2 m). CO_2 emissions were determined using the method described by Anderson (1982). Plastic cylinders 10 cm in diameter and 20 cm in height were used for work. 10 g in case of mineral soil and 5 g in case of organic material were placed in the cylinder during a controlled laboratory incubation. The cylinders with soil samples containing soil moisture of approximately 60% of water holding capacity were then placed in a beaker with a water at the bottom in order to simulate the field conditions of a paddy. The water content (%) was controlled during soil incubation. Then soil samples aliquots were brought at 20°C in sealed plastic bottles with 1 M NaOH. The amount of CO_2 trapped by an alkaline solution was measured by titration after 7 days of incubation. The incubation was carried out for 112 days.

Statistics

Data normal distribution was verified and a variance analysis (ANOVA) and post hoc test (Fisher's least significant difference) were performed. Differences were considered significant at $p < 0.05$.

Statistical data processing and analysis were carried out using standard methods in software packages MS Excel 2016, Past (version 3.20), Statistica 64 (version 10).

Results

General soil properties

The studied soils differ significantly in terms of C and N content (Table 2). The content of carbon increased due to the ornithogenic factor impact on the topsoil horizon. Upper horizons of ornithogenic soils have in average 4.5% C content while non-ornithogenic soils have less content of C in topsoil – 3.3%. Maximum of C content has samples of *Deschampsia Antarctica* and Freshbar (7.5 and 20% respectively). An accumulation of ornithogenic origin organic matter in humus horizons was also observed that unambiguously indicates the most important role of birds in the substances transfer from their coastal zone to the glacier surface. At the same time, organic matter does not remain "functionally dead", but, due to its dark color, promotes localized ice melting and the formation of microdepressions.

The C content, with regard to mineral horizons, was generally comparable to similar indicators at control plots. Decreasing of organic matter in lower soil horizons was observed both in ornithogenic and non-ornithogenic soils. Ornithogenic factor had a low impact on mineral horizons. Exactly the same picture is in case of N content: average values in upper horizons are 0.7 and 0.3% in ornithogenic and non-ornithogenic soils respectively. These data differ significantly ($p<0.05$).

This accumulation of organic matter of ornithogenic origin is confirmed by both an increased concentration of total organic carbon compared to non-ornithogenic soil samples, and a lower C/N ratio there – the most important indicator of the metabolism of any soil. The C/N ratio decreased two-fold in ornithogenic areas, because bird factor induced the organic residues mineralization. Thus, the ornithogenic factor affects not only soil formation in the traditional meaning (Parnikoza et al., 2015), but also the formation of soil-like bodies formed in places where cryoconites accumulate.

Analysis of pH_{H2O} values (water extract) in soils showed the predominance of close to neutral values ($5.6 < pH < 6.5$) in humus horizons and weakly acidic ($5.1 < pH < 5.5$) in lower horizons (under peat horizons) in case of ornithogenic soils; the predominance of neutral and close to neutral values ($5.6<pH<7.5$) in humus horizons and weakly alkaline and alkaline reactions ($7.0<pH<8.5$) in lower horizons in case of non-ornithogenic soils (Table 2).

It should be noted that the studied ornithogenic soils are characterized by significant acidification of the fine earth both due to the organic acids that produced plants (mosses, *Deschampsia antarctica*) inhabit these soils and the decomposition products of the organic matter guano.

Table 2. General soil properties.

Plot, depth, cm	C, %	N, %	C/N	pH_{H2O}
Ornithogenic soils				
Bel 12, 0-2	5.42±0.67	0.63±0.02	8.63	4.9
Bel 12, 2-12	3.98±0.45	0.42±0.03	9.48	5.9
Bel 14, 0-2	4.98±0.24	0.88±0.05	5.66	6.0
Bel 14, 2-15	2.32±0.78	0.43±0.05	5.40	6.9
Bel 16, Deschampsia antarctica	7.45±0.45	0.89±0.12	8.37	5.9
Bel 17, 0-2	5.32±0.21	0.53±0.03	8.10	6.0
Bel 17, 2-7	4.30±0.65	0.45±0.06	7.98	6.2
Bel 23, 0-1	4.31±0.23	0.53±0.03	8.10	5.9
Bel 23, 1-23	2.34±0.93	0.24±0.01	9.75	5.5
Bel 24, Freshbar	20.01±0.25	6.12±0.01	3.27	5.0
Bel 25, 0-1	1.56±0.32	0.22±0.02	7.09	5.5
Bel 25, 1-4	2.02±0.51	0.45±0.02	4.49	5.6
Bel 25, 4-30	1.02±0.05	0.12±0.01	8.50	5.4
Non-ornithogenic soils				
Bel 5, 0-2	3.54±0.12	0.40±0.04	8.85	5.7
Bel 5, 2-16	1.67±0.15	0.21±0.09	7.95	6.0
Bel 26, 0-1	3.31±0.67	0.38±0.11	8.71	5.8
Bel 26, 1-6	2.21±0.84	0.23±0.02	9.61	7.8
Bel 26, 6-27	1.02±0.54	0.12±0.03	8.50	7.0
Bel 27, 0-5	3.21±0.65	0.22±0.03	14.59	5.9
Post hoc test Ornithogenic soils – Non-ornithogenic soils	p<0.05	p<0.05	0.07	p<0.05
Singnificance of differences	Significant	Significant	Insignificant	Significant

CO_2 mineralization rates

Mineralization rates of soil organic matter in upper horizons of ornithogenic soils (Bel 12, Bel 14, Bel 24) turned out to be statistically significantly higher than in non-ornithogenic soils ($p<0.05$) (Table 3, Figure 2, 3). The cumulative production of C-CO_2 by the upper horizons of ornithogenic soils averaged 373.9 mg C-CO_2/100 g, by non-ornithogenic soils – almost 2.5 times less. Values of C-CO_2 cumulative production by the lower, non-surface horizons of ornithogenic soils were comparable to those of non-ornithogenic soils.

Table 3. Average CO_2 emission rates, mg CO_2/100 g soil/day.

Plot, depth, cm	Weeks				
	1-3	4-7	8-11	12-15	16-19
Ornithogenic soils					
Bel 12, 0-2	141.08	66.17	65.00	53.33	48.35
Bel 12, 2-12	24.04	31.58	27.05	24.90	19.08
Bel 14, 0-2	131.68	70.87	87.69	68.28	55.24
Bel 14, 2-15	21.96	19.24	32.25	20.99	16.26
Bel 16, Deschampsia antarctica	20.64	19.33	26.94	21.21	16.76
Bel 17, 0-2	15.16	13.44	15.69	17.69	20.27
Bel 17, 2-7	20.17	21.26	24.08	20.12	17.98
Bel 23, 1-23	39.03	32.64	45.57	43.16	26.14
Bel 24, Freshbar	84.72	62.52	73.08	55.82	51.72
Bel 25, 1-4	25.34	23.85	23.72	20.98	20.32
Bel 25, 4-30	31.62	23.18	32.83	24.83	18.43
Non-ornithogenic soils					
Bel 5, 0-2	66.88	54.46	84.77	66.32	51.67
Bel 5, 2-16	29.85	28.12	24.36	26.89	22.27
Bel 26, 0-1	87.27	79.87	86.03	84.60	62.85
Bel 26, 1-6	21.46	18.95	28.44	21.88	16.84
Bel 26, 6-27	21.97	20.54	23.81	25.09	17.90
Bel 27, 0-5	22.17	18.83	21.82	20.19	16.21
Post hoc test Ornithogenic soils – Non-ornithogenic soils	p<0.05	p<0.05	0.46	0.34	0.49
Singnificance of differences	Significant	Significant	Insignificant	Insignificant	Insignificant

The data obtained (Table 3) showed that the total amount of CO_2 released from the soil has 2 peaks over time: the first peak - at 1-3 weeks, at the very beginning of the experiment, the second peak - at 8-11 weeks. This tendency is typical almost for all studied soils of both ornithogenic and non-ornithogenic origin. The post-hoc test showed essential differences between ornithogenic and non-ornithogenic plots only for the first two experiment periods (1-3 and 4-7 weeks) ($p<0.05$). The decrease in the rate of CO_2 release during the first month of soil samples incubation is apparently due to the consumption of easily available substrates. An increase in the rate of CO_2 production by soil horizons in the second half of the incubation period (3-4 months) is associated with the mineralization of inaccessible and deficient components (as sources of energy and nutrition) of soil organic matter by microorganisms.

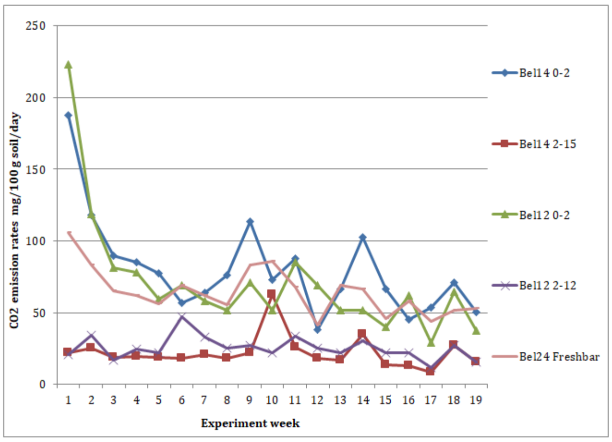


Figure 2. CO_2 emission rates in ornithogenic soils, mg/100 g soil/day

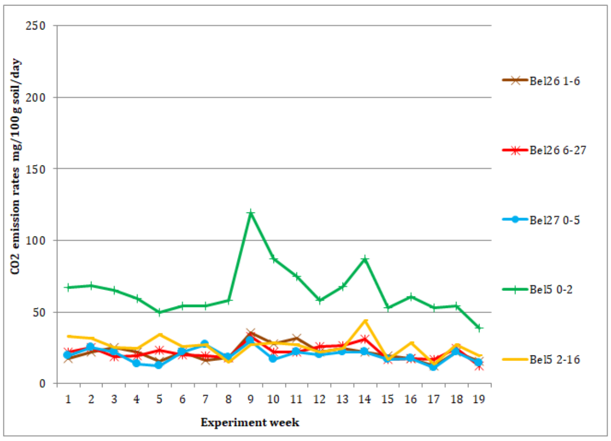


Figure 3. CO_2 emission rates in non-ornithogenic soils, mg/100 g soil/day

CO_2 emission and SOM stability to mineralization

The amount of C–CO_2 produced by the incubated soil simultaneously characterizes both the metabolic activity of soil microorganisms and the ability of organic matter to mineralize. The content of potentially mineralizable carbon in the soil gives a general idea of the mineralization capacity of organic matter: the greater a proportion of potentially mineralizable carbon (PMC), the less stable soil organic matter and more susceptible to various mineralizing effects (Semenov et al., 2008, 2009; Kadono et al., 2009). The data on the rate of organic matter mineralization (Table 4) show that the total amount of CO_2 released from studied soil samples decreased over time. This tendency is more pronounced for upper soil horizons than for lower organo-mineral. A maximum of PMC content was found in the upper horizons of ornithogenic soils (Bel 12, Bel 14) (38.5 g/kg), while the proportion of potentially mineralizable carbon in the Bel 24 Freshbar soil, which has the highest C content (20.01 ± 0.25%), was 1.7 times lower (Table 4). The data of mineralization degree according to the C-CO_2 content (table 4), as well as in the case of CO_2 release intensity, show 2 peaks in time. The difference between C-CO_2/TOC ratio values were statisticaly significant for topsoil horizons (ornithogenic and non-ornithogenic) ($p <0.05$).

The PMC percentage proportion of the total amount of organic carbon characterizes the mineralization capacity or stability of soil organic matter: the wider this ratio, the higher the stability of organic matter (Semenov et al., 2008; Kadono et al., 2009). The data obtained showed that ornithogenic soil (Bel 25) was characterized by the highest mineralization capacity - 84.69%. The mineralization capacity of the upper horizons in non-ornithogenic soils was, on average, lower than in ornithogenic soils. However, the opposite picture is observed for the lower horizons - ornithogenic soils are characterized by a reduced proportion of PMC in the total amount of organic matter. Therefore, a significant change of SOM quality occurs under the influence of the ornithogenic factor.

The stabilization of organic matter are the processes that increase its resistance to biotic and abiotic influences and lead to an increase in the turnover time of organic matter in the soil due to the acquired protected state. Destabilization is the reverse process of stabilization, as a result of which components of organic matter become less resistant to degradation and more available for microorganisms use (Swift, 2001; Six et al., 2006). The highest stability of organic matter was found for ornithogenic soils (Table 4). The rate of mineralization in lower mineral horizons of studied soils is lower than in surface horizons. Probably, the composition of soil humic acids (the ratio of carboxyl groups and aliphatic components) changes under the influence of the ornithogenic factor, which can cause a change in the mineralization rate of organic matter. Therefore, structural changes in the organic matter system under the influence of the ornithogenic factor play an essential role in the organic matter stabilization for soils (Ejarque and Abakumov, 2016).

Table 4. Portions of C mineralized on weeks and portion of total minerlized carbon to TOC content.

Plot	Depth, cm	C mineralized, gC-CO_2/kg soil fine earth, weeks					C-CO_2/TOC, %
		1-3	4-7	8-11	12-15	16-19	
Ornithogenic soils							
Bel 12	0-2	38.55	18.08	17.76	14.57	13.21	14.07
Bel 12	2-12	6.57	8.63	7.39	6.80	5.21	60.59
Bel 14	0-2	35.98	19.36	23.96	18.66	15.09	13.84
Bel 14	2-15	6.00	5.26	8.81	5.73	4.44	38.66
Bel 16	Deschampsia antarctica	5.64	5.28	7.36	5.80	4.58	132.14
Bel 17	0-2	4.14	3.67	4.29	4.83	5.54	128.45
Bel 17	2-7	5.51	5.81	6.58	5.50	4.91	78.07
Bel 23	1-23	10.66	8.92	12.45	11.79	7.14	21.94
Bel 24	Freshbar	23.15	17.08	19.97	15.25	14.13	86.45
Bel 25	1-4	6.92	6.52	6.48	5.73	5.55	29.18
Bel 25	4-30	8.64	6.33	8.97	6.78	5.03	11.81
Non-ornithogenic soils							
Bel 5	0-2	18.27	14.88	23.16	18.12	14.12	19.37
Bel 5	2-16	8.16	7.68	6.66	7.34	6.08	20.47
Bel 26	0-1	23.84	21.82	23.50	23.12	17.17	13.88
Bel 26	1-6	5.86	5.18	7.77	5.98	4.60	37.68
Bel 26	6-27	6.00	5.61	6.50	6.85	4.89	16.99
Bel 27	0-5	6.06	5.14	5.96	5.52	4.43	53.00
Post hoc test Ornithogenic soils – Non-ornithogenic soils		$p<0.05$	$p<0.05$	0.47	0.34	0.49	$p<0.05$
Singnificance of differences		Significant	Significant	Insignificant	Insignificant	Insignificant	Significant

Discussion

Soils exposed to ornithogenic factors showed significant differences in general chemical properties. Firstly, essential changes in the TOC content have been observed there due to a great role of guano organic matter in the soil-forming process. Non-ornithogenic soils are characterized by decreased nitrogen and carbon content, therefore it in turn increases C/N ratio compared to ornithogenic soil. These results correspond with data of Abakumov (2018) and Parnikoza et al. (2015), who showed a significant alteration in the quality of organic matter that occurs in post-ornithogenic soil. What is more, pH values decreased compared to ornithogenic soil because of organic acids that produced plants (mosses, *Deschampsia antarctica*) inhabit these soils and the decomposition products of the organic matter guano.

Cluster analysis was carried out in order to group studied plots according to the content of potentially mineralizable carbon in soils. Dendrograms of studied areas similarity are shown in Figure 4. Clustering was performed using a UPGMA method (unweighted pair group method with arithmetic mean). Cluster analysis, carried out using the Jaccard index and the single bond (nearest neighbor) method, identified two groups according to the principle of soil genesis: ornithogenic and non-ornithogenic soils (Figure 4), separately indicating the group of ornithogenic soils with the maximum rates of soil organic matter mineralization (Bel14 and Bel12). The merging of these two clusters occurs when the similarity rate is slightly higher than 50%. The noted soils grouping reflects the transformation processes specificity of organic substances in studied soils. Apparently, soils grouping is due to the predominance of organic matter transformation processes caused by the ornithogenic factor.

At the same time, a proportion of organic carbon mineralized during the experiment (%) was lower in non-ornithogenic samples than in ornithogenic ones. These data correspond with findings of Alekseev and Abakumov (2020a), who showed a significant alteration in the organic matter quality in post-ornithogenic soils. It has already shown that aromatic compounds portion is slightly more in soils formed on substances carried by birds compared to soils under monospecies of bryophytes or lichens communities (Abakumov and Fattakhova, 2015; Abakumov and Alekseev, 2018). This is explained by the fact that birds use mostly the *Deschampsia antarctica* remains for building nests, which contain an increased proportion of phenylpropane organic precursors (Alekseev and Abakumov, 2020a). This can affect the rate of SOM mineralization in post-ornithogenic and non-ornithogenic soils. Therefore, structural changes in a system of soil organic matter play an important role in its stabilization for post-ornithogenic soils, besides the SOM oxidation degree regulates mineralization rates and other indicators of the quality of post-ornithogenic SOM. Therefore, it can be concluded that the most stabilized SOM is found for ornithogenic materials, where the humification degree and TOM transformation are the highest. Processes of organic matter stabilization begin immediately from the moment it enters the soil, where it undergoes destruction, decomposition and mineralization. Soil microorganisms are active agents not only for biodegradation of organic matter, but also for its stabilization. Thus, there are more microorganisms in ornithogenic soil that can lead to acceleration of mineralization rates and organic matter stabilization.

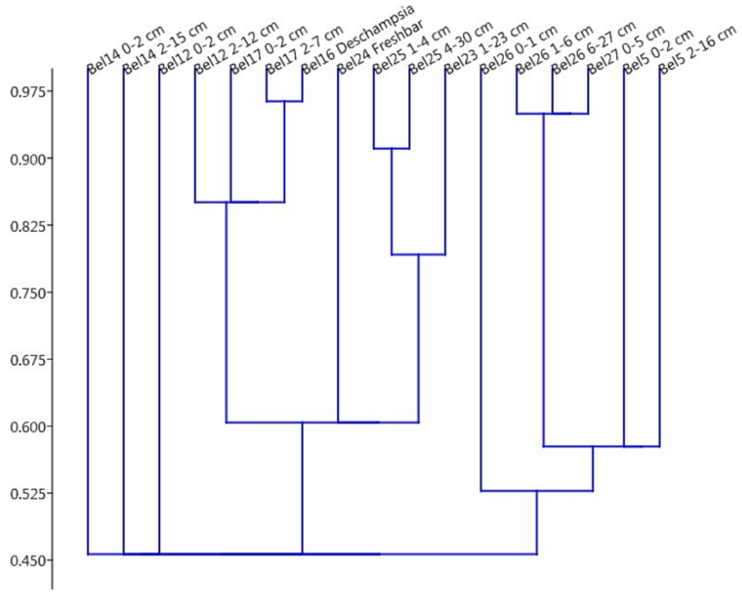


Figure 4. Dendrograms of studied areas similarity (Jaccard index, single bond (nearest neighbor) method).

Organic matter mineralization in soils occurs according to the various factors acting on them. On the basis of the results obtained, an attempt was made to identify the main environmental factors that determine the mineralization rate as a value on which these factors can have a direct effect.

The following factors, that could be assessed directly, or reflected in a certain gradation by expert assessment method, were identified:

- factors describing the genesis of the studied soils - the effect of the ornithogenic factor;
- factors describing the vegetation cover of the studied areas: moss-lichen cover, *Deschampsia antarctica* and guano, ornithogenic material;
- factors that describe soil characteristics and the depth of horizons: pH, C and N content, C/N ratio.

A degree of factors influence was assessed using the Canonical Correspondence Analysis (CCA) (Figure 5). Three factors that have the greatest impact on the rate of soil organic matter mineralization can be distinguished: pH, C content and origin (ornithogenic/non-ornithogenic soils). The depth of soil horizons influence on mineralization in lesser extent.

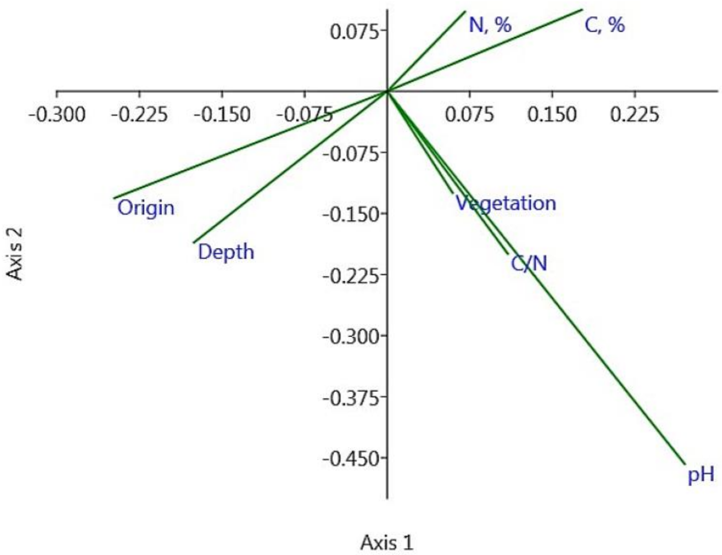


Figure 5. Environmental factors affecting the rate of organic matter mineralization in the studied soils.

Finally, results obtained suggest that additional laboratory incubation experiments are needed for investigation of various Antarctic post-ornithogenic environments in order to determine the role of the origin and quality of SOM and soil type in the rate of SOM stabilization and to better understand possible post-ornithogenic mineralization risks.

Conclusion

Soil processes in post-ornithogenic soils differ from those in not subjected to this factor soils. Study results indicate that soils under the current ornithogenic influence are characterized by an increased content of carbon and nitrogen with a rather narrow ratio of C/N. The amount of CO_2, in general, released over the entire experiment period is quite large for both ornithogenic and non-ornithogenic soils.

Comparing the resistance parameters of soil organic matter to mineralization, it can be concluded that the most stabilized organic matter is characteristic of ornithogenic soils of the studied area. Thus, the avifauna favors and increases the rate of the mineralization process by several times. An acceleration in the organic matter mineralization rate leads to an increase in nutrients amount available to plants, as in the case of the studied soils.

The accumulation of guano, nests building by penguins and other birds lead to the formation of specific soil polypedones. Apart from direct birds influence on soils localities of ornithogenic edaphotopes, their influence spreads through partial dissolution and substances migration in the landscape, nitrification, which leads to a post-ornithogenic successions start and a radical change in the local geochemistry of the landscape.

Therefore, ornithogenic soil formation is a special phenomenon of pedogenesis in the Southern Hemisphere, which expressed in the most diverse forms of morphological organization and processes of biogeochemical transformation. Thus, further study of CO_2 emissions is needed, with the aim of better characterizing post-ornithogenic SOM dynamics creating an approach to model this process.

Acknowledgments

This study was supported Grant of Saint-Petersburg State University "Urbanized ecosystems of the Russian Arctic: dynamics, state and sustainable development" and Russian Foundation for Basic Research, projects No: 19-05-50107 and 19-54-18003. The authors gratefully acknowledge Russian Antarctic Expedition, especially the head of seasonal expedition 2017-2018 V.N. Churun, for providing scientific and logistic support during the field work. Carbon was measured in Research park of Saint-Petersburg State University, Chemical Analysis and Materials Research Centre".

References

Abakumov, E., Alekseev, I., 2018. Stability of soil organic matter in Cryosols of the maritime Antarctic: insights from ^{13}C NMR and electron spin resonance spectroscopy. *Solid Earth* 9: 1329-1339.

Abakumov, E., Mukhametova, N., 2014. Microbial biomass and basal respiration of selected Sub-Antarctic and Antarctic soils in the areas of some Russian polar stations. *Solid Earth* 5: 705-712.

Abakumov, E.V., 2010. The sources and composition of humus in some soils of West Antarctica. *Eurasian Soil Science* 43: 499-508.

Abakumov, E.V., 2014a. Micromorphological characteristics of ornithogenic soil formation in Antarctica. *Russian Ornithology Journal* 23(1030): 2353-2357. [in Russian].

Abakumov, E.V., 2014b. Zoogenic pedogenesis as the main biogenic soil process in Antarctica. *Russian Ornithology Journal* 23(972): 576-584. [in Russian].

Abakumov, E.V., 2018. Birds role in nutrient regime formation in soils of the Fildes Peninsula (West Antarctica). *Russian Ornithology Journal* 27(1623): 2757-2760. [in Russian].

Abakumov, E.V., Fattakhova, Yu.M., 2015. Structural composition of humic substances in ornithogenic soils of Antarctica according to nuclear magnetic resonance (13-C). *Russian Ornithology Journal* 24(1165): 2463-2466. [in Russian].

Abakumov, E.V., Lupachev, A.V., 2011/2012. Soil diversity of Antarctic terrestrial ecosystems (in the areas of Russian Antarctic Stations). *Ukrainian Antarctic Journal* 10-11: 222-228.

Abakumov, E.V., Lupachev, A.V., Parnikoza, I.Yu., 2018. Ornithogenic soils of Antarctica: diversity, properties, functioning. Proceedings of III International Scientific and Practical Conference "The Natural Environment of Antarctica: Environmental Problems and Protection". 17-19 September 2018. Belarus. pp. 59-61.

Abakumov, E.V., Parnikoza, I.Y., Vlasov, D.Yu., Lupachev, A.V., 2016. Biogenic–abiogenic interaction in Antarctic ornithogenic soils. In: Biogenic—Abiogenic Interactions in Natural and Anthropogenic Systems. Frank-Kamenetskaya, O.V., Panova, E.G., Vlasov, D.Yu. (Eds.). Springer, pp. 237-248.

Alekseev, I., Abakumov, E., 2020b. Permafrost table depth in soils of Eastern Antarctica oases, King George and Ardley Islands (South Shetland Islands). *Czech Polar Reports* 10(1): 7-22.

Alekseev, I., Zverev, A., Abakumov, E., 2020. Microbial communities in permafrost soils of Larsemann Hills, Eastern Antarctica: environmental controls and effect of human impact. *Microorganisms* 8(8): 1202.

Alekseev, I.I., Abakumov, E.V., 2018. Acid-alkali properties and mesomorphological organization of soils in maritime Antarctica: Fildes Peninsula (King George Island) and Ardley Island (South Shetland Islands). *Russian Ornithology Journal* 27(1653): 3911-3918. [in Russian].

Alekseev, I.I., Abakumov, E.V., 2020a. Ornithogenic soils of the Antarctic Maritimo: genesis, chemical composition, organic matter. Abstracts of International Scientific Conference "Comprehensive Research of the Natural Environment of the Arctic and Antarctic". 2-4 March 2020. Saint Petersburg. Russia. pp. 170-172. [in Russian].

Anderson, J.P.E., 1982. Soil respiration. In. Methods of soil analysis, Part 2- Chemical and Microbiological Properties, Page, A.L., Keeney, D. R., Baker, D.E., Miller, R.H., Ellis, R. Jr., Rhoades, J.D. (Eds.). ASA-SSSA, Madison, Wisconsin, USA. pp. 831-871.

Bockheim, J.G., 2013. Paleosols in the Transantarctic Mountains: indicators of environmental change. *Solid Earth* 4: 451-459.

Bruun, T.B., Elberling, B., de Neergaard, A., Magid, J., 2015. Organic carbon dynamics in different soil types after conversion of forest to agriculture. *Ecosystems* 26(3): 272-283.

Campbell, I.B., Claridge, G.G.C., 1987. Antarctica: soils, weathering processes and environment. Elsevier, Amsterdam. 367p.

Debasish-Sasha, Kukal, S.S., Bawa, S.S., 2014. Soil organic carbon stock and fractions in relation to land use and soil depth in the degraded shiwaliks hills of lower Hymalayas. *Land Degradation and Devevelopment* 25(5): 407-416.

Dmitrakova, J., Abakumov, E., 2019. Dynamics of soil organic carbon of reclaimed lands and the related ecological risks to the additional CO_2 emission. In: Urbanization: challenge and opportunity for soil functions and ecosystem services. Proceedings of the 9th SUITMA Congress. Vasenev V., Dovletyarova E., Cheng Z., Prokof'eva T., Morel J., Ananyeva, N. (Eds.). Springer Geography. Springer, pp. 97-105.

Ejarque, E., Abakumov, E., 2016. Stability and biodegradability of organic matter from Arctic soils of Western Siberia: insights from ^{13}C-NMR spectroscopy and elemental analysis. *Solid Earth* 7: 153-165.

IPCC, 2007. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Solomon, S., Qin, D., Manning, M., Chen, Z., Marquis, M., Averyt, K.B., Tignor, M., Miller, H.L., (Eds.). Cambridge, United Kingdom, New York, USA. 996p. Available at [Access date: 07.10.2020]: https://archive.ipcc.ch/pdf/assessment-report/ar4/wg1/ar4_wg1_full_report.pdf

Ivanov, A.N., 2013. Ornithogenic geosystems of the North Pacific islands. Moscow. 228p. [in Russian].

Ivanov, A.N., Avessalomova, I.A., 2012. Ornitogenous ecosystems as a geochemical phenomenon of the biosphere. *Biosphere* 4(4): 385-396. [in Russian].

Kadono, A., Funakawa, S., Kosaki, T., 2009. Factors controlling potentially mineralizable and recalcitrant soil organic matter in humid Asia. *Soil Science Plant Nutrition* 55(2): 243-251.

Michel, R.F.M., Schaefer, C.E.G.R., Dias, L.E., Simas, F.N.B., Benites, V.M., Mendonça, E.S., 2006. Ornithogenic gelisols (cryosols) from Maritime Antarctica: pedogenesis, vegetation and carbon studies. *Soil Science Society of America Journal* 70(4): 1370-1376.

Muñoz-Rojas, M., Jordán, A., Zavala, L.M., De la Rosa, D., Abd-Elmabod, S.K., Anaya-Romero, M., 2015. Impact of land use and land cover changes on organic carbon stocks in Mediterranean soils (1956–2007). *Land Degradation and Development* 26(2): 168-179.

Novara, A., Rühl, J., La Mantia, T., Gristina, L., La Bella, S., Tuttolomondo, T., 2015. Litter contribution to soil organic carbon in the processes of agriculture abandon. *Solid Earth* 6: 425-432.

Parnikoza, I., Abakumov, E., Korsun, S., Klymenko, I., Netsyk, M., Kudinova, A., Kozeretska, I., 2016. Soils of the Argentine Islands, Antarctica: diversity and characteristics. *Polarforschung* 86(2): 83-96.

Parnikoza, I.Yu., Abakumov, E.V., Dikiy, I.V., Pilipenko, D.V., Shvidun, P.P., Kozeretskaya, I.A., Kunakh, V.A., 2015. Birds influence on the spatial distribution of Deschampsia antarctica Desv. of Galindez Islands (Argentine Islands, Coastal Antarctica). Bulletin of St. Petersburg State University. Ser. 3: Biology (1): 78-97. [in Russian].

Parras-Alcántara, L., Lozano-García, B., Brevik, E.C., Cerdà, A., 2015. Soil organic carbon stocks assessment in Mediterranean natural areas: a comparison of entire soil profiles and soil control sections. *Journal of Environmental Management* 155: 219-228.

Peng, F., Quangang, Y., Xue, X., Guo, J., Wang, T., 2015. Effects of rodent-induced land degradation on ecosystem carbon fluxes in an alpine meadow in the Qinghai-Tibet Plateau, China. *Solid Earth* 6: 303-310.

Pereira, T.T.C., Schaefer, C.E.G.R., Ker, J.C., Almeida, C.C., Aimeida, I.C.C., 2013. Micromorphological and microchemical indicators of pedogenesis in Ornithogenic Cryosols (Gelisols) of Hope Bay, Antarctic Peninsula. *Geoderma* 193/194: 311-322.

Rein, G., 2013. Smouldering fires and natural fuels. In: Fire phenomena and the earth system: an interdisciplinary guide to fire science. Belcher, C.M. (Ed.). John Wiley & Sons, Oxford. pp.15-33.

Schuur, E.A.G., McGuire, A.D., Schädel, C., Grosse, G., Harden, J.W., Hayes, D.J., Hugelius, G., Koven, C.D., Kuhry, P., Lawrence, D.M., Natali, S.M., Olefeldt, D., Romanovsky, V.E., Schaefer, K., Turetsky, M.R., Treat, C.C., Vonk, J.E., 2015. Climate change and the permafrost carbon feedback. *Nature* 520: 171-179.

Semenov, V.M., Ivannikova, L.A., Kuznetsova, T.V., Semenova, N.A., Tulina, A.S., 2008. Mineralization of organic matter and the carbon sequestration capacity of zonal soils. *Eurasian Soil Science* 41: 717-730.

Semenov, V.M., Ivannikova, L.A., Tulina, A.S., 2009. Stabilization of organic matter in the soil. *Agrochemistry* 10: 77-96. [in Russian].

Shishov, L.L., Tonkonogov, V.D., 2004. Classification and diagnostics of Russian soils. Soil Institute of Dokuchayev, Moscow, Russia. 341p. [in Russian].

Simas, F.N.B., Schaefer, C.E.G.R., Filho, M.R.A., Francelino, M.R., Filho, E.I.F., da Costa, L.M., 2008. Genesis, properties and classification of Cryosols from Admiralty Bay, maritime Antarctica. *Geoderma* 144: 116-122.

Simas, F.N.B., Schaefer, C.E.G.R., Melo, V.F., Albuquerque-Filho, M.R., Michel, R.F.M., Pereira, V.V., Gomes M.R.M., da Costa, L.M., 2007a. Ornithogenic cryosols from Maritime Antarctica: Phosphatization as a soil forming process. *Geoderma* 138(3-4): 191-203.

Simas, F.N.B., Schaefer, C.E.G.R., Mendonca, E.S., Silva, I.R., Santana, R.M., Ribeiro, A.S.S., 2007b. Organic carbon stocks in permafrost-affected soils from Admiralty Bay, Antarctica. *Journal of research of the U.S. Geological Survey* 1047: 76-79.

Six, J., Frey S.D., Thrieth, R.K., Batten, K.M., 2006. Bacterial and fungal contributions to carbon sequestration in agroecosystems. *Soil Science Society of America Journal* 70(2): 555-569.

Swift, R.S., 2001. Sequestration of carbon by soil. *Soil Science* 166(11): 858-871.

Terauds, A., Chown, S.L., Morgan, F., Peat, H.J., Watts, D.J., Keys, H., Convey, P., Bergstrom, D.M., 2012. Conservation biogeography of the Antarctic. *Diversity and Distributions* 18(7): 726-741.

Tsibart, A., Gennadiev, A., Koshovskii, T., Watts, A., 2014. Polycyclic aromatic hydrocarbons in post-fire soils of drained peatlands in western Meshchera (Moscow region, Russia). *Solid Earth* 5: 1305-1317.

Ugolini, F.C., Bockheim, J.G., 2008. Antarctic soils and soils formation in a changing environment: A review. *Geoderma* 144(1-2): 1-8.

Vorobyova, L.A., 2006. Theory and practice of the chemical soil analysis. GEOS, Moscow, Russia. 400p. [in Russian].

Wasak, K., Drewnik, M., 2015. Land use effects on soil organic carbon sequestration in calcareous Leptosols in former pastureland – a case study from the Tatra Mountains (Poland). *Solid Earth* 6: 1103-1115.

WRB, 2015. International soil classification system for naming soils and creating legends for soil maps. World Soil Resources Reports No. 106. Food and Agriculture Organization of the United Nations (FAO), Rome, Italy. 192p. Available at [access date: 07.10.2020]: http://www.fao.org/3/i3794en/I3794en.pdf

Yu, B., Stott, P., Di, X.Y., Yu, H.X., 2012. Assessment of land cover changes and their effect on soil organic carbon and soil total nitrogen in Daqing Prefecture, China. *Land Degradation and Development* 25(6): 520-531.

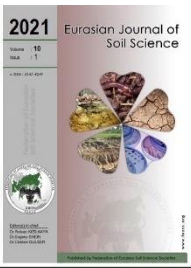
Zaccone, C., Rein, G., D'Orazio, V., Hadden, R.M., Belcher, C.M., Miano, T.M., 2014. Smouldering fire signatures in peat and their implications for palaeoenvironmental reconstructions. *Geochimica et Cosmochimica Acta* 137: 134-146.

Zhao, H., Tong, D.Q., Lin, Q., Lu, X., Wang, G., 2012. Effect of fires on soil organic carbon pool and mineralization in a Northeastern China wetland. *Geoderma* 189-190: 532-539.

Eurasian Journal of Soil Science 2021, 10(3), 191- 198

Eurasian Journal of Soil Science

Journal homepage : http://ejss.fesss.org



Effects of nutrient enriched municipal solid waste compost on soil fertility, crop yield and nutrient content in brinjal

Marufa Sultana [a], M. Jahiruddin [b], M. Rafiqul Islam [b], M. Mazibur Rahman [b], Md. Anwarul Abedin [b,*]

[a] Soil Science Division, Bangladesh Agricultural Research Institute, Gazipur, Bangladesh
[b] Department of Soil Science, Bangladesh Agricultural University, Mymensingh, Bangladesh

Article Info

Received : 08.07.2020
Accepted : 03.02.2021
Available online : 15.02.2021

Author(s)

M. Sultana
M. Jahiruddin
M.R. Islam
M.M. Rahman
M.A. Abedin *

* Corresponding author

Abstract

Composting is a good option of solid waste recycling, but its use by the farmers is limited because of its low nutrient status. Our study has considered organic amendments to increase nutrient status of MSW compost. We prepared three types of amended compost by mixing 20% mustard oil cake (MOC) and 30% poultry manure (PM) or cowdung (CD) or sugarcane press mud (SPM) with 50% MSW compost. *Trichoderma viridi inoculum* was used to accelerate the composting process. Different amendments improved the nutrient level of MSW compost. A field experiment was conducted to measure the performances of amended MSW composts alone and with fertilizers on yield and nutrient content of brinjal (*Solanum melongena*) and soil fertility. The experiment was carried out at Bangladesh Agricultural University research farm having silt loam texture, 6.7 pH and 2.79% organic matter; the soil was Aeric Haplaquept under the order Inceptisols. There were 10 treatments consisting of chemical fertilizers (urea, TSP, MoP, gypsum & zinc sulphate) and four types of MSW compost (3 enriched and 1 unenriched). The nutrient status of soil had increased due to application of composts. Based on the results of fruit (edible portion) yield and N, P, K and S concentrations of brinjal, and soil nutrient availability, the mixture 50% fertilizers +10 t ha^{-1} of enriched compost (MSW + MOC + SPM in a ratio of 5:2:3) was found as the best treatment. Results of this study have significant value in fertilizer management strategies for brinjal cultivation in sub-tropical countries.

Keywords: Brinjal, MSW compost, mustard oil cake, poultry manure, sugarcane press mud.

Introduction

Brinjal (*Solanum melongena*), also known as eggplant and aubergine, is grown worldwide and used as a vegetable. It is a high-fiber, low-calorie food that is rich in nutrients, with many health benefits include reducing the risk of heart disease, control of blood sugar and weight loss (Gürbüz et al., 2018; Naeem and Ugur, 2019). It is a simple and delicious addition to any healthy diet.

Fertilizer is a major input in crop production. To reduce fertilizer cost, environmental degradation and restore soil fertility, the use of organic amendment has a significant value. To achieve agricultural sustainability, the use of organic amendment has achieved prime importance in recent years, particularly under intensive cropping system in tropical and sub-tropical countries.

Composting of municipal solid waste (MSW) has recently gained good attention from the point of protection of environmental degradation, saving of land filling area, cost of incineration and scope of its use for crop

: https://doi.org/10.18393/ejss.880503
: http://ejss.fesss.org/10.18393/ejss.880503
Publisher : Federation of Eurasian Soil Science Societies
e-ISSN : 2147-4249

production (Sultana, 2020). However, the use of MSW compost is limited since MSW compost is generally poor in essential plant nutrients and the crops do not respond to its exclusive addition. For this reason, the crop farmers mostly rely on chemical fertilizers for higher crop yield without or with less use of compost.

An opportunity exists to enhance the nutrient value of compost by addition of some organic amendments viz. green manure, cowdung and mustard oil cake (Torkashvand, 2010). MSW compost amendment may result in a significant enhancement of heavy metal loadings in the amended top soils. As reported by Achiba et al. (2009), a 5-year application of MSW compost increased the organic matter and N content, while increasing the heavy metal concentration in the soil. Thus, mixing of some organic materials (e.g. mustard oil cake, poultry manure, sugar press mud) with MSW compost would increase the nutrient value and decrease the heavy metal contents due to dilution for addition of amendments the heavy metals (e.g. Pb, Cd, Ni) concentration of MSW compost. Thus, some organic materials such as mustard oil cake, poultry manure, sugarcane press mud could be appropriate materials for the production of nutrient enriched MSW compost with lesser impact to the environment, lower in cost operation and reduction in the weight of compost easily transportable to the farmer's field.

Nevertheless, single manure or fertilizer can't sustain soil health and crop yield. Thus, an integrated approach with combined use of compost and fertilizers is important. The benefits of integrated use of compost and fertilizers in terms of improvement of crop yield, crop quality and soil fertility are widely reported (Kavitha and Subramanian, 2007; Jahiruddin et al., 2012; Bilkis, 2015; Kanton et al., 2016; Youssef and Eissa, 2017; Aktar et al., 2018). Sustainable agriculture requires use of organic fertilizers for steady nutrients supply and improving soil organic matter, soil physical and chemical properties and crop productivity (Rekaby et al., 2020). Soil organic matter influences on the processes occurring in the soil (Gülser and Candemir, 2012; Cercioğlu et al., 2014).

The present study aimed at nutrient enrichment of MSW compost using locally available nutrient rich materials in a suitable proportion and evaluating the influence of nutrient enriched MSW compost on soil fertility, fruit yield and nutrient content in brinjal.

Material and Methods

Production of nutrient enriched MSW compost

MSW compost was collected from the Mymensingh Eco Park where an NGO, Gramaus (Grameen Manobic Unnayan Sangstha), produces compost from solid wastes of the Mymensingh City, Bangladesh. MSW compost was mixed with four different types of organic materials in a suitable proportion to upgrade the nutrient level of MSW compost. Mustard oil cake (MOC), poultry manure (PM), cowdung (CD) and sugarcane press mud (SPM) were used as amended materials. These five organics were analyzed for N, P, K and S contents; the results being shown in Table 1.

Table 1. Nutrient status of MSW compost, mustard oil cake, cowdung, poultry manure and sugar press mud

Organic material	**% N**	**%P**	**%K**	**%S**
MSW compost	1.14	0.23	0.87	0.27
Mustard oil cake	4.70	1.06	0.91	0.93
Cowdung	1.07	0.57	0.54	0.32
Poultry manure	1.33	0.80	0.89	0.42
Sugarcane press mud	1.59	0.09	0.64	0.51

The N, P, K and S levels in four different types of amended compost are given in Table 2. *Trichoderma* was used for every MSW compost treatment (T_3 – T_{10}) in order to accelerate composting process (AyanfeOluwa et al., 2017). *T. viridi* inoculum was added to the amended and unamended MSW compost at a rate of 1 litre broth (liquid media) per ton compost, the fungal count being 10^6 cfu mL^{-1}. The concentration of N and P in the amended MSW compost had manifold increased over unamended MSW compost. The procedure for determining nutrient contents of different organic materials and MSW composts is stated in nutrient analysis section under field experiment.

Table 2. Nutrient level of different types of compost

Types compost	**%N**	**%P**	**%K**	**%S**
Compost 1	1.41	0.33	1.01	0.41
Compost 2	3.14	0.84	0.84	0.52
Compost 3	2.91	0.62	0.77	0.45
Compost 4	3.22	0.40	0.81	0.32

Compost 1 = MSW 100%; Compost 2 = MSW 50% + MOC 20% + PM 30%; Compost 3 = MSW 50% + MOC 20% + CD 30%; Compost 4 = MSW 50% + MOC 20% + SPM 30% .

Field experiment

Location and site

The field trial with rice was conducted at Bangladesh Agricultural University (BAU) research farm, Mymensingh (24°56.11' N, 89°55.54′ E) which belongs to Old Brahmaputra Floodplain (FAO/UNDP, 1988) with non-calcareous dark grey floodplain soil characteristics. According to US Soil Taxonomy, the soil is Aeric Haplaquept under the Order Inceptisols and as per FAO Soil Unit it is Chromic-Eutric Gleysols. The location has a subtropical humid climate and is characterized by hot and humid summer and cold winter. The research field was medium high land.

Soil characteristics

The soil (0-15 cm) was silt loam (14% sand, 70% silt and16% clay) having 6.7 pH (water), 2.79% organic matter (Nelson and Sommers, 1982), 0.17% Kjeldahl N (Bremner and Mulvaney, 1982), 4.1 mg kg^{-1} Olsen P (Olsen and Sommers, 1982), 0.089 cmol (+) kg^{-1} NH_4OAc extractable K (Knudsen et al.,1982), 17.1mg kg^{-1} $CaCl_2$ extractable S (Fox et al., 1964), 0.65 mg kg^{-1} DTPA extractable Zn (Lindsay and Norvell, 1978) and 0.24 mg kg^{-1} $Ca(H_2PO_4)_2$ extractable B (Bingham, 1982).

Treatments and design

There were 10 treatments with different combinations of chemical fertilizers (urea, TSP, MoP, gypsum and $ZnSO_4.7H_2O$) and four types of compost. *Trichoderma* inoculum was added to the MSW compost one month ahead of its field application. The details of the treatments are depicted in Table 3. The aim of the experiments was to reduce the use of chemical fertilizers by 50% through supplementing with MSW compost (50%) + MOC (20%) + PM/CD/SPM (30%). Amount of nutrient addition through fertilizers and compost is given in Table 3. The 100% fertilizer dose for urea, TSP, MoP and gypsum was 300, 180, 210 and 80, respectively. The experiment was laid out in a randomized complete block design (RCBD), with three replications.

Table 3. Nutrient addition through fertilizers and compost (kg ha^{-1})

Treatments	N		P		K		S	
	CF	compost	CF	Compost	CF	Compost	CF	Compost
T_1 : Control	0	0	0	0	0	0	0	0
T_2 : 100% CF	135	0	36	0	105	0	15	0
T_3 : Compost 1	0	71	0	33	0	101	0	41
T_4 : Compost 2	0	157	0	84	0	84	0	52
T_5 : Compost 3	0	146	0	62	0	77	0	45
T_6 : Compost 4	0	161	0	40	0	81	0	32
T_7 : 50% CF + T_3	68	71	18	33	53	101	8	41
T_8 : 50% CF + T_4	68	157	18	84	53	84	8	52
T_9 : 50% CF + T_5	68	146	18	62	53	77	8	45
T_{10} : 50% CF + T_6	68	161	18	40	53	81	8	32

Compost 1 =MSW 100%; Compost 2 =MSW 50% + MOC 20% + PM 30%; Compost 3 =MSW 50% + MOC 20% + CD 30%; Compost 4 = MSW 50% + MOC 20% + SPM 30%

CF = Chemical fertilizer, MSW = Municipal solid waste, MOC = Mustard oil cake, PM = Poultry manure, CD = Cowdung, SPM = Sugar press mud

50% N mineralization from compost during one crop season

Crop management

The plots received nutrient enriched compost and/or fertilizers as per treatments. Fertilizers such as urea, TSP, MoP and gypsum were used as sources of N, P, K and S, respectively. The one-third dose of urea and the full dose of all other fertilizers were applied as basal to the individual plots after layout preparation. The second split of urea was applied after 30 days of planting and the third split was after 60 days.

The seedlings of brinjal (var. BARI begun1) were transplanted on 12 November 2017 with a spacing of 80cm × 60cm. After transplanting, the field was irrigated to ensure better seedling establishment. The second irrigation was given 20 days after transplanting. The crop generally needed irrigation once a weak depending on the soil moisture condition. Weeds were managed by two hand-weeding at 15 and 30 DAS. Plant protection measures viz. insecticide and fungicide spray were done to keep the crop free from any insect and pathogen attack. Fruits were picked up when they attained maturity and the weight was recorded. Various growth and yield characters of the crop for each plot were recorded. The characters included plant height (cm), number of branches $plant^{-1}$, fruit length (cm), fruit diameter (cm), number of fruits $plant^{-1}$, individual fruit weight and fruit yield (kg $plot^{-1}$, then converted to t ha^{-1}). The fruits from every plot were chemically analyzed for N, P, K and S concentrations.

Nutrient analysis

For N determination, H_2SO_4 digestion (Kjeldahl method) and for P, K and S determination HNO_3-H_2O_2 digestion procedures were followed (Page et al., 1982). The amount of N, P, K and S in the acid digest was measured by the methods as used for soil analysis. Nitrogen in the digest was estimated by distillation with 10N NaOH followed by titration of the distillate trapped in H_3BO_3 indicator solution with 0.01N H_2SO_4 (Bremner and Mulvaney, 1982). The K concentration in the acid digest was determined by flame photometer. The amount of P in the digest was determined colorimetrically and the S determined turbidmetriclly, as indicated in the soil characteristics section.

Statistical analysis

All the data (plant growth, yield, yield components, fruit nutrient contents and soil analysis after harvest) were statistically analyzed by "R", version 3.4.3 software. The analysis of variance for every parameter was performed by F-test and mean comparisons of the treatments were done by Duncan's Multiple Range test (DMRT), where $P<0.05$ was considered as the threshold value for significance (Gomez and Gomez, 1984).

Results and Discussion

The growth and yield components, fruit yield, nutrient concentrations, and changes in soil properties were examined as the treatment effects.

Crop yield

The fruit yield of brinjal due to different treatments varied from 6.6 – 59.7 t ha^{-1}, showing that neither fertilizers nor compost alone produced better yield, their combined use resulted in better yield (Figure 1). The T_{10} treatment comprising 50% fertilizers + compost 4 (MSW + MOC + sugar press mud in a ratio of 5:2:3) demonstrated the best fruit yield. The highest yield was not statistically different from that obtained with T_6, T_8 and T_9 treatments, but they all showed their superiority over T_1 – T_5 and T_7 treatments. The results are clearly indicative of the benefits of the integrated use of compost and fertilizers. About 50% reduction of chemical fertilizers is possible through the use of organic fertilizers. The control receiving neither fertilizer nor compost (T_1) recorded the lowest fruit yield. The yield benefits due to compost with and without fertilizers were 2.9 – 60.1% over exclusive fertilizer application.

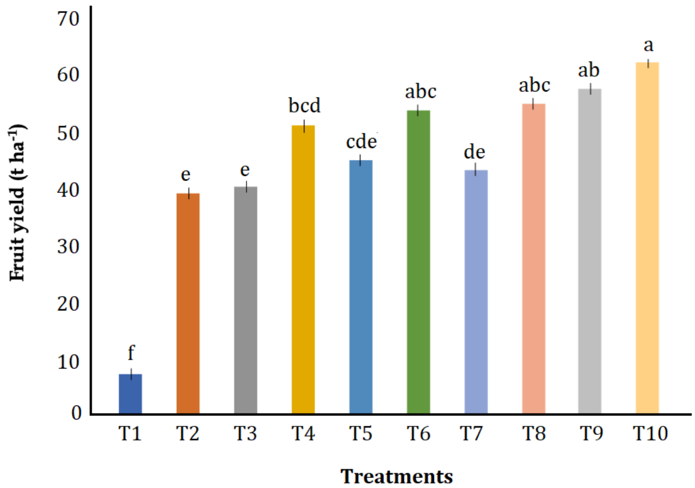


Figure 1. Effects of compost and fertilizer treatments on the fruit yield of brinjal
[Treatment details are given in Table 3]

The press mud based fertilizer-compost treatment (T_{10}) performed the highest yield (59.7 t ha^{-1}) which could be due to its higher nitrogen content (3.52%N, 161 kg N ha^{-1} addition, Tables 2, 3) and also could be higher capacity of this compost to increase the availability of native soil nutrients through higher biological activity (Pengthamkeerati et al., 2011). As stated by Eghball et al. (2002), manure having higher total N content had more N readily available for crops. The positive effects of integrated application of chemical fertilizers and manure or compost are reported on other solanaceous crops, as in potato (*Solanum tuberosum*) (Parmar et al., 2007; Kumar et al., 2012; Islam et al., 2013; Haque, 2014) and tomato (*Solanum lycopersicum*) (Rodge and Yadlod, 2009; Singh et al., 2013).

Growth and yield parameters

The growth and yield contributing characters such as plant height ranged from 61.2 - 84.5 cm, number of branches plant^{-1} from 14.3 - 34.3, fruit length 6.44 - 9.08 cm, fruit diameter 3.9 - 5.48 cm, number of fruits plant^{-1} 22.3 - 80.3 and individual fruit weight 210 - 470 g over the treatments (Table 4). For all parameters, the fertilizer-compost combined treatments exhibited better performances and of them, the T_{10} treatment which contained 50% dose of chemical fertilizers and compost type 4 (50% MSW + 20% MOC + 30% SPM) showed the highest performances.

Table 4. Effects of different compost and fertilizer treatments on the growth and yield contributing characters of brinjal (cv. BARI begun 1)

Treatments	Plant height (cm)	No. of branches plant^{-1}	Fruit length (cm)	Fruit diameter (cm)	No. of fruits plant^{-1}	Individual fruit wt. (kg)
T_1 : Control	61.2d	14.3d	6.44d	3.91d	22.3f	0.021c
T_2 : 100% CF	75.5ab	30.5ab	8.29abc	4.92bc	56.3de	0.045a
T_3 : Compost 1	64.2cd	19.7cd	7.40cd	4.59c	49.0e	0.041b
T_4 : Compost 2	77.9ab	21.2cd	8.01bc	4.89bc	62.0cd	0.047a
T_5 : Compost 3	70.3bcd	34.3a	8.20abc	4.90bc	70.3bc	0.042b
T_6 : Compost 4	73.5bc	25.2bc	8.30abc	4.99abc	70.3bc	0.042b
T_7 : 50% CF + T_3	75.5ab	30.0ab	7.92bc	4.87bc	58.3d	0.044ab
T_8 : 50% CF + T_4	84.5a	34.2a	8.44ab	5.27ab	74.3ab	0.043ab
T_9 : 50% CF + T_5	79.5ab	34.3a	8.51ab	4.90bc	76.3ab	0.044ab
T_{10} : 50% CF + T_6	78.5ab	30.7ab	9.08a	5.48a	80.3a	0.046a
Level of sig.	*	**	*	*	**	**
CV (%)	7.70	8.34	7.20	6.49	6.76	5.53
SE (±)	1.16	1.02	0.47	0.25	0.89	0.004

Compost 1= MSW 100%; Compost 2 = MSW 50% + MOC 20% + PM 30%; Compost 3 =MSW 50% + MOC 20% + CD 30%; Compost 4 = MSW 50% + MOC 20% + SPM 30% .
SE (±) = Standard error of means, CV= Coefficient of variation; *, $P < 0.05$; **, $P < 0.01$
In a column, the means followed by the same letters are not significantly different at 5% level by DMRT.

The yield of a crop is a complex character which is influenced by several component crop characters. Thus, the increase in fruit yield can be attributed to the increase in yield attributes as evidenced by a good correlation of fruit yield with plant height ($r=0.798$; $P < 0.01$), number of branches plant^{-1} ($r=0.680$; $P < 0.05$), fruit length ($r=0.925$; $P < 0.001$), fruit diameter ($r=0.923$; $P < 0.001$), number of fruits plant -1 ($r=0.966$; $P < 0.001$) and individual fruit weight ($r=0.892$; $P < 0.001$).

Nutrient concentrations of rice grain and straw

The N, P, K and S concentrations of brinjal fruit were significantly influenced by the different treatments (Table 5). The N concentration of brinjal varied from 0.097-0.412% (0.606 – 2.58 % protein, calculated as %N × 6.25) across the treatments. The T_2 treatment (sole fertilizer) showed the highest fruit N concentration, which was statistically similar to that observed with T_4, T_6 and T_{10} treatments. The P, K and S concentrations of brinjal across the treatments ranged from 0.017-0.066%, 0.012-0.050% and 0.015-0.036%, respectively. For P concentration T_4 treatment, for K concentration, the T_9 treatment and for S concentration T_{10} gave the displayed results. The T_1 treatment, i.e. control treatment always showed the lowest brinjal N, P, K and S concentrations. As reported by Rekaby et al. (2020), organic amendment with biochar, humic acid or compost increased the nutrient uptake by barley plants and influenced the chlorophyll synthesis in plant tissues.

Table 5. Effects of compost and fertilizer treatments on N, P, K and S concentrations of brinjal (cv. BARI begun 1)

Treatments	N (%)	P (%)	K (%)	S (%)
T_1 : Control	0.097 d	0.017 c	0.012 g	0.015 b
T_2 : 100% CF	0.412 a	0.065 a	0.025 f	0.035 a
T_3 : Compost 1	0.291 bc	0.064 a	0.028 e	0.033 a
T_4 : Compost 2	0.354 ab	0.066 a	0.035 d	0.035 a
T_5 : Compost 3	0.314 bc	0.051 b	0.043 b	0.030 a
T_6 : Compost 4	0.331 abc	0.058 ab	0.039 c	0.031 a
T_7 : 50% CF + T_3	0.314 bc	0.048 b	0.045 b	0.031 a
T_8 : 50% CF + T_4	0.256 bc	0.047 b	0.049 a	0.031 a
T_9 : 50% CF + T_5	0.291 bc	0.047 b	0.050 a	0.032 a
T_{10} : 50% CF + T_6	0.363 ab	0.056 ab	0.049 a	0.036 a
Significance	*	**	**	**
CV (%)	7.74	5.17	4.44	6.20
SE (±)	1.37	0.093	0.096	0.089

Compost 1= MSW 100% ; Compost 2= MSW 50% + MOC 20% + PM 30%; Compost 3=MSW 50% + MOC 20% + CD 30%; Compost 4 = MSW 50% + MOC 20% + SPM 30% .
SE (±) = Standard error of means, CV= Coefficient of variation; *, $P < 0.05$; **, $P < 0.01$
In a column, the means followed by the same letters are not significantly different at 5% level by DMRT.

There was a significant positive correlation between fruit N with other nutrient concentrations, strongly with P (r=0.0.904, P<0.001) and S (r=927, P<0.001) and weakly with K (r=0.427, P<0.20). Plants maintain a reasonably constant nutrient ratio in its body. In the present study, we found a N:P ratio of 5.4-6.5 (mean 5.8), N:K ratio of 7.0-10.4 (mean 8.6) and N:S ratio of 8.8-10.7 (mean 9.6) in brinjal fruit. Protein is a polymer of amino acids and sulphur is a constituent of some amino acids viz. cysteine, cystine and methionine, and RNA and DNA is a constituent of base (N), sugar and phosphate.

Nutrient level of post-harvest soil

The soils from every plot after harvest of brinjal were analyzed for N, P, K and S contents. Total N content in soil was the highest (0.183%) in T_5 treated plot which was statistically similar to the all combined treatments i.e. T_7, T_8, T_9 and T_{10} treatments with the values of 0.174, 0.176, 0.175 and 0.178%, respectively (Table 6). Except in control plot, the total N content of soil had increased after compost-fertilizer treatments, in comparison with initial soil N value (0.12%). The P availability in soil had increased in all treated soils including control plot (Table 6). The T_{10} treatment showed the highest value (23.7 mg.kg^{-1}) which was significantly different from all other treatments. Next to T_{10}, the other three combined treatments (T_7, T_8 and T_9) were statistically identical. Application of manure and fertilizers added alone or in combination increased the available K content of soils (Table 6), the values being 13.3-21.5 mg.kg^{-1}. The highest K availability was noted with the press mud based compost (T_{10}) which was significantly higher over all other treatments, except T_8 (poultry manure based treatment) having the value of 19.2 mg kg^{-1}. All the treatments except control, exclusive fertilizer or compost showed higher S availability over the initial soil S (7.10 mg kg^{-1}). Like soil P and K contents, the T_{10} treatment had the highest S availability (13.79 mg kg^{-1}) followed by T_9 having the value of 12.59 mg kg^{-1}, they were statistically similar. Nonetheless, T_9 and T_8 treated plots had similar soil S content (Table 6). For all nutrients, the soils of control (T_1) plots exhibited the lowest values, showing 0.009% N, 10.0 mg kg^{-1} P, 3.2 mg kg^{-1} K and 4.26 mg kg^{-1} S against the initial levels of 0.12% N, 4.08 mg kg^{-1} P, 3.47 mg kg^{-1} K and 7.10 mg kg^{-1} S, respectively.

Table 6. Nutrient status of soils after crop harvest

Treatments	Total N (%)	Available P (mg kg^{-1})	Available K (mg kg^{-1})	Available S (mg kg^{-1})
T_1 : Control	0.115 d	10.0 d	3.2 f	4.26 f
T_2 : 100% CF	0.123 c	14.2 c	15.2 de	6.94 e
T_3 : Compost 1	0.132 b	10.3 d	13.3 e	6.48 e
T_4 : Compost 2	0.144 a	16.8 b	14.7 e	7.41 e
T_5 : Compost 3	0.136 a	13.7 c	13.6 g	7.31 e
T_6 : Compost 4	0.147 a	17.9 b	16.4 cd	8.24 d
T_7 : 50% CF + T_3	0.127 b	18.2 b	17.5 c	10.09 c
T_8 : 50% CF + T_4	0.136 a	18.2 b	19.2 a	11.29 b
T_9 : 50% CF + T_5	0.130 b	19.0 b	18.2 b	12.59 ab
T_{10} : 50% CF + T_6	0.141 a	23.7 a	21.5 a	13.79 a
Level of significance	**	**	**	**
CV (%)	4.66	8.23	7.18	3.92
SE (±)	0.007	1.28	0.87	0.69
Initial status	**0.121**	**11.20**	**3.47**	**7.10**

Compost 1= MSW 100% ; Compost 2= MSW 50% + MOC 20% + PM 30%; Compost 3=MSW 50% + MOC 20% + CD 30%; Compost 4 = MSW 50% + MOC 20% + SPM 30% .
SE (±) = Standard error of means, CV= Coefficient of variation; **, P < 0.01
In a column, the means followed by the same letters are not significantly different at 5% level by DMRT.

The results indicate that the N, K and S contents of soils in control plots (no fertilizer or compost added) decreased after brinjal cropping while the soil P content had little increased. The T_{10} treatment (50% fertilizer + press mud based compost) showed the best positive effect on soil nutrients (P, K and S) which was presumably due to higher mineralization. Thus, it is likely that the residual effects of organic amendment would have positive contribution to the next crop(s). Malik and Chauhan (2014) stated that integrated treatment (organic and inorganic) gave the higher values for soil N, P and K contents whereas the inorganic treatment gave significantly lower values for those nutrients. Rekaby et al. (2020) reported higher availability of nutrients in Egypt soils after organic amendment (biochar, humic acid, compost). As observed by Demir and Gülser (2015), application of rice husk compost improved the N, P and K status of soil.

Conclusion

Mixing of 20% mustard oilcake and 30% sugarcane press mud or poultry manure or cowdung with 50% MSW compost had markedly improved the nutrient value of MSW compost. The use of amended compost resulted in better yield with higher nutrient (N, P, K and S) concentration of brinjal fruit (edible portion). The integrated use of 50% chemical fertilizers and 50% compost mixture (50% MSW + 20% MOC + 30% SPM at a rate of total 10 t ha^{-1}) produced the best result. The nutrient status of soil had increased due to application of composts and it decreased in control plots. This study has useful implications for fertilizer management and recommendation strategies for different crops and soils.

Acknowledgement

This research was supported by the World Bank funded Higher Education Quality Enhancement Project (HEQEP) implemented by the University Grants Commission (UGC), Bangladesh.

References

Achiba, W.B., Gabteni, N., Lakhdar, A., Laing, G. D., Verloo, M., Jedidi, N., Gallali, T., 2009. Effects of 5-Year Application of municipal solid waste compost on the distribution and mobility of heavy metals in a Tunisian calcareous soil. *Agriculture, Ecosystems and Environment* 130(3-4): 156–163.

Aktar, S., Islam, M.S., Hossain, M.S., Akter, H., Maula, S., Hossain, S.S.F., 2018. Effects of municipal solid waste compost and fertilizers on the biomass production and yield of BRRI dhan 50. *Progressive Agriculture* 29(2): 82-90.

AyanfeOluwa, O.E., AdeOluwa, O.O., Aduramigba-Modupe, V.O., 2017. Nutrient release dynamics of an accelerated compost: A case study in an Alfisol and Ultisol. *Eurasian Journal of Soil Science* 6(4): 350-356.

Bilkis, S., 2015. Mineralization of different types of manure and their field performances in the potato-mungbean-rice and rice-fallow-rice cropping patterns. PhD Thesis, Department of Soil Science, Bangladesh Agricultural University, Mymensingh, Bangladesh.

Bingham, F.T., 1982. Boron. In: Methods of Soil Analysis, Part 2, Chemical and microbiological properties, Second Edition. Number 9, Page, A.L., Keeney, D. R., Baker, D.E., Miller, R.H., Ellis, R. Jr., Rhoades, J.D. (Eds.). ASA-SSSA, Madison, Wisconsin, USA. pp. 431-448.

Bremner, J.M, Mulvaney, C.S., 1982. Nitrogen-Total. In: Methods of Soil Analysis, Part 2, Chemical and microbiological properties, Second Edition. Number 9, Page, A.L., Keeney, D. R., Baker, D.E., Miller, R.H., Ellis, R. Jr., Rhoades, J.D. (Eds.). ASA-SSSA, Madison, Wisconsin, USA. pp. 595-624.

Cercioğlu, M., Okur, B., Delibacak, S., Ongun, A.R., 2014. Changes in physical conditions of a coarse textured soil by addition of organic wastes. *Eurasian Journal of Soil Science* 3(1): 7-12.

Demir, Z., Gülser, C., 2015. Effects of rice husk compost application on soil quality parameters in greenhouse conditions *Eurasian Journal of Soil Science* 4 (3): 185-190.

Eghball, B., Wienhold, B. J., Gilley, J.E., Eigenberg, R.A., 2002. Mineralization of manure nutrients. *Journal of Soil and Water Conservation* 57(6): 470–473.

FAO/UNDP, 1988. Land Resources Appraisal of Bangladesh for Agricultural Development, Rome, Italy. pp. 1-570. Available at [Access date : 08.07.2020]: http://www.fao.org/3/s7223e/s7223e.pdf

Fox, R.L., Olson, R.A., Rhoades, H.F., 1964. Evaluating the sulfur status of soils by plants and soil tests. *Soil Science Society of America Journal* 28(2): 243-246.

Gomez, K.A., Gomez, A.A., 1984. Statistical Procedures for Agricultural Research, John Wiley and Sons, New York.

Gürbüz, N., Uluişik, S., Frary, A., Frary, A., Doğanlar, S., 2018. Health benefits and bioactive compounds of eggplant. Food Chemistry 268: 602-610.

Gülser, C., Candemir, F., 2012. Changes in penetration resistance of a clay field with organic waste applications. *Eurasian Journal of Soil Science* 1(1): 16-21.

Haque, M.A., 2014. Mineralization of bioslurry and its integrated use with fertilizers in the rice based cropping systems. PhD Thesis, Department of Soil Science, Bangladesh Agricultural University, Mymensingh.

Islam, M.M., Akhter, S., Majid, N.M., Ferdous, J., Alam, M.S., 2013. Integrated nutrient management for potato (Solanum tuberosum) in grey terrace soil (AricAlbaquipt). *Australian Journal of Crop Science* 7(9): 1235-1241.

Jahiruddin, M., Rahman, M.A., Haque, M.A, Rahman, M.M., Islam, M.R., 2012. Integrated nutrient management for sustainable crop production in Bangladesh. *Acta Horticulturae* 958: 85-90.

Kanton, R.A.L., Prasad, P.V.V., Mohammed, A. M., Bidzakin, J.K, Ansoba, E.Y., Asungre, P.A., Lamini, S., Mahama, G., Kusi, F., Sugri, I., 2016. Organic and Inorganic Fertilizer Effects on the Growth and Yield of Maize in a Dry Agro-Ecology in Northern Ghana. *Journal of Crop Improvement* 30(1): 1-16.

Kavitha, R., Subramanian, P., 2007. Effect of enriched soil waste compost application on growth, plant nutrient uptake and yield of rice. *Journal of Agronomy* 6(4): 586-592.

Knudsen, D., Peterson, G.A., Pratt, P. F. 1982. Lithium, sodium and potassium. In: Methods of Soil Analysis, Part 2, Chemical and microbiological properties, Second Edition. Number 9, Page, A.L., Keeney, D. R., Baker, D.E., Miller, R.H., Ellis, R. Jr., Rhoades, J.D. (Eds.). ASA-SSSA, Madison, Wisconsin, USA. pp. 225-245.

Kumar, M., Baishaya, L.K., Ghosh, D.C., Gupta, V.K., Dubey, S.K., Das, A., Patel, D.P., 2012. Productivity and soil health of potato (Solanum tuberosum L.) field as influenced by organic manures, inorganic fertilizers and biofertilizers under high altitudes of eastern Himalayas. *Journal of Agricultural Science* 4(5): 223-234.

Lindsay, W.L., Norvell, W.A., 1978. Development of a DTPA Test for zinc, iron, manganese and copper. *Soil Science Society America Journal* 42(3): 421-428.

Malik, S.S., Chauhan, R.C., 2014. Impact of organic farming on soil chemical properties. *Journal of International Academic Research for Multidiciplinary* 2(7): 349-360.

Naeem, M.Y., Ugur, S., 2019. Nutritional content and health benefits of eggplant. *Turkish Journal of Agriculture – Food Science and Technology* 7(sp3): 31-36.

Nelson, D.W., Sommer, L.E., 1982. Total Carbon, Organic Carbon and Organic Matter. In: Methods of Soil Analysis, Part 2, Chemical and microbiological properties, Second Edition. Number 9, Page, A.L., Keeney, D. R., Baker, D.E., Miller, R.H., Ellis, R. Jr., Rhoades, J.D. (Eds.). ASA-SSSA, Madison, Wisconsin, USA. pp. 539-579.

Olsen, S.R., Sommer, L.E., 1982. Phosphorus. In: Methods of Soil Analysis, Part 2, Chemical and microbiological properties, Second Edition. Number 9, Page, A.L., Keeney, D. R., Baker, D.E., Miller, R.H., Ellis, R. Jr., Rhoades, J.D. (Eds.). ASA-SSSA, Madison, Wisconsin, USA. pp. 403-430.

Page, A.L., Keeney, D. R., Baker, D.E., Miller, R.H., Ellis, R. Jr., Rhoades, J.D. (Eds.). 1982. Methods of Soil Analysis, Part 2, Chemical and microbiological properties, Second Edition. Number 9, ASA-SSSA, Madison, Wisconsin, USA.

Parmar, D.K., Sharma, A., Chaddha, S., Sharma, V., Vermani, A., Mishra, A., Gautam, G., Kumar, V., 2007. Increasing potato productivity and profitability through integrated plant nutrient system in the north-western Himalayas. *Potato Journal* 34(3-4): 209-215.

Pengthamkeerati, P., Motavalli, P.P., Kremer, R.J., 2011. Soil microbial activity and functional diversity changed by compaction, poultry litter and cropping in a claypan soil. *Applied Soil Ecology* 48(1): 71–80.

Rekaby, S.A., Mahrous, Y.M.A., Hegab, S.A., Eissa, M.A., 2020. Effect of some organic amendments on barley plants under saline condition. *Journal of Plant Nutrition* 43(12): 1840-1851.

Rodge, B.M., Yadlod, S.S., 2009. Effect of organic and inorganic fertilizers on growth, yield and quality of tomato (Lycopersicon esculentum Mill.). *Asian Journal of Horticulture* 4(1): 221–224.

Singh D.V., Mukhi S.K., Mishra S.N., 2013. Impact of integrated nutrient management on tomato yield under farmers field conditions. *International Journal of Agriculture, Environment and Biotechnology* 34(6): 1047-51.

Sultana, M., 2020. Nutrient enrichment of MSW compost by organic amendments and its effects on soils and crops. PhD Thesis, Department of Soil Science, Bangladesh Agricultural University, Mymensingh, Bangladesh.

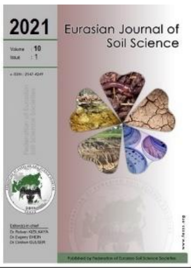
Torkashvand, A.M., 2010. Improvement of compost quality by addition of some amendments. *Australian Journal of Crop Science* 4(4): 252-257.

Youssef, M.A., Eissa, M.A., 2017. Comparison between organic and inorganic nutrition for tomato. *Journal of Plant Nutrition* 40 (13): 1900-1907.

Eurasian Journal of Soil Science 2021, 10(3), 199 - 206

Eurasian Journal of Soil Science

Journal homepage : http://ejss.fesss.org



Soil properties and performance of celosia (*Celosia Argentea*) as affected by compost made with *Trichoderma asperellum*

Adenike Fisayo Komolafe [a,*], Christianah Olubunmi Kayode [a], Dorcas Tinuke Ezekiel-Adewoyin [b], Olufemi Emmanuel AyanfeOluwa [a], David Ogundeji Ogunleti [c], Aderemi Isaiah Makinde [a]

[a] Department of Agriculture, Federal College of Agriculture, Ibadan, Nigeria
[b] Department of Soil Science and Land Management, Federal University of Technology, Minna, Nigeria
[c] Department of Horticulture and Landscape, Federal College of Agriculture, Ibadan, Nigeria

Article Info

Received : 02.08.2019
Accepted : 07.02.2021
Available online : 15.02.2021

Author(s)

A.F. Komolafe *
C.O. Kayode
D.T. Ezekiel-Adewoyin
O.E. AyanfeOluwa
D.O. Ogunleti
A.I. Makinde

* Corresponding author

Abstract

This study evaluated the effect of two plant materials (*Panicum maximum* and *Tridax procumbens*) composted with cow dung, with or without *Trichoderma asperellum* inoculation on soil properties and yield of celosia in 2014 and 2015. The treatments were tridax-based compost without *Trichoderma* (TBC), tridax-based compost with *Trichoderma* (TTBC), panicum-based compost without *Trichoderma* (PBC), panicum-based compost with *Trichoderma* (TPBC) and control (no compost). All compost were applied at 240 kgN/ha. The design was RCBD with three replicates and data analyzed using ANOVA at $\alpha_{0.05.}$ Results showed that compost enhanced growth, nutrient uptake and yield of celosia. In 2014, highest fresh weight (57.09 t/ha) was obtained from plant treated with TPBC, which compared favourably with TTBC TTBC (57.00 t/ha) but significantly higher than TBC (43.85 t/ha) and PBC (47.32 t/ha) while control gave the least significant value (20 t/ha). A similar trend was obtained in 2015. This infers that plants that received inoculated compost gave better yield compared to uninoculated compost. Post-cropping soil chemical analysis revealed that compost improved soil N, P, K and organic C. This shows that *Trichoderma* inoculated compost could be better than the uninoculated compost for celosia production in an Alfisol.

Keywords: Accelerated compost, Celosia, Soil chemical properties, *Trichoderma asperellum*.

Introduction

Maintenance of soil fertility under continuous cropping has only been made possible through the use of fertilizer (Das and Mandal, 2015). Mineral, unlike organic fertilizers with their quick-release formula gave rescue treatment to plant that is malnourished and this has greatly increased crop yields (Omolayo and Ayodele, 2009). However, unconscious excessive application of this fertilizer can make the quick-releasing salts to build up fast through its mobility status in soil, it can cause soil acidity, run off or leaching of soil nutrients and land degradation (Plaster, 2014). These identified negative effects on soil environment have renewed research interest in organic fertilizers.

Compost is a form of organic fertilizer produced from organic wastes, including municipal and agricultural wastes, urban wastes, sewage, activated sludge, household wastes, sawdust, etc. Organic materials decompose naturally by the activities of microorganisms from the environment. These natural (conventional) composting procedures take a longer period before it matures. It takes three to eight months

: https://doi.org/10.18393/ejss.880541
: http://ejss.fesss.org/10.18393/ejss.880541
Publisher : Federation of Eurasian Soil Science Societies
e-ISSN : 2147-4249

depending on the nature of the organic substrates (recalcitrant or labile) involved and methodology in use (Adejuyigbe et al., 2006). The recalcitrant organic substrate like lignin, cellulose and hemi-cellulose degraded partially and transformed to organic matter at lower rate; however, research has found out some cultured microorganisms like *Trichoderma* spp which can be introduced into compost pile in order to hasten the decomposition rate of these recalcitrant organic substrates. Hence, the cultured microbes serve as compost accelerator which offers the possibilities for reducing the maturity period of compost from the conventionally known method time to three weeks (Badar et al., 2014). The technology has the potential to increase the level of production of compost thereby making it available to farmers (AyanfeOluwa, 2019).

Celosia (*Celosia argentea)* is one of the most highly acceptable leaf vegetable grown in southern Nigeria. It is rich in iron, protein, energy, vitamin A and vitamin C (Grubben and Denton, 2004). However, the yield and composition is strongly influenced by environmental factors, age of plant at harvest, soil fertility and fertilizer type (Ojeniyi et al., 2009). The objective of this research is therefore to evaluate the effects of compost prepared with *Trichoderma asperellum* inoculation on growth and yield of celosia.

Materials and Methods

Composting and field trial were conducted at the experimental site of the Federal College of Agriculture, Ibadan in the year 2014 and 2015, longitude 7° 33'N and latitude 3° 56°E at elevation of 183 m above sea level. The average annual rainfall recorded for the location for a period of sixteen years was 1289.2 mm (Junge et al., 2010) while the range of annual temperature was 21.3 to 31.2°C. It was noted that the rainfall amount in 2014 was higher than in 2015 (Figure 1). The soil which is sandy loam belongs to Typic Kanhaplustalf and locally classified as Iwo series (Nwachokor and Uzu, 2008). Iwo series is a gravelly soil derived from coarse grained, granite and gneiss which is classifield in the order of Alfisol (Harpstead, 1974).

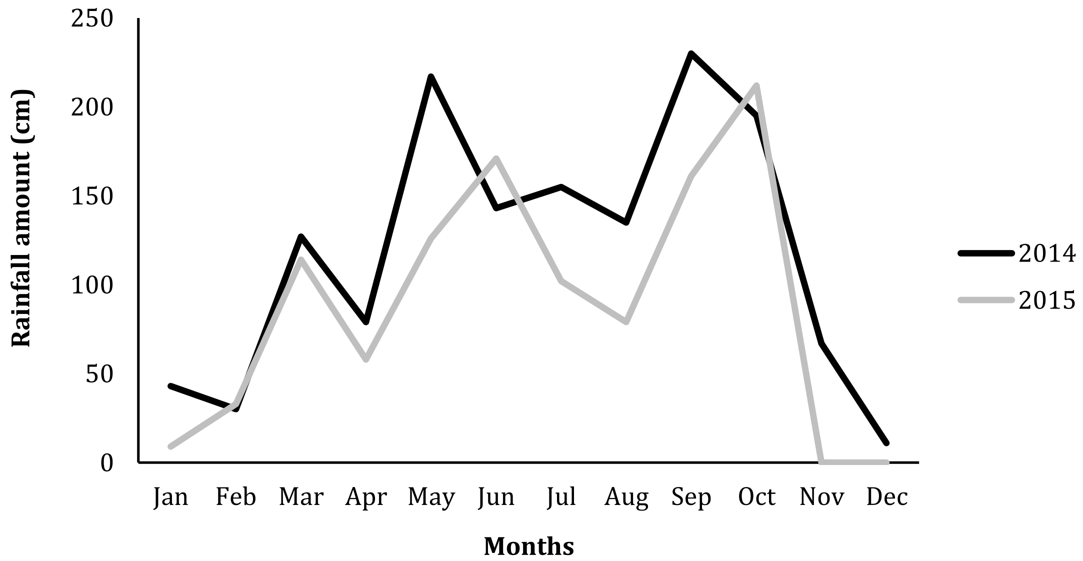


Figure 1. Rainfall data for the years of cropping in the experimental location (Source: NASA-Power)

Compost evaluated in this study was prepared from two plant materials; *Tridax procumbens* and *Panicum maximum* with cow dung which was composted with or without *Trichoderma asperellum* inclusion to give a total number of four compost which were tridax-based compost without *Trichoderma* (TBC), tridax-based compost with *Trichoderma* (TTBC), panicum-based compost without *Trichoderma* (PBC) and panicum-based compost with *Trichoderma* (TPBC). The plants were chopped into smaller particles of below 5 cm using cutlass while Indore hot heap method of composting was adopted. The dimension of each compost pile was 2 m x 3 m with 1.5 m height; its walls were lined with black polythene sheet and the plant material was layered with cow dung in a 3:1 ratio. Pure cultured plate of *Trichoderma asperellum* which was sourced from International Institute of Tropical Agriculture, Ibadan was multiplied with potato dextrose agar in the laboratory, following the procedure of Heritage et al. (1996). The rate of *Trichoderma* application was 0.05% of the total weight of the substrates (about 500 g compost activator per 1000 kg substrate). The compost heaps were monitored till maturity; turning was done fortnightly and pH and ambient temperature observed weekly. At maturity, the different compost were evacuated from the heap, air dried, shredded, bagged and stored under shade. The different compost were sampled for analysis to determine the nutrient composition. The nutrient composition of compost (Table 1) revealed that *Trichoderma* inoculated compost irrespective of composting material had higher concentration of nutrients than uninoculated ones. The TTBC contained 15.3 g/kg N, 27.6 g/kg P and 3.50 g/kg K, TPBC contained 14.3 g/kg N, 11.7 g/kg P and 3.00 g/kg K, PBC contained 13.3 g/kg N, 14.5 g/kg P and 5.20 g/kg K while TBC contained 13.2 g/kg N, 21.6 g/kg P and 3.3 g/kg K.

Table 1. Nutrient Composition of Composts used in the study

Compost	N, g/kg	P, g/kg	K, g/kg
Tridax based compost with *Trichoderma* (TTBC)	15.3	27.6	3.50
Panicum based compost with *Trichoderma* (TPBC)	14.3	11.7	3.00
Panicum based compost without *Trichoderma* (PBC)	13.3	14.4	5.20
Tridax based compost without *Trichoderma* (TBC)	13.2	21.6	3.30

The land preparation was carried out by ploughing and harrowing after which pre-cropping soil samples were collected at 0-15 cm depth and the composite sample was air dried and sieved with 2 mm diameter mesh for routine analysis. The chemical properties of the soil (Table 2) revealed that the soils were slightly acidic with pH of 6.7 and 6.1, respectively for both years. The total nitrogen (0.9 and 0.8 g/kg) and organic carbon content (8.5 and 8.3 g/kg), respectively were low. The available P (14 and 13 mg/kg) were medium while exchangeable K (0.2 cmol/kg) were also low (FMARD, 2012). The treatments imposed on celosia were five; tridax-based compost with *Trichoderma asperellum* (TTBC), panicum-based compost with *Trichoderma asperellum* (TPBC), Panicum-based compost without *Trichoderma asperellum* (PBC), Tridax-based compost without *Trichoderma asperellum* (TBC) and control (no compost application). All compost treatments were applied at the rate of 240 kg N/ha. The experiments were laid out in a randomized complete block design with three replications. The dimension of each plot was 1 m x 1.5 m (1.5 m^2) with 0.5 m space between plots and 1 m space between blocks. The compost were spread on the plots and worked into the soil at two weeks before sowing. The seeds of *Celosia argentea* were sown by drilling method at 25 cm interval between the rows. Weeding was done manually by uprooting. Data collection commenced at four weeks after sowing (4 WAS). Six (6) plants were randomly selected and tagged per plot for assessment of growth performance (plant height, leave count and stem girth). At 6 WAS, three plants were uprooted per plot, washed and oven dried at 65°C till constant weight to determine the dry matter. It was thereafter milled to determine the nutrient concentration, and nutrient uptake was calculated. Harvesting was done by uprooting at 5, 6, 7 and 8 WAS. Fresh yield obtained from each plot was weighed and recorded separately after which cumulative yield per plot was calculated. Post-cropping soil samples were collected per plot at 0-15 cm and processed for routine analysis. Particle size analysis was carried out according to Gee and Or (2002), pH by pH meter (Thomas, 1996) and organic carbon by Walkley-Black procedure (Nelson and Sommers, 1996). Available P was determined"according to the procedure of Murphy and Riley (1962) and total exchangeable acidity by titrimetry method. Exchangeable bases (Ca^{2+}, K^+, Mg^{2+} and Na^+) were extracted by 1N neutral ammonium acetate, K^+ and Na^+ read by flame photometry and Ca^{2+} and Mg^{2+} read by Atomic absorption spectrophotometry. Effective cation exchange capacity was obtained using summation method. Data collected were analysed using analysis of variance and means separated by Duncan multiple range test (DMRT) at $\alpha_{0.05}$.

Table 2. Physical and chemical properties of pre-cropping soil

Parameters		Soil Value
Particle size distribution	Silt (g/kg)	116
	Clay (g/kg)	84
	Sand (g/kg)	800
	Textural class	Sandy loam
pH (H_2O)		6.7
Organic carbon (g/kg)		8.5
Av. P (mg/kg)		14
Total N (g/kg)		0.9
Exchangeable bases	Ca^{2+} (cmol/kg)	4.8
	Na^+ (cmol/kg)	0.4
	K^+ (cmol/kg)	0.2
	Mg^{2+} (cmol/kg)	0.8
Ex. acidity (H^+)		0.1
ECEC (cmol/kg)		6.3

Results

The effect of compost treatments on growth parameters of celosia in both years is presented in Figure 2. In the first year, TPBC had the tallest plants at 4 and 8 WAS (49.46 and 68.55 cm) though not significantly different (p>0.05) from other treatments, except control at 4 WAS and that of TTBC at 8 WAS. In the second year, TTBC gave the tallest plant (49.89 cm) at 4 WAS, which was not significantly different from TPBC (49.86 cm) and PBC (49.37 cm) though higher than TBC (31.38 cm), while control (26.17 cm) had the shortest plant. At 8 WAS, there was no significant difference in the height of plants obtained from all compost applied, though TPBC (62.85 cm) was the highest, while control (35.29 cm) had the shortest plant. The highest leave count (30 and 20) was obtained from TPBC at 8 WAS, though, not significantly different from other treated plants but the control (12 and 10) in the first and second year, respectively. The widest stem girth (1.86 and 4.47 cm) was obtained from TTBC at 4 and 8 WAS at first year though were not significantly different from others except PBC (1.47 and 3.13 cm), while the control (1.02 and 3.13 cm) had the thinnest stem girth at 4 and 8 WAS, respectively. In the second year, plants that received TPBC (2.05 and 3.59 cm) had the widest stem girth which was comparable to TTBC (1.94 and 3.37 cm) while the uninoculated compost (PBC and TBC) had less stem girth and control (1.00 and 2.40 cm) recorded the lowest values of stem girth at 4 and 8 WAS, respectively.

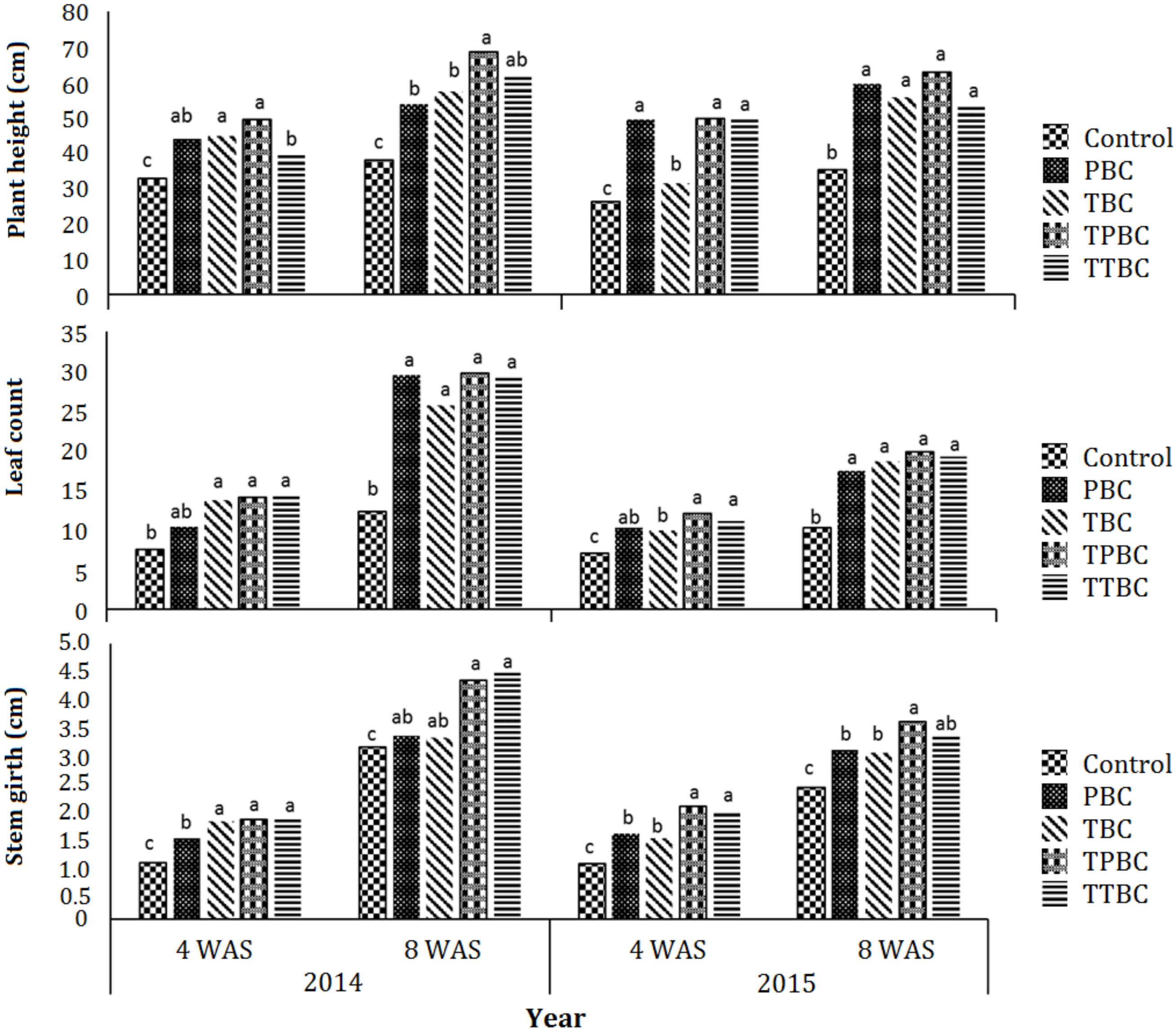


Figure 2. Effect of compost treatments on growth parameter of celosia

Legend: PBC: Panicum-based compost without Trichoderma, TBC: Tridax-based compost without Trichoderma, TPBC: Panicum-based compost with Trichoderma, TTBC: Tridax-based compost with Trichoderma

The result of nutrients uptake by celosia is presented in Table 3. Plant treated with TPBC had the highest N uptake (6.10 g/plant) which differed not significantly from TTBC (6.02 g/plant) but higher than PBC (5.50 g/plant), TBC (4.07 g/plant) and control (2.43 g/plant) in the first year. In the second year, plant treated with TBC had the highest N uptake (6.65 g/plant) which differed not significantly from TPBC (6.36 g/plant), TTBC (6.01 g/plant) and PBC (6.42 g/plant) but higher than control (2.28 g/plant). The difference in the P uptake across the treatments were not significant in the first year; however, in the second year, plant treated with TPBC had the highest P uptake (0.69 g/plant) which was similar to PBC (0.64 g/plant), TTBC (0.61 g/plant) but significantly higher than TBC (0.52 g/plant) and control (0.43 g /plant). The differences in K uptake among the treatments differed significantly in both years In the first year, plant treated with TPBC had the highest K uptake (7.67 g/plant) which was similar to TTBC (7.63 g/plant) and TBC (6.7 g/plant) but significantly higher than PBC (6.53 g/plant) and control (5.47 g/plant). In the second year, plant treated with TTBC had the highest K uptake (6.39 g/plant) which was similar to other treated plants but the control (3.46 g/plant).

Table 3. Effects of compost treatments on the nutrient uptake (g/plant) by celosia

Treatments	2014			2015		
	N- uptake	P- uptake	K- uptake	N-uptake	P- uptake	K-uptake
Control	2.43c	0.51	5.47c	2.28b	0.43b	3.46c
PBC	5.50ab	0.47	6.53b	6.42a	0.64ab	5.21b
TBC	4.07b	0.47	6.7ab	6.65a	0.52b	5.88b
TPBC	6.10a	0.47	7.67a	6.36a	0.69a	6.07a
TTBC	6.02a	0.43	7.63a	6.01a	0.61ab	6.39a

Means with same letter (s) in a column are not significantly different at 5% by DMRT
Legend: PBC: Panicum-based compost without *Trichoderma* , TBC: Tridax-based compost without *Trichoderma,* TPBC: Panicum-based compost with *Trichoderma*, TTBC: Tridax-based compost with *Trichoderma*

The result of celosia fresh yield is shown in Figure 3. In the first year the difference in the yield obtained from plants treated with both TTBC and TPBC (57.09 and 57.00 t/ha, respectively) differed not significantly but were significantly higher than TBC and PBC (43.85 and 47.32 t/ha, respectively). The control resulted in the lowest significant yield (28.34 t/ha). In the second year, TPBC resulted into the highest yield (48.72 t/ha) which differed not significantly from TTBC (47.45 t/ha) but significantly higher than other treated plants, while the control produced the lowest yield (20.03 t/ha).

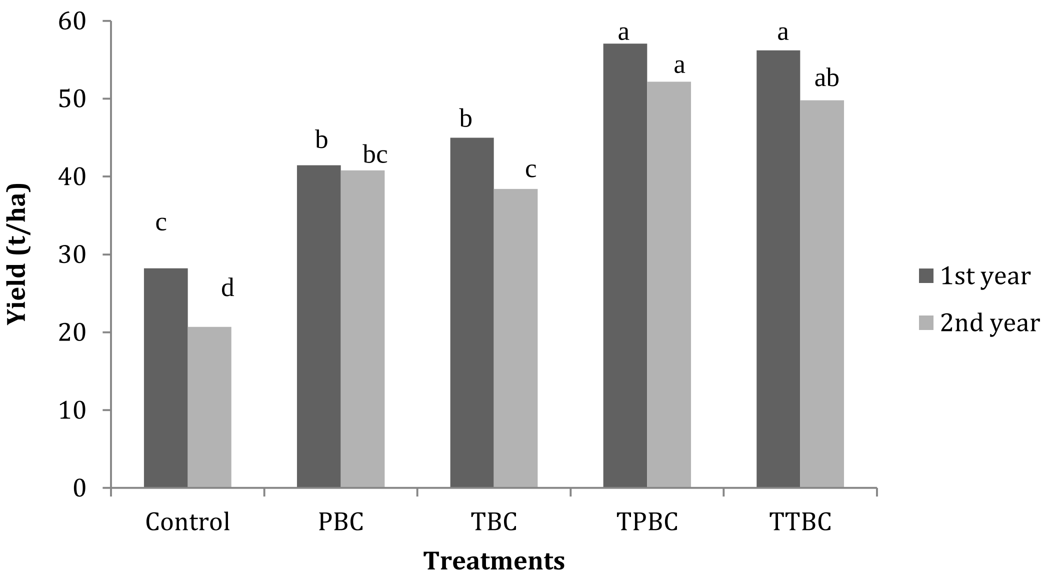


Figure 3. Effect of compost treatments on fresh yield of celosia
Legend: PBC: Panicum-based compost without *Trichoderma*, TBC: Tridax-based compost without *Trichoderma*, TPBC: Panicum-based compost with *Trichoderma*, TTBC: Tridax-based compost with *Trichoderma*

The result of post-cropping soil chemical properties is shown in Table 4. In the first year, soil treated with TTBC had significantly higher organic carbon content (16.1 g/kg) which differed not significantly from other compost treatments but was significantly higher than the control (6.2 g/kg). The available P was significantly higher in soil treated with TPBC (37 mg/kg), though similar to other compost treatments except the control (10 mg/kg). The result of total N, Na^+, K^+ and Ca^{2+} followed the same trend with soil treated with

TPBC having the highest significant value (1.6 g/kg, 0.8 cmol/kg, 0.5 cmol/kg and 5.3 cmol/kg, respectively), though, they were not significantly different from other compost treatments but were significantly higher than the control (0.6 g/kg, 0.2 cmol/kg, 0.2 cmol/kg and 2.1 cmol/kg, respectively). Soils treated with Trichoderma inoculated compost; TTBC and TPBC had significantly higher values of Mg^{2+} (2.3 and 2.4 cmol/kg) and ECEC (8.0 and 9.1 cmol/kg), respectively than those that received uninoculated compost; TBC and PBC (Mg^{2+}; 1.1 and 1.0 cmol/kg, ECEC; 6.7 and 6.4 cmol/kg), respectively. Control plot had the least significant values of Mg^{2+} (0.4 cmol/kg) and ECEC (2.0 cmol/kg). In the second year, soil treated with TTBC had the highest levels of organic carbon (15.4 g/kg) and available P (21 mg/kg) with no significant differences among other compost treatments applied but control had significant lower values (organic carbon; 7.5 g/kg and P; 11 mg/kg). The differences among the treatments differed not significantly with respect to Ca^{2+}, Na^{+}, H^{+} and K^{+}. The highest significant value of Mg^{2+} (5.27 c/mol/kg) was obtained from soil treated with TPBC, though, was not significantly different from TTBC (4.11 cmol/kg) and PBC (4.03 cmol/kg) but was significantly higher than TBC (2.67 cmol/kg). Control had the least significant value (1.37 cmol/kg). The TPBC treated soil had the highest significant ECEC (7.44 cmol/kg) while the control plot gave the lowest significant value (3.01 cmol/kg).

Table 4. Effects of compost treatments on chemical properties of soil before and after cropping

Treatments	pH	Org. C (g/kg)	Avail. P (mg/kg)	Total N (g/kg)	Exchangeable bases (cmol/kg)				H^{+} (cmol/kg)	ECEC (cmol/kg)
					Na^{+}	K^{+}	Ca^{2+}	Mg^{2+}		
2014										
Pre-cropping soil properties										
	6.7	8.5	14	0.9	0.4	0.2	4.8	0.8	0.1	6.3
Post-cropping soil properties										
Control	6.4	6.2b	10b	0.6b	0.2b	0.2b	2.1b	0.4c	0.1	2.0c
PBC	6.4	15.4a	31a	1.6a	0.6a	0.4a	4.3a	1.0b	0.1	6.4b
TBC	6.3	14.7a	32a	1.5a	0.7a	0.4a	4.4a	1.1b	0.1	6.7b
TPBC	6.3	15.9a	37a	1.6a	0.8a	0.5a	5.3a	2.4a	0.1	9.1a
TTBC	6.5	16.1a	35a	1.6a	0.7a	0.4a	4.5a	2.3a	0.1	8.0a
	ns								ns	
2015										
Pre-cropping soil properties										
	6.1	8.3	13	0.8	0.4	0.2	2.5	0.6	0.1	3.8
Post-cropping soil properties										
Controls	6.6a	7.5b	11c	0.6c	0.3	0.3	1.1	1.4c	0.1	3.0c
PBC	6.5a	14.6a	17b	1.5a	0.2	0.3	1.1	4.0ab	0.1	5.8b
TBC	6.3b	12.3a	18b	1.2b	0.3	0.3	1.4	2.7b	0.1	4.7b
TPBC	7.0a	13.2a	19ab	1.7a	0.2	0.3	1.6	5.3a	0.1	7.4a
TTBC	6.5a	15.4a	21a	1.6a	0.2	0.3	1.2	4.1ab	0.1	5.9b
					ns	ns	ns		ns	

Means with same letter (s) in a column are not significantly different at 5% by DMRT

Legend: PBC: Panicum-based compost without *Trichoderma,* TBC: Tridax-based compost without *Trichoderma,* TPBC: Panicum-based compost with *Trichoderma,* TTBC: Tridax-based compost with *Trichoderma*

Discussion

There was consistent increase in growth parameters across the compost applied to the celosia in both years. However, the value obtained in the first year was higher than that of the second year. This was because there was an unusual dry spell at the middle of the rainy season of that year (Figure 1) and this fell into the period when the crop was at its log phase. This agrees with the report of (Adejuyigbe et al., 2006) that climate played a crucial role on the performance of fertilizer. The compost treatments improving the growth parameters of celosia suggest that the compost mineralized for the plant use. Thus, tridax and panicum-based compost could be suitable soil amendments for spinach growth. This is in agreement with the report of (Sanni and Adesina, 2012) compost enhanced the growth of celosia.

The nutrient uptake of celosia was improved by compost application irrespective of inoculation, this is in line with the findings of Kayode et al. (2018) where organic amendments enhanced uptake of N, P, K, Ca and Mg by plants. However, compost inoculated with *T. asperellum* performing better than the uninoculated ones implies that *T. asperellum* aided the mineralization of nutrients in line with the report of Baldi et al. (2010) and Mbouobda et al. (2014). This is in agreement with the reports that rapid composting methods improved compost quality and efficiency (Rasapoor et al., 2009; Jusoh et al., 2013). The efficiency of *T.*

asperellum isolate on compost nutrient availability to onion plants has also been confirmed by Ortega-García et al. (2015).

The yield of celosia recorded revealed that the plant that received inoculated compost responded better compared to uninoculated compost, regardless of composting materials. This confirms that the presence of *Trichoderma* has a great influence in hastening the release of nutrients to plant, hence, improved the yield; which validated the findings of Jusoh et al. (2013) that rapid compost improved the yield of crops than conventional ones). The compost applied improved the soil nutrient status after cropping in comparison with the control. This is in concordance with the findings of Hossain et al. (2017) that compost improved the post-cropping chemical properties. This confirmed the gradual nutrient release nature of compost as reported by Tejada and Gonzalez (2007). Of note is the improvement of organic carbon, phosphorus and ECEC. The sharp increase in soil organic carbon confirmed the potential of compost to sequestrate carbon and this confirmed the recommendation of composting as a method for greenhouse gas emission reduction (UNFCCC/CCNUCC, 2007).

Conclusion

The result of this work revealed that the growth, nutrient uptake and fresh yield of celosia were higher in celosia plants treated with Trichoderma inoculated compost relative to uninoculated ones while both the inoculated and uninoculated compost improved the postcropping soil chemical properties. Therefore, the use of Trichoderma asperellum as compost additive could be recommended to farmers in order to hasten the readiness of compost as well as improving the yield of crop and soil chemical properties. However, it is recommended that further studies be carried out using different organic substrates as composting materials with Trichoderma asperellum inoculation as additive.

References

Adejuyigbe, C,O., Tian, G., Adeoye, G.O., 2006. Influence of soil microarthropods on the decomposition of Leguminous Plant residues. *ASSET series A* 6(1): 259 - 269.

AyanfeOluwa, O.E., 2019. Availability of nutrients from an accelerated compost for maize (Zea mays) production in two soil types. *Communications in Soil Science and Plant Analysis* 50(12): 1476 - 1486.

Badar, R., Aslam, I., Ibrahim, S., Shabbir, S., 2014. Comparative effect of compost with and without microbial inoculants on the growth of Vigna radiate. *International Journal of Advances in Pharmacy, Biology & Chemistry* 3(1): 100-105.

Baldi, E., Toselli, M., Marangoni, B., 2010. Nutrient partitioning in potted peach (Prunuspersica l.) trees supplied with mineral and organic fertilizers. *Journal of Plant Nutrition* 33(14): 2050 – 2061.

Das, D.K., Mandal, M., 2015. Advanced technology of fertilizer uses for crop production. In: Fertilizer Technology I Synthesıs. Sinha, S., Pant, K.K., Bajpai, S. (Eds.). Studium Press, LLC, USA. pp. 101-150.

Diacono, M., Montemurro, F., 2010. Long-term effects of organic amendments on soil fertility. A review. *Agronomy for Sustainable Development* 30: 401–422.

FMARD, 2012. Fertilizer use and Management Practices for crops in Nigeria. Federal Ministry of Agriculture and Rural Development (FMARD), Federal Fertilizer Department. Chude, V. et al. (Eds.). Abuja, Niigeria.

Gee, G.W., Or, D., 2002. Particle size analysis. In: Methods of Soil Analysis Part 4, Physical Methods. Dane, J.H., Topp, G.C., (Eds). Book series 5. Soil Science Society of America (SSSA) Book Series No. 5, ASA-SSSA, Madison, Wisconsin, USA. pp. 255 – 294.

Grubben, G.J.H., Denton, O.A., 2004. PROTA Vegetables - Plant resources of Tropical Africa 2. PROTA Foundation Backhuys Publishers/CTA, Wageningen, Netherlands. 669p.

Harpstead, M.I., 1974. The classification of some Nigerian soils. *Soil Science* 116: 437-447

Heritage, J., Evans, E.C.V., Killington, R.A., 1996. Introductory microbiology. Cambridge University Press Cambridge, UK. 248p.

Hossain, M.Z., Von Fragstein, Niemsdorff, P., Heß, J., 2017. Effect of different organic wastes on soil properties and plant growth and yield: a review. Scientia Agriculturae Bohemica 48 (4): 224–237.

Junge, B., Alabi, T., Sonder, K., Marcus, S., Abaidoo, R., Chikoye, D., Stahr, K., 2010. Use of remote sensing and GIS for improved natural resources management: case study from different agroecological zones of West Africa. *International Journal of Remote Sensing* 31(23): 6115 - 6141.

Jusoh, M.L.C., Manaf, L.A., Latiff, P.A., 2013. Composting of rice straw with effective microorganisms (EM) and its influence on compost quality. *Iranian Journal of Environmental Health Science & Engineering* 10: 17.

Kayode, C.O., Adeoye, G.O., Ezekiel-Adewoyin, D.T., AyanfeOluwa, O.E., Ogunleti, D.O., Adekunle, A.F., 2018. Influence of Cocoa Pod Husk-Based Compost on Nutrient Uptake of Okra (Abelmoschus esculentus (L.) MOENCH) and soil properties on an Alfisol. *Communications in Soil Science and Plant Analysis* 48(17): 2113-2122.

Mbouobda, H.D., Fotso, F.O.T.S.O., Djeuani, C.A., Baliga, M.O., Omokolo, D.N., 2014. Comparative evaluation of enzyme activities and phenol content of Irish potato (Solanum tuberosum) grown under EM and IMO manures Bokashi. *International Journal of Biological and Chemical Sciences* 8(1): 157-166.

Murphy, J., Riley, J.P., 1962. A modified single solution method for the determination of phosphate in natural waters. *Analytica Chimica Acta* 27: 31-36.

Nelson, D.W., Sommers, L.E., 1996. Total carbon and soil organic matter. In: Methods of Soil Analysis. Part 3, Chemical Methods. Sparks, D.L. Page, A.L., Helmke, P.A., Loeppert, R.H., Soltanpour, P.N., Tabatabai, M.A., Johnston, C.T., Sumner, M.E. (Eds.). American Society of Agronomy, Soil Science Society of America. Madison, Wisconsin, USA. pp. 961-1010.

Nwachokor, M.A., Uzu, F.O., 2008. Updated classification of some soil series in Southwestern Nigeria. *Journal of Agronomy* 7(1): 76-81.

Ojeniyi, S.O., Makinde, E.A., Odedina, S.A., Odedina, J.N., 2009. Effect of Organic, organomineral and NPK fertilizer on Nutritional Quality of Amaranthus in Lagos, Nigeria. *Nigerian Journal of Soil Science* 19(2): 129-134.

Omolayo, F.O., Ayodele, O.J., 2009. Response of Amaranth (Amaranthus hybridus) to different rates and times of urea fertilizer application, *Nigerian Journal of Soil Science* 19(2): 135-139.

Ortega-García, J.G., Montes-Belmont, R., Rodríguez-Monroy, M., Augusto Ramírez-Trujillo, J., Suárez-Rodríguez, R., Sepúlveda-Jiménez, G., 2015. Effect of *Trichoderma asperellum* applications and mineral fertilization on growth promotion and the content of phenolic compounds and flavonoids in onions. *Scientia Horticulturae* 195: 8-16.

Plaster, E.J., 2014. Soil Science and Management. Delmar Cengage Learning. 544 pp.

Rasapoor, M., Nasrabadi, T., Kamali, M., Hoveidi, H., 2009. The effects of aeration rate on generated compost quality, using aerated static pile method. *Waste Management* 29(2): 570-573.

Sanni, K.O., Adesina, J.M., 2012. Response of water hyacinth manure on growth attributes and yield of Celosia argentea L. (Lagos Spinach). *Journal of Agricultural Technology* 8(3): 1109-1118.

Tejada, M., Gonzalez, J.L., 2007. Application of different organic wastes on soil properties and wheat yield. *Agronomy Journal* 99(6): 1557 - 1606.

Thomas, G.W., 1996. Soil pH and soil acidity. In: Methods of Soil Analysis Part 2 Chemical and Microbiological Properties 2nd Edition, Page, A.L., et al. (Eds). American Society of Agronomy, Soil Science Society of America, Madison, Wisconsin, USA. pp. 475–490.

UNFCCC/CCNUCC, 2007. Approved baseline and monitoring methodology AM0039. Methane emissions reduction from organic waste water and bioorganic solid waste using co-composting. United Nations Framework Convention on Climate Change (UNFCCC)/The United Nations Framework Convention on Climate Change (CCNUCC), AM0039/Version 02, Sectoral Scope 13, EB 35.

Eurasian Journal of Soil Science 2021, 10(3), 207 - 214

Eurasian Journal of Soil Science

Journal homepage : http://ejss.fesss.org

Feasibility of sewage sludge application in rice-wheat cropping system

Hanuman Singh Jatav [a,b], Satish Kumar Singh [b], Surendra Singh Jatav [b], Vishnu D. Rajput [c,]*, Svetlana Sushkova [c]

[a] Department of Soil Science and Agricultural Chemistry, Sri Karan Narendra Agriculture University-Jobner-303329 (Rajasthan), India

[b] Department of Soil Science and Agricultural Chemistry, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi-221005, U.P., India

[c] Southern Federal University, Rostov-on-Don 344006 Russia

Article Info

Received : 28.10.2020
Accepted : 08.02.2021
Available online : 15.02.2021

Author(s)

H.S. Jatav
S.K. Singh
S.S. Jatav
V.D. Rajput *
S. Sushkova

* Corresponding author

Abstract

A field experiment was conducted to find out the effect of the conjoint application of sewage sludge (SS) and fertilizers on the yield of rice-wheat cropping system using a randomized block design. The grain yield ranged between 24.99 ± 4.24 to 66.32 ± 2.58 q ha^{-1} and 22.50 ± 0.55 to 50.37 ± 1.07 q ha^{-1} in Ist year grown rice and wheat, respectively. Among all the treatments, T_3 (100% recommended dose of fertilizer (RDF) + 30 t ha^{-1} SS) recorded a significantly highest grain yield of rice crop (66.32 and 63.37 q ha^{-1}) and wheat crop (50.37 and 46.91 q ha^{-1}) during 2015-16 and 2016-17 years, respectively. The straw yield in Ist rice and Ist wheat ranged between 55.11 to 81.22 q ha^{-1} and 35.86 to 56.62 q ha^{-1}, whereas straw yield in IInd rice and IInd wheat were noticed between 48.42 to 79.31 q ha^{-1} and 30.45 to 52.32 q ha^{-1}, respectively. The finding clearly shows that the application of SS significantly enhances the yield of rice-wheat crops, and could be an option to a sustainable use of SS. However, the precautionary measure should be followed before use. In addition, the application of SS also indicates the improvement in soil health and sustainability.

Keywords: Heavy metals, nutrient status, microbial community, organic matter, sewage treatment plants.

Introduction

Sewage sludge (SS) consists of multi-element along with a good amount of organic matter (OM). It has the capacity to improve the physico-chemical characteristics and biological properties of the soil, and is beneficial for plant growth and development (Ye et al., 2019). However, SS also contains some amount of heavy metals and organic pollutants that can adversely affect soil micro-organisms (Seleiman et al., 2020). Furthermore, the toxic elements move through the food chain due to their uptake and accumulation by crops, posing a possible threat to human health as well (Jatav et al., 2016; Singh and Singh, 2020; Chaplygin et al., 2020; 2021). The worlds' population is increasing and concentrating in urban areas. This trend is particularly intense in developing countries, and an additional 2.1 billion people are expected to be living in cities by 2030 (Jatav et al., 2018a; Egidi et al., 2020).

Sewage sludge production is increasing at a faster rate as more and more wastewater treatment facilities are being developed. It is a product of sewage treatment plants (STPs) and results from the removal of solids and organic matter from the sewage (Agoro et al., 2020). On average about 38,354 million liters of sewage

: https://doi.org/10.18393/ejss.880677
: http://ejss.fesss.org/10.18393/ejss.880677
Publisher : Federation of Eurasian Soil Science Societies
e-ISSN : 2147-4249

with an equivalent amount of sludge per day generated in India (Saha et al., 2018). It is a mixture of water, inorganic and organic materials removed from wastewater releases from various sources such as domestic and industrial sewage, stormwater, runoff from roads and other paved areas, through physical, biological, and chemical treatments (Jatav et al., 2018b; Wang et al., 2020). The solid material remaining after sewage treatment is referred to as 'bio-solids' or 'SS'. Often these materials can be obtained at little or no cost to farmers or landowners (Kidder, 2001).

The utilization of SS in agriculture is gaining popularity as a source of waste disposal. It has been widely used in many countries around the world, in the European community; over 40% of SS (10.13 Mt) is used as fertilizer in agriculture (Bouwen, 2009). The high nutrients and the OM contents of SS make it an excellent fertilizer to enhance soil fertility and crop production. However, the presence of heavy metals is a major concern for utilizing the SS in agriculture, moreover, its utilization in a proper manner could make it suitable to fulfill the nutritional requirement of the crops (Smith, 2009; Latare et al., 2014; Cieślik et al., 2015; Kumar et al., 2020). As the rice-wheat cropping system is the dominant cropping system, therefore, its suitability was judged to use as a test crop (Jatav et al., 2018a). Seeking its suitability for agriculture purposes to buildup soil fertility, SS was used to investigate the feasibility in the rice-wheat cropping system. The main objective to conduct the study is to find out a possible sustainable way to use the SS in the cropping system without impairing the grain and straw quality.

Material and Methods

The experiment was conducted in a randomized block design (RBD) during the years 2015-16 and 2016-17, using 10 treatments (Table 1) in triplicate on rice (*Oryza sativa,* L.) and wheat (*Triticum aestivum.* L) as test crop (Variety Hybrid Rice -Arize-6444; Wheat- HD-3086 Pusa Gautmi) at Agriculture Research Farm, Banaras Hindu University, Varanasi, U.P. (India). The recommended dose of fertilizer (RDF) was applied 150:60:60 kg $N:P_2O_5:K_2O$ ha^{-1} for rice crop and 120:60:60 kg $N:P_2O_5:K_2O$ ha^{-1} for the wheat crop. The SS was applied only in the first year of during rice crop.

Table 1. Treatment details of the experiment

Treatments	2015-16		2016-17	
	Ist Rice	Ist Wheat	IInd Rice	IInd Wheat
T_0	Without fertilizer, Control	Control	Control	Control
T_1	100% RDF	100% RDF	100% RDF	100% RDF
T_2	100% RDF + 20 t ha^{-1} SS	100% RDF	100% RDF	100% RDF
T_3	100% RDF + 30 t ha^{-1} SS	100% RDF	100% RDF	100% RDF
T_4	50% RDF + 20 t ha^{-1} SS	50% RDF	50% RDF	50% RDF
T_5	60% RDF + 20 t ha^{-1} SS	60% RDF	60% RDF	60% RDF
T_6	70% RDF + 20 t ha^{-1} SS	70% RDF	70% RDF	70% RDF
T_7	50% RDF + 30 t ha^{-1} SS	50% RDF	50% RDF	50% RDF
T_8	60% RDF + 30 t ha^{-1} SS	60% RDF	60% RDF	60% RDF
T_9	70% RDF + 30 t ha^{-1} SS	70% RDF	70% RDF	70% RDF

The samples of SS were collected from the Bhagwanpur STPs plant (Varanasi, U.P., India) and processed for different laboratory analyses, i.e., physical, chemical, and biological properties. The analysis of initial soil and SS has been presented in Table 2. Sewage sludge in the tank of Bhagwanpur STPs and final processing of SS by 2 mm manual sieving has been shown in Figure 1. The location of Bhagwanpur STPs and their different component of process have been depicted in Figure 2. The various analysis of SS was done as per standard methods. The bulk density (Piper, 1966); water holding capacity (Piper, 1966); moisture percent by moisture box; pH and EC (Jackson, 1973); Organic carbon (Walkley and Black, 1934); available nitrogen (Subbiah and Asija, 1956); available phosphorus (Olsen et al., 1954); available potassium (Hanway and Heidel, 1952); available sulphur (Chesnin and Yien, 1951); total micronutrients and heavy metals (Nieuwenhuize et al., 1991); micronutrients (Fe, Cu, Mn and Zn) and heavy metals (Cd, Cr, Ni and Pb) (Agilent FS-240; Lindsay and Norvell, 1978).

The bacteria, fungi, and actinomycetes colonies were observed by serial dilution on Asparagine-Mannitol agar medium (Thornton, 1922), rose Bengal streptomycin agar medium (Martin, 1950), and Ken Knight and Munaier's medium by pour plate method (Chhonkar et al., 2002). The enzymatic activities such as urease by urea hydrolyzed method (Tabatabai and Bremner, 1972); alkaline phosphatase and dehydrogenase by triphenyl tetrazolium chloride (TTC) method were also determined (Page et al., 1982).

Table 2. Physico- bio-chemical properties of experimental site (0-15 cm depth) and sewage sludge after final processing by 2 mm sieve

Properties	Parameter	Initial Soil	Sewage sludge
Physical	Bulk Density (mg m^{-3})	1.40 ± 0.12	1.21 ± 0.09
	WHC (%)	40.15 ± 2.18	51.24 ± 2.26
	Moisture (%)	7.21 ± 0.95	9.53 ± 1.14
Chemical	pH (soil:water, 1:2.5)	8.24 ± 0.51	6.58 ± 0.62
	EC (dS m^{-1})	0.15 ± 0.01	2.49 ± 0.02
	Organic Carbon (%)	0.46 ± 0.04	8.19 ± 0.59
	Available content	(kg ha^{-1})	(mg kg^{-1})
	N	141.72 ± 5.01	155.43 ± 4.23
	P	17.42 ± 0.26	68.56 ± 3.15
	K	132.74 ± 5.06	174.19 ± 5.85
	S (mg kg^{-1})	14.65 ± 0.92	49.82 ± 3.06
	Total content (%)		
	N	-	1.72 ± 0.11
	P	-	1.34 ± 0.08
	K	-	0.97 ± 0.04
	S	-	1.14 ± 0.07
	DTPA extractable (mg kg^{-1})		
	Fe	42.65 ± 2.47	87.64 ± 5.12
	Cu	2.17 ± 0.04	27.18 ± 2.48
	Zn	1.02 ± 0.05	29.52 ± 2.59
	Mn	11.41 ± 0.12	34.78 ± 3.11
	Cd	0.21 ± 0.03	4.22 ± 0.14
	Cr	0.34 ± 0.04	9.42 ± 0.85
	Ni	2.71 ± 0.07	12.39 ± 1.14
	Pb	0.11 ± 0.01	9.24 ± 0.94
	Total (mg kg^{-1})		
	Fe	188.40 ± 6.21	482.54 ± 14.60
	Cu	32.42 ± 2.14	234.91 ± 11.80
	Zn	88.92 ± 4.28	152.85 ± 7.81
	Mn	119.31 ± 5.42	258.45 ± 9.48
	Cd	0.55 ± 0.09	22.51 ± 3.45
	Cr	2.12 ± 0.12	49.31 ± 4.65
	Ni	9.24 ± 1.04	62.39 ± 5.25
	Pb	6.79 ± 0.08	41.58 ± 2.87
Biological	Bacteria (10^{-6}cfu g^{-1} soil)	14.50 ± 0.29	38.65 ± 2.54
	Fungi (10^{-4}cfu g^{-1} soil)	7.20 ± 0.21	24.55 ± 3.65
	Actinomycetes (10^{-5}cfu g^{-1} soil)	17.25 ± 0.35	39.20 ± 2.84
	Dehydrogenase (µg TPF released g^{-1} soil day^{-1})	22.35 ± 2.75	72.56 ± 4.26
	Urease (µg urea hydrolysed g^{-1} soil h^{-1})	112.54 ± 4.18	288.20 ± 6.41
	Phosphatase (µg p-PNP formed g^{-1} soil day^{-1})	48.28 ± 2.14	212.59 ± 3.85

Data represent mean of three samples with standard error (±)


Figure 1. Sewage sludge in tank of Bhagwanpur STPs and sewage sludge in final processing by 2 mm sieve (Jatav et al., 2018b)

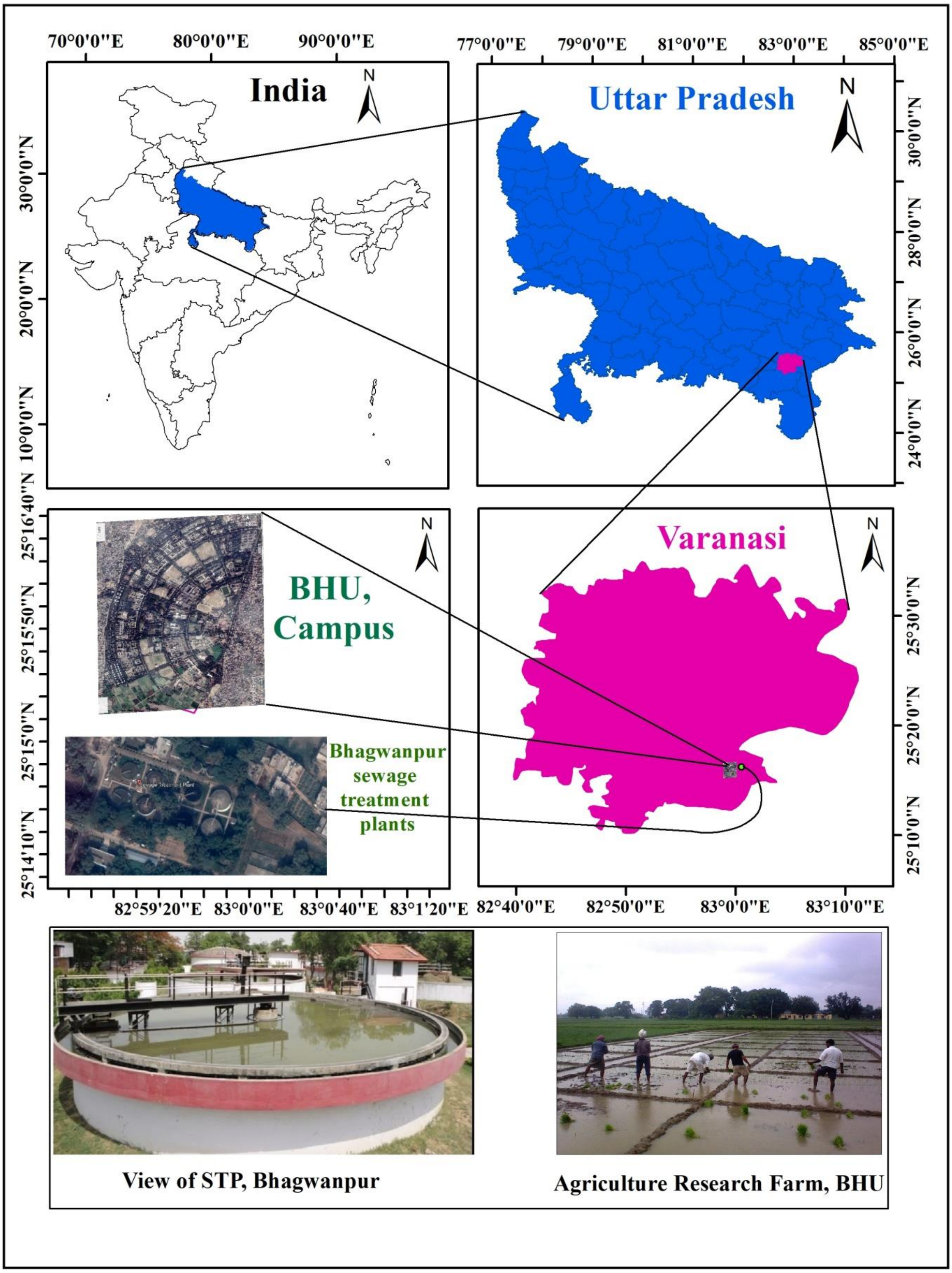


Figure 2. Location of Bhagwanpur sewage treatment plant (STPs) and experimental trial

Results and Discussion

The initial soil properties are depicted in the Table 2. The physical properties of experimental soils are as bulk density- 1.40±0.12; WHC- 40.15±2.18; Moisture- 7.21±0.95, and chemical properties are as pH- 8.24±0.51; EC- 0.15±0.01, Organic Carbon- 0.46 ± 0.04, available N, P, K S content 141.72±5.01, 17.42±0.26, 132.74±5.06, 14.65±0.92, respectively. The available content of Fe, Cu, Zn, Mn, Cd, Cr, Ni and Pb are 42.65±2.47, 2.17±0.04, 1.02±0.05, 11.41±0.12, 0.21±0.03, 0.34±0.04, 2.71±0.07, 0.11±0.01, respectively. Whereas the total content of Fe, Cu, Zn, Mn, Cd, Cr, Ni and Pb are 188.40±6.21, 32.42±0.14, 88.92±4.28, 119.31±5.42, 0.55±0.09, 2.12±0.12, 9.24±1.04, 6.79±0.08. The biological properties of experimental soil were observed as bacterial (14.5±0.29), fungal (7.2±0.21), and actinomycetes (22.35±2.75) colonies. The enzymatic activities were recorded as dehydrogenase (22.35±2.75), Urease (112.54±4.18) and Phosphatase (48.28±2.14).

Grain yield

A critical examination of data presented in Table 3 and Figure 3 showed that significantly higher grain yield was recorded with all combined treatments of SS as compared to treatments without fertilization. The grain yield ranged between 24.99 to 66.32 q ha^{-1} and 22.50 to 50.37 q ha^{-1} in Ist rice and Ist wheat, respectively. Treatment, T_3 (100% RDF + 30 t ha^{-1} SS) showed the highest grain yield of rice crop (66.32 and 63.37 q ha^{-1}) and in wheat crop (50.37 and 46.91 q ha^{-1}) during 2015-16 and 2016-17 years. The lower grain yield was recorded with the application of (T_0) control (24.99 and 17.87 q ha^{-1}) of the rice crop and (22.50 and 16.46 q ha^{-1}). The treatment, T_1 (100% RDF) was found at par with T_6 (20 t ha^{-1} SS+70% RDF), T_7 (30 t ha^{-1} SS+50% RDF), and T_8 (30 t ha^{-1} SS+60% RDF) where SS was applied along with fertilizer in Ist rice crop.

Table 3 Effect of conjoint application of sewage sludge and fertilizers on grain yield

	2015-16		2016-17	
	I- Rice	I- Wheat	II- Rice	II- Wheat
T_0 (WF)	24.99 ± 4.24^{d}	22.50 ± 0.55^{e}	17.87 ± 3.14^{f}	16.46 ± 1.09^{e}
T_1 (RDF 100)	58.28 ± 2.80^{abc}	40.60 ± 2.62^{bcd}	59.26 ± 1.90^{abc}	42.44 ± 1.83^{abc}
T_2 (RDF 100+SS 20)	64.47 ± 3.69^{ab}	47.87 ± 2.02^{ab}	62.00 ± 1.69^{ab}	45.95 ± 2.16^{ab}
T_3 (RDF 100+SS 30)	66.32 ± 2.58^{a}	50.37 ± 1.07^{a}	63.37 ± 0.63^{a}	46.92 ± 0.22^{a}
T_4 (RDF 50+SS 20)	52.13 ± 2.44^{c}	35.94 ± 3.44^{d}	48.56 ± 2.65^{e}	35.12 ± 3.44^{d}
T_5 (RDF 60+SS 20)	54.70 ± 2.61^{bc}	37.59 ± 2.62^{cd}	50.75 ± 2.34^{de}	36.90 ± 0.73^{cd}
T_6 (RDF 70+SS 20)	58.62 ± 1.59^{abc}	41.15 ± 2.07^{bcd}	55.28 ± 0.69^{cd}	40.52 ± 0.92^{bcd}
T_7 (RDF 50+SS 30)	59.80 ± 2.35^{abc}	42.25 ± 3.09^{bcd}	55.83 ± 1.55^{bcd}	40.91 ± 2.85^{abcd}
T_8 (RDF 60+SS 30)	61.46 ± 2.74^{abc}	43.35 ± 3.34^{abcd}	56.93 ± 0.96^{bc}	41.02 ± 0.76^{abcd}
T_9 (RDF 70+SS 30)	63.65 ± 2.62^{ab}	44.72 ± 0.73^{abc}	59.12 ± 0.99^{abc}	42.09 ± 0.57^{abc}

(Mean of 3 replicates ± standard error. Values with the same letter differ nonsignificantly ($p > 0.05$). Different letters for each parameter show a significant difference at $p < 0.05$)

In IInd rice the treatment, T_1 (100% RDF) was at par with T_9 where 30 t ha^{-1} SS+70% RDF was applied. In Ist wheat, the treatment T_1 (100% RDF) was found at par with T_6, T_7, and T_8 where SS was applied with reducing doses of fertilizer. During the IInd wheat crop T_1 (100% RDF) was found at par with T_6, T_7, T_8, and T_9 where 20 t ha^{-1} SS+70% RDF, 30 t ha^{-1} SS+50% RDF, 30 t ha^{-1} SS+60% RDF and 30 t ha^{-1} SS+60% RDF were applied, respectively. In Ist rice crop treatment T_2, T_3, T_8 and T_9 were 10.62%; 13.80% 5.46% and 9.21%, respectively higher as compared to treatment T_1 where 100% RDF was applied. In the case of IInd rice the treatment T_2, T_3, T_7, T_8 and T_9 were 17.91%; 24.06% 4.06% 6.53% and 10.15%, respectively were higher as compared to treatment T_1. During the Ist wheat crop experiment, grain yield of treatment T_2 (20 t ha^{-1} SS+100% RDF) and T_3 (30 t ha^{-1} SS+60% RDF) showed 4.62% and 6.94% increases over 100% RDF (T_1). In the case of IInd wheat the treatment T_2 (20 t ha^{-1} SS+100% RDF) and T_3 (30 t ha^{-1} SS+60% RDF) showed 8.27% and 10.56% yield increment over 100 % RDF (T_1).

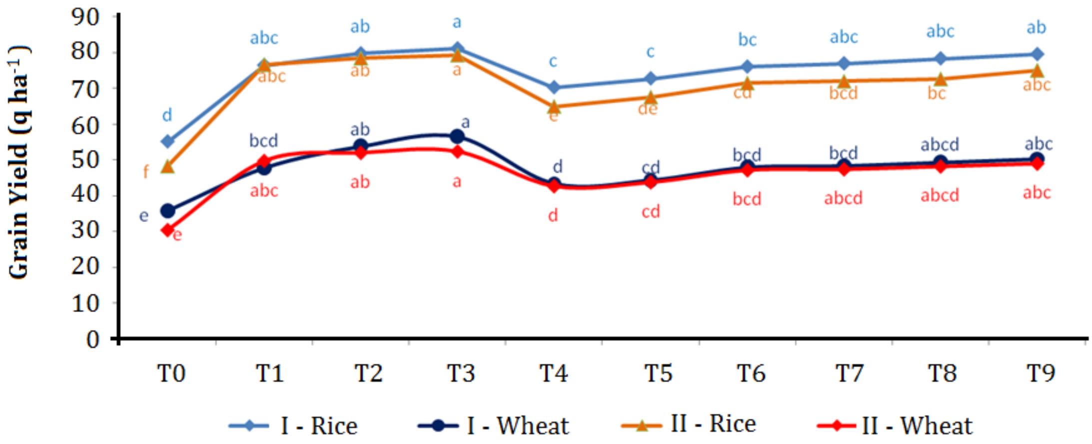


Figure 3. Effect of conjoint application of sewage sludge and fertilizers on grain yield of rice wheat cropping system

Generally, crop yield is considered to be the weight of grain or any other economic product on which crop is harvested. It has been reported by the scientist that the regular supply of crop nutrition has resulted in the optimum yield of the crop (Ali et al., 2008). The SS is found to be a good source for the nutrient that can properly supply nutrients. The optimum availability of nutrient will be helpful to the plant to enhance its potential yield. The SS was a feasible source to provide the all-necessary nutrient for the proper growth development in both years (Latare et al., 2014; Delibacak et al., 2020; Kumar et al., 2020).

Straw yield

The data presented in Table 4 on straw yield showed a significantly higher yield was recorded with all combined treatments of fertilizers and SS as compared to without fertilized treatment (T_1). The straw yield in Ist rice and Ist wheat ranged between 55.11 to 81.22 q ha^{-1} and 35.86 to 56.62 q ha^{-1}, respectively. The straw yield in IInd rice and IInd wheat ranged between 48.42 to 79.31 q ha^{-1} and 30.45 to 52.32 q ha^{-1}, respectively. The treatment, T_3 (100% RDF + 30 t ha^{-1} SS) recorded a significantly highest straw yield of rice crop (81.20 and 79.31 q ha^{-1}) and in wheat crop (56.62 and 52.32 q ha^{-1}) during 2015-16 and 2016-17 years, respectively than the other treatments. The treatment T_1 (100% RDF) show at par results with treatment T_2, T_5, T_6, T_7, T_8, and T_9 in the Ist rice crop. In the case of the Ist wheat crop, the treatment T_1 (100% RDF) was found at par with treatment T_2, T_6, T_7, T_8 and T_9. During the IInd rice experiment, the treatment T_2 (100% RDF + 20 t ha^{-1} SS) and T_3 (100% RDF + 20 t ha^{-1} SS) were found at par whereas, in the case of IInd wheat treatment, T_1(100% RDF) was found at par with T_2, T_5, T_6, T_7, T_8 and T_9. The significantly lower straw yield was recorded with the application of (T_0) control (55.1 and 48.42 q ha^{-1}) of the rice crop, and (35.86 and 30.45 q ha^{-1}) of the wheat crop during both years, respectively. In Ist rice crop treatment T_2, T_3, T_7, T_8 and T_9 were 4.30%, 6.11%, 0.61%, 2.42% and 3.95%, respectively higher as compared to treatment T_1 where 100% RDF was applied. In the case of IInd rice, the treatment T_2 and T_3 were 2.32% and 3.43%, respectively, higher as compared to treatment T_1. During the Ist wheat crop experiment on straw yield of treatment T_2 (20 t ha^{-1} SS+100% RDF), T_3 (30 t ha^{-1} SS+60% RDF), T_7 (30 t ha^{-1} SS+50% RDF), T_8 (30 t ha^{-1} SS+60% RDF) and T_9 (30 t ha^{-1} SS+70% RDF) showed 12.53%, 18.25%, 1.13%, 3.13% and 5.14% higher over 100 % RDF (T_1). Whereas, in the case of IInd wheat only treatment T_2 (20 t ha^{-1} SS+100% RDF) and T_3 (30 t ha^{-1} SS+60% RDF) showed 4.59% and 5.31% straw yield increment over 100 % RDF (T_1) respectively.

Table 4. Effect of conjoint application of sewage sludge and fertilizers on straw yield

2015-16		2016-17	
I- Rice	I- Wheat	II- Rice	II- Wheat
55.11 ± 3.80^{c}	35.86 ± 1.70^{c}	48.42 ± 2.86^{f}	30.45 ± 2.03^{c}
76.54 ± 5.23^{ab}	47.88 ± 2.97^{ab}	76.68 ± 0.55^{ab}	49.68 ± 2.12^{ab}
79.83 ± 1.76^{ab}	53.88 ± 2.90^{ab}	78.46 ± 1.67^{a}	51.96 ± 2.22^{ab}
81.22 ± 2.85^{a}	56.62 ± 3.69^{a}	79.31 ± 1.17^{a}	52.32 ± 2.15^{a}
70.33 ± 3.25^{b}	43.48 ± 4.04^{bc}	65.02 ± 1.32^{e}	42.66 ± 4.04^{b}
72.85 ± 3.93^{ab}	44.44 ± 2.14^{bc}	67.63 ± 1.55^{de}	43.76 ± 2.54^{ab}
76.12 ± 2.24^{ab}	48.01 ± 2.47^{ab}	71.55 ± 0.85^{cd}	47.11 ± 0.44^{ab}
77.01 ± 2.53^{ab}	48.42 ± 4.52^{ab}	72.02 ± 1.66^{bcd}	47.35 ± 4.52^{ab}
78.39 ± 2.20^{ab}	49.38 ± 3.69^{ab}	72.70 ± 0.60^{bc}	48.15 ± 3.69^{ab}
79.56 ± 1.86^{ab}	50.34 ± 1.17^{ab}	75.07 ± 1.15^{abc}	48.94 ± 1.17^{ab}

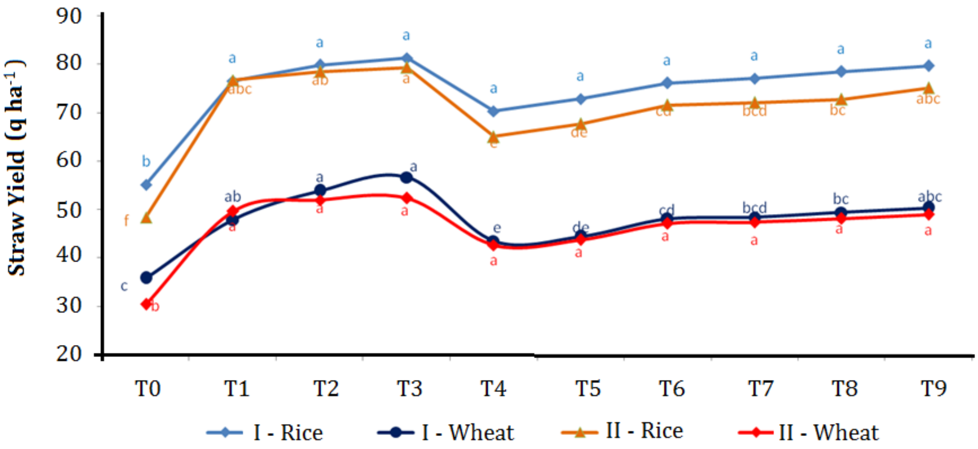


Figure 4. Effect of conjoint application of sewage sludge and fertilizers on straw yield of rice wheat cropping system

An increase in the chlorophyll concentration of leaf is responsible for increased photosynthetic rate and ultimately photosynthetic products resulting in higher straw yield (Basu et al., 1998). Adequate N nutrition accelerates the mining capacity of the plant and resulted in better root development, increased the number of tillers, length and width of leaves, plant height as well as the dry matter that will responsible for an increase in straw yield (Latare et al., 2017). A significant increase in straw yield might be due to the availability of all essential elements to the rice and wheat crop in sufficient amounts by the application of SS. Similar results were reported by Latare et al. (2017) and concluded that the crop yield enhanced with the application of SS, and stated the maximum straw yield of rice in treatment where 40 t ha^{-1} SS (S_{40}) was applied (52.57 g pot^{-1}) followed by RDF (49.37 g pot^{-1}). It was higher than the control. In wheat, it was maximum with RDF (34.08 g pot^{-1}) followed by S_{40} (30.34 g pot^{-1}) increased 43 and 36% over without SS application (S_0).

The SS application enhances the availability of nutrient in soil which is helpful for proper plant growth and development. The enhancement in the yield is resulted due to the application of SS which remains available till prolong time as its decomposition rate is slow.

Conclusion

The possible application of sewage sludge along with fertilizer enhances the grain and straw yield of both rice and wheat crops. Sewage sludge consists of multi-elements along with a good amount of organic matter. Therefore, it could be a good source of nutrients and precaution should be followed to use the sewage sludge. Current findings supported safe and sustainable application SS; however further long-term experiments are required in realistic conditions. The application of 70% RDF + 20 t ha-1 SS is more feasible and safer to use for batter yield.

Acknowledgement

The authors are thankful to the General Manager, Ganga Pollution Control Unit, Uttar Pradesh Jal Nigam STPs Bhagwanpur Sewage Treatment Plant (STPs) for providing sewage sludge for study purpose. The authors are also like to acknowledge Department of Soil Science and Agricultural Chemistry, Institute of Agricultural Sciences, Banaras Hindu University for providing infrastructure and appreciated support as well as University Grants Commission, New Delhi for providing financial support during the tenure of research work in the form of Fellowship and Supported by the Ministry of Science and Higher Education of the Russian Federation within the framework of the state task in the field of scientific activity (No. 0852-2020-0029).

References

Agilent FS-240, 2019. Flame Atomic Absorption Instruments. Available at [Access date: 13.12.2019]: https://www.agilent.com/en/product/atomic-spectroscopy/atomic-absorption/flame-atomic-absorption-instruments/240fs-aa

Agoro, M.A., Adeniji, A.O., Adefisoye, M.A., Okoh, O.O., 2020. Heavy metals in wastewater and sewage sludge from selected municipal treatment plants in Eastern Cape Province, South Africa. *Water* 12(10): 2746.

Ali, S., Khan, A.R., Mairaj, G., Arif, M., Fida, M., Bibi, S., 2008. Assessment of different crop nutrient management practices for yield improvement. *Australian Journal of Crop Science* 2(3): 150-157.

Basu, P.S., Sharma, A., Sukumaran, N.P., 1998. Changes in net photosynthetic rate and chlorophyll fluorescence in potato leaves induced by water stress. *Photosynthetica* 35(1): 13-19.

Bouwen, P., 2009. The European Commission. In: Lobbying the European Union: Institutions, actors, and issues. Coen, D., Richardson, J. (Eds.). Oxford University Press, Oxford, UK. pp.19–38.

Chaplygin, V., Mandzhieva, S., Minkina, T., Sushkova, S., Barahov, A., Nevidomskaya, D., Kızılkaya, R., Gülser, C., Chernikova, N., Mazarji, M., Iljina, L., Rajput, V., 2020. Accumulating capacity of herbaceous plants of the Asteraceae and Poaceae families under technogenic soil pollution with zinc and cadmium. *Eurasian Journal of Soil Science* 9(2): 165 – 172.

Chaplygin, V.A., Minkina, T.M., Mandzhieva, S.S., Nazarenko, O.G., Zimulina, I.V., Bauer, T.V., Litvinov, Yu. A., Rajput. V., 2021. Heavy metals in agricultural crops of Rostov region through the example of soft wheat (Triticum aestivum). IOP Conference Series: Earth and Environmental Science, Volume 624, International Conference on World Technological Trends in Agribusiness 4-5 July 2020, Omsk City, Western Siberia, Russian Federation. 624, 012204.

Chesnin, L., Yien, C.H., 1951. Turbidimetric determination of available sulfates. *Soil Science Society of America Journal* 15(C):149-151.

Chhonkar, P.K., Bhadraray,S., Patra, A.K., Purakayastha, T.J., 2002. Experiments in Soil Biology and Biochemistry. Westville Publishing House, New Delhi, India. 180p.

Cieślik, B.M., Namieśnik, J.,Konieczka, P., 2015. Review of sewage sludge management: standards, regulations and analytical methods. *Journal of Cleaner Production* 90: 1-15.

Delibacak, S., Voronina, L., Morachevskaya, E., Ongun, A.R., 2020. Use of sewage sludge in agricultural soils: Useful or harmful. *Eurasian Journal of Soil Science* 9(2): 126-139.

Egidi, G., Salvati, L., Vinci, S., 2020. The long way to tipperary: City size and worldwide urban population trends, 1950-2030. *Sustainable Cities and Society* 60: 102148.

Hanway, J.J., Heidel, H., 1952. Soil analysis method as used in Iowa State College, Soil Testing Laboratory. *Iowa Agriculture* 57: 1-31.

Jackson, M.L., 1973. Soil Chemical Analysis. Prentice Hall of India Pvt. Ltd., New Delhi, India. 498p.

Jatav, H.S., Singh, S.K., Singh, Y.V., Paul, A., Kumar, V., Singh, P., Jayant, H., 2016. Effect of biochar on yield and heavy metals uptake in rice grown on soil amended with sewage sludge. *Journal of Pure and Applied Microbiology* 10(2): 1367-1377.

Jatav, H.S., Singh, S.K., Singh, Y., Kumar, O., 2018a. Biochar and sewage sludge application increases yield and micronutrient uptake in rice (Oryza sativa L.). *Communications in Soil Science and Plant Analysis* 49(13): 1617-1628.

Jatav, H.S., Singh, S.K., Yadav, J.S., 2018b. Cumulative effect of sewage sludge and fertilizers application on enhancing soil microbial population under rice - wheat cropping system. *Journal of Experimental Biology and Agricultural Sciences* 6 (3): 538-543.

Kidder, G., 2001. Using waste products in forage production. In: Florida Forage Handbook. Chambli, C.G. (Eds.). University of Florida. Gainesville, FL. USA. 142: 88-93.

Kumar, V., Sharma, P.K., Jatav, H.S., Singh, S.K., Rai, A., Kant, S., Kumar, A., 2020. Organic amendments application ıncreases yield and nutrient uptake of mustard (BrassicaJuncea) grown in chromium- contaminated soils. *Communications in Soil Science and Plant Analysis* 51(1): 149-159.

Latare, A.M., Omkar, K., Singh, S.K., Gupta, A., 2014. Direct and residual effect of sewage sludge on yield, heavy metals content and soil fertility under rice-wheat system. *Ecological Engineering* 69: 17-24.

Latare, A.M., Singh, S.K., Kumar, O., 2017. Yield and profitability of rice-wheat sequence with conjunctive application of sewage sludge and chemical fertilisers. *Indian Journal of Fertilisers* 13 (7): 50-61.

Latare, A.M., Singh, S.K., Omkar, K., 2018. Impact of sewage sludge application on soil fertility, microbial population and enzyme activities in soil under rice-wheat system. *Journal of the Indian Society of Soil Science* 66(3): 300-309.

Lindsay, W.L., Norvell, W.A., 1978. Development of a DTPA soil test for zinc, ıron, manganese, and copper. *Soil Science Society of America Journal* 42(3): 421-428.

Martin, J.P., 1950. Use of acid rose Bengal and Streptomycin in the plate method for estimating soil fungi. Soil Science 69(3): 215-232.

Nieuwenhuize, J., Poley-Vos, C.H., van den Akker, A.H., van Delft, W., 1991. Comparison of microwave and conventional extraction techniques for the determination of metals in soils, sediment and sludge samples by atomic spectrometry, *Analyst* 116: 347-351.

Olsen, S.R., Cole, C.V., Watanabe, F.S., Dean, L.A., 1954. Estimation of available phosphorus in soils by extraction with sodium bicarbonate. U.S. Department of Agriculture, Circular No 939, USA, 19p.

Page, A.L., Keeney, D. R., Baker, D.E., Miller, R.H., Ellis, R. Jr., Rhoades, J.D. (Eds.). 1982. Methods of Soil Analysis, Part 2, Chemical and microbiological properties, Second Edition. Number 9, ASA-SSSA, Madison, Wisconsin, USA.

Piper, C.S., 1966. Soil and plant analysis. University of Adelaide Press, Australia.

Saha, S., Saha, B.N., Hazra, G.C., Pati, S., Pal, B., Kundu, D., Bag, A.G., Chatterjee, N., Batabyal, K., 2018. Assessing the suitability of sewage-sludge produced in Kolkata, India for their agricultural use. *Proceedings of the Indian National Science Academy* 84(3): 781-792.

Seleiman, M.F., Santanen, A.,Mäkelä, P.S., 2020. Recycling sludge on cropland as fertilizer-Advantages and risks. *Resources, Conservation and Recycling* 155: 104647.

Singh, S.P., Singh, M.K., 2020. Soil Pollution and Human Health. In: Plant Responses to Soil Pollution. Singh, P., Singh, S.K., Prasad, S.M. (Eds.). Springer, Singapore. pp. 205-220.

Smith, S.R., 2009. A critical review of the bioavailability and impacts of heavy metals in municipal solid waste compost compared to sewage sludge. *Environment International* 35(1): 142-156.

Subbiah, B., Asija, G.L., 1956. Alkaline permanganate method of available nitrogen determination. *Current Science* 25: 259-260.

Tabatabai, M.A.,Bremner, J.M., 1972. Assay of urease activity in soils. *Soil Biology and Biochemistry* 4(4): 479-487.

Thornton, H.C., 1922. On the development of standardized agar medium for counting of soil bacteria with special regard to repression of spreading colonies. *Annals of Applied Biology* 9(3-4): 241-274.

Walkley, A., Black, I.A., 1934 An examination of Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Science* 37(1): 29-37.

Wang, S., Zhao, S., Uzoejinwa, B.B., Zheng, A., Wang, Q., Huang, J., Abomohra, A.E.F., 2020. A state-of-the-art review on dual purpose seaweeds utilization for wastewater treatment and crude bio-oil production. *Energy Conversion and Management* 222: 113253.

Ye, S., Zeng, G., Wu, H., Liang, J., Zhang, C., Dai, J., Xiong, W., Song, B., Wu, S., Yu, J., 2019. The effects of activated biochar addition on remediation efficiency of co-composting with contaminated wetland soil. *Resources, Conservation and Recycling* 140: 278-285.

Eurasian Journal of Soil Science 2021, 10(3), 215 - 221

Eurasian Journal of Soil Science

Journal homepage : http://ejss.fesss.org

Effects of vermicompost applications on Atterberg Limits and workability of soils under different soil moisture contents

Zeynep Demir *

Soil, Fertilizer and Water Resources Central Research Institute, Ankara, Turkey

Article Info

Received : 21.09.2020
Accepted : 20.02.2021
Available online : 01.03.2021

Author(s)

Z. Demir *

* Corresponding author

Abstract

The present research was conducted to assess the effects of vermicompost (VC) treatments under different soil moisture contents on consistency limits of sandy-clay-loam (SCL) soils in which lettuce (*Lactuca sativa* var. *crispa*) was cultivated in a greenhouse. Liquid limit (LL), plastic limit (PL), plasticity index (PI), consistency index (Ic) and clay activity (A) values were investigated. Three different VC doses (0, 2.5 and 5% w/w) were applied at 3 different soil moisture contents (100% FC-field capacity, 50% FC and 25% FC). Experiments were conducted in 3 replications over 27 experimental plots (3×3x3). Increasing LL and PL values were observed with increasing VC doses. The greatest LL (46.6%) and PL (37.7%) values were obtained from the 5% VC treatment under high soil moisture content (100%FC) and the lowest LL (35.0%) and PL (23.0%) were obtained from the control treatment under low soil moisture content (25%FC). LL had significant correlations with VC (0.848**), PL (0.904**), PI (0.565**), Ic (0.668**) and A (0.548**). Ic had significant correlations with VC (0.815**), PL (0.417*) and PI (0.740**). As compared to the control treatments, Ic values increased by 13.0% and 21.9% respectively with 2.5% and 5% VC treatments. Ic values were greater than 0.75. Therefore, it was observed that the sandy-clay-loam soils could be cultivated without any structural deformations at FC or higher moisture contents with vermicompost application. Moisture content upper limits for optimal tillage without any structural destructions were suggested as 26.8%, 34.9% and 36.9% for 0%VC, 2.5%VC and 5%VC treatments, respectively. Present findings indicated that VC treatments extended the range of moisture for workability.

Keywords: Atterberg Limits, vermicompost, soil water regimes, soil cultivation, sandy-clay-loam soil.

Introduction

Vermicompost offers a bio-oxidative process through the epigeic earthworms and various microorganisms for stabilization and biodegradation of organic materials (Kızılkaya and Hepşen Türkay, 2014; Ceyhan et al., 2015; Mupambwa and Mnkeni, 2018; Kızılkaya et al., 2021). Inorganic fertilizers have several negative impacts on soil quality and they are also costly practices. Therefore, growers are always searching for compatible and affordable organic sources to improve soil fertility and the other quality parameters. Vermicompost (VC) emerges right at this point as a reliable alternative of inorganic fertilizers (Kizilkaya et al., 2012; Arancon et al., 2008). Vermicompost improves soil microbial activity, aeration and water holding capacity, thus offers an excellent soil amendment (Orozco et al., 1996). Previous researchers reported several positive effects of vermicompost on soil quality parameters (Aksakal et al., 2016; Demir, 2019; Demir, 2020). Soil organic matter (OM) influences both surface area and porosity; however, the water held at greater suctions increases more because an increment in the surface area is expected as an immediate

: https://doi.org/10.18393/ejss.888643
: http://ejss.fesss.org/10.18393/ejss.888643
Publisher : Federation of Eurasian Soil Science Societies
e-ISSN : 2147-4249

influence of the OM treatments. The effects of soil OM on soil physical characteristics include increased water holding capacity, decreased bulk density and promoted structural development (Paradelo et al., 2009).

Atterberg limits describe consistency of soils based on soil moisture contents (Terzaghi et al., 1996). Therefore, they are usually referred as consistency limits (liquid limit, LL; plastic limit, PL; plasticity index, PI = LL -PL). Consistency limits were used to assess soil workability for various practices such as cultivation, tillage, harvest and etc. (de Jong et al., 1990). They are also commonly used in soil classification for engineering purposes. Besides, Atterberg limits provide information for interpreting several soil physical and mechanical characteristics such as bearing capacity, shear strength, shrink-swell potential, compressibility and specific surface (McBride, 2008). They are especially used in soil mechanics and geotechnical engineering. Plasticity largely depends on specific surface area of soil particles, thus on clay content and soil particle size distribution (de Jong et al., 1990; Seybold et al., 2008). Soil plasticity is also influenced by exchangeable cations of the soils (Schjonning, 1991) and clay mineralogy (Cerato, 2001). Furthermore, OM content was reported to effect soil plasticity. OM plays significant roles in agricultural lands (Dexter et al., 2008). The present research was conducted to investigate the effects of different vermicompost treatments under different soil moisture levels on consistency limits (LL, PL and PI), consistency index and clay activity of sandy-clay-loam (SCL) soils in which lettuce (*Lactuca sativa* var. *crispa*) was grown in a greenhouse.

Material and Methods

Experimental treatments

Experiments were conducted in greenhouses of Soil, Fertilizer and Water Resources Central Research Institute in Ankara between 24 March and 10 July of 2017. Indoor air temperature was set at 24/20 °C (day/night) and relative humidity was set at 50-55%. Experiments were conducted with 3 different vermicompost (VC) treatments (0, 2.5 and 5% VC (w/w:VC/soil) treatments applied at 3 different soil moisture levels (100, 50 and 25% of field capacity, FC). There were 9 treatments (3×3) in 3 replications. Lettuce (*Lactuca sativa* var. *crispa*) seedlings were transplanted into 7 L plastic pots filled with soil plus VC at specified doses. Following the transplantation, seedlings were irrigated to 100% of FC. Soil moisture was monitored for 2 weeks. Experimental pots were weighed to get the amount of irrigation water to be applied under each soil moisture regime (100%FC, 50%FC, 25%FC). Following the harvest, soil samples were taken for mechanical analyses.

Soil analyses

Hydrometer method was used to get soil particle size distribution (Demiralay, 1993). Field capacity (FC) was determined with the aid a pressure plate (Hillel, 1982). Soil pH values were measured with a pH meter and electrical conductivity (EC) values were measured with an EC-meter (Kacar, 1994). Scheibler calcimeter was used to determine soil lime contents (Soil Survey Staff, 1993). Soil organic matter (OM) was determined with the use of Modified Walkley-Black method (Kacar, 1994). Consistency limits (LL, PL and PI) were analyzed in accordance with the principles specified in Demiralay (1993). PI was calculated as the difference between LL and PL (PI = LL – PL) and Consistency index (Ic) was calculated as Ic = (LL-FC) / PI. Clay activity (A) was determined as A = PI / (% clay) (Baumgartl, 2002). Experimental soils were sandy-clay-loam (SCL) (sand: 56.8%, silt: 18.5%, clay: 24.7%) in texture, slightly alkaline (pH=7.75) with insufficient OM and medium $CaCO_3$ (5–15%) contents and none saline according to EC (1.59 dS m^{-1}) (Soil Survey Field and Laboratory Methods Manual, 2014). General properties of vermicompost are provided in Table 1.

Table 1. Analysis results of vermicompost

pH	EC, dS m^{-1}	OM, %	Total N, %	P_2O_5, kg da^{-1}	K_2O, kg da^{-1}	Ca, ppm	Mg, ppm	Fe, ppm	Mn, ppm	Zn, ppm
7.1	6.5	65.5	2.2	7.3	12.8	25.1	6.6	2.1	271.9	216.0

Statistical analyses

Experimental data were subjected to analysis of variance with the use of SPSS 16.0 software. Duncan's multiple range test was employed to compare significant means at P≤0.01 significance level. Correlations between soil characteristics were assessed through Pearson's correlation coefficients.

Results and Discussion

The effects of vermicompost (VC) treatment on liquid limit and plastic limit under three different soil moisture regimes are presented in Figure 1A and B. The effects of VC treatments on LL and PL were found to be significant (p<0.01) (Table 2). Such effects of VC on LL and PL increased with increasing treatment doses. The greatest LL (46.6%) and PL (37.7%) values were obtained from the 5% VC treatment under high soil moisture content (100%FC) and the lowest LL (35.0%) and PL (23.0%) were obtained from the control treatment under low soil moisture content (25%FC). Increasing LL and PL values were observed with increasing VC doses. LL and PL values might be associated with the change in OM content due to vermicompost applications. VC treatments improve soil OM contents and thus increase water holding capacity, then increase soil moisture-dependent parameters like LL and PL (Bhushan and Sharma, 2002). Aksakal et al. (2016) also reported increasing soil OM contents with VC treatments. Demir (2019) reported that VC applications under 3 different soil moisture contents significantly increased the soil OM content of the soils. Gülser and Candemir (2004) indicated that organic waste incorporation into soils increased LL and PL of the soils. Demiralay and Güresinli (1979) classified soil based on liquid limit as low plastic for LL of <30%, medium plastic for LL of between 30-50% and highly plastic for LL of >50%. Present LL values varied between 35.0 - 46.6%, thus, present soils were classified as medium plastic. LL and PL limit values vary with the clay content of the soils, clay type, OM content and the type of exchangeable cations. Increasing LL and PL limit values were reported with increasing OM and clay content (Baumgartl, 2002; Gülser and Candemir, 2004; Aksakal et al., 2013). As compared to the control, LL values increased with 5% VC treatments by about 19.1%, 22.5% and 32.4% for low (25%FC), medium (50%FC) and high (100%FC) soil moisture contents, respectively. The increase in PL with 5% VC treatments was respectively calculated as 17.4%, 15.9% and 40.4% for low (25%FC), medium (50%FC) and high (100%FC) soil moisture contents. Demir (2019) reported that VC treatments increased soil moisture content at FC. Such an increase than increased soil consistency limits (LL and PL). It was indicated by Hemmat et al. (2010) that increasing specific surface areas also increased soil LL and PL values.

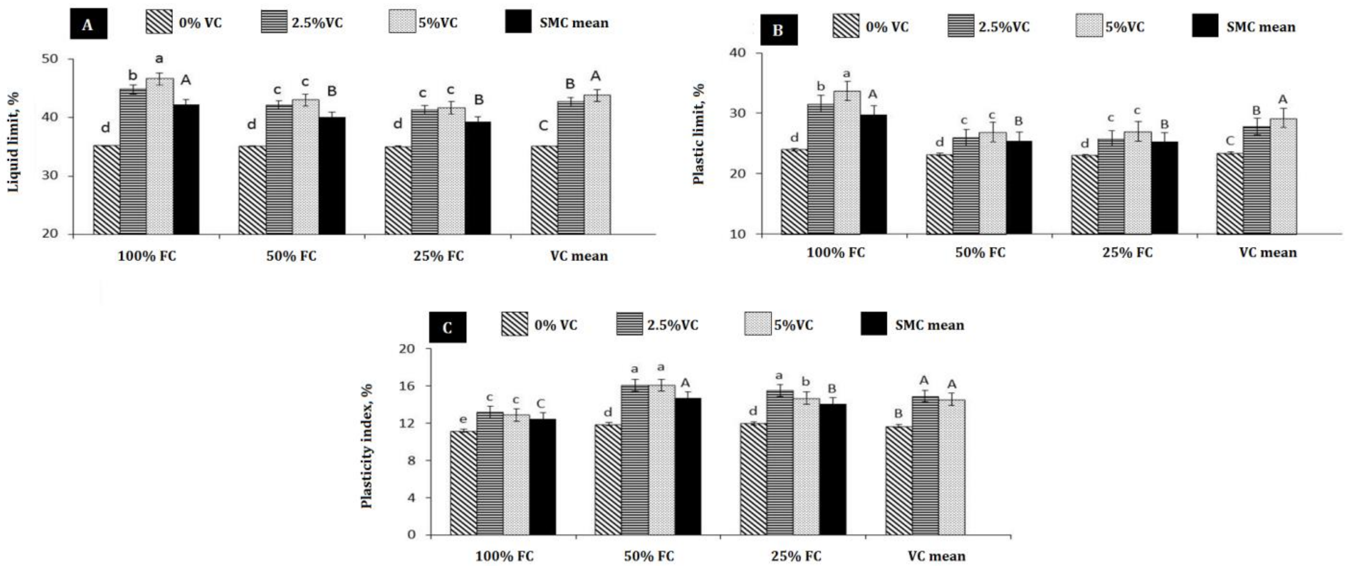


Figure 1. Effects of VC applications under different soil moisture contents on liquid limit (A), plastic limit (B) and plasticity index (C). VC: vermicompost, SMC: soil moisture content, FC: field capacity

Table 2. Descriptive statistics for the soil characteristics

	Minimum	Maximum	Mean	Std. Deviation	CV, %
LL	33.76	47.31	40.53	4.26	10.5
PL	22.19	34.74	26.80	3.56	13.3
PI	11.16	16.30	13.74	1.84	13.4
Ic	0.75	1.04	0.90	0.09	10.0
A	0.45	0.70	0.57	0.08	14.0

LL: liquid limit, PL: plastic limit, PI: plasticity index, Ic: consistency index, A: activity of clays

The highest PI value (16.1%) was observed in 2.5% VC treatment under medium soil moisture content (50%FC) and the lowest PI value (11.2%) was obtained from the control treatment under the high soil water content (100%FC) (Figure 1C). It was observed that 5% VC treatments increased PL and reduced PI, thus improved workability of the soils without any structural destructions. The PI designates the workable moisture range of the soils without generating compaction problems. Soils with greater PI values are more susceptible to compaction (Aksakal et al., 2013). LL also plays an important role in PI value. Jumikis (1984) classified soils based on PI values as: low plastic for PI of <7; medium plastic for PI values of between 7-17; high plastic for PI values of >17. According to this classification, present soils with PI values of between 11.2-16.1 were classified as medium plastic, thus considered to be less susceptible to compaction.

Activity (A) of clays is largely designated by dominant clay mineral of the soils (Campbell, 1991). Baumgartl (2002) classified soils based on A values as: active soils (smectite) for A values of >1.25; normal soils (illite) for A values of between 0.75-1.25; inactive soils (kaolinite) for A values of <0.75). Clay activity values of present soils varied between 0.46 and 0.69 which were less than 0.75 (Figure 2B). Thus, present soils were classified as inactive soils dominated by kaolinite clay mineral with slight swell-shrink potential.

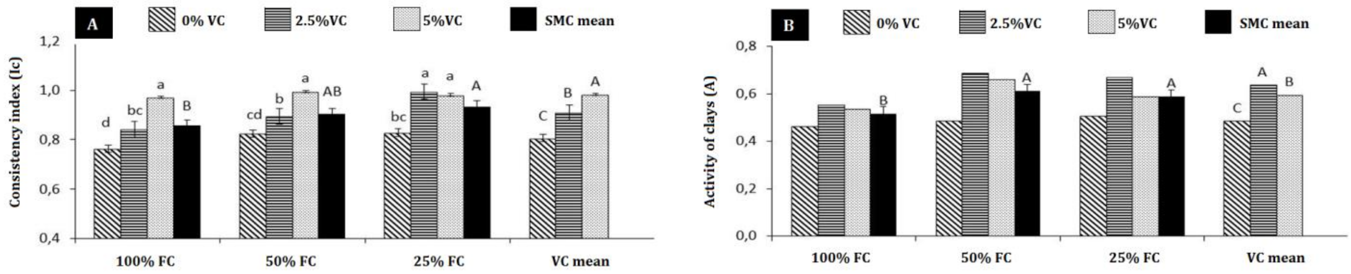


Figure 2. Effects of VC applications under different soil moisture contents on consistency index (A) and activity of clays (B). VC: vermicompost, SMC: soil moisture content, FC: field capacity

Pearson correlation coefficients between parameters are presented in Table 3. LL had significant positive correlations with VC (0.848**), PL (0.904**), PI (0.565**), Ic (0.668**) and A (0.548**). Ic had significant positive correlations with VC (0.815**), PL (0.417*) and PI (0.740**). Sarı et al. (2017) reported that VC had significant positive correlations with LL and PL of different textured soils. Archer (1969) reported highly positive correlations between soil OM and PL of silty-loam soils. Similar correlations among the soil characteristics were also reported by Gülser et al. (2008, 2009), Gülser and Candemir (2004, 2006) and Aksakal et al. (2013).

Table 3. Pearson correlation coefficients between soil parameters

	VC	Clay	Silt	Sand	LL	PL	PI	Ic
Clay	-							
Silt	-	-0.774**						
Sand	-	0.129	-0.727**					
LL	0.848**	-0.009	-0.066	0.113				
PL	0.678**	0.010	-0.047	0.063	0.904**			
PI	0.650**	-0.040	-0.062	0.140	0.565**	0.159		
Ic	0.815**	0.155	-0.185	0.121	0.668**	0.417*	0.740**	
A	0.556**	-0.066	-0.076	0.191	0.548**	0.158	0.960**	0.737**

** significant at 1% level, * significant at 5% level, VC: vermicompost, LL: liquid limit, PL: plastic limit, PI: plasticity index, Ic: consistency index, A: activity of clays

Soil moisture ranges for workability of the soils

VC treatments increased Ic values as compared to the control (Figure 2A). The greatest Ic (0.99) was observed in 5% VC of the medium soil moisture content (50%FC) and the lowest Ic (0.76) was obtained from the control of the high soil moisture content (100%FC). A great significance was assigned to soil moisture for workability (Dexter and Bird, 2001). Critical moisture contents (dry and wet limits) should be specified for soil workability to reduce the tillage-induced destructions in soil structure (Obour et al., 2017). Obour et al. (2018) also reported increasing range of moisture for tillage with increasing organic matter contents. Soil workability is largely dependent on soil OM contents. In this study, Ic values increased by 13.0% with 2.5% VC and by 21.9% with 5% VC treatments. Significant increases were observed in Ic values of the soils with increasing VC doses. Ic designates soil consistency at a certain moisture content. The soils at plastic limit will have an Ic value of 1.0 and the soils at liquid limit will have an Ic of 0. The Ic values of between 0.75 – 1.00 indicate the optimal range of moisture. When the soils are cultivated at Ic value of <0.75, significant structural destruction will be encountered. Such conditions will reduce hydraulic conductivity, aeration, uptake of plant nutrients and negatively affect plant growth and microbial activity (Baumgartl, 2002). In this study, Ic values were greater than 0.75. Therefore, it was observed that the sandy-clay-loam soils could be cultivated without any structural deformations at FC or higher moisture contents with vermicompost application. Moisture content upper limits for optimal tillage without any structural destructions were suggested as 26.8%, 34.9% and 36.9% for 0%VC, 2.5%VC and 5%VC treatments, respectively.

Mueller et al. (2003) reported Ic of 1.15 and 90% of PL as the maximum soil moisture content for optimum tillage of cohesive soils. Dexter and Bird (2001) stated optimum moisture for soil workability as the moisture content in which the highest number of small aggregates can be obtained as a result of soil cultivation and this value is equal to approximately 90% of the PL. Gülser and Candemir (2006) reported optimum soil water contents as around the field capacity for workability. In another study, Gülser et al. (2009) studied soil moisture contents for suitable workability and reported clay content as between 72.30 - 79.40% and indicated that experimental soils could be cultivated without structural destructions at FC (40.4%) or at moisture contents of between 33.2 - 40.4%. In present study, calculated gravimetric water contents (W) for Ic values of 0.75, 1.00, 1.15 and %90 PL are presented in Figure 3. It seems that soil moisture contents at FC were suitable for the cultivation of soils. However, greater moisture contents were suggested as 26.8, 34.9 and 36.9% for 0% VC, 2.5%VC and 5%VC treatments, respectively. Petelkau (1984) stated that the most suitable soil cultivation takes place at humidity held at a matrix potential of -5 kPa and the moisture retained at this value varied between 50-65% in clay soils, 40-75% in loamy soils and 20-85% in loamy sand textured soils.

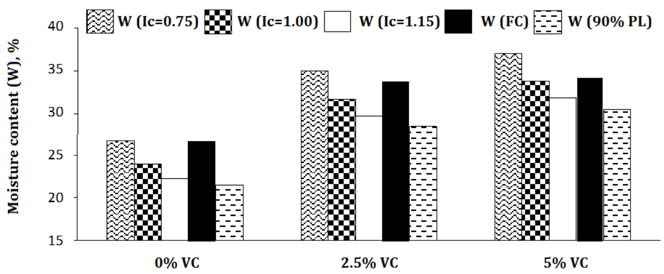


Figure 3. Soil moisture contents (W) at FC and different index of consistency values for suitable workability (VC: vermicompost, FC: field capacity. PL: plastic limit, Ic: consistency index)

Conclusion

Present findings revealed that VC treatments (0%VC, 2.5%VC and 5%VC) under different soil moisture contents (100%, 50% and 25%FC) increased liquid limit, plastic limit, plasticity index and consistency index of sandy-clay-loam soils as compared to the control treatment. Moisture content upper limits for optimal tillage without any structural destructions were suggested as 26.8%, 34.9% and 36.9% for 0%VC, 2.5%VC and 5%VC treatments, respectively. VC treatments increased Ic values as compared to the control. Ic values were greater than 0.75. Therefore, it was observed that the sandy-clay-loam soils could be cultivated without any structural deformations at FC or higher moisture contents with vermicompost application. Significant increases were observed in Ic values of the soils with increasing VC application rates. These findings clearly showed that VC treatments extended the range of field workability. It was concluded that addition of vermicompost under different soil moisture contents into a sandy-clay-loam soil significantly influenced soil mechanical properties. Present findings indicated that vermicompost applications in to sandy-clay-loam soil was useful for cultivation of soil.

Acknowledgement

The author would like to thank the Soil, Fertilizers and Water Resources Central Research Institute and Prof. Dr. Abdullah Baran and Çağla Temiz (PhD student) for providing working environment and facilities for this study.

References

Aksakal, E.L., Angin, İ., Oztas, T., 2013. Effects of diatomite on soil consistency limits and soil compactibility. *Catena* 101: 157-163.

Aksakal, E.L., Sari, S., Angin. İ., 2016. Effects of vermicompost application on soil aggregation and certain physical properties. *Land Degradation and Development* 27(4): 983-995.

Arancon, N.Q., Edwards, C.A., Babenko, A., Cannon, J., Galvis, P., Metzger, J.D., 2008. Influences of vermicomposts, produced by earthworms and microorganisms from cattle manure, food waste and paper waste, on the germination, growth and flowering of petunias in the greenhouse. *Applied Soil Ecology* 39(1): 91-99.

Archer, J.R., 1969. The application of Atterberg Limits to agricultural soils. ADAS, Shardlow, UK.

Baumgartl, T., 2002. Atterberg Limits. In: Encyclopedia of Soil Science. Lal, R. (ed.). Marcel Dekker Inc, New York, USA. pp:89-93.

Bhushan, L., Sharma, P.K., 2002. Long-term effects of lantana (Lantana spp. L.) residue additions on soil physical properties under rice- wheat cropping. I. Soil consistency, surface cracking and clod formation. *Soil and Tillage Research* 65(2): 157-167.

Campbell, D.J., 1991. Liquid and plastic limits. In: Soil analysis-physical methods. Smith, K.A., Mullins, C.E. (Eds.). Marcel Dekker Inc, New York, USA. pp. 367–398.

Cerato, A.B., 2001. Influence of specific surface area on geotechnical characteristics of fine-graded soils. MSc Thesis, Department of Civil and Environmental Engineering, University of Massachusetts, Amherst, MA, USA.

Ceyhan, V., Akça, İ., Kızılkaya, R., Veselova, A., Novikova, K., 2015. The financial feasibility of hazelnut husk and sewage sludge based vermicompost production. *Eurasian Journal of Soil Science* 4(4): 259 – 265.

de Jong, E., Acton, D.F., Stonehouse, H.B., 1990. Estimating the Atterberg limits of southern Saskatchewan soils from texture and carbon contents. *Canadian Journal of Soil Science* 70(4): 543-554.

Demir, Z., 2019. Effects of Vermicompost on soil physicochemical properties and lettuce (Lactuca sativa Var. Crispa) yield in greenhouse under different soil water regimes. *Communications in Soil Science and Plant Analysis* 50(17): 2151-2168.

Demir, Z., 2020. Alleviation of adverse effects of sodium on soil physicochemical properties by application of vermicompost. *Compost Science and Utilization* 28(2): 100-116.

Demiralay, I. 1993. Toprak Fiziksel Analizleri. Atatürk Üniversitesi Ziraat Fakültesi Yayınları No: 143, Erzurum, Turkey. 131p. [in Turkish]

Demiralay, İ., Güresinli, Y.Z., 1979. Erzurum ovası topraklarının kıvam limitleri ve sıkışabilirliği üzerinde bir araştırma. *Atatürk Üniversitesi Ziraat Fakültesi Dergisi* 10(1-2): 77-93. [in Turkish]

Dexter, A.R., Bird, N.R.A., 2001. Methods for predicting the optimum and the range of soil water contents for tillage based on the water retention curve. *Soil and Tillage Research* 57(4): 203-212.

Dexter, A.R., Richard, G., Arrouays, D., Czyz, E.A., Jolivet, C., Duval, O., 2008. Complexed organic matter controls soil physical properties. *Geoderma* 144(3-4): 620-627.

Gülser, C., Candemir, F., 2004. Changes in atterberg limits with different organic waste applications. International Soil Congress (ISC) on Natural Resource Management for Sustainable Development, June 7-10, 2004. Erzurum. Turkey.

Gülser, C., Candemir, F., 2006. Some mechanical properties and workability of Ondokuz Mayıs University Kurupelit campus soils. *Ondokuz Mayıs Üniversitesi Ziraat Fakültesi Dergisi* 21(2): 213-217. [in Turkish]

Gülser, C., İç, S., Candemir, F., Demir, Z., 2008. Effects of rice husk application on mechanical properties and cultivation of a clay soil with and without planting. International Meeting on Soil Fertility Land Management and Agroclimatology. 29 October-01 November 2008. Kuşadası, Turkey.

Gülser, C., Selvi, K.Ç., İç, S., 2009. Some mechanical properties and workability of soils in a Karadeniz Agricultural Research Institute Field. *Tarım Makinaları Bilimi Dergisi* 5 (4): 423-428.

Hemmat, A., Aghilinategh, N., Rezainejad, Y., Sadeghi, M., 2010. Long- term impacts of municipal solid waste compost, sewage sludge and farmyard manure application on organic carbon, bulk density and consistency limits of a calcareous soil in central Iran. *Soil and Tillage Research* 108(1-2): 43-50.

Hillel, D., 1982. Introduction to Soil Phyics. Academic Press Limited, London. UK. 392p.

Jumikis A.R., Soil Mechanics. Robert E. Krieger Publishing Company Inc., Malabar, Florida, USA. 576p.

Kacar, B., 1994. Bitki ve Toprağın Kimyasal Analizleri. Toprak Analizleri III. Ankara Üniversitesi Ziraat Fakültesi Eğitim, Araştırma ve Geliştirme Vakfı Yayınları No:3, Ankara. 705p. [in Turkish]

Kızılkaya, R., Hepşen Türkay, F.Ş., 2014. Vermicomposting of anaerobically digested sewage sludge with hazelnut husk and cow manure by Earthworm Eisenia foetida. *Compost Science and Utilization* 22(2): 68-82.

Kızılkaya, R., Yertayeva, Z., Kaldybayev, S., Murzabayev, B., Zhapparova, A., Nurseitov, Z., 2021. Vermicomposting of anaerobically digested sewage sludge with hazelnut husk and cow manure by earthworm Eisenia foetida. *Eurasian Journal of Soil Science* 10(1): 38 - 50.

Kizilkaya, R., Turkay, F.S., Turkmen, C., Durmus, M., 2012. Vermicompost effects on wheat yield and nutrient contents in soil and plant. *Archives of Agronomy and Soil Science* 58: 175-179.

McBride, R.A., 2008. Soil consistency and lower plastic limits. In: Soil Sampling and Methods of Analysis. Carter, M.R., Gregorich, E.G. (Eds.) 2nd edition, CRC Press. pp. 761-769.

Mueller, L., Schindler, U., Fausey, N.R., Lal, R., 2003. Comparison of methods for estimating maximum soil water content for optimum workability. *Soil and Tillage Research* 72(1): 9-20.

Mupambwa, H.A., Mnkeni, P.N.S., 2018. Optimizing the vermicomposting of organic wastes amended with inorganic materials for production of nutrient-rich organic fertilizers: a review. *Environmental Science and Pollution Research* 25: 10577-10595.

Obour, P.B., Jensen, J.L., Lamandé, M., Watts, C.W., Munkholm, N.J., 2018. Soil organic matter widens the range of water contents for tillage. *Soil and Tillage Research* 182: 57-65.

Obour, P.B., Lamandé, M., Edwards, G., Sørensen, S.G., Munkholm, N.J., 2017. Predicting soil workability and fragmentation in tillage: a review. *Soil Use and Management* 33(2): 288-298.

Orozco, F.H., Cegarra, J., Trujillo, L.M., Roig, A., 1996. Vermicomposting of coffee pulp using the earthworm Eisenia fetida: effects on C and N contents and the availability of nutrients. *Biology and Fertility of Soils* 22: 62–166.

Paradelo, R., Moldes, A.B., Barral, M.T., 2009. Amelioration of the physical properties of slate processing fines using grape marc compost and vermicompost. *Soil Science Society of America Journal* 73(4): 1251- 1260.

Petelkau, H., 1984. Auswirkungen von Schadverdichtungen auf Bodenigenschaften und Pflanzenertrag sowie Massnahmen zu ihrer Minderung. Grundlagen und Verfahren der rationellen Bodenbearbeitung und Erschliessung des Unterbodens fuer Pflanzen. Akademia der Landwirtschaftswissenschaften der DDR, Tagungsbericht Nr. 227: 25-34. [in German]

Sarı, S., Aksakal, E.L., Angın, İ., 2017. Influence of vermicompost application on soil consistency limits and soil compactibility. *Turkish Journal of Agriculture and Forestry* 41: 357-371.

Schjonning, P., 1991. Soil mechanical properties of seven Danish soils. Danish Institute of Agricultural Sciences, Internal Report No. S2176, Research Centre Foulum, Tjele, Denmark, 33p.

Seybold, C.A., Elrashidi, M.A., Engel, R.J., 2008. Linear regression models to estimate soil liquid limit and plasticity index from basic soil properties. *Soil Science* 173(1): 25-34.

Soil Survey Field and Laboratory Methods Manual, 2014. Soil Survey Investigations Report No. 51 Version 2. USDA-NRCS. National Soil Survey Center, Kellog Soil Survey Laboratory. Available at [Access date: 21.09.2020]: https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1244466.pdf

Soil Survey Staff, 1993. Soil survey manual. Handbook No: 18. USDA Handbook 18. Washington, D.C. USA. Available at [Access date: 21.09.2020]: https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcseprd1335011.pdf

Terzaghi, K., Peck, R.B., Mesri, G., 1996. Index properties of soils. In: Soil mechanics in engineering practice. 3rd Edition. John Willey & Sons Inc. New York, USA. pp.3-31.

Eurasian Journal of Soil Science 2021, 10(3), 222 - 235

Eurasian Journal of Soil Science

Journal homepage : http://ejss.fesss.org

Spatio analysis of soil quality assessment in semi-arid ecosystem using a minimum data set

İnci Demirağ Turan *

Samsun University, Faculty of Economic, Administrative and Social Sciences, Department of Geography, Samsun, Turkey

Article Info

Received : 05.10.2020
Accepted : 30.03.2021
Available online : 10.04.2021

Author(s)

İ.Demirağ Turan *

* Corresponding author

Abstract

Land degradation especially as a result of the rapid increase in demand and pressure in the population, have emerged as one of the most important problems. Many model approaches, especially regarding land degradation and desertification, have been developed and continue to be developed on the world. The MEDALUS (Mediterranean Desertification and Land Use) which is one of the famous models has been developed for an environment assessment program contributed to by 31 groups and 10 countries in 1999. This model includes the Environmental Sensitive Areas (ESA) index include climate, soil, land use-land cover, and management index. This current study aims to evaluate the soil quality indexes by using the total data set (TDS) and minimum data set (MDS) of the lands in Konya Basin, which is an arid and semiarid terrestrial ecosystem, with MEDALUS approach. The TDS consisted of nine soil quality parameters measured on 1019 samples: pH, Electrical Conductivity (EC), Organic Matter (OM), texture, $CaCO_3$, depth, parent material, and slope. In addition, Principal components analysis (PCA) was used to determine which parameters were to be selected in the MDS. The MDS parameters consisted of slope, pH, OM, $CaCO_3$. After those process, different interpolation models in order to create spatial distribution maps of parameters and SQI (Soil Quality Index). Results classified 13.59% of the total area has as low, while 84.110% of the study area' soil indicated area moderate by the SQI in terms of. Accordingly MDS, it was determined that 80.41% of the study area was in the medium-quality category, while only 2.01% was in the high-quality category. In the study area, minimum data set is seen that similar to the soil quality distribution in the total data set.

Keywords: Soil quality index, principal components analysis, arid-semi arid, Konya basin.

Introduction

In the last century, land degradation and desertification, especially as a result of the rapid increase in demand and pressure in the population, have emerged as one of the most important and irreversible environmental problems. This degradation leads to the loss of biological and economic productivity by the soil losing its functional property, which is one of the most important elements of the terrestrial ecosystem.

Land degradation is defined as the loss or reduction of biological and economic productivity resulting from land use in irrigated agricultural lands or pasture, forest, and scrublands in agricultural production dependent on rainfall or from human activities and natural consequences (United Nation, 1994). Major processes of land degradation are particularly the consequences of soil and vegetation degradation. When combined with excessive biophysical and socio-economic damages in arid areas, land degradation causes irreversible consequences leading to desertification. Therefore, land degradation is an environmental threat

: https://doi.org/10.18393/ejss.912986
: http://ejss.fesss.org/10.18393/ejss.912986

Publisher : Federation of Eurasian Soil Science Societies
e-ISSN : 2147-4249

not only on a local or regional scale but also on a continental or even a global scale. According to the United Nations Convention to Combat Desertification (UNCCD, 2017), it has been estimated in recent studies that 1 to 6 billion hectares of land have already been degraded. In addition, according to estimates, this environmental problem will directly or indirectly threaten the welfare of more than 3 billion people in the world (IPBEE, 2018). Desertification is the degradation and impoverishment of arid and semi-arid terrestrial ecosystems as a result of climatic conditions and human activities (Kosmas et al., 1999a). Therefore, desertification and land degradation are among the most important problems of all countries. Accurately identifying areas susceptible to land degradation and desertification caused by both natural reasons and human activities is quite difficult due to the complex structure of nature. But despite all this difficulty, thanks to the recent scientific and technological developments, significant progress has been made as a result of studies that especially identify the characteristics of soils and reveal their spatial distribution. Many model approaches, especially regarding desertification and land degradation, have been developed and continue to be developed. As some examples of these approaches, (FAO-UNEP, 1984), model Turkmenistan (Babaev, 1985), GLASOD (Oldeman et al., 1991), DPSIR-FRAMEWORK (GIWA, 2001) can be given.

Another approach to identify areas susceptible to land degradation and desertification is the MEDALUS (Kosmas et al., 1999b) model. In order to investigate the negative effects of desertification and to take precautions, Mediterranean countries developed the project MEDALUS (Mediterranean Desertification And Land Use, (Kosmas et al., 1999b) carried out by the European Commission. Within the scope of the MEDALUS model, the environmentally sensitive areas index (ESA, Environmental Sensitive Areas) for sensitive areas at risk of desertification has been developed. The components that make up the ESA index are climate, soil, land use, and management (Bayramin, 2003; Salvati and Zitti, 2005). The MEDALUS model is widely used in many countries as it successfully yields the most dangerous areas regarding land degradation (De Paola et al., 2013; Allouche and Gad, 2014; Symeonakis et al., 2014; Prăvălie et al., 2017; Uzuner and Dengiz, 2020). The soil quality index in the MEDALUS model is one of the frequently used indices (Ozşahin et al., 2017). Studies are carried out on the soil quality index used in this model (Bayramin, 2003; Dengiz et al., 2004; Sepehr et al., 2007; Contador et al., 2009; Lahlaoi et al., 2017; Budak et al., 2018; Demirağ Turan et al., 2019).

Turkey is a country that is faced with land degradation and desertification at a significant level. We can list these risks as climate, topography, geology, vegetation, the characteristics of arable or non-arable land, pasture and forest areas, pasture grazing practices (overgrazing by sheep, goats, and cattle), arable land management, erosion, and population growth (Uzuner and Dengiz, 2020). In the study they carried out using 48 indicators and 37 sub-indicators, Türkeş et al. (2020) concluded that 12.7% of the land in Turkey was in the low-risk group, 53.2% in the medium-risk group, and 25.5% in the high-risk group. At least 15% of sub-basins of Konya closed basin are at high risk of desertification (Türkeş et al. 2020). Besides, 32.2% of Turkey's total land is in the low and very low category in terms of soil quality (Uzuner and Dengiz, 2020).

A total data set is formed with the parameters considered while determining the soil quality index. However, the minimum data set is created by making use of some approaches apart from the total data set in terms of time, cost and workload, especially obtaining data from large geographical areas in a short time. Moreover, Şeker et al (2017) reported that the use of minimum data sets in determining soil quality factors gives the best results in terms of economy, labor, and data quality produced. One of the most commonly used approaches to create a minimum data set is principal components analysis. Principal components analysis is widely used in order to reduce criteria in different areas (Shukla et al., 2006; Karaca et al., 2021). In this context, while Şenol et al. (2020) created minimum data set with soil texture, penetration resistance, available water capacity, pH, and some plant nutrient elements for SQI, Uzner and Dengiz (2020) used soil texture, parent material slope, depth, drainage and coarse material as soil indicators for SQI based on MEDALUS

Semi-arid and arid areas, which are more vulnerable to environmental variations and are therefore more fragile, constitute about 65% of the total surface area of Turkey. These areas will be at higher risk of degradation in the near future because drought periods will be more frequent and severe due to global climate change (Kadıoğlu, 2012). The average annual precipitation is 300-350 mm in the region except for the southern parts of the Konya closed basin (İnan et al., 2006). In addition, Orhan and Ekercin (2015) reported that it was determined that surface temperature values increased between 2.00-3.00 °C in Konya closed basin between 1984 and 2011. In this sense, Konya Basin is getting sensitive from climate change and anthropogenic effects. This study aims to i) evaluate the soil quality indexes ii) compare SQI of the total and minimum data set of the lands in Konya Basin with MEDALUS approach.

Material and Methods

General features of the study area

Konya Basin has an area of approximately 53,850 km^2. The study area constitutes a considerable part of Central Anatolia. It is located between 36° 55' 15" - 39° 29' 15'' north latitudes and 31° 19' 26" - 35° 03' 38'' east longitudes and within the administrative borders of Konya, Ankara, Nevşehir, Aksaray, Niğde, Karaman, Mersin, Antalya, and Isparta (Figure 1). Its altitude varies between approximately 800-3400 m above sea level.

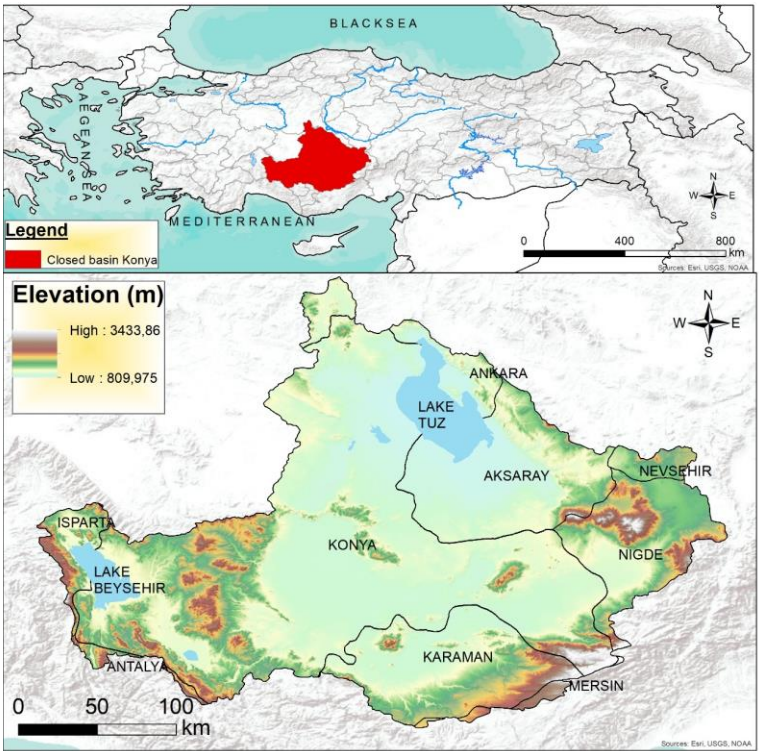


Figure 1. Location map of the study area

The fact that a decrease of 20-25 mm has been recorded in the basin compared to the normal rainfall over the years shows that the climate character has shifted from semi-arid climate type to arid climate type (Şen and Başaran, 2007). Average temperatures in the basin vary between -0.4°C and 23°C annually (Yılmaz, 2010).

The land use/land cover distribution map of the study area according to CORINE 2018 is given in Figure 2, and the spatial and proportional distributions are given in Table 1 (European Environment Agency, 2018). Accordingly, the highest distribution is sparsely vegetated areas with an area of 8.625 km^2. Green urban areas, sport and leisure facilities, rice fields, beaches, dunes, sands, and watercourses are the categories that take up the least space in the study area (Table 1).

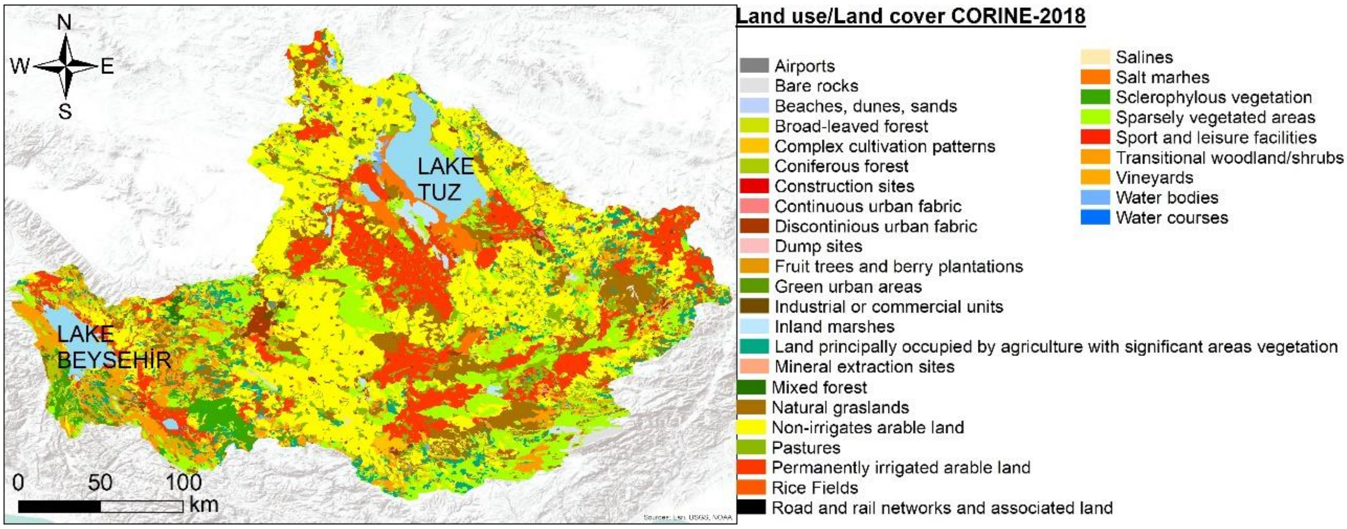


Figure 2. CORINE 2018 land use / land cover map of the study area.

Table 1. Area and proportional distributions of CORINE 2018 land use / land cover

Land use/ Land cover	km²	%	Land use/Land cover	km²	%
Continuous urban fabric	36	0.07	Complex cultivation patterns	3245	6.03
Discontinious urban fabric	1012	1.88	Land principally occupied by agriculture with significant areas vegetation	4355	8.09
Industrial or commercial units	349	0.65	Broad-leaved forest	254	0.47
Road and rail networks and associated land	27	0.05	Coniferous forest	439	0.82
Airports	32	0.06	Mixed forest	161	0.30
Mineral extraction sites	24	0.04	Natural graslands	7271	13.50
Dump sites	20	0.04	Sclerophylous vegetation	955	1.77
Construction sites	51	0.09	Transitional woodland/shrubs	3922	7.28
Green urban areas	3	0.01	Beaches, dunes, sands	5	0.01
Sport and leisure facilities	4	0.01	Bare rocks	483	0.90
Non-irrigates arable land	2642	4.91	Sparsely vegetated areas	8625	16.02
Permanently irrigated arable land	7795	14.48	Inland marshes	498	0.92
Rice Fields	5	0.01	Salt marhes	3616	6.71
Vineyards	141	0.26	Salines	98	0.18
Fruit trees and berry plantations	261	0.48	Water courses	4	0.01
Pastures	4460	8.28	Water bodies	3057	5.68
			Total	53850	100

Soil samples and physical and chemical analyses of soils

Considering the topographic structure and land use status of the land, 1091 soil samples were taken randomly to represent each type of land and different topographic features (Figure 3). Soil depth at the sampling points was determined with the help of a auger. Soils were pounded and sieved through a 2-mm sieve to prepare them for physical and chemical analyses. The texture properties of soils were determined according to the Bouyoucos hydrometer method (Bouyoucos, 1962); soil reaction (pH) and electrical conductivity (EC) were with a glass electrode pH meter in the prepared 1: 2.5 soil-water mixture (Soil Survey Staff, 1992); lime contents were determined by Scheibler calcimeter (Soil Survey Staff, 1992); the organic matter was determined by the Walkley-Black method modified by Jackson (Jackson, 1958).

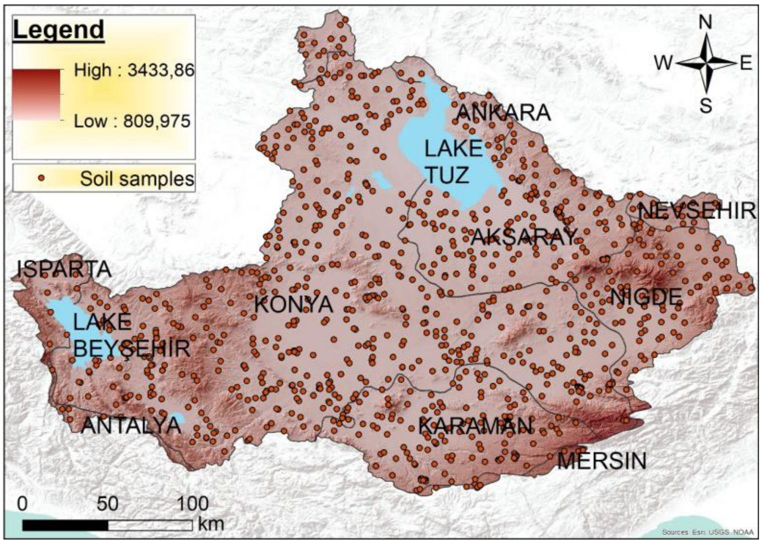


Figure 3. Soil sampling pattern on the study area

The slope map of the study area was produced from the digital elevation model with a scale of 1:25.000. In addition, the parent material parameter was determined by digitizing the 1: 25.000 scaled geology maps prepared by the General Directorate of Mineral Research and Exploration.

Interpolation methods were used to determine the spatial distribution of soil parameters and soil quality index for each point. Among the most used interpolation methods, deterministic methods of inverse distance weighting (IDW), radial basis functions (RBF), and kriging/cokriging methods from stochastic methods were preferred. The most commonly used methods in comparison of methods are root mean square error (RMSE), mean absolute error (MAE) are methods. For this study, RMSE was preferred, and 15 methods used for interpolation were compared. The method that yielded the lowest RMSE value was evaluated as the most suitable method. The following formula was used in the calculation of RMSE:

$$RMSE = \sqrt{\frac{\sum (z_{i^*} - z_i)^2}{n}}$$

In the equation, Z_i is estimated value, Z_{i^*} is the measured value and n refers to the number of samples.

Determination of soil quality index

The geometric mean of the scores obtained by soil quality index parameters included in the MEDALUS model helps determine the sensitivity of the lands to desertification. If the parameters defined in an area take high values, that land is defined as highly sensitive to desertification (Kosmas et al., 1999b). In this present study, besides the indicators for determining the soil quality index in the MEDALUS model, parameters such as organic matter, lime, electrical conductivity, and pH were added in order to increase the sensitivity in soil quality index value. The pH and lime content of soils were included in the soil quality index due to their effects on the usefulness of nutrients, organic matter content, and physical, chemical and biological properties of the soil. In addition, the EC parameter was added due to its effect on healthy plant growth. The scoring of these added soil properties was made using the studies of Kosmos et al. (1999b) (Table 2).

Table 2. Parameters and their index values used for SQI according to Kosmas et al. (1999b)

	Classes	Evaluation	Description	İndex
Texture	**1**	Very Good	L	1.0
	2	Good	SCL, SiCL, CL	1.2
	3	Moderate	SL, SiL, LS	1.5
	4	Low	SiC, C, SC	1.7
	5	Very Low	S, Si ve More than 60% Clay	2.0
Parent Material	**1**	Good	Shale, schist, basic and Ultra basic rocks conglomerates non-cemented materials	1.0
	2	Moderate	Limestone, marble, granite, rhyolite, lgnibrite, gneiss, silt stone, sandstone	1.7
	3	Low	Marl (for perennial plants the marl score should be 1.0), pyrosilicates	2.0
Slope (%)	**1**	Slightly slope and flat	< % 6	1.0
	2	Slightly slope	%6-18	1.2
	3	Steeply slope	%18-35	1.5
	4	Very Steeply slope	> % 35	2.0
Depth (cm)	**1**	Deep	>75 cm	1.0
	2	Moderate	75-30 cm	1.33
	3	Shallow	15-30 cm	1.66
	4	Very shallow	< 15 cm	2.0
EC (dS/m) (Bakr et al., 2012)	**1**	Good	<1.2	1.0
	2	Slightly	1.2-2,5	1.2
	3	Moderate	2.5-4,5	1.5
	4	Saline	4.5-9,0	1.7
	5	Very saline	>9.0	2.0
pH	**1**	Very Strogly Acidic	< 5.0	2.0
	2	Strongly Acidic	5.1-5,5	1.8
	3	Moderate Acidic	5.6-6,0	1.6
	4	Light Acidic	6.1-6,5	1.2
	5	Neutral	6.6-7,3	1.0
	6	Slightly alkaline	7.4-8,0	1.2
	7	Moderate Alkaline	8.1-8,5	1.6
	8	Strongly Alkaline	>8.5	2.0
OM (%)	**1**	Very High	>4.0	1.0
	2	High	3.0-4,0	1.2
	3	Moderate	2.0-3,0	1.4
	4	Low	1.0-2,0	1.6
	5	Very Low	0.5-1,0	1.8
	6	Exremely Low	<0.5	2.0
$CaCO_3$ (%)	**1**	Very Less calcareous	0-2	1.4
	2	Less calcareous	2-4	1.2
	3	Moderate calcareous	4-8	1.0
	4	Calcareous	8-15	1.2
	5	Very Calcareous	15-30	1.6
	6	Excessively Calcareous	>30	2.0

The following formula is used for the soil quality index:

$$SQI_{TDS} = (\text{Texture} * \text{Main material} * \text{Slope} * \text{Depth} * \text{pH} * \text{OM} * \text{Lime} * \text{EC})^{1/8}$$

In the calculation of the soil quality index, the total data set including texture, parent material, slope, depth, pH, OM, lime, and EC were considered. From the total data set obtained, thematic maps were created separately for the parameters, and then the soil quality distribution of the study area was made by calculating with the geometric mean. After this process, the minimum data set was created with the help of principal components analysis (Doran and Parkin, 1994; Qi et al., 2009; Nabiollahi et al., 2017). As a result of the analysis, groups with eigenvalues equal to or greater than 1 were accepted as factors, and the critical factor load was taken as 0.5 (Wander and Bollero, 1999; Andrews et al., 2002). For each factor, it was determined that soil parameters with high factor loads are the most representative parameters and have absolute values at 10% of the highest factor load (Sharma et al., 2005; Govaerts et al., 2006).

Results and Discussion

Determination of interpolation model for spatial distribution

Knowing the soil quality is important in terms of determining both desertification and land degradation and sustainable land use and soil management practices. While considering the parameters for soil quality, some physicochemical analyses were made on the 1019 soil samples collected from the study area. The lowest RMSE values among the 15 interpolation models in order to create spatial distribution maps of parameters considered are given in Table 3. Accordingly, for EC and pH, the Gaussian model of Natural Kriging was determined to be suitable, while RBF Completely Regularized Spline model was considered suitable for OM. RBF Spline With Tension was determined for lime, and a simple Kriging Spline With Tension model was identified for texture.

Table 3. Interpolation models and RMSE values applied for parameters.

Interpolation models			Soil Parameters				
			EC	pH	OM	$CaCO_3$	Texture
Inverse Distance Weighing (IDW)	IDW-1		0.903	0.615	0.974	13.544	0.237
	IDW-2		0.913	0.628	1.026	13.773	0.246
	IDW-3		0.953	0.651	1.079	14.316	0.257
Radial Basis Function (RBF)	TPS		28.111	0.903	3.957	24.478	0.426
	CRS		0.894	0.613	**0.973**	13.245	0.260
	SWT		0.891	0.615	0.975	**13.217**	0.252
Kriging	Ordinary	Gaussian	**0,877**	**0.611**	1.008	14.058	0.235
		Spherical	0,887	0.618	1.006	13.329	0.233
		Exponential	0,881	0.617	1.008	13.607	0.234
	Simple	Gaussian	0.901	0.626	0.989	14.080	0.234
		Spherical	0.902	0.622	0.976	13.231	**0.232**
		Exponential	0.906	0.621	0.982	13.695	0.233
	Universal	Gaussian	0.878	0.627	1.008	14.058	0.235
		Spherical	0.887	0.612	1.006	13.329	0.233
		Exponential	0.881	0.617	1.008	13.607	0.234

TPS:ThinPlateSplin, CRS: CompletelyRegularizedSpline, SWT: SplineWithTension OM: Organic matter, EC: Electrical Conductivity, $CaCO_3$: Lime

The spatial and proportional distributions of the parameters in the study area are given in Table 4, and the distribution maps are presented in Figure 4. Accordingly, 23.8% of the study area consists of deep soils. Deep soils spread over the lands in the basin base of the study area (Figure 4). An area of 42.3 km^2 is in the medium category as the parent material. The medium category is widespread except in the south and southwest parts of the study area (Figure 4). In terms of texture, 62.9% of the study area is in the good category, and in terms of the OM index category, 78.8% is in the very low category. 4.6 km^2 area of the basin is in the very steep slope category and is spread over the mountainous areas surrounding the study area (Fig. 4). 74% of the basin is in the good category in terms of EC. 63.2% of it constitutes a very calcareous area (Table 4). The lime ratio is quite high on the basin floor. In addition, it is in the medium alkaline category in terms of pH, excluding the local areas in the east and west of the basin. This area constitutes approximately 74.4% of the area.

Table 4. Spatial and proportional distributions of the study area soil parameters

Soil depth index	Area km²	Area %	Parent material index	Area km²	Area %	Texture index	Area km²	Area %	OM index	Area km²	Area %
1.0: Deep	12.8	23.8	1.0: Good	11.6	21.5	1.00: Very good	16.5	30.6	1.2: High	0.8	1.5
1.33: Moderate	17.4	32.4	1.7: Moderate	42.3	78.5	1.2: Good	33.9	62.9	1.4: Moderate	9.9	18.3
1.66: Shallow	9.9	18.4				1.5: Moderate	3.3	6.1	1.8: Very low	42.5	78.8
2.0: Very shallow	13.7	25.5				1.7:Low	0.2	0.4	2.0:Extremely low	0.7	1.3
Total	53.9	100.0		53.9	100.0	Total:	53.9	100.0	Total	53.9	100.0
EC index	**Area km²**	**Area %**	**pH index**	**Area km²**	**Area %**	**Slope index**	**Area km²**	**Area %**	**Lime index**	**Area km²**	**Area %**
1.0:Good	39.9	74.1	1.2: Slightly alkaline	12.9	23.9	1.0:Slightly slope and flat	31.7	58.8	1.2: Less calcareous	6.2	11.5
1.2:Slightl	12.2	22.7	1.6: Moderate alkaline	40.1	74.4	1.2:Slightly slope	10.6	19.7	1.6: Very calcareous	13.6	25.3
1.5:Moderate	1.8	3.2	2.0: Strongly alkaline	0.9	1.7	1.5: Steeply slope	7.0	13.0	2.0: Excessively calcareous	34.0	63.2
1.7:Saline	0.0	0.0				2.0: Very steeply slope	4.6	8.5			
Total	53.9	100.0		53.9	100.0	Total	53.9	100.0		53.9	100.0

Distribution of the soil quality index in the Basin

According to the MEDALUS model total soil quality index, soil texture, parent material, slope, depth, EC, pH, organic matter, and lime parameters were used. Soil texture is thought to have a significant impact on soil quality. Soil texture affects soil water content and soil temperature (Chodak and Niklińska, 2010; Sugihara et al., 2010). Vinhal-Freitas et al. (2013) concluded in their study on Brazilian agricultural lands that soil texture plays an important role in soil quality indicators in Brazilian agricultural lands. Also Juhos et al. (2019) examined soil quality in agricultural lands in Central Europe by evaluating soil texture, groundwater table level, soil organic carbon, pH, calcium carbonate, electrical conductivity, sodium, nitrogen, phosphorus, potassium, sulfur, magnesium, copper, zinc, and manganese properties. In addition, by performing the principal components analysis in this study, soil texture, groundwater table level, soil organic carbon, pH, sodium, potassium, phosphorus, and zinc were determined for the minimum data set. The texture parameter indices in the study area varied between 1.0 and 1.7 (Figure 4). It was determined that the texture category with a 1.2 index value showed wider distribution in the study area. Soils with this index value do not cause erosion by the surface flow of water reaching the soil with irrigation and rain. This shows that the resistance to desertification is high.

The parent material parameter index values were defined using the geological map of the study area. İn the study they conducted, Allouche and God (2014) evaluated the parent material, soil texture, depth, and slope characteristics while determining the soil quality in terms of water movement in the soil and its resistance to erosion. They concluded that 62.5% of the parent material in the study area was at a medium level in terms of soil erosion. Shale, schist, basic and ultrabasic rocks, and conglomerates and non-cemented materials were classified as good (1.0), while limestone and marble were classified as quite hard, and the parent materials such as granite, rhyolite, ignimbrite, gneiss, siltstone, and sandstone, which constitute soils with generally acidic character and low nutrient content when decomposed, were classified as medium (1.7). In the study area, the medium index value of the main material covers the most (42262 km^2) area (Figure 4, Table 4).

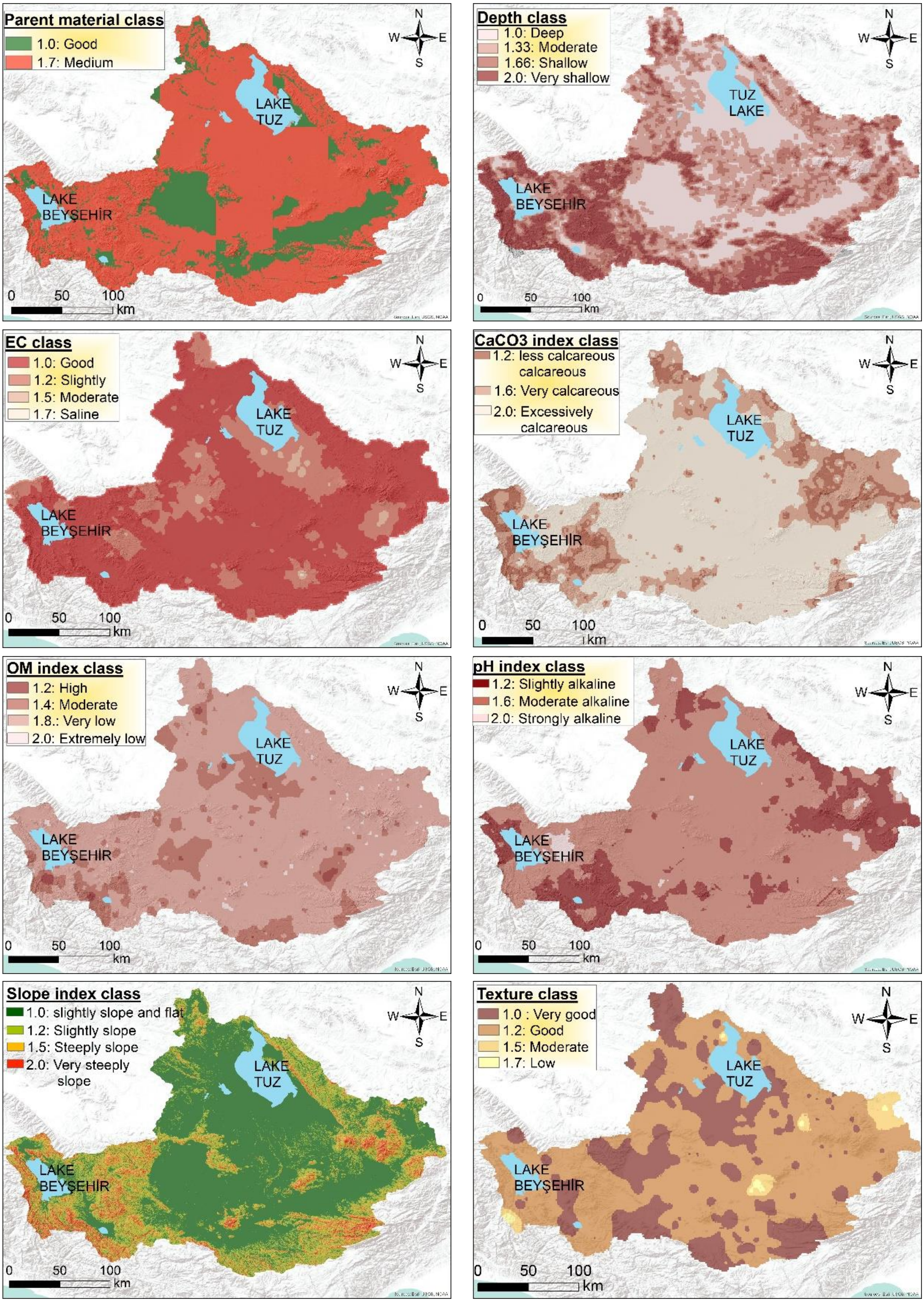


Figure 4. Distribution maps of soil parameters of the study area

It is known that the slope parameter affects the variation of soil quality (Ayoubi et al., 2014; Fu et al., 2004; Raiesi, 2017; Khormali et al., 2019). Nabiollahi (2018) conducted field measurements in order to identify the effects of the slope on soil quality in agricultural lands. They reached the conclusion that low soil quality values were determined on slopes with high slope values and where land use was converted to agriculture, and that soil quality should be restored by adopting sustainable practices and abandoning excessive grazing in these areas. In their study, Paz-Kagan et al. (2016) revealed the soil quality by determining the physical, chemical, and biological properties of the soil. They investigated the effect of slope, exposure, land use, vegetation, and grazing density on soil quality, and the effects of each factor on the study areas were determined. Areas with severe erosion as a result of heavy and torrential rains are areas with high slope. While the agricultural lands on the floor of the Konya plain have low index values, the slope values increase in the high areas that form the surrounding forest areas (Figure 4). While 31.670 km^2 (58.812%) of the study area is comprised of the areas where the slope values representing the plain floor are low, 4.600 km^2 (8.542%) of it has very steep slope values (Table 4).

Soil depth is important in terms of showing the stage of desertification. In many soil quality studies, soil depth has been taken as an important indicator of desertification (Mijangos and Garbisu, 2010; Salvati et al., 2011; Kladivko et al., 2014; de Paul Obade and Lal, 2016; Prăvălie et al., 2017). The European Environment Agency has mapped the soil quality of some southern European states using parameters based on the parent material, soil depth, texture, and slope (European Environment Agency, 2009). Kosmas et al. (1999b) stated in his study that soil depth decreases especially in arid/semi-arid lands, in areas vulnerable to erosion, or areas with heavy rainfall. The decrease in soil depth causes soil quality to decrease. 43,891 km^2 of the study area, which is characterized by a semi-arid climate, has a shallow and very shallow index value (Figure 4, Table 4). The distribution of very and very shallow soils is observed in the mountainous areas around the Konya plain. On the floor land where the slope degree decreases towards the middle of the basin, deep soils are prevalent (Figure 4).

Using water that is not of suitable quality for irrigation or wrong irrigation techniques especially leads to land degradation and desertification through the salinization of agricultural land. As Kosmos et al. (1999a) has pointed out, increased concentrations of salts reduce the natural vegetation and weaken the functioning ability of soils. Increasing population, excessive agricultural activities, unconscious and excessive use of fertilizers, flood irrigation and the salt content of the water used to increase the salinity problems in the soils. Determination of soil's electrical conductivity (EC) is an important factor in revealing the soil character (Corwin and Lesh, 2005). Corwin et al. (2006) evaluated the management in soil quality with electrical conductivity (EC) values at soil sampling points in the study they conducted in central California. The results obtained in this research were an assessment of drainage water reuse and practices for EC on soil quality in central California. In their study, Johnson et al. (2001) determined the quality status and appropriate management system according to the EC category. According to the map obtained by the salinity indexes in the study area, there is no process as salinity causing desertification in the study area (Figure 4). 74.065% of the study area is in the good category in terms of salinity. Especially the south of Tuz Gölü (Salt Lake) in the study area is in the saltier category in terms of salinity.

Soil pH is a significant soil parameter that plays a role in biotic and abiotic properties in the soil, especially in the nutrition of plants and affecting the usefulness of nutrients. In generally arid and semi-arid regions with high pH soil, the high calcium ions in the environment react with phosphates, and thus, plants are unable to take them (Sanyal and De Datta, 1991). Callesen et al. (2019) revealed the relationship between soil quality indicators, pH, and sustainable forest management in Northern and Baltic forest soils. In the study conducted by Cotching and Kidd (2010), pH, organic carbon, extractable phosphorus, changeable sodium percentage, and aggregate stability were selected as soil quality indicators. According to the index values, it is seen that there are many problematic areas in the study area (Figure 4). The majority of the study area, 74.377%, show a medium-alkaline property. In addition, the east of the study area and a portion of the western parts (0.932 km^2) were determined to have high alkaline properties.

The chemical properties of the soil are very important in terms of yield and plant health (Franzluebbers and Stuedemann, 2009; Bhogal et al., 2011). Among the chemical properties, lime is an important parameter in terms of determining the usefulness of plant nutrients. Lime parameter is also used in soil quality studies (Abuzaid et al., 2021; Karaca et al., 2021). In their study, Santos-Francés et al. (2019) classified the indicators for soil quality as the best value, less good and optimal value. They stated that the lime content of 15% was the most suitable value. When we look at the distribution of lime in the study area, it is seen that the excessively calcareous soils cover an area of 34,020 km^2 (63.175%). These areas are in the bottomlands of the study area.

By evaluating all parameters together, a distribution map in the study area was produced with the soil quality index algorithm used in the MEDALUS method (Figure 5). Accordingly, while 45.293 km^2 (84.110%) of the study area has medium quality, 13.59% of it has low quality soil distribution (Table 5).

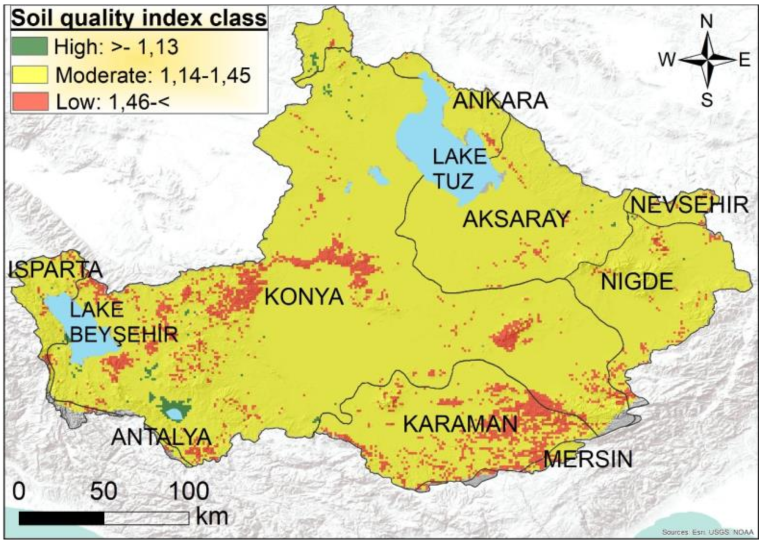


Figure 5. Soil quality map according to the total data set of the study area

Table 5. Soil quality index areal and proportional distribution of the study area

Class	Decription	index	Area(km^2)	Ratio (%)
1	High	>1.13	1.235	2.293
2	Moderate	1.14-1.45	45.293	84.110
3	Low	1.46 <	7.322	13.597
			53.850	100.000

In addition, a minimum data set was created in order to determine the most effective ones among the selected indicators, principal components analysis was performed in this regard. As a result, groups with eigenvalues equal to or greater than 1 were accepted as factors. 4 factors with eigenvalues greater than 1 were determined. According to the results obtained, 71.34% of the total change is explained by these factors (Table 6). When more than one indicator under a single factor has a high load, the correlation coefficient is checked for the minimum data set (Andrews et al., 2002). Variables with good correlations with each other are considered redundant, and one is considered for the minimum data set. In this study, when choosing the loads for the factors, the correlations between them were also examined (Table 7). The slope for the 1st factor after Varimax conversion has high loads. OM was the property with the highest load for factor 2, lime for factor 3, and pH for factor 4. Similarly, in the study conducted by Santos-Francés et al. (2019), lime and pH were found to be parameters with high factor loading. In their study, Karaca et al. (2021) formed the minimum data set of 26 parameters that they considered for soil quality from 8 parameters including OM and EC parameters.

Tablo 6. Results of Principal component for soil properties

Principal component	**1**	**2**	**3**	**4**
Eigenvalue	1.590	1.220	1.100	1.000
Percent	27.590	23.350	21.830	20.560
Cumulative percent	29.590	44.950	58.780	71.340
Eigenvectors				
Texture	0.237	-0.412	0.541	0.449
Parent Material	-0.509	-0.227	-0.179	-0.340
Slope	**0.743**	-0.008	-0.043	-0.116
pH	0.058	0.369	-0.416	**0.612**
$CaCO_3$	-0.160	0.369	**0.725**	-0.235
OM	-0.078	**0.816**	0.010	-0.096
EC	-0.346	0.167	0.278	0.460
Deep	0.738	0.200	0.068	-0.154

Bold factor loadings selected as MDS.

Table 7. Correlation matrix of parameters

	Texture	Parent Material	Slope	pH	$CaCO_3$	OM	EC	Deep
Texture	1.000							
Parent Material	-0.053	1.000						
Slope	0.089*	-0.174**	1.000					
pH	-0.202**	0.010	0.008	1.000				
$CaCO_3$	-0.263**	0.111**	-0.284**	0.223**	1.000			
OM	-0.208**	-0.009	-0.169**	-0.001	0.232**	1.000		
EC	-0.061	0.112**	-0.148**	-0.079*	0.106**	0.200**	1.000	
Deep	-0.037	-0.290**	0.436**	-0.050	-0.153**	-0.035	-0.222**	1.000

*: $p<0.05$ level of significance, **: $p<0.01$ level of significance

The soil quality map for the minimum data set obtained was created by using an algorithm in the MEDALUS method again.

$$SQI_{MDS}= (Slope * pH * OM * Lime)^{1/4}$$

A soil quality distribution map was prepared in line with the MEDALUS model with the minimum data set (Figure 6). Accordingly, it was determined that 43.30 km^2 (80.41%) of the study area was in the medium-quality category, while 1.08 km^2 (2.01%) was in the high-quality category (Table 8). In the study area, it is seen that the soil quality is low in Konya and Karaman provinces, similar to the soil quality distribution in the total data set. It was determined that there was significant parallelism between the soil quality maps created with both the total data set and the minimum data set obtained in line with the MEDALUS method.

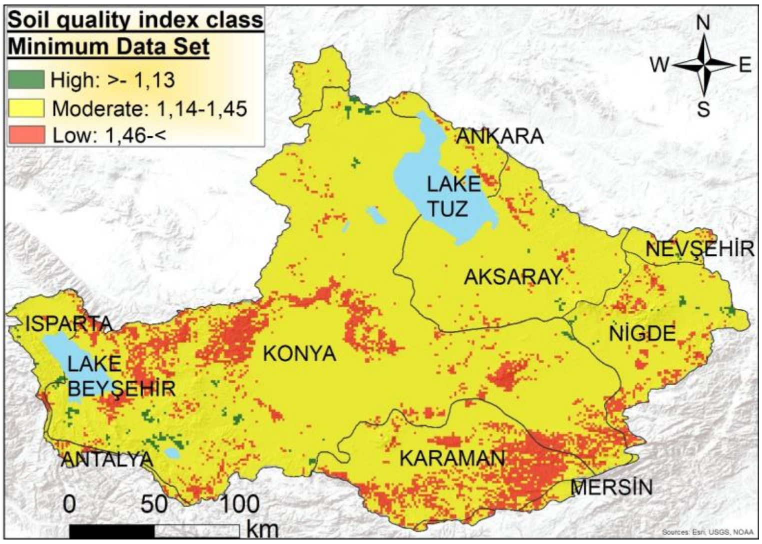


Figure 6. Soil quality map according to the minimum data set of the study area

Table 8. Soil quality index areal and proportional distribution according to the minimum data set of the study area

Class	Decription	index	Area (km^2)	Ratio (%)
1	High	>1.13	1.08	2.01
2	Moderate	1.14-1.45	43.30	80.41
3	Low	1.46 <	9.47	17.59
			53.85	100.00

Conclusion

Detailed soil quality studies are very important for sustainable soil management and determination of land degradation-desertification sensitivity. With this study, some physical and chemical properties of the soils in Konya Basin, which is a semi-arid region, were determined, and their distribution in the study area was identified by using interpolation methods. The soil quality index, which is an important component of the MEDALUS method, was determined both through the indicators included in the model and by adding some parameters that play important roles in the productivity functions of soils, and quality index categories of the study area were identified. Accordingly, 84.110% of the study area is in the medium category in terms of soil quality. The area of 7.322 km^2 has low soil quality, and 1.235 km^2 has high soil quality. Soil quality is lower around the settlements in the study area. In addition, the minimum data set was created with principal component analysis, and with the four parameters obtained, the soil quality distribution map was re-produced. Accordingly, 80.41% of the study area is in the medium category in terms of soil quality. 9.47 km^2 of the area has low soil quality, and 1.08 km^2 has high soil quality. When the soil quality index obtained from the total and minimum data sets was compared, it was determined that the compatibility was significantly high.

The results of this study are very important not only for regional scale but also for both nationally and internationally in terms of desertification. The results obtained can guide practices in this area in order to both minimize and reduce desertification processes. With this method, which allows the addition and subtraction of different parameters, by using different parameters in different areas, the soil quality risk studies on the scale of the basin can be pioneered.

References

Abuzaid, A.S., Abdellatif, A.D., Fadl, M.E., 2021. Modeling soil quality in Dakahlia Governorate, Egypt using GIS techniques. *The Egyptian Journal of Remote Sensing and Space Science* [in press]

Allouche, K.F., Gad, A., 2014. A comparison of methods for mapping the environmental sensitivity areas for desertification of a Mediterranean landscape using remote sensing and GIS applications. *European Academic Research* II(8): 10233-10253. Available at [Access date: 10.05.2020]: http://euacademic.org/UploadArticle/1070.pdf

Andrews, S.S., Karlen, D.L., Mitchell, J.P., 2002. A comparison of soil quality indices methods for vegetable production system in northern California. *Agriculture, Ecosystems & Environment* 90: 25–45.

Ayoubi, A., Emami, N., Ghaffari, N., Honarjoo, N., Sahrawat, K.L., 2014. Pasture degradation effects on soil quality indicators at different hill slope positions in a semiarid region of western Iran. *Environmental Earth Sciences* 71: 375–381.

Babaev, A.G., 1985. Methodological principles of desertification processes assessment and mapping, Ashgabat, Turkmenistan. *Desert Research Institute,* Ashgabat, Turkmenistan. 72p.

Bayramin, İ., 2003. Beypazari topraklarinin MEDALUS metoduna göre toprak kalite indekslerinin belirlenmesi. *Harran Üniversitesi Ziraat Fakültesi Dergisi* 7 (3-4): 29-35. [in Turkish]

Bhogal, A., Nicholson, F.A., Young, I., Sturrock, C., Whitmore, A.P., Chambers, B.J., 2011. Effects of recent and accumulated livestock manure carbon additions on soil fertility and quality. *European Journal of Soil Science* 62(1): 174–181.

Bouyoucos, G.J., 1962. Hydrometer method improvement for making particle size analysis of soils. *Agronomy Journal* 54(5): 179-186.

Budak, M., Günal, H., Çelik, İ., Yıldız, H., Acir, N., Acar, M., 2018. Environmental sensitivity to desertification in northern Mesopotamia; application of modified MEDALUS by using analytical hierarchy process. *Arabian Journal of Geosciences* 11: 481.

Callesen, I., Clarke, N., Lazdinš, A., Varnagiryte-Kabasinskiene, I., Raulund-Rasmussen, K., 2019. Nutrient release capability in Nordic and Baltic forest soils determined by dilute nitric acid extraction – Relationships with indicators for soil quality, pH and sustainable forest management. *Ecological Indicators* 96: 540-547.

Chodak, M., Niklińska, M. 2010. Effect of texture and tree species on microbial properties of mine soils. *Applied Soil Ecological* 46: 268–275.

Contador, J.L., Schnabel, S., Gutiérrez, A.G., Fernández, M.P., 2009 Mapping sensitivity to land degradation in Extremadura. SW Spain. *Land Degradation & Development* 20(2): 129-144.

Corwin, D.L., Lesch, S.M., 2005. Characterizing soil spatial variability with apparent soil electrical conductivity: Part II. Case study. *Computers and Electronics in Agriculture* 46(1-3): 135–152.

Corwin, D.L., Lesch, S.M., Oster, J.D., Kaffka, S.R., 2006. Monitoring management-induced spatio–temporal changes in soil quality through soil sampling directed by apparent electrical conductivity. *Geoderma* 131(3-4): 369 – 387.

Cotching, W.E., Kidd, D.B., 2010. Soil quality evaluation and the interaction with land use and soil order in Tasmania, Australia. *Agriculture, Ecosystems and Environment* 137(3-4): 358–366.

De Paola, F., Ducci, D., Giugni, M., 2013. Desertification and erosion sensivity. A case study southern Italy: the Tusciano river catchment. *Environmental Earth Science* 70: 2179-2190.

de Paul Obade, V., Lal, R., 2016. Towards a standard technique for soil quality assessment. *Geoderma* 265: 96–102.

Demirağ Turan, İ., Dengiz, O., Özkan, B., 2019. Spatial assessment and mapping of soil quality index for desertification in the semi-arid terrestrial ecosystem using MCDM in interval type-2 fuzzy environment. *Computers and Electronics in Agriculture* 164; 1004933.

Dengiz, O., Özden, Ş., Başkan, O., Özcan, H., 2004. Determination of soil quality index of bala statefarm soils according to the medalus methodology. *International Soil Congress on Natural Resource Management for Sustainable Development* 7-10 June 2004, Erzurum, Turkey.

Doran, J.W., Parkin, B.T., 1994. Defining and assessing soil quality. In: Defining Soil Quality for a Sustainable Environment. Doran, J.W., Coleman, D.C., Bezdicek, D.F., Stewart, B.A. (Eds.). Soil Science Society of America Inc., Madison, WI, USA, pp. 3–21.

European Environment Agency, 2009. Indices of climate, soil and vegetation quality. Available at [Access date: 10.05.2020]: https://www.eea.europa.eu/data-and-maps/data/indices-of-climate-soil-and-vegetation-quality-1
European Environment Agency, 2018. CORINE Land Cover. Available at [Access date: 10.05.2020]: https://www.eea.europa.eu/publications/COR0-landcover/at_download/file
FAO-UNEP, 1984. Provisional methodology for assessment and mapping of desertification. Food and Agriculture Organization of the United Nations /United Nations Environmental Programme. Rome, Italy. 84p.
Franzluebbers, A.J., Stuedemann, J.A., 2009. Soil-profile organic carbon and total nitrogen during 12 years of pasture management in the Southern Piedmont USA. *Agriculture, Ecosystems and Environment* 129(1-3): 28–36.
Fu, B.J., Liu, S.L., Chen, L.D., Lu, Y.H., Qiu, J., 2004. Soil quality regime in relation to land cover and slope position across a highly modified slope landscape. *Ecological Research* 19: 111–118.
GIWA, 2001. DPSIR framework for state of environment reporting (Driving Forces–Pressures–State–Impacts–Responses). Global International Water Assessment, European Environment Agency. 104p.
Govaerts, B., Sayre, K.D., Deckers, J., 2006. A minimum data set for soil quality assessment of wheat and maize cropping in the highlands of Mexico. *Soil and Tillage Research* 87: 163–174..
İnan, N., Şen, E., Başaran, N., 2006. Konya Ovasının İklimi. Devlet Meteoroloji İşleri Genel Müdürlüğü No: 4, Ankara, Turkey. [in Turkish]
IPBES, 2018. The assessment report on land degradation and restoration. Summary for policymakers. Available at [Access date: 10.05.2020]: https://ipbes.net/sites/default/files/spm_3bi_ldr_digital.pdf
Jackson, M.L., 1958. Soil Chemical Analysis, Prentice Hall Inc. Englewood Cliffs, New Jersey, USA. 498p.
Johnson, C.K., Doran, J.W., Duke, H.R., Weinhold, B.J., Eskridge, K.M., Shanahan, J.F., 2001. Field-scale electrical conductivity mapping for delineating soil condition. *Soil Science Society America Journal* 65(6): 1829 – 1837.
Juhos, K., Czigány, S., Madarász, B., Ladányi, M., 2019. Interpretation of soil quality indicators for land suitability assessment – A multivariate approach for Central European arable soils. *Ecological Indicators* 99: 261-272.
Kadıoğlu, M., 2012. Türkiye'de İklim Değişikliği Risk Yönetimi. Türkiye'nin İklim Değişikliği II. Ulusal Bildiriminin Hazırlanması Projesi Yayını. T.C. Çevre ve Şehircilik Bakanlığı, Ankara, Turkey. 172p. [in Turkish]
Karaca, S., Dengiz, O., Demirağ Turan, İ., Özkan, B., Dedeoğlu, M., Gülser, F., Sargin, B., Demirkaya, S., Ay, A., 2021. An assessment of pasture soils quality based on multi-indicator weighting approaches in semi-arid ecosystem. *Ecological Indicators* 121: 107001.
Khormali, F., Ajami, A., Ayoubi, S., Srinivasarao, C.H., Wani, S.P., 2009. Role of deforestation and hillslope position on soil quality attributes of loess-derived soils in Golestan province, Iran. *Agriculture, Ecosystems and Environment* 134: 178–189.
Kladivko, E.J., Helmers, M.J., Abendroth, L.J., Herzmann, D., Lal, R., Castellano, M.J., Mueller, D.S., Sawyer, J.E., Anex, R.P., Arritt, R.W., Basso, B., Bonta, J.V., Bowling, L.C., Cruse, R.M., Fausey, N.R., Frankenberger. J.R., Gassman, P.W., Gassmann, A.J., Kling, C.L., Kravchenko, A., Lauer, J.G., Miguez, F.E., Nafziger, E.D., Nkongolo, N., O'Neal, M., Owens, L.B., Owens, P.R., Scharf, P., Shipitalo, M.J., Strock, J.S., Villamil, M.B., 2014. Standardized research protocols enable transdisciplinary research of climate variation impacts in corn production systems. *Journal of Soil and Water Conservation* 69(6): 532–542.
Kosmas, C., Gerontidis, St., Detsis, V., Zafiriou, Th., Marathianou, M., 1999b. The island of Lesvos (Greece). In: The MEDALUS Project: Mediterranean desertification and land use. Manual on key indicators of desertification and mapping environmentally sensitive areas to desertification. Kosmas, C., Kirkby, M., Geeson, N., (Eds.). European European Commission, Community Research, Project Report. pp.66-73. Available at [Access date: 10.05.2020]: http://www.comap.ca/kmland/display.php?ID=253&DISPOP=VRCPR
Kosmas, C., Kirkby, M.J., Geeson, N., 1999a. The MEDALUS Project: Mediterranean desertification and land use. Manual on key indicators of desertification and mapping environmentally sensitive areas to desertification. European European Commission, Community Research, Project Report. 88p. Available at [Access date: 10.05.2020]: http://www.comap.ca/kmland/display.php?ID=253&DISPOP=VRCPR
Lahlaoi, H., Rhinane, H., Hilali, A., Lahssini, S., Moukrim, S., 2017. Desertification assessment using MEDALUS model in watershed Oued El Maleh, Morocco. *Geosciences* 7(3): 50.
Mijangos, I., Garbisu, C., 2010. Consequences of soil sampling depth during the assessment of the effects of tillage and fertilization on soil quality: a common oversight. *Soil and Tillage Research* 109(2): 169–173.
Nabiollahi, K., Golmohamadi, F., Taghizadeh-Mehrjardi, R., Kerry, R., Davari, M., 2018. Assessing the effects of slope gradient and land use change on soil quality degradation through digital mapping of soil quality indices and soil loss rate. *Geoderma* 318: 16-28.
Nabiollahi, K., Taghizadeh-Mehrjardi, R., Kerry, R., Moradian, S., 2017. Assessment of soil quality indices for salt-affected agricultural land in Kurdistan Province, Iran. *Ecological Indicators* 83: 482–494.
Oldeman, L.R., Hakkelingr, T.A., Sombroek, W.G., 1991. World Map of the Status of Human-induced Soil Degradation (GLASOD): An explanatory note. International Soil Reference and Information Centre (ISRIC)/ United Nations Environment Programme (UNEP), Nairobi, Kenya. 27p.
Orhan, O., Ekercin, S., 2015. Konya kapalı havzasında uzaktan algılama ve CBS teknolojileri ile iklim değişikliği ve kuraklık analizi. TUFUAB VIII. Teknik Sempozyumu 21-23 Mayıs 2015, Konya, Turkey. [in Turkish]
Ozsahin, E., Pektezel, H., Eroglu, I., 2017. Soil quality index (SQI) analysıs of Tekirdag province using GIS (Thrace, Turkey). *Fresenius Environmental Bulletin* 26(4): 3005-3014.

Paz-Kagan, T., Ohana-Levi, N., Herrmann, I., Zaady, E., Henkin, Z., Karnieli, A., 2016. Grazing intensity effects on soil quality: A spatial analysis of a Mediterranean grassland. *Catena* 146: 100–110.

Prăvălie, R., Săvulescu, I., Patriche, C., Dumitraşcu, M., Bandoc, G., 2017. Spatial assessment of land degradation sensitive areas in southwestern Romania using modified MEDALUS method. *Catena* 153: 114-130.

Qi, Y., Darilek, J.L., Huang, B., Zhao, Y., Sun, W., Gu, Z. 2009. Evaluating soil quality indices in an agricultural region of Jiangsu Province, China. *Geoderma* 149(3-4): 325–334.

Raiesi, F., 2017. A minimum data set and soil quality index to quantify the effect of land use conversion on soil quality and degradation in native rangelands of upland arid and semiarid regions. *Ecological indicators* 75: 307-320.

Salvati, L., Bajocco, S., Ceccarelli, T., Zitti, M., Perini, L., 2011. Towards a process-based evaluation of land vulnerability to soil degradation in Italy. *Ecological Indicators* 11 (5): 1216–1227.

Salvati, L., Zitti, M., 2005. Land degradation in the Mediterranean basin: Linking biophysical and economic factors into an ecological perspective. *Biota - International Journal of Biology and Ecology* 5: 67– 77.

Santos-Francés, F., Martínez-Graña, A., Ávila-Zarza, C., Criado, M., Sánchez, Y., 2019. Comparison of methods for evaluating soil quality of semiarid ecosystem and evaluation of the effects of physico-chemical properties and factor soil erodibility (Northern Plateau, Spain). *Geoderma* 354: 113872.

Sanyal, S.K., De Datta, S.K., 1991. Chemistry of Phosphorus Transformations in Soil. In: Advances in Soil Science. Stewart, B.A. (Ed.). Springer-Verlag, New York, USA. pp. 1-120

Sepehr, A., Hassanli, A.M., Ekhtesasi, M.R., Jamali, J.B., 2007. Quantitative assessment of desertification in south of Iran using MEDALUS method. *Environmental Monitoring and Assessment* 134: 243.

Sharma, K.L., Mandal, U.K., Srnivas, K., Vittal, K.P.R., Mandal, B., Grace, J.K., Ramesh, V. 2005. Long-term soil management effects on crop yields and soil quality in a dryland Alfisol. *Soil and Tillage Research* 83(2): 246–259.

Shukla, M.K., Lal, R., Ebinger, M., 2006. Determining soil quality indicators by factor analysis. *Soil and Tillage Research* 87(2): 194–204.

Soil Survey Staff, 1992. Procedures for Collecting Soil Samples and Methods of Analysis For Soil Survey. Soil Surv. Invest. Rep. I. U.S. Gov. Print. Office, Washington D.C., USA.

Sugihara, S., Funakawa, S., Kilasara, M., Kosaki, T., 2010. Effect of land management and soil texture on seasonal variations in soil microbial biomass in dry tropical agroecosystems in Tanzania. *Applied Soil Ecology* 44: 80–88.

Symenoakis, E., Karathanasis, N., Koukoulas, S., Panagopoulos, G., 2014. Monitoring sensitivity to land degradation and desertification with the envıronmentally sensitive area index: the case of Lesvos ısland. *Land Degradation and Development* 27(6): 1562-1573.

Şeker, C., Özaytekin, H.H., Neğis, H., Gümüş, İ., Dedeoğlu, M., Atmaca, E., Karaca, Ü., 2017. Identification of regional soil quality factors and indicators: a case study on an alluvial plain (central Turkey). *Solid Earth* 8(3): 583–595.

Şen, E., Başaran, N., 2007. Küresel ısınma sürecinde Konya Ovasının bazı iklim verilerinde meydana gelen değişmeler ve eğilimler. Uluslararası Küresel İklim Değişikliği ve Çevresel Etkileri Konferansı. 18-20 Ekim 2007. Konya, Turkey. [in Turkish]

Şenol, H., Alaboz, P., Demir, S., Dengiz, O., 2020. Computational intelligence applied to soil quality index using GIS and geostatistical approaches in semiarid ecosystem. *Arabian Journal of Geosciences* 3:1235.

Türkes, M., Öztas, T., Tercan, E., Erpul, G., Karagöz, A., Dengiz, O., Doğan, O., Şahin, K., Avcıoğlu, B., 2020. Desertification vulnerability and risk assessment for Turkey via an analytical hierarchy process model. *Land Degradation Development* 31(2): 205–214.

UNCCD, 2017. United Nations Convention to Combat Desertification. Global Land Outlook first edition (2017) Available at [Access date: 10.05.2020]: https://knowledge.unccd.int/glo/GLO_first_edition

United Nations, 1994. Elaboration of an international convention to combat desertification in countries experiencing serious drought and/or desertification, particularly in Africa. Final text of the Convention. Available at [Access date: 10.05.2020]: https://wedocs.unep.org/handle/20.500.11822/27569

Uzuner, Ç., Dengiz, O., 2020. Desertification risk assessment in Turkey based on environmentally sensitive areas. *Ecological Indicators* 114,106295.

Vinhal-Freitas, I.C., Ferreira, A.S., Corrêa, G.F., Wendling, B., 2013. Land use impact on microbial and biochemical indicators in agroecosystems of the Brazilian Cerrado. *Vadose Zone Journal* 12(1): 1–8.

Wander, M.M., Bollero, G.A., 1999. Soil quality assessment of tillage impacts in Illinois. *Soil Science Society of America Journal* 63(4): 961-971.

Yılmaz, S., 2010. Havza Koruma Eylem Planlarının Hazırlanması Projesi Konya Kapalı Havzası. TÜBİTAK Marmara Araştırma Merkezi Çevre Enstitüsü, Proje Nihai Raporu 5098115 ÇE.10.49. [in Turkish]

Eurasian Journal of Soil Science 2021, 10(3), 236 - 242

Eurasian Journal of Soil Science

Journal homepage : http://ejss.fesss.org

Assessment of ecotoxicity of the bismuth by biological indicators of soil condition

Lyudmila Sudina *, Sergey Kolesnikov, Tatiana Minnikova, Kamil Kazeev, Svetlana Sushkova, Tatiana Minkina

Southern Federal University, Academy of Biology and Biotechnology, Rostov-on-Don, Russia

Article Info

Received : 11.11.2020
Accepted : 12.04.2021
Available online : 23.04.2021

Author(s)

L. Sudina *
S. Kolesnikov
T. Minnikova
K. Kazeev
S. Sushkova
T. Minkina

* Corresponding author

Abstract

The present study was performed for the ecotoxicity assessment of the bismuth (Bi) effect on the biological indicators of soil condition: total number of soil bacteria, catalase activity, dehydrogenases activity and germination of Radish seeds and length of the Radish roots. Three soil types with significantly different resistance ability to heavy metal pollution were studied: Haplic Chernozems Calcic, Haplic Arenosols Eutric and Haplic Cambisols Eutric.Soil contamination of Bi was simulated in the lab (3, 30 and 300 mg kg^{-1} dry weight). Changes in the biological parameters of the soil were assessed at 10 day treatment. The data obtained showed that the soils contaminated with Bi in South Russia generally characterized by oppression of the biological properties. The total number of bacteria and enzymatic activity (catalase and dehydrogenases) decreased over the Bi contamination. The indicators of phytotoxicity (germination of radish seeds) increase when bismuth 3 and 30 mg kg^{-1} is added to the soil. The degree of deterioration in biological properties depends on the concentration of Bi in the soil and the period of time after the onset of pollution. Resistance of soil types to Bi pollution can be described by the following decreasing series: Haplic Chernozem Calcic > Haplic Arenosols Eutric > Haplic Cambisols Eutric. The following regional maximum permissible concentrations (rMPC) of Bi have been proposed: Haplic Chernozem Calcic – 8.5 mg kg-^{1}, Haplic Arenosols Eutric – 2.2 mg kg^{-1} and Haplic Cambisols Eutric – 1.8 mg kg^{-1}.

Keywords: Biotesting, bismuth, pollution, soil biological properties.

Introduction

Soil pollution with heavy metals is a serious problem in all countries of the world (Zhang et al., 2011a; Murtić et al., 2020). Bismuth (Bi) is characterized by a low content in the Earth's crust (Kabata Pendias and Pendias, 2010). Bi is used along with nitrogen, carbon and chlorine (Kasimov and Vlasov, 2012). The use of Bi leads to an increased content of Bi in all environmental components (Meyer et al., 2007; Soriano et al., 2012). The main sources of pollution of the environment and soil with Bi are the metalworking industry (Cortada et al., 2012) and cars (Xiong et al., 2015). Ore deposits containing Bi increase its background content in the soil cover up to 300 times (Yurgenson and Gorban, 2017). The increased content of Bi in soil leads to its accumulation in plants (Wei et al., 2011) and in the human body, causing many pathological conditions (Li et al., 2014).

A number of ongoing studies reveal more and more evidence of the negative effects of Bi on soil enzymatic activity and soil bacteria (Murata, 2006), plants (Zhang et al., 2011b), earthworms (Omouri et al., 2018), and humans (Liu et al., 2011). However, several studies have found a stimulating effect of Bi nanoparticles on

: https://doi.org/10.18393/ejss.926759
: http://ejss.fesss.org/10.18393/ejss.926759
Publisher : Federation of Eurasian Soil Science Societies
e-ISSN : 2147-4249

plant length (Nagata, 2015). The effect of Bi on the biological properties of soils remains insufficiently studied.

The main objective of this study was to estimate of ecotoxicity of the bismuth by biological indicators of soil condition: total number of soil bacteria, catalase activity, dehydrogenases activity and germination of Radish seeds and length of the Radish roots.

Material and Methods

Soil sampling

A variety of soils found in the South of Russia with considerably different properties as to their resistance to heavy metal contamination were selected as study objects: Haplic Chernozem Calcic, Haplic Arenosols Eutric and Haplic Cambisols Eutric (WRB, 2015). Soil samples were taken from the upper soil layer (0-0.10 m) because of the most intensive heavy metals accumulation in the upper soil layer from the territory of the southern Russia located far from potential contamination sources by Bi (Figure 1) (Kabata Pendias and Pendias, 2010). The map of sample The data provides on the particular places of soil sampling and a brief analysis of their basic physical and chemical soil indicators (Table 1).

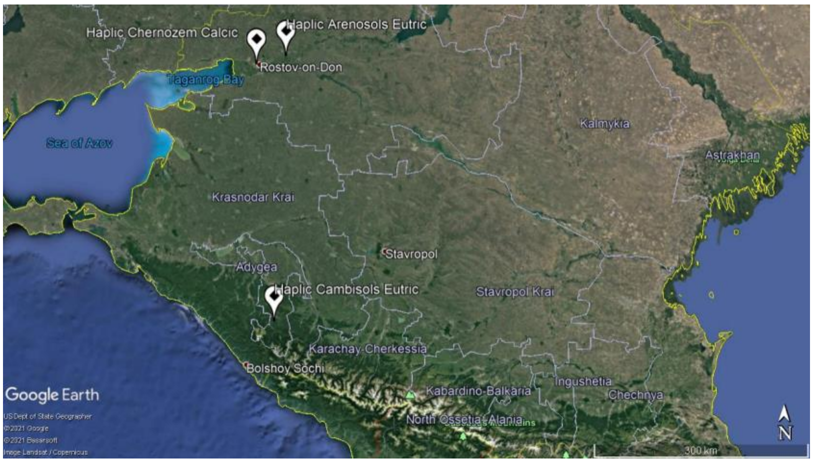


Figure 1. Soil sampling map

Table 1. Description of soil sampling areas

Soil type	Sampling area	Geographical coordinates	Land type	Humus content, %	pH	Particle size distribution
Haplic Chernozem Calcic	The Botanical Garden, Southern Federal University, Rostov-on-Don	47°14'17.54"N 39°38'33.22"E	Arable land	3.70±0.10	7.80±0.30	Heavy loam
Haplic Arenosols Eutric	Rostov Region, Ust'-Donetskiy district	47°21'02.36"N 40°09'34.40"E	Grass and cereal steppe	2.30±0.08	6.80±0.20	Sandy loam
Haplic Cambisols Eutric	Republic of Adygea, Nickel settlement	44°10'38.94"N 40°09'28.14"E	Horn beam and beech forest	1.80±0.06	5.80±0.03	Heavy loam

Modelling experiments

A model experiment on soil contamination with bismuth was carried out in triplicate. Bi values are expressed in conditionally permissible concentrations (CPCs). This is due to the detection of toxicity of heavy metals and metalloids at three background concentrations of elements in the soil (Kolesnikov et al., 2020). The average background content of Bi in the soil is 1 mg kg^{-1} (Alekseenko and Alekseenko, 2013). The effect of various concentrations of Bi 1, 10 and 100 CPC (3, 30 and 300 mg kg^{-1}, respectively) was studied. Our interest in studying extremely high concentrations of Bi in soil is determined by its significant values in the area of highways up to 930–1891 mg kg^{-1} (Elekes and Busuioc, 2010).

Bi was added to the soil in the form of nitrate. The amount of nitrate ion entering the soil at the maximum dose of Bi in the experiment was 0.06% of the content in $Bi(NO_3)_3$. In addition, unlike other Bi^{3+}compounds, the nitrate ion is rapidly absorbed by the soil biota (Egorysheva et al., 2015). Bi nitrate, dissolved in water, was introduced into the soil (1 kg) and incubated at optimal moisture content (60% of the field moisture capacity) and a temperature of 20-22°C in growth chamber Binder KBW 240 (GOST RISO 22030-2009, 2009).

Analysis of biological properties

Our attention was focused on the study of the biological properties of the soil, since they are the most sensitive to chemical attack (Kolesnikov et al., 2019). The determination of the biological properties of soils was carried out 10 days after contamination. A longer incubation period increases the difference in the state of the soil incubated in the laboratory from its state in natural conditions (Kolesnikov et al., 2020; Kızılkaya et al., 2021). Biological indicators were studied by methods of soil science and ecology (Table 2).

Table 2. Characteristics of biological indicators of soil condition

Biological indicators	Measure unit	Methods
Total number of bacteria	10^9 in 1g of soil	luminescent microscopy
Catalase activity	ml O_2 g^{-1} soil 1 min^{-1}	by the rate of decomposition of H_2O_2
Dehydrogenases activity	mg of TPF 10 g^{-1} soil 24 h^{-1}	according to the rate of conversion of TTC to TPF
The germination of radish seeds	% of control	to change germinationof radish (*Raphanus sativus L.*) after 7 days of the experiment
The length of the radish roots	% of control	to change of length of the roots in radish (*Raphanus sativus L.*) after 7 days of the experiment

According to the above biological indicators, the integral indicator of the biological state (IIBS) of the soil was determined (Kolesnikov et al., 2019). For the calculation of IIBS, the value of each of the above indicators on the control (in unpolluted soil) was taken as 100% and relative to it, the percentages in other experimental variants (in polluted soil) were expressed as a percentage. For the IIBS condition maximum value of each index (100%) is chosen from array data and was expressed for other variants of experiments by Equation 1:

$$B_1 = \frac{B_x}{B_{max}} \times 100\% \tag{1}$$

where B_1 — is the relative score of the indicator; B_x — the actual value of the indicator; B_{max} — is the maximum value of the indicator.

Then relative values of several mostly informative indices of soil biological condition such as activity of catalase and dehydrogenases, total number of bacteria, length of roots, germination of radish seeds were summed. Thereafter, average assessment point of studied indices was calculated for each variant by Equation 2:

$$B = \frac{B_1 + B_2 + \ldots + B_n}{N} \tag{2}$$

where B — average estimated score of indicators; B_1....B_n — the relative score of the indicator; N — is the number of indicators.

The integral index of the soil biological condition is calculated by Equation 3:

$$IIBS = \frac{B}{B_{max}} \times 100\% \tag{3}$$

where B — is the average estimated score of all indicators; B_{max} — is the maximum estimated score of all indicators.

During diagnostics of contamination value of each index in non-contaminated soil is taken as 100% and with reference to it value of the same index in the contaminated soil is expressed in percent. Then determined the average value of five selected indicators for each experiment. The obtained value IIBS is expressed as a percentage concerning the control (to 100%). The methodology used allows you to integrate the relative values of different indicators, the absolute values of which cannot be integrated since they have different units of measurement.

Statistical Analyses

To check the reliability of the results, an analysis of variance was carried out followed by the determination of the least significant difference (LSD). Data are means of three replicate biological samples. Error bars show least significant difference (LSD) at $p \leq 0.05$ level. Variation statistics (mean values, dispersion) was determined, reliability of different samples was established by using dispersion analysis (Student's t test) and the correlation analysis (Pearson correlation coefficient) was conducted. Statistical data processing was carried out using Statistica 12.0 and Python 3.6.5 Matpolib package.

Results and Discussion

Variation of biological indicators in soils after bismuth contamination

It has been established that contamination with Bi generally leads to deterioration in the biological properties of soils in the South of Russia (Figure 2, Figure 3).

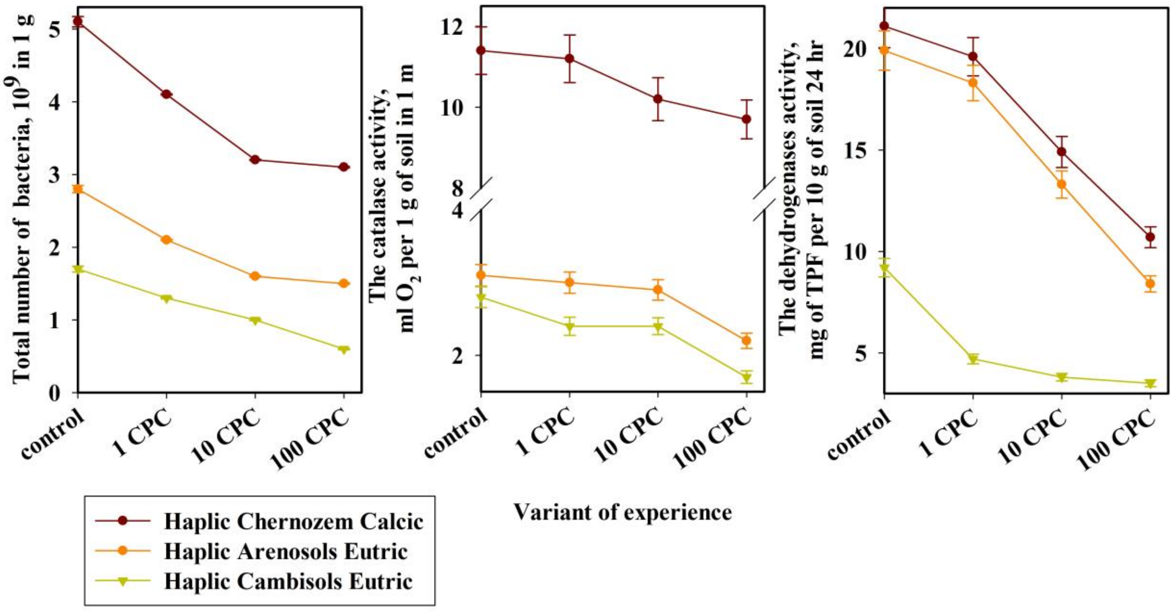


Figure 2. Soil biological properties in the Bi contaminated soil

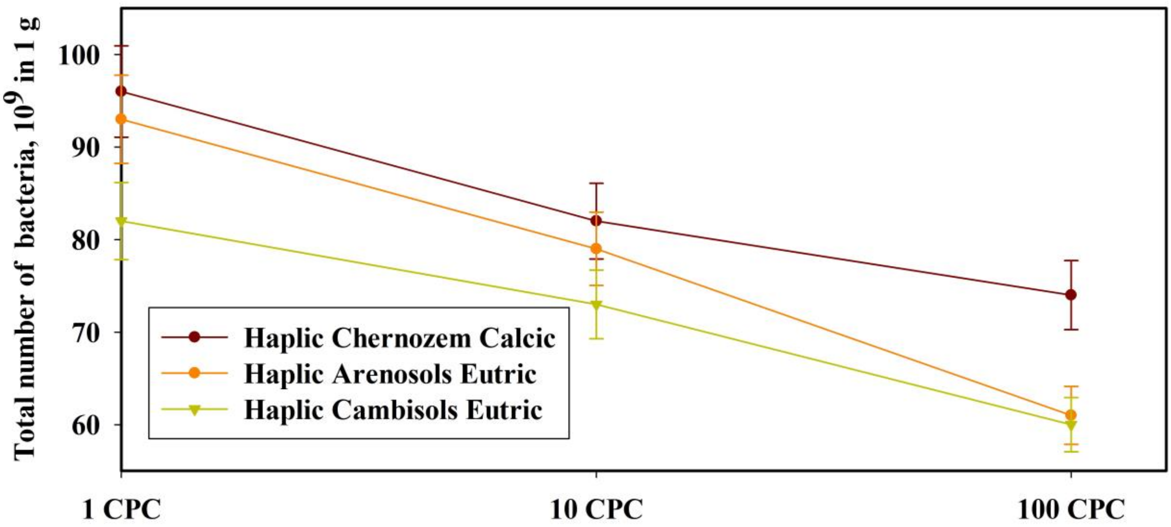


Figure 3. Total number of bacteria in the Bi contaminated soil

For Haplic Chernozem Calcic, when using Bi 10 and 100 CPC, there was a decrease in catalase activity by 11% and 15% of control, significant dehydrogenases activity– by 29% and 49% of control, radish root length– by 15% and 21% of control (Figure 4). The total number of bacteria decreased with the introduction of all investigated concentrations by 20%, 37% and 39%, respectively, of the control (Figure 3). IIBS Haplic Chernozem Calcic with the introduction of Bi 10 and 100 CPC decreased by 18% and 26%, respectively. For Haplic Cambisols Eutric, the toxic effect was already observed with 1 CPC Bi nitrate. The maximum toxic effect was observed for the total number of bacteria – 65% of the control, catalase activity – 39% of the control and dehydrogenases - 62% of the control. IIBS Haplic Cambisols Eutric decreased with the introduction of 1, 10 and 100 CPC Bi by 18, 27 and 40%, respectively. Murata (2006) established the degree of suppression of the total number of bacteria and activity of dehydrogenases when Bi compounds were introduced into Haplic Cambisols Eutric.

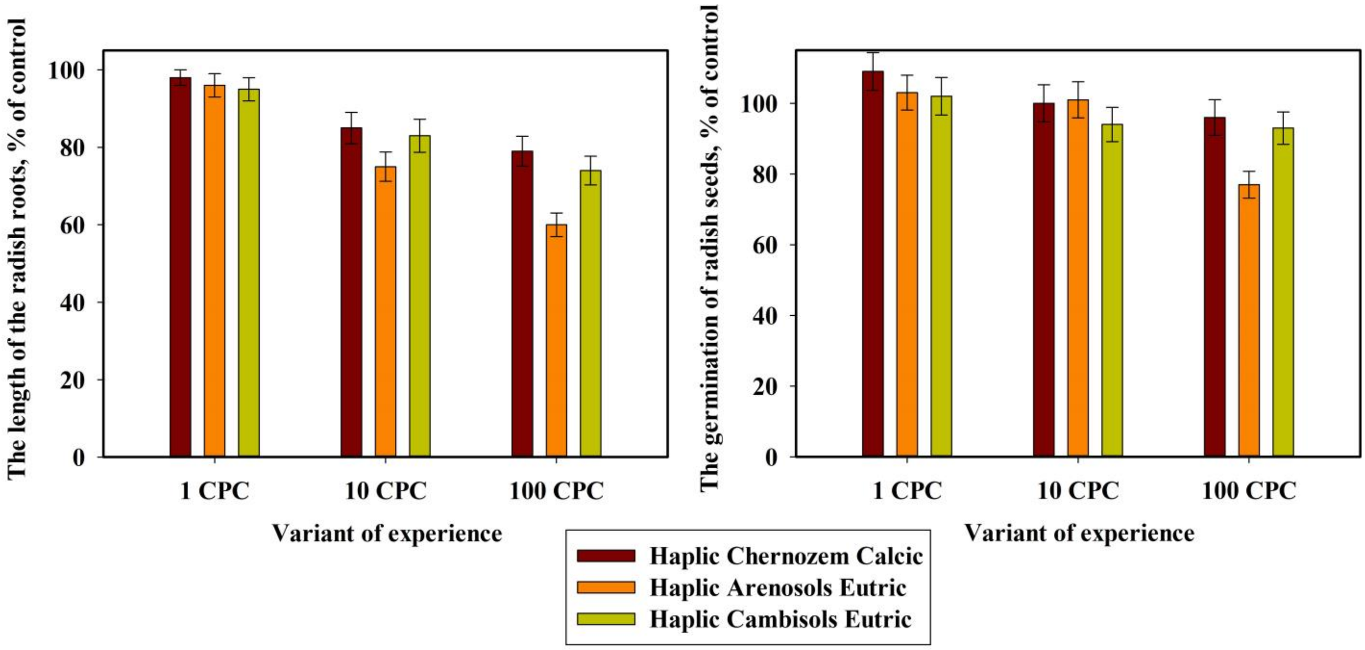


Figure 4. Morpho-biometric characteristics of the radish in the Bi contaminated soil

In Haplic Arenosols Eutric with Bi 10 and 100 CPC, inhibition of activity of dehydrogenases was also observed by 33 and 58% of the control were contaminated. There is a dose-effect relationship. The maximum toxic effect in the soil of Bi 10 and 100 CPC was determined for the total number of bacteria – 43% and 46%, respectively. A 29% decrease in catalase activity from control was recorded when 100 CPC Bi was added to Haplic Arenosols Eutric. By adding 10 and 100 CPC Bi to Haplic Arenosols Eutric, radish roots are inhibited by 25% and 40% of control. IIBS Haplic Arenosols Eutric with Bi 10 and 100 CPC decreased by 21% and 39%, respectively.

A low dose (1 CPC) of Bi nitrate resulted in unreliable stimulation of radish seed germination when applied to all types of soils. Nagata (2015), studying the effect of Bi nitrate on the root length of *Arabidopsis thaliana*, found that high concentrations inhibit root growth, while low concentrations, on the contrary, stimulate. The total number of bacteria was significantly reduced when applied to all types of soils, regardless of the dose of Bi. The largest decrease in the total number of bacteria was recorded at a dose of 100 CPC for Haplic Cambisols Eutric at 65% of the control. In the overwhelming majority of cases, a decrease in the total number of bacteria, catalase and dehydrogenase activity, as well as the length of radish roots was observed (Figure 4). When comparing soil resistance to Bi pollution, the following series was obtained: Haplic Chernozem Calcic (84) > Haplic Arenosols Eutric (78) > Haplic Cambisols Eutric (72).

The light particle size distribution of Haplic Arenosols Eutric and the acidic reaction of the Haplic Cambisols Eutric medium (pH = 5.8), as well as the low organic matter content (1.8 and 2.3%, respectively), contribute to the high mobility and, therefore, the high ecotoxicity of Bi in these soils.

Calculate and assessment of bismuth contaminated soils by the environmental regional maximum permissible concentration (rMPCs)

Previously, it was found that soil contamination with chemicals causes a violation of its ecosystem functions in a strict sequence: information functions, biochemical, physicochemical, chemical and integral functions and physical (Kolesnikov et al., 2019). When developing environmental standards for soil contamination, we used this sequence. IIBS soil is an objective indicator of dysfunction of a particular ecosystem. Prevention of degradation of soil ecosystem functions is an important task in the development of environmental standards. Thus, a drop in IIBS of more than 10% indicates a serious deterioration in soil functioning. It is proposed to call this value for each type of soil the regional maximum permissible concentration (rMPCs) for a specific pollutant in the soil (Kolesnikov et al., 2019). To determine the rMPCs of pollutants, we used a regression equation describing the dependence of the IIBC fall on the proportion of pollutants in the soil.

According to Table 3, the concentration of 8.5 mg kg^{-1} Bi in Haplic Chernozem Calcic corresponds to a 10% decrease in soil IIBS. Biconcentration of 8.5 mg kg^{-1} should be considered the MPC for Bi in Chernozem. Thus, the rMPC of Bi for Haplic Chernozem Calcic is 8.5 mg · kg^{-1}, Haplic Arenosols Eutric– 2.2 mg kg^{-1}, and Haplic Cambisols Eutric– 1.8 mg kg^{-1}.

Table 3. Scheme of environmental standards for bismuth contaminated soils in the South of Russia related to a degree of failure of ecosystem functions

Soil	Not polluted	Little degree of pollution	Average degree of pollution	Strong degree of pollution
Degree of soil IIBS decline*	< 5 %	5 – 10 %	10 – 25 %	> 25 %
Disturbed ecosystem functions**	–	Informational value	Chemical, physical and chemical, biochemical, holistic	Physical
Soil	Bismuth concentration in soil, mg kg^{-1}			
Haplic Chernozem Calcic	<2.5	2.5–8.5	8.5–350	>350
Haplic Arenosols Eutric	<0.9	0.9–2.2	2.2–30	>30
Haplic Cambisols Eutric	< 0.8	0.8–1.8	1.8–20	> 20
Soil remediation techniques	Non-required	Phyto remediation, washings	Chemical reclamation	Full removal of contaminated layer

* IIBS evaluation according to Kolesnikov et al. (2019).

**Classification of soil ecosystem functions according to Dobrovolskiy and Nikitin (2006).

In addition, Table 3 presents the most effective soil remediation methods when the soil is contaminated with a specific concentration of Bi. The higher the Bi concentration in the soil, the more necessary chemical remediation and removal of the topsoil. The proposed rMPCs should be used in the implementation of various environmental protection measures, such as: environmental impact assessment (EIA), selection of methods for remediation of contaminated soils, etc. rMPCs should be used to assess soils not only in the South of Russia, but also similar soils around the world.

Conclusion

The results obtained showed that the soils contaminated with bismuth in the studied soils generally lose their biological properties: the total number of bacteria and the enzymatic activity (catalase and dehydrogenases) are reduced. The indicators of phytotoxicity (germination of radish seeds) increase when bismuth 3 and 30 mg kg^{-1} is added to the soil. The degree of deterioration of biological properties depends on two factors: the concentration of bismuth in the soil and the period of time after the start of contamination. The calculation and assessment of soil bismuth contamination by ecological regional maximum permissible concentrations (MPC) showed that, bismuth rMPCs for Haplic Chernozem Calcic is 8.5 mg kg^{-1}, Haplic Arenosols Eutric – 2.2 mg kg^{-1} and Haplic Cambisols Eutrics – 1.8 mg kg^{-1}. The established rMPCs should be referred to when implementing various environmental activities such as: environmental impact assessment (EIA), soil and ecosystem monitoring practices, choice of polluted soil reclamation techniques, risk assessment of technogenic disasters, soil certification, etc. The suggested rMPCs can be referred to for soil assessment not only in the South of Russia but also in similar soils worldwide.

Acknowledgements

Authors would also like to express acknowledgements to the criticism and constructive comments of the anonymous referees. The study was carried out with the support of the Ministry of Science and Higher Education of the Russian Federation within the framework of a state assignment (Southern Federal University, project No. 0852-2020-0029) and state support of the leading scientific schools of the Russian Federation (grant of the President of the Russian Federation SSh-2511.2020.11).

References

Akay, A., Sert, D., 2020. The effects of whey application on the soil biological properties and plant growth. *Eurasian Journal of Soil Science* 9 (4): 349-355.

Akimenko, Y.V., Kolesnikov, S.I., Kazeev, K.S., Minnikova, T.V., 2018. Biodiagnostics of consequences of soil contamination with modern biocides. 18th International Multidisciplinary Scientific GeoConference SGEM 2018. Conference Proceedings. 2-5 July 2018. Albena, Bulgaria. 18: 41–48.

Alekseenko, V.A., Alekseenko, A.V., 2013. Chemical elements in geochemical systems. Soil clarks of residential landscapes. Southern Federal University Press, Rostov on Don, Russia. 380p. [in Russian].

Cortada, U., Hidalgo, M.C., Martínez, J., Rey, J., 2018. Impact in soil caused by metal (loid)s in lead metallurgy. The case of Cruz Smelter (Southern Spain). *Journal of Geochemical Exploration* 190: 302–313.

Dobrovolskiy, G., Nikitin, E., 2006. Soil ecology – doctrine about ecological functions of soils. Moscow State University Nauka, Moscow, Russia. 362p. [in Russian].

Egorysheva, A.V., Ellert O.G., Zubavichus Y.V., Gajtko O.M., Efimov N.N., Svetogorov R.D., Murzin V.Yu., 2015. New complex bismuth oxides in the Bi_2O_3–NiO–Sb_2O_5 system and their properties. *Journal of Solid State Chemistry* 225: 97–104.

Elekes, C.C., Busuioc, G., 2010. The mycoremediation of metals polluted soils using wild growing species of mushrooms. Latest Trends on Engineering Education 1(1): 36–39. 22-24 July 2010, Varna, Bulgaria.

GOST RISO 22030-2009, 2009. National standard of Russian Federation. Soil quality. Biological methods. Chronic phytotoxicity for higher plants, Moscow, Russia. 20p.

Kabata-Pendias, A., Pendias, X., 2010. Trace Elements in Soils and Plants. 4th Edit. Boca Raton, CRC Press, FL, USA. 548p.

Kasimov, N., Vlasov, D., 2012.Technophilic ability of chemical elements in the early XXI century. Moscow State University. Moscow, Russia. Geography 5(1): 15–22 [in Russian].

Kızılkaya, R., Yertayeva, Z., Kaldybayev, S., Murzabayev, B., Zhapparova, A., Nurseitov, Z., 2021. Vermicomposting of anaerobically digested sewage sludge with hazelnut husk and cow manure by earthworm Eisenia foetida. *Eurasian Journal of Soil Science* 10 (1): 38-50.

Kolesnikov, S.I., Kazeev, K.S., Akimenko, Y.V., 2019. Development of regional standards for pollutants in the soil using biological parameters. *Environmental Monitoring and Assessment* 191: 544.

Kolesnikov, S.I., Tsepina, N.I., Sudina, L.V., Minnikova, T.V., Kazeev, K. S., Akimenko, Y.V., 2020. Silver ecotoxicity estimation by the soil state biological indicators. *Applied and Environmental Soil Science* Article ID 1207210.

Li, Z.Y, Ma, Z.W., van der Kuijp T.J., Yuan, Z.W., Huang, L., 2014. A review of soil heavy metal pollution from mines in China: Pollution and health risk assessment. *Science of the Total Environment* 468: 843–853.

Liu, B., Wu, F., Li, X., Fu, Zh., Deng, Q., Mo, C., Zhu, J., Zhu. Y., Liao, H., 2011. Arsenic, antimony and bismuth in hu-man hair from potentially exposed individuals in the vicinity of antimony mines in Southwest China. *Microchemical Journal* 97(1): 20–24.

Meyer, J., Schmidt, A., Michalke, K., Hensel, R., 2007. Volatilisation of metals and metalloids by the microbial population of analluvial soils. *Systematic and Applied Microbiology* 30(3): 229–238.

Murata, T., 2006. Effects of bismuth contamination on the growth and activity of soil microorganisms using thiols as model compounds. *Journal of Environmental Science and Health - Part A Toxic/Hazardous Substances and Environmental Engineering* 41(2): 161–172.

Murtić, S., Sijahović, E., Čivić, H., Tvica, M., Jurković, J., 2020. In situ immobilisation of heavy metals in soils using natural clay minerals. *Plant, Soil and Environment* 66: 632–638.

Nagata, T., 2015. Growth inhibition and IRT1 induction of Arabidopsis thaliana in response to bismuth. *Journal of Plant Biology* 58(5): 311–317.

Omouri, Z., Hawari, J., Fournier, M, Robidoux, P.Y., 2018. Bioavailability and chronic toxicity of bismuth citrate to earth-worm Eisenia andrei exposed to natural sandy soil. *Ecotoxicology and Environmental Safety* 147: 1–8.

Reus, T.L., Machado, T.N., Bezerra, A.G.Jr., Marcon, B.H., Paschoal, A.C.C., Kuligovski, C., de Aguiar, A.M., Dallagiovanna, B., 2018. Dose-dependent cytotoxicity of bismuth nanoparticles produced by LASiS in a reference mammalian cell line BALB/C 3T3. *Toxicology in Vitro* 53: 99–106.

Soriano, A., Pallarés, S., Pardo, F., Vicente, A.B., Sanfeliu, T., Bech, J., 2012. Deposition of heavy metals from particulate settleable matter in soils of an industrialised area. *Journal of Geochemical Exploration* 113: 36–44.

Wei, C., Deng, Q., Wu, F., Fu, Z., Xu, L., 2011. Arsenic, antimony, and bismuth uptake and accumulation by plants in an old antimony mine, China. *Biological Trace Element Research* 144(1-3): 1150–1158.

WRB, 2015. International soil classification system for naming soils and creating legends for soil maps. World Soil Resources Reports No. 106. Food and Agriculture Organization of the United Nations (FAO), Rome, Italy. 192p. Available at [access date: 11.11.2020]: http://www.fao.org/3/i3794en/I3794en.pdf

Xiong, Q.L., Zhao, W.J., Guo, X.Y., Shu, T.T., Chen, F.T., Zheng, X.X., Gong, Z.N., 2015. Dustfall heavy metal pollution dur-ing winter in North China. *Bulletin of Environmental Contamination and Toxicology* 95(4): 548–554.

Yurgenson, G.A, Gorban, D.N., 2017. Features of bismuth distribution in soils, technosoils and plants of the Sherlovoaya mountain ore region. *International Journal of Applied and Fundamental Research* 7: 111–116 [in Russian].

Zhang, C., Qiao, Q., Piper, J.D.A., Huang, B., 2011a. Assessment of heavy metal pollution from a Fe-smelting plant in urban river sediments using environmental magnetic and geochemical methods. *Environmental Pollution* 159(10): 3057–3070.

Zhang, N., Fu, N., Fang, Z., Feng, Y., Ke, L., 2011b. Simultaneous multi-channel hydride generation atomic fluorescence spectrometry determination of arsenic, bismuth, tellurium and selenium in tea leaves. *Food Chemistry* 124(3): 1185–1188.

Eurasian Journal of Soil Science 2021, 10(3), 243 - 250

Eurasian Journal of Soil Science

Journal homepage : http://ejss.fesss.org

Assessment of Water Cloud Model based on SAR and optical satellite data for surface soil moisture retrievals over agricultural area

Rida Khellouk [a,*], Ahmed Barakat [a], Aafaf El Jazouli [a], Hayat Lionboui [b], Tarik Benabdelouahab [b]

[a] Georesources and Environment Laboratory, Faculty of Sciences and Techniques, Sultan My Slimane University, Béni-Mellal, Morocco

[b] Natural Resources and Environment Department, National Institute of Agronomic Research, Rabat, Morocco

Article Info

Received : 26.08.2020
Accepted : 18.04.2021
Available online : 23.04.2021

Author(s)

R. Khellouk *
A. Barakat
A. El Jazouli
H. Lionboui
T. Benabdelouahab

* Corresponding author

Abstract

Water availability to plants a significant role in agricultural areas, especially in arid and semi-arid areas. This research aimed to evaluate the potential of Water Cloud Model (WCM) for retrieving surface soil moisture, which is associated to water availability, in a semi-arid areas based on the combination between Sentinel-1B SAR (Synthetic Aperture Radar) and optical Sentinel-2B data. The performance of the applied model was assessed using ground observed soil moisture (0-5 cm). Accuracy evaluation was performed by the cross-validation method (k-fold), it showed a coefficients of determination (R^2) of 0.65 and RMSE of 1.45%. The obtained results show a good concordance between retrieved model and ground observed surface soil moisture. In addition, this model was used for the mapping spatio-temporal variation of soil moisture at high spatial resolution in the study areas. This approach could be used by environmentalists and decision-makers as a practical tool for monitoring and estimating the change of surface moisture content.

Keywords: Remote sensing, Soil moisture, Sentinel-1B, Sentinel-2B, WCM, SAR, agricultural areas.

Introduction

The agricultural area is an important socioeconomic and strategic sector, especially in arid and semi-arid regions and half of the world's food comes from rainfed areas (Seckler et al., 1999; Geerts and Raes, 2009). In Morocco, water content availability is the principal factor for crop growth and final yield. Soil moisture, which is associated to water availability, is considered one of the most important agricultural variables (Jawson and Niemann, 2007; Sun et al., 2012; Benabdelouahab et al., 2015; Khellouk et al., 2019). In arid and semi-arid dryland conditions, the soil moisture estimation provides important information for assessing water content availability for vegetation growth, crop drought and yield prediction monitoring (Zhao et al., 2014; Yang et al., 2015; Pablos et al., 2017; Whyte et al., 2018). In face of the importance of soil moisture, its spatial and temporal assessment is difficult. The conventional methods based on in-situ observations provides very accurate punctual results (Chu, 2018). However, these soil moisture measurements; it is unable to extend it and generalized it for a large area due to its high cost and the large spatial heterogeneity of soil properties, vegetation cover and topography (Benabdelouahab et al., 2015).

In contrast with the previous methods, remote sensing tools provide efficient approaches for surface soil moisture retrievals at large-scale with high temporal and spatial resolution and low cost (Entekhabi et al.,

: https://doi.org/10.18393/ejss.926813
: http://ejss.fesss.org/10.18393/ejss.926813
Publisher : Federation of Eurasian Soil Science Societies
e-ISSN : 2147-4249

2010; Benabdelouahab et al., 2019). Three main remote sensing methods are employed for estimating soil moisture from spectral information: The optical, thermal infrared (TIR) and microwave (MW) ranges of the electromagnetic spectrum (Sadeghi et al., 2015). The optical methods are based on spectral indices behaviors related to soil water content changes. The application of these methods are simple, but can be easily affected by meteorological conditions (Sadeghi et al., 2015). For infrared thermal methods, they make it possible to estimate surface soil moisture basing on thermal characteristics (Verstraeten et al., 2006). However, in areas completely covered by vegetation, information on soil radiation is masked by the vegetation cover, which influences the accuracy of the soil moisture assessment. Therefore, these methods are applicable for monitoring soil moisture in bare and sparse vegetation areas in cloudless conditions (Khellouk et al., 2018). However, microwave remote sensing (SAR) at has stronger frequencies and longer wavelengths has a higher penetrating ability, which is less affected by weather conditions, and can be used to monitor various surface parameters, including surface soil moisture, over agricultural regions (Benabdelouahab et al., 2019).

Many models based on SAR remote sensing have been proposed to recover soil moisture, including the Oh model (Oh et al., 1992), IEM model (Fung and Chen, 1992), Dubois model (Dubois et al., 1995) and Baghdadi model (Baghdadi et al., 2016). These models cannot be applied directly for estimating surface soil moisture over densely vegetated areas due to the speckle effects caused by the vegetation leaves structure (Prakash et al., 2012). For this purpose, Attema and Ulaby (1978) have been developed the semi-empirical Water Cloud Model (WCM) to remove scattering effect of vegetation cover in order to estimate soil moisture content. This model has been applied in several areas for multiple SAR satellites, such as C-band ASAR and SPOT/HRV data (Zribi et al., 2014), ESA's ENVIronment SATellite (ENVISAT) platform (Kumar et al., 2012), X-band SAR data (El Hajj et al., 2016), TERRASAR-X data (Gorrab et al., 2015). Furthermore, several studies have shown that the results of soil moisture retrieval are precise when optical and microwave data were integrated rather than using separate microwave data (Notarnicola et al., 2006; Hosseini and Saradjian, 2011). In this context, the objective of this work is considerering a synergy of Sentinel-1B Synthetic Aperture Radar (SAR) and optical Sentinel-2B data to evaluate the potential of Water Cloud Model (WCM) for estimating soil moisture in the central provinces of Fkih-Ben Saleh and Khouribga (Morocco). In addition, the model was applied to mapping the surface soil moisture. The soil moisture maps analysis, accurately indicate the spatiotemporal change of soil moisture content status in the study area. The area chosen is subject to recurrent drought and rainfall irregularity, and whose results from this study can be exploited to improve land-use planning, crop choices, and soil and water management.

Material and Methods

Study area

The study zone is located in the Beni-Mellal-Khénifra region, Morocco (32°25'- 33°01'N; 7°26'- 7°15'W) covering 2157 ha (Figure 1). Their economy is mainly based on agricultural activities due to soil types (fertile soils) (Barakat et al. 2017; Ennaji et al. 2018; Oumenskou et al. 2018). At the site, the altitude varies between 440 and 882 meters above the mean sea level.

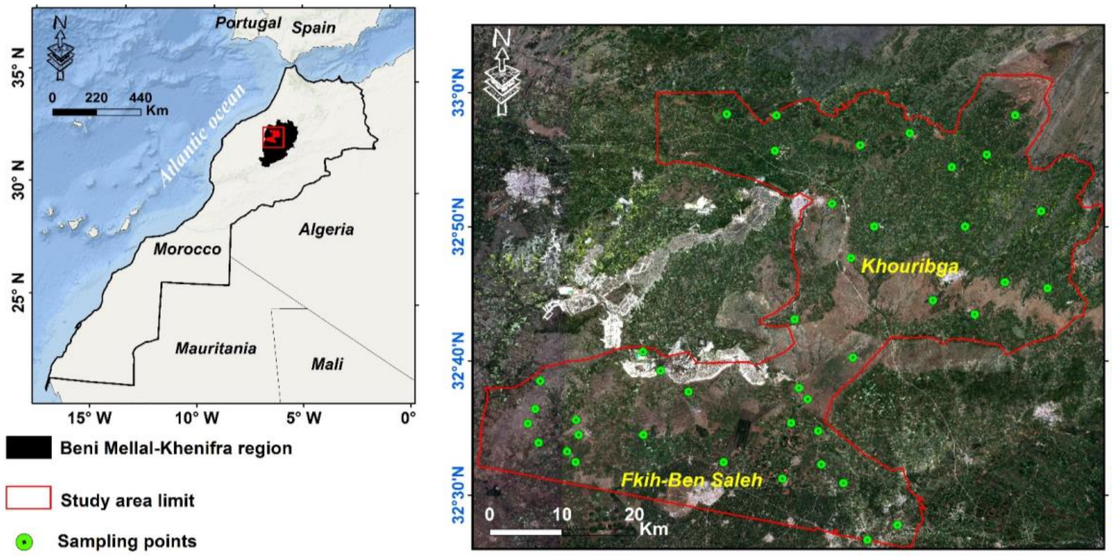


Figure 1. Localization of the study area and sampled points

In this region, cultivated land covers a total area of 70%, which is dominated by cereal crops (42.7%). The climate is semi-arid with mean annual temperature of 3.5°C in winter and 38°C in summer, the total annual rainfall is 350 mm with an annual evaporation of around 1800 mm. The rainy season starts in November and ends in March while the dry season is from April to October. The study area is dominated by dry agricultural land. So, in this area, the surface soil moisture presents is one of the essential parameters of agricultural growth and can directly affect crop productivity.

Soil moisture data

The measurement of soil moisture content covered the study site were collected randomly at the depth of 0-5 cm (Figure 1). At the sampling sites, these soil samples were georeferenced with a with a GPS receiver, packed in polyethylene bags, labelled and transported to the laboratory for preparation and analysis. Then, the soil surface moisture content of each sample taken was determined in the laboratory by the oven drying method at 105 °C for about 18 hours by comparing weights before and after drying. The percentage of soil moisture is calculated using the expression below.

$$\text{Soil moisture}\ (\%) = \frac{(\text{Weight before drying} - \text{Weight after drying})}{\text{Weight before drying}} \times 100 \quad (1)$$

The soil sampling was collected simultaneously with satellite imagery acquisition dates to obtain a good agreement between measured and predicted soil moisture from remotely sensed data. The soil moisture sampling have been converted to shapefile points, which allows to extract pixel values from each satellite image linked spatially and temporally to ground measurements.

Satellite data and processing

Sentinel-1B SAR data

Sentinel-1 (S1) satellites are an important part of the European Copernicus program (Global Monitoring for Environment and Security-GMES). The Sentinel-1 operates in a C-band SAR sensor (5.4 GHz frequency), and provides double polarization: vertical-vertical (VV) and vertical-horizontal (VH) imagery with a spatial resolution of 10 m.

In this study, five Sentinel-1 SAR images covering the studied area from 21 January to 26 June 2018 were acquired (Table 1). These satellite imageries were acquired during different periods of growing season for agricultural crops. It was freely downloaded from the Open Access Hub site (https://scihub.copernicus.eu/dhus/#/home). Then, the acquired SAR images was processed using the SNAP software (Sentinel Application Platform) (http://step.esa.int/main/toolboxes/snap). The geometric correction was applied using the Range-Doppler terrain correction algorithm. Then, the speckle filtering was applied using refined lee filter. In addition, the radiometric calibration was used to derive the backscattering coefficient data. Finally, the backscattering coefficient (in linear/Digital number format) is converted to decibels (dB) unit using SNAP software.

Sentinel-2B optical data

The Sentinel-2B optical images of the study site were acquired with atmospheric and geometric corrections from Theia Scientific Expertise Center (https://www.theia-land.fr/) (Table 1). The acquired satellite images are characterized by a high spatial resolution 10 meters and temporal resolution 5 days. For each image date, the Normalized Difference Vegetation Index (NDVI) was then calculated with the Red (Band 4) and Near-Infrared (NIR) (Band 8) using the equation 2:

$$\text{NDVI}= (\text{NIR}- \text{RED})/(\text{NIR}+\text{RED}) \quad (2)$$

Table 1. List of satellite data acquired over study area.

Data type	Time of acquisition	Data type	Time of acquisition
Sentinel-1 B	21 January 2018 26 February 2018 22 March 2018 24 April 2018 26 June 2018	Sentinel-2 B	19 January 2018 23 February 2018 23March 2018 20 April 2018 26 June 2018

The acquisition dates of some Sentinel-2B and SAR Sentinel-1B images are different; the maximum differences between these Sentinel-2B and SAR data is four days, whose NDVI values show low variation.

Methods

The overall procedure applied in this study to estimate soil moisture is represented in Figure 2. First, in order to derive the backscattering coefficient, the acquired Sentinel 1 radar data were pre-processed. Then, for each pixel the backscattering coefficients values that corresponding spatially to each ground measurement were extracted according to the coordinates (X, Y). In addition, the NDVI index images covering the study area were calculated based on the bands 4 and 8 of acquired Sentinel-2B images. Then, the vegetation indices (NDVI) values of each sample were extracted according to the coordinates (X, Y).

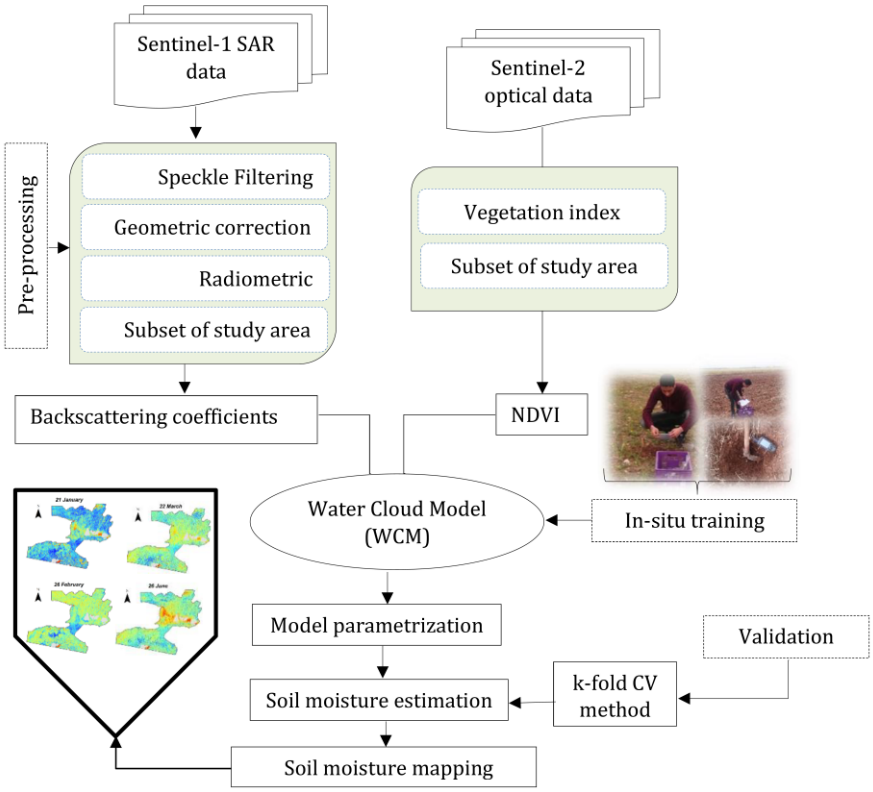


Figure 2. Flowchart of the methodology followed in this study

Afterwards, the extracted values were used for parametrization and calculate the components of the Water Cloud Model (WCM). This model links the backscattering coefficient (σ^0) to surface soil moisture (Kumar et al., 2015). It compounds the backscatter coefficients due to vegetation (σ^0_{veg}) and to the soil (σ^0_{soil}). The σ^0_{veg} of WCM depends on vegetation characteristics (Bala et al., 2015; Bousbih et al., 2017). In this model, the total backscattering coefficient (σ^0) is expressed by the following formulas:

$$\sigma^0 = \sigma^0_{veg} + T^2\, \sigma^0_{soil} \tag{3}$$

Where σ^0 is the total backscattering coefficient (dB), σ^0_{soil} represents the soil backscattering coefficient and σ^0_{veg} represents the vegetation backscattering coefficient. T^2 is a bidirectional attenuation parameter for radar waves passing through vegetation.

$$T^2 = \exp(-2BV_1 \sec(\theta)) \tag{4}$$

$$\sigma^0_{veg} = A\, V_1 \cos(\theta)\, (1 - T^2) \tag{5}$$

Where V_1 is the vegetation indicator (NDVI); A and B are empirical coefficients that depends on the vegetation parameter. In this research we used that defined by (Bousbih et al., 2017) in a study area with land cover similar to our study area; θ is incident angle (°) of Sentinel-1 image, it was derived from metadata file for each acquired satellite images.

The soil contribution σ^0_{soil} is expressed by a linear regression equation as a function of the surface soil moisture:

$$\sigma^0_{soil} = C + D \times SM \tag{6}$$

C and D are the coefficients of bare soils, which are, characterizes the relationship between surface soil moisture and radar signal. These parameters were defined on the basis of simple linear correlation between the soil backscatter coefficient and the in situ measurements (soil moisture).

Substituting the parameters leads to get the formula of Water Cloud Model (WCM):

$$\sigma^0\ (\text{dB}) = A\ \text{NDVI} \cos(\theta)\ (1 - \exp(-2B\text{NDVI} \sec(\theta))) + (C + D \times SM) \tag{7}$$

The soil moisture obtained by equation 7 is expressed in dB unit. Therefore, to have the soil moisture in quantitative unit we headed the parameter (SM) of the equation 7 to get the formula of soil moisture (SM):

$$SM = \frac{(\sigma^0 - (A\,V1 \cos(\theta)\ (1 - \exp(-2BV1 \sec(\theta)))))}{\frac{\exp(-2BV1 \sec(\theta))}{D}} - C \tag{8}$$

The model prediction results were assessed using field data of soil moisture. Then, this model was applied to map the spatio-temporal variability of surface soil moisture. These maps were generated for each date of the satellite image acquired.

Evaluation and Validation of soil moisture retrieval model

The evaluation was carried out by comparing the applied model results and observed measurements. Soil moisture data measured at 41 sampling sites were used for the model evaluation. This evaluation was carried out using two statistical parameters such as the coefficient of determination (R^2) to analyze the linear relationship between the measured soil moisture and the estimated soil moisture (equation 9) and the root mean square error (RMSE) to assess the differences between values estimated by a model and the values measured (equation 10).

$$R^2 = \left(\frac{\sum_{i=1}^{n} (x_i - \bar{x}) \cdot (y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n} (x_i - \bar{x})^2 \cdot \sum_{i=1}^{n} (y_i - \bar{y})^2}} \right)^2 \tag{9}$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n} (y_i - x_i)^2}{n}} \tag{10}$$

where: x_i and y_i representing the measured and estimated soil moisture values, respectively;

and $\bar{y}$ representing the mean of measured and estimated soil moisture values respectively;

i represents an identifier varying from 1 to n; n represents the number of measured values.

The predictive accuracy of a model was assessed using the cross validation approach (k-fold CV) (Cassel, 2007). This statistical approach is based on k replicate samples of measured data, (k-1) / k of data for model construction and the remaining 1/k for model testing. We emphasize that the random k-fold CV takes k independent samples of size N*(k-1)/k (Cassel, 2007). In this study, we used 33.3% of data for validation, the remaining 66.6% was used as training data, with N = 10 repetitions.

Results and Discussion

Water cloud model parametrization

The WCM characterized by two important components, namely : (i) the soil backscattering coefficient (σ^0_{soil}), which can be determined by using a linear regression with measurement of soil moisture, and (ii) the vegetation water content (σ^0_{veg}) that can be handled by Vegetation Index (NDVI) (Bala et al., 2015; Bousbih et al., 2017). The application of this model was parameterized based on NDVI as vegetation indicator, ground observed soil moisture (0-5 cm) and SAR data. The first component concerns the soil contribution σ^0_{soil} (equation 6) which is defined based on the correlation between the soil backscatter coefficient and the ground measurements of surface soil moisture. The results obtained is σ^0_{soil} = -0.16* SM-17.90 with D= -0.16 and C= -17.90. The second component is the vegetation backscattering coefficient (σ^0_{veg}) that is characterized by two coefficients A and B (equation 4 and 5). In this research, we used that defined by (Bousbih et al., 2018) in a study area with land cover similar to our study area [A=0.18 and B=0.25]. The NDVI retrieved by the optical data was used as a vegetation index. It is the most effective index and the most used in several studies (El Hajj et al., 2018; Rawat et al., 2019) for soil moisture estimation of based on Water cloud model. The set of results derived for each parameter were integrated in the model in order to generate the water cloud model (WCM) in (dB). Then, an inversion approach (Zhuo et al., 2019) of this model was applied to transform the WCM values into a percentage unit, as expressed by the equation 8.

Assessment of Water Cloud Model (WCM)

The relationship between observed and estimated soil moisture using the WCM is shown in the scatter plot (Figure 3). A linear correlation between the observed and estimated soil moisture was observed, which reveal that the approach discuss handle here can be effective and successfully used to retrieval of surface soil moisture in study site over agricultural area. The statistical analysis of the results showed the level of agreement of the derived soil moisture model with the observed soil moisture. The evaluation model statistical indicators obtained were 0.70 and 1.30% for R^2 and RMSE, respectively.

In order to validate the obtained results, we have compared the observed surface soil moisture values and those predicted by using the cross validation method, (Figure 4). The validation model statistical parameters obtained for predicted soil moisture in study area were 0.65 and 1.45% for R^2 and RMSE, respectively. These results are in good agreement with those reported by Bao et al. (2018) obtaining an R^2 of 0.62. Also, Rawat et al. (2019) reported similar results using the WCM for estimation of soil moisture over agricultural area using Landsat-8 and Sentinel-1 satellite data in Punjab state (India). This model gives encouraging results for an accurate estimate of soil moisture. It can be applied to monitoring the soil moisture status in regional areas.

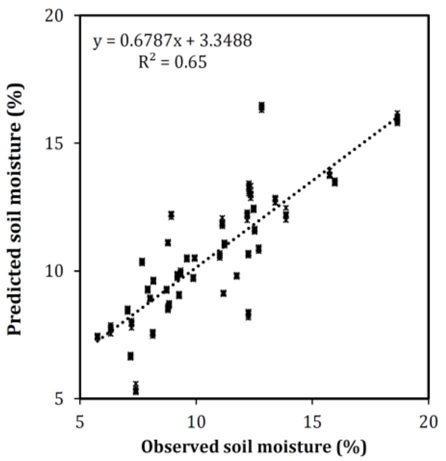


Figure 3. Linear relationship between the observed soil moisture and the soil moisture estimated by the WCM

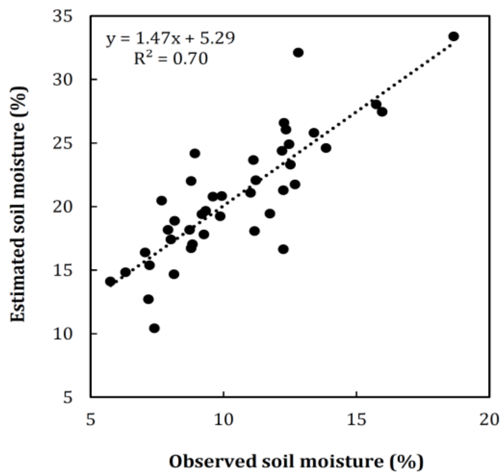


Figure 4. Comparison between observed and predicted soil moisture (%) using the k-fold cross validation

In the present work, the assessment of Water Cloud Model based on SAR and optical satellite data for surface soil moisture retrievals over agricultural area showed significant results. The main advantage of our methodology is the possibility of retrieving soil moisture using freely available SAR and optical remote sensing data. It can be offering many advantages for a number of research and environmental applications.

Soil moisture mapping

Soil moisture mapping is an important technique for analyzing the spatial variability of soil water content levels. In this study, soil moisture mapping was performed using the WCM model and Sentinel-1B and Sentinel-2B data over the study site. Figure 5 represent the soil moisture maps covering the study area during the agricultural season 2018 (from January to June). The maps obtained are clearly showed that the different classes of soil surface moisture distribution varied from 0% (red color) to> 23% (blue color).

Spatial analysis of maps has shown that areas with low soil moisture levels (0-11%) are located in the middle and south-east of the study site, they cover a large area in early January and at the end of June, this is the case on January 21, March 22, April 24 and June 26. This spatial distribution in these zones can be explained by the soil texture types (loam-clay soils, loam soils) and low rainfall levels. Contrariwise, the northern part is characterized by a significant increase in the soil moisture levels (January 21, March 22 and April 24), these levels of soil moisture are explained by the topographical parameters (high altitude :700-1000 m), the increase in mean of rainfall and the predominance of clay soil.

Precipitation is the main source of soil water content in all parts of the study area. In all derived maps, the percentage of soil moisture depends on the date of acquisition of the satellite data and the date of rainfall. More than the gap is longer more than the soil moisture rate is decreased and vice versa. For example in the map of January 21, high soil moisture was noted which is explained by the rate of rainfall before this date (12 mm). However, in 26 June, the distribution of soil moisture is lower than other dates. The distribution of soil moisture in this period (summer) can be justified by the increase in precipitation and decrease in evaporation due to the drop average in temperature (38°C).

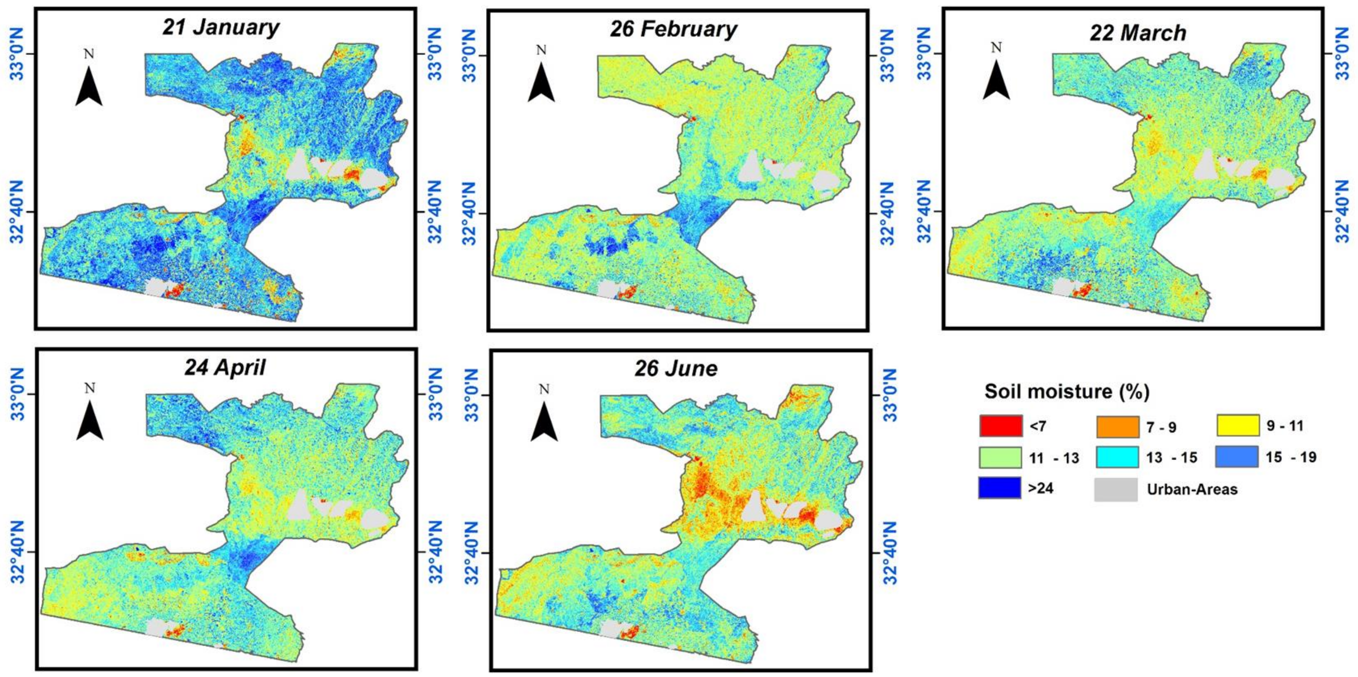


Figure 5. Spatial distribution of the surface soil moisture from 21 January to 26 June -2018 in the study area

Conclusion

In dry regions, soil moisture estimation can avoid numerous socio-economic issues by helping farmers to make informed decisions for improving their agricultural production. Thus, the aim of this research was to evaluate the potential of WCM to estimate the surface soil moisture using SAR and optical satellite data. Model accuracy of the retrieval soil moisture has tested and found good agreement with ground observed soil moisture. In addition, this model was used for the mapping spatio-temporal variation of soil moisture during the agricultural season (2018) in the study area. The mapping results showed the distribution and the different variations of surface water content over the whole study area. We concluded that the tested approach could be used as an efficient tool to estimate, monitoring and mapping the variation in surface soil moisture in dry areas. It can be applied by farmers for crop management and monitoring.

References

Attema, E.P.W., Ulaby, F.T., 1978. Vegetation modeled as a water cloud. *Radio Science* 13(2): 357-364.

Baghdadi, N., Choker, M., Zribi, M., El-hajj, M., Paloscia, S., Verhoest, N., Lievens, H., Baup, F., Mattia, F., 2016. A New Empirical Model for Radar Scattering from Bare Soil Surfaces. *Remote Sensing* 8(11): 920.

Bala, A., Rawat, K.S., Misra A., Srivastava, A., 2015. Vegetation indices mapping for Bhiwani district of Haryana (India) through LANDSAT-7ETM+ and remote sensing techniques. *Journal of Applied and Natural Science* 7(2): 874-879.

Bao, Y., Lin, L., Wu, S., Deng, K.A.K., Petropoulos, G.P., 2018. Surface soil moisture retrievals over partially vegetated areas from the synergy of Sentinel-1 and Landsat 8 data using a modified water-cloud model. *International Journal of Applied Earth Observation and Geoinformation* 72: 76-85.

Barakat, A., Hilali, A., El Baghdadi, M., Touhami, F., 2017. Landfill site selection with GIS-based multi-criteria evaluation technique. A case study in Béni Mellal-Khouribga Region, Morocco. *Environmental Earth Sciences* 76(12): 413.

Benabdelouahab, T., Balaghi, R., Hadria, R., Lionboui, H., Minet, J., Tychon B., 2015. Monitoring surface water content using visible and short-wave infrared SPOT-5 data of wheat plots in irrigated semi-arid regions. *International Journal of Remote Sensing* 36(15): 4018-4036.

Benabdelouahab, T., Derauw, D., Lionboui, H., Hadria, R., Tychon, B., Boudhar, A., Barbier, C., 2019. Using SAR data to detect wheat irrigation supply in an irrigated semi-arid area. *Journal of Agricultural Science* 11(1): 21-30.

Bousbih, S., Zribi, M., Lili-Chabaane, Z., Baghdadi, N., El Hajj, M., Gao, Q., Mougenot, B., 2017. Potential of Sentinel-1 radar data for the assessment of soil and cereal cover parameters. *Sensors* 17(11): 2617.

Cassel, D.L., 2007. Re-sampling and simulation, the SAS way. Proceedings of the SAS Global Forum 2007 Conference, SAS Institute Inc., Cary, NC.

Chu, D., 2018. MODIS remote sensing approaches to monitoring soil moisture in Tibet, China. *Remote Sensing letters* 9(12): 1148-1157.

Dubois, P.C., van Zyl, J., Engman, T., 1995. Measuring soil moisture with imaging radars *IEEE Transactions on Geoscience and Remote Sensing* 33(4): 915–926.

El Hajj, M., Baghdadi, N., Zribi, M., Bazzi, H., 2018. Coupling Sentinel-1 and Sentinel-2 Images for Operational Soil Moisture Mapping. 2018 IEEE International Geoscience and Remote Sensing Symposium 22-27 July 2018. Valencia, Spain. pp. 5537-5540.

El Hajj, M., Baghdadi, N., Zribi, M., Belaud, G., Cheviron, B., Courault, D., Charron, F., 2016. Soil moisture retrieval over irrigated grassland using X-band SAR data. *Remote Sensing of Environment* 176: 202–218.

Ennaji, W., Barakat, A., Karaoui, I., El Baghdadi, M., Arioua, A., 2018. Remote sensing approach to assess salt-affected soils in the north-east part of Tadla plain, Morocco. *Geology, Ecology, and Landscapes* 2(1): 22-28.

Entekhabi, D., Reichle, R.H., Koster, R.D., Crow, W.T., 2010. Performance metrics for soil moisture retrievals and application requirements. *Journal of Hydrometeorology* 11(3): 832-840.

Fung, A. K., Li, Z., Chen, K.S., 1992. Backscattering from a randomly rough dielectric surface. *IEEE Transactions on Geoscience and Remote Sensing* 30(2): 356–369.

Gorrab, A., Zribi, M., Baghdadi, N., Mougenot, B., Fanise, P., Chabaane, Z., 2015. Retrieval of both soil moisture and texture using TerraSAR-X images. *Remote Sensing* 7(8): 10098-10116.

Geerts, S., Raes, D., 2009. Deficit irrigation as an on-farm strategy to maximize crop water productivity in dry areas. *Agricultural Water Management* 96(9): 1275-1284.

Hosseini, M., Saradjian, M., 2011. Soil moisture estimation based on integration of optical and SAR images. *Canadian Journal of Remote Sensing* 37(1): 112–121.

Jawson, S.D., Niemann, J.D., 2007. Spatial patterns from EOF analysis of soil moisture at a large scale and their dependence on soil, land-use, and topographic properties. *Advances in Water Resources* 30(3): 366–381.

Kumar, K., Rao, H.P.S., Arora, M.K., 2015. Study of water cloud model vegetation descriptors in estimating soil moisture in Solani catchment. *Hydrological Processes* 29(9): 2137-2148.

Kumar, K., Hari Prasad, K.S., Arora, M.K., 2012. Estimation of water cloud model vegetation parameters using a genetic algorithm. *Hydrological Sciences Journal* 57(4): 776–789.

Notarnicola, C., Angiulli, M., Posa, F., 2006. Use of radar and optical remotely sensed data for soil moisture retrieval over vegetated areas. *IEEE Transactions on Geoscience and Remote Sensing* 44(4): 925–935.

Oh, Y., Sarabandi, K., Ulaby, F.T., 1992. An empirical model and an inversion technique for radar scattering from bare soil surfaces. *IEEE Transactions on Geoscience and Remote Sensing* 30(2): 370–381.

Oumenskou, H., El Baghdadi, M., Barakat, A., Aquit, M., Ennaji, W., Karroum, L.A., Aadraoui, M., 2019. Multivariate statistical analysis for spatial evaluation of physicochemical properties of agricultural soils from Beni-Amir irrigated perimeter, Tadla plain, Morocco. Geology, Ecology, and Landscapes 3(2): 83-94.

Pablos, M., Martínez-Fernández, J., Sánchez, N., González-Zamora, Á., 2017. Temporal and spatial comparison of agricultural drought indices from moderate resolution satellite soil moisture data over northwest Spain. *Remote Sensing* 9(11): 1168.

Prakash, R.; Singh, D.; Pathak, N.P., 2012. A fusion approach to retrieve soil moisture with SAR and optical data. IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing 5(1): 196–206.

Rawat, K.S., Singh, S.K., Pal, R.K. 2012, 2019. Synergetic methodology for estimation of soil moisture over agricultural area using Landsat-8 and Sentinel-1 satellite data. *Remote Sensing Applications: Society and Environment* 15: 100250.

Khellouk, R., Barakat, A., Jazouli, A.E., Boudhar, A., Lionboui, H., Rais, J., Benabdelouahab, T., 2019. An integrated methodology for surface soil moisture estimating using remote sensing data approach. *Geocarto International*

Khellouk, R., Barakat, A., Boudhar, A., Hadria, R., Lionboui, H., El Jazouli, A., Benabdelouahab, T., 2018. Spatiotemporal monitoring of surface soil moisture using optical remote sensing data: a case study in a semi-arid area. *Journal of Spatial Science* 65(3): 481-499.

Sadeghi, M., Jones, S.B., Philpot, W.D., 2015. A linear physically-based model for remote sensing of soil moisture using short wave infrared bands. *Remote Sensing of Environment* 164: 66–76.

Seckler, D., Barker, R., Amarasinghe, U., 1999. Water scarcity in the twenty-first century. *International Journal of Water Resources Development* 15(1-2): 29–42.

Sun, L, Sun, R., Li, X., Liang, S., Zhang, R., 2012. Monitoring surface soil moistures tatus based on remotely sensed surface temperature and vegetation index information. *Agricultural and Forest Meteorology* 166-167: 175–187.

Verstraeten, W.W., Veroustraete, F., van der Sande, C.J., Grootaers, I., Feyen, J., 2006. Soil moisture retrieval using thermal inertia, determined with visible and thermal spaceborne data, validated for European forests. *Remote Sensing of Environment* 101: 299-314.

Whyte, A., Fredinos, K.P., Petropoulos, G.P., 2018. A new synergistic approach for monitoring wetlands using Sentinels - 1 and 2 data with object-based machine learning algorithms. *Environmental modelling & Software* 104: 40–54.

Yang, Y., Guan, H., Long, D., Liu, B., Qin, G., Qin, J., Batelaan, O., 2015. Estimation of surface soil moisture from thermal infrared remote sensing using an improved trapezoid method. *Remote Sensing* 7(7) : 8250-8270.

Zhao, L., Yang, K., Qin, J., Chen, Y., Tang, W., Lu, H., Yang, Z.L., 2014. The scale-dependence of SMOS soil moisture accuracy and its improvement through land data assimilation in the central Tibetan Plateau. *Remote Sensing of Environment* 152: 345-355.

Zhuo, W., Huang, J., Li, L., Zhang, X., Ma, H., Gao, X., Xiao, X., 2019. Assimilating soil moisture retrieved from Sentinel-1 and Sentinel-2 data into WOFOST model to improve winter wheat yield estimation. *Remote Sensing* 11(13):1618.

Zribi, M., Kotti, F., Wagner, W., Amri, R., Shabou, M., Lili-Chabaane, Z., Baghdadi, N., 2014. Soil moisture mapping in a semiarid region, based on ASAR/Wide Swath satellite data. *Water Resources Research* 50(2): 823–835.

Eurasian Journal of Soil Science 2021, 10(3), 251 - 258

Eurasian Journal of Soil Science

Journal homepage : http://ejss.fesss.org

Transformation of plant and soil covers of the Botanical nature monument "Pine forest near Venetsiya village" (Russia) as a result of a windfall

Ruslan Suleymanov [a,b]*, Mikhail Yakimov [b], Peter Liebelt [c], Pavel Shirokikh [a], Azamat Suleymanov [a], Evgeny Abakumov [d], Ilgiza Adelmurzina [b], Elvera Bakieva [b], Ilgiz Asylbaev [f]

[a] Ufa Institute of Biology, Ufa Federal Research Center Russian Academy of Sciences, Ufa, Russia
[b] Bashkir State University, Faculty of Earth Sciences and Tourism, Department of Geodesy, Cartography and Geographical Information Systems, Ufa, Russia
[c] Martin Luther University Halle-Wittenberg, Institute of Geosciences and Geography, Halle (Saale), Germany
[d] Saint Petersburg State University, Faculty of Biology, Department of Applied Ecology, Saint Petersburg, Russia
[e] Bashkir State Agrarian University, Faculty of Agrotechnologies and Forestry, Department of Soil Science, Agrochemistry and Precision Agriculture, Ufa, Russia

Article Info

Received : 16.10.2020
Accepted : 18.04.2021
Available online : 23.04.2021

Author(s)

R. Suleymanov *
M. Yakimov
P. Liebelt
P. Shirokikh
A. Suleymanov
E. Abakumov
I. Adelmurzina
E. Bakieva
I. Asylbaev

* Corresponding author

Abstract

The article presents the results of complex research (research was conducted in 2019) of the Botanical natural monument territory "Pine forest near Venetsiya village" (Russia). In 2007, part of the nature monument territory was destroyed by a hurricane, resulting in massive windfall. The purpose of the research was to study the processes of evolution of natural complexes (vegetation and soil cover) in the areas affected by the hurricane. Classification of vegetation was done according to the Braun-Blanquet and Kopečký and Hejný approaches. NDVI (Normalized Difference Vegetation Index) was used to estimate the amount of photosynthetically active biomass. Changes in morphological, physical and chemical properties were studied in the soil cover. The conducted research showed that the vegetation of the natural monument is represented by relict pine and broad-leaved pine forests. Under the pine canopy linden and birch are dominated. In the herb layer grow in various combinations of nemoral and boreal species. Soil cover is represented by Gray-humus (Umbric Luvisol). There is a strong transformation of vegetation in the areas damaged by the hurricane in 12 years (2007-2019). There is an active formation of highly productive herbaceous vegetation and renewal of deciduous stands, which leads to an increase in biomass (confirmed by changes in NDVI). The terminal stage of the restoration succession will be the formation of secondary deciduous and mixed nemoral forests. The active development of grass vegetation leads to the formation of a sod horizon on the surface of the soil with a thickness of about 14 cm. There is also an increase in the content of organic carbon, alkaline-hydrolyzable nitrogen and mobile phosphorus, the value of electrical resistivity increases and acidification of the soil solution.

Keywords: Pine forest, soil properties, vegetation type, windfall.

Introduction

One of the negative impacts of global climate change is the occurrence of wind storms such as hurricanes and tornado. According to forecasts, as the average global temperature rises, their intensity and strength will

: https://doi.org/10.18393/ejss.926882
: http://ejss.fesss.org/10.18393/ejss.926882
Publisher : Federation of Eurasian Soil Science Societies
e-ISSN : 2147-4249

only increase (Long et al., 2018; Santoro and D'Amato, 2019). They affect not only coastal areas and islands, but also inland areas (Chernokulsky and Shikhov, 2018; Sahoo et al., 2019; De Beurs et al., 2019; Ezer, 2020). Currently, hurricanes, for example, have been appearing in new places where they've never met before (Hoffmann et al., 2018; Barrett et al., 2020). With great destructive power, wind storms cause huge loss of life and property damage (Moore, 2017; Diaz and Joseph, 2019; Cui and Caracoglia, 2019). They also have a strong impact on natural complexes, such as coastal wetlands, (Majidzadeh et al., 2020; Mo et al., 2020), tropical dry forests (Novais et al., 2020), deciduous forests (Santoro and D'Amato, 2019), agricultural land (Strader et al., 2018; Baker et al., 2020) and sandy sediments (Meixler, 2017).

Recently, cases of hurricanes have become more frequent in Russia, including the Republic of Bashkortostan. They influence the forests, which leads to the formation of windfalls. As a result of sharp change of ecological factors, determining the functioning of forest ecosystems, change of structure of plant communities and correlation of dominance of various herbaceous species of plants in the ground cover is observed (Shirokikh et al., 2017; Shikhov and Chernokulsky, 2018). Thus, there is a need to study the processes of evolution of natural complexes (vegetation and soil cover) destroyed as a result of the hurricane. Studies will allow to determine the direction of their development and assess the potential of self-recovery in the same natural and climatic conditions to develop methods for their restoration.

Material and Methods

The research was conducted on the territory of the Botanical nature monument of regional importance "Pine forest near Venetsiya village". The site is located in the northwestern part of the Republic of Bashkortostan (Dyurtyuli city, Venetsiya village) on the right bank of the Belaya River (Figure 1). The natural monument was created on July 17, 1965, and has scientific, environmental, and recreational significance. The total area is 490.0 hectares (The Register..., 2016).

Figure 1. Map of the study area (image source: www.google.com/intl/ru/earth).

Note: the basic soil pits are shown as triangles, the small soil pits as circles

The natural complex of the monument is represented by relict pine and broad-leaved pine forests on the sandy terraces of the Belaya River. Dominated by bilberry, lingonberry, and nemoral pine-deciduous forests. Tree stand are highly productive, the average age of pines is 45-80 years, and individual stands reach 100 years or more. They belong to the green zone and forbidden lanes. Under the pine canopy linden and birch are dominated. In the undergrowth are common *Euonymus verrucosa*, *Lonicera xylosteum, Coryllus avellana, Sorbus aucuparia* and *Padus avium*. In the herb layer grow in various combinations of nemoral and boreal species. There is a rare species - *Chimaphila umbellata* (L.) W.P.C. Barton, included in the Red book of the

Republic of Bashkortostan (2011). Unfortunately, in 2007, a significant part of the pine forests was destroyed by a hurricane, so it is necessary to adjust the area and borders of the natural monument (Cadastral..., 2019).

The geomorphological area is located on the III floodplain terrace of the Belaya River with heights of 70-90 m. The area is composed of sands, sandy loams and loams of yellowish-brown Upper Quaternary time (Kadilnikov, 1964).

According to the physical and geographical regionalization, this area belongs to the forest natural and climatic zone of the coniferous-broadleaved forest subzone. The climate at study area characterized as moderate continental with average humidity or as warm-summer humid continental (Dfb) by the Köppen climate classification (Beck et al., 2018). The average annual temperature is +1.7°C, the average temperature in January is -14.9°C, the average temperature in July is +18°C, the duration of the frost-free period is 88-100 days, the annual rainfall is 515-580 mm, the height of snow cover is 30-50 cm (Kadilnikov, 1964).

Research has been was conducted at two key sites. The first site it is the area of the botanical nature monument that was not affected by the hurricane (nature area), the second site it is the area that was affected by the hurricane. The study of vegetation and soil cover was conducted in the studied areas.

Moreover, the geobotanical description was performed on plots where soil pits were located. Geobotanical releves and classification of vegetation was done according to the Braun-Blanquet (Westhoff and van der Maarel, 1978) and Kopečký and Hejný (1974) approaches. The syntaxon names follow the International Code of Phytosociological Nomenclature (Weber et al., 2000). The names of plant species are given by the species list of Czerepanov (1995).

To estimate the amount of photosynthetically active biomass was used the Normalized Difference Vegetation Index (NDVI). The calculation was based on space images from Landsat 5 (L5) and Landsat 8 (L8) satellites with a spatial resolution of 30 m, received from the U.S. Geological Survey archive (https://earthexplorer.usgs.gov/). Imaging dates: 16 July 2006 (L5 satellite); 12 June 2008 (L5 satellite); 13 August 2013 (L8 satellite); 2 June 2019 (L8 satellite). NDVI Index calculations were performed using ENVI 5.2 software package. The final thematic maps and area calculations were made in MapInfo 12.5 geographic information system.

Soil classification, diagnostics of the soil profile and genetic horizons ware carried out taking into account the substantive genetic classification (Shishov et al., 2004). Basic profiles (1D-2019 and 2D-2019) and small pits (five each) at key sites were laid to most fully reflect the state of natural complexes. Soil samples for chemical analysis were taken from genetic horizons. Field soil moisture content was determined in the field by using Soil Moisture Sensor SM 150, soil penetration was measured from the soil surface to a depth of 45 cm in 2.5 cm intervals by using Soil Compaction Meter FieldScout SC 900 equipped a metal rod with a cone (size 1/2 inch). Electrical resistivity was determined using the Landmapper ERM-03 instrument (Pozdnyakov, 2008). Soil temperature was measured by soil thermometer AM-6. Measurement of illumination on the soil surface was carried out with a portable lux meter CEM DT-86.

Chemical analyses were carried out using standard methods reported in Arinushkina (1970) and Sokolov (1975): the total organic carbon using the Tyurin method with termination according to Orlov and Grindel (Arinushkina, 1970); alkaline hydrolyzable nitrogen, according to Cornfield (Sokolov, 1975); available phosphorus according to Chirikov (Sokolov, 1975); soil reaction by potentiometry (Arinushkina, 1970). The statistical analyses were performed by using MS Excel 2007.

Results and Discussion

The soil cover was studied and the soil section № 1D-2019 was made in the area without the impact of the hurricane. In this territory are distributed the nemoral pine-deciduous forests. According to the Braun-Blanquet approaches this forests belonging of the association *Tilio cordatae-Pinetum sylvestris* Martynenko 2009 prov. (suballiance *Tilio-Pinenion* Martynenko et Shirokikh 2009 prov. alliance *Aconito lycoctoni–Tilion cordatae* Solomeshch et Grigoriev in Willner et al. 2016, order *Carpinetalia betuli* P.Fukarek 1968 class *Carpino-Fagetea sylvaticae* Jakucs ex Passarge 1968).

The tree stand is well developed. In the first tree layer is dominated by pine (*Pinus sylvestris*), which has a projective cover of 40% with an average height of 24-26 m and a trunk diameter of 28-34 cm. Under the pine canopy, the species of broad-leaved trees are dominated: linden (*Tilia cordata*), maple (*Acer platanoides*), and elm (*Ulmus glabra*). The projective cover varies from 25 to 40% and the height does not exceed 6 m. In the undergrowth are common *Coryllus avellana, Sorbus aucuparia,* and *Padus avium*.

The shrub layer is almost undeveloped and is represented by small specimens of *Lonicera xylosteum, Euonymus verrucosa, Rosa majalis, Rubus idaeus,* and *Daphne mezereum.*

As a result of the strong shading of the tree canopy of linden, maple, and elm, the herb layer is poorly developed. The total projective cover of the herb layer varies from 5 to 20%, with an average of 15% in depending of shading of trees. The main cover of the herb layer is created by the *Pteridium aquilinum, Calamagrostis arundinacea, Brachypodium pinnatum, Aegopodium podagraria*. With high frequency are present the species of nemoral broad-leaved forests (*Melica nutans, Fragaria vesca, Viola mirabilis, Pulmonaria obscura, Glechoma hederacea, Lathyrus vernus, Stellaria holostea* etc). The average height of the herb layer varies from 20 to 40 cm.

In the area affected by the hurricane the soil cover was studied and the soil section № 2D-2019 was made. This area represents of vegetation that was formed after the mass windfall of nemoral pine-deciduous forests of ass. *Tilio cordatae-Pinetum sylvestris*, and subsequently the felling and transportation of broken trees, as well as the burning of felling residues.

On the most of the territory are distributed by meadows with high projective cover (70-85%). In the herb layer dominated by rhizome cereals: *Poa angustifolia, Poa pratensis, Agrostis tenuis, Calamagrostis epigeios*. The typical species of meadows (*Achillea millefolium, Hypericum perforatum, Galium album, Vicia cracca, Lathyrus pratensis, Linaria vulgaris, Filipendula vulgaris* and others) and ruderal vegetation (*Artemisia absinthium, Taraxacum officianle, Picris hieracioides, Cirsium setosum*) are also present in the floristic composition.

Among the meadow vegetation, individual specimens or small groups are distributed of different age of trees, represented by broad-leaved and small-leaved species. They have been preserved in the undergrowth after a hurricane and logging. The projected cover of the trees varies from 5 to 50% with a height of 0,5-4,0 m. The main projective cover is mainly created by birch (*Betula pendula*) and pine (*Pinus sylvestris*). With less abundance, linden (*Tilia cordata*) and elm (*Ulmus glabra*) are present in tree composition. Rarely meet the maple (*Acer platanoides*), willow (*Salix caprea*), rowan (*Sorbus aucuparia*), and bird cherry (*Padus avium*). As a rule, under the canopy of trees, the herbage is very sparse and is represented mainly by meadow species.

According to the Braun-Blanquet and Kopečký and Hejný approaches, this community can be belonging to the basal community *Calamageostis epigeios-Tilia cordata* [Festucion pratensis/Aconito-Tilion] of alliance *Festucion pratensis* Sipajlova et al. 1985 (order *Arrhenatheretalia* R. Tx. 1931, class *Molinio-Arrhenatheretea* R. Tx. 1937).

To study the dynamics of biomass and vegetation cover over time it is widely used the NDVI. (Pisek et al., 2015; Chakraborty et al., 2018; Fern et al., 2018). Areas with different levels of bioproductivity can be identified using the NDVI too (Peng et al., 2019). Riihimäki et al. (2017) notes that the highest NDVI values and biomass are usually found in areas with low altitudes and high levels of solar radiation on the slopes of the south and southwest exposure. Landsat data have been widely used to obtain NDVI because of their long archive and relatively high spatial resolution (Zhu and Liu, 2015; Tucker et al., 2020).

Table 1. Dynamics of area change under different vegetation types

NDVI*	2006 year		2007 year	2008 year		2014 year		2019 year	
	S, km²	%		S, km²	%	S, km²	%	S, km²	%
-1–0	0.098	1.6		0.562	9.4	0.236	4.0	0.135	2.3
0–0.1	0.077	1.3		0.250	4.2	0.242	4.1	0.110	1.8
0.1–0.2	0.124	2.1		0.387	6.5	0.747	12.5	0.517	8.7
0.2–0.3	0.433	7.3		0.692	11.6	1.557	26.1	1.092	18.3
0.3–0.4	2.376	39.8		1.606	26.9	1.267	21.2	1.115	18.7
0.4–0.5	1.825	30.6	Hurricane	1.348	22.6	0.856	14.3	0.914	15.3
0.5–0.6	0.450	7.5		0.578	9.7	0.551	9.2	0.685	11.5
0.6–0.7	0.247	4.1		0.262	4.4	0.275	4.6	0.534	9.0
0.7–0.8	0.155	2.6		0.136	2.3	0.117	2.0	0.457	7.7
0.8–1	0.180	3.0		0.144	2.4	0.117	2.0	0.406	6.8
Total	5.965	100.0		5.965	100.0	5.965	100.0	5.965	100.0

*Note: **NDVI** values: -1.0–0.1 – bare soil, roads; 0.1–0.3 – thin meadow vegetation; 0.3–0.5 – pine forest with a dense woodland; 0.5–0.6 – sparse pine forest dominated by broad-leaved species; 0.6–1.0 – broad-leaved forests

Before the hurricane in 2007, more than 80% of the research area was occupied by light coniferous and light coniferous-broad-leaved forests, so the main contribution to the formation of NDVI values is made by the standing pine, whose crowns occupy a large area (Table 1, Figure 2). The rest of the territory is occupied by mixed broad-leaved forests and small areas of meadow vegetation. In 2007, a storm destroyed part of the pine forests on the monument's territory. This was followed by clearing the area of fallen trees, which resulted in additional damage to the surface layers and a sharp decline in phytomass. Since 2009, in some areas affected by the windfall, the removal of the sod layer and planting of pine seedlings were carried out, so by 2014 compared to 2008 there was a slight increase in areas with bare soil and thinned vegetation (Figure 2). However, much of the area affected by the hurricane was left to natural recovery. Later, in place of windfalls, ruderal and meadow vegetation with prevailing cereals was formed. And in their place, the renewal of broad-leaved (*Tilia cordata, Ulmus glabra, Acer platanoides, Padus avium*) and small-leaved (*Betula pendula*) trees began. This is confirmed by the results of the NDVI analysis, which shows a gradual increase in phytomass and a decrease in the areas of disturbed sites and thinned weed-meadow vegetation (Figure 2). In 2019, areas with NDVI values between 0.5 and 1.0 are already above the 2006 values. Such differences are explained by the lower biomass and photosynthetic activity of pine forests compared to meadow vegetation and the emerging secondary broadleaved forests (Chernetskiy et al., 2011; Adamovich et al., 2018; Pisman et al., 2018).

Table 2. Description of soil profile under a pine forest

Profile Name:	1D-2019
Location:	N 55.519208, E 54.884311
Area Description:	Pine forest, the small slope of the southern exposition.
Altitude:	86 m above sea level
Horizon:	O, 0-4 cm. Forest litter of various degrees of decomposition, fir-needles, cones, leaves, tree branches. AY, 4-16 cm. Dark brown, slightly wet, unstructured, sandy loam, plant, and tree roots, border to the next horizon is interfingering. C, 16-50 cm. Light brown, wet, unstructured, sandy loam, crumbly soil structure, plant and tree roots.
Soil Name:	Gray-humus (Umbric Luvisol)

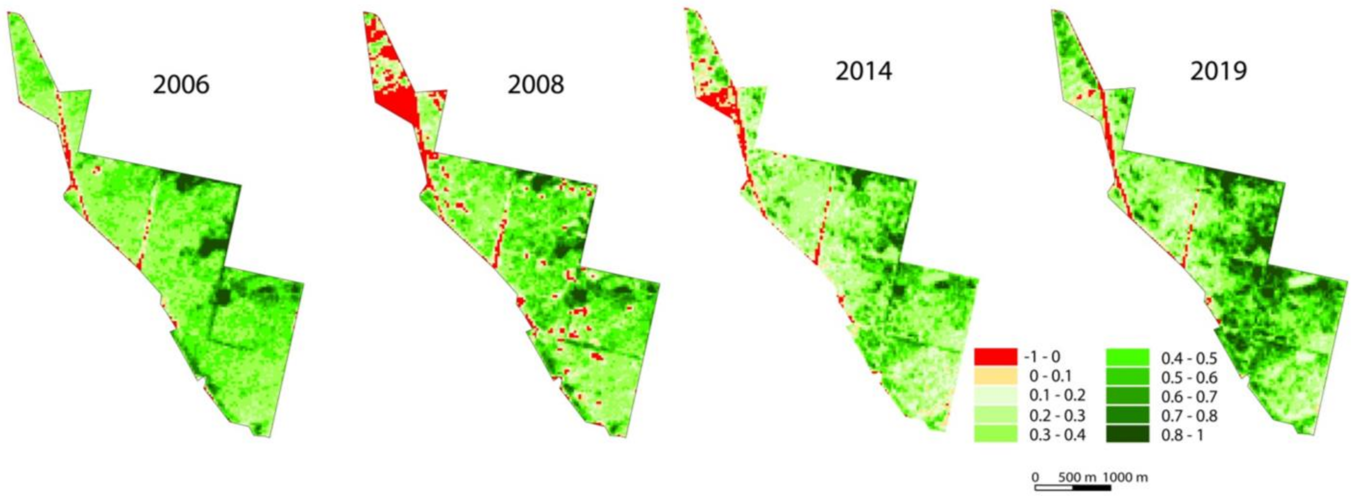


Figure 2. Change of NDVI values in the territory botanical nature monument «Pine forest near Venetsiya village» (2006, 2008, 2014, 2019 – years; NDVI values: -1.0–0.1 – bare soil, roads; 0.1–0.3 – thin meadow vegetation; 0.3–0.5 – pine forest with a dense woodland; 0.5–0.6 – sparse pine forest dominated by broad-leaved species; 0.6–1.0 – broad-leaved forests)

Active renewal of herbal and woody vegetation led to formation of the sod layer at the soil and changes in its physical and chemical characteristics. To study the changes in soil properties in the areas affected by the hurricane, we give their morphological description. The morphological description of the studied soils is given in Table 2, 3.

The analysis of morphological properties of soils shows that in the post-hurricane areas as a result of their overgrowth with meadow motley grass the formation of sod horizon with a capacity of approximately 14 cm occurred. These areas are also characterized by a high level of illumination (10140 lx) compared to the areas occupied by forest (621 lx). Intensive insolation promotes greater warming of the soil profile in the post-hurricane area (temperature approximately 2°C higher than in the area under the forest), which causes intensive evaporation of soil moisture (field moisture in the sod horizon is only 5.2%) (Table 4). Determination of soil density using penetrometer showed that in the studied areas the values of resistance to penetration into the soil of the metal rod with a cone at the end to a depth of 45 cm are within the normal range (0-1379 kPa) for root system growth. Differences in density between soil profiles are insignificant and are caused by spatial heterogeneity of the territory soil cover (Figure 3).

Table 3. Description of soil profile in the area affected by the hurricane

Profile Name:	2D-2019
Location:	N 55.528133, E 54.873336
Area Description:	Windfall, the small slope of the southern exposition
Altitude:	73 m above sea level
Horizon:	AO, 0-14 cm. Gray, slightly wet, sandy loam, Soil structure in the form of powder and lumps, densely rooted, the transition to the next horizon is gradual. AY, 14-26 cm. Dark Brown, slightly wet, unstructured, sandy loam, plant and tree roots, border to the next horizon is interfingering. C, 26-60 cm. Light brown, wet, unstructured, sandy loam, crumbly soil structure, plant and tree roots.
Soil Name:	Gray-humus (Umbric Luvisol)

Table 4. Physical properties of soils (field definition)

Horizon, depth, cm	Field moisture	Electrical resistivity	Temperature	Illuminance (on soil surface)
	%	Ohm m	°C	lx
		Soil Profile 1D-2019		
AY, 4-16	18.2 ± 3.9	1373 ± 754	15.7 ± 0.2	621 ± 43
C, 16-50	11.6 ± 0.9	2900 ± 271	14.4 ± 0.1	-
		Soil Profile 2D-2019		
AO, 0-14	5.2 ± 1.7	3481 ± 1408	17.7 ± 0.2	10140 ± 507
AY, 14-26	17.9 ± 4.5	3608 ± 1798	16.3 ± 0.2	-
C, 26-60	12.5 ± 0.7	2743 ± 378	13.9 ± 0.1	-

mean ± standard deviation, n = 6

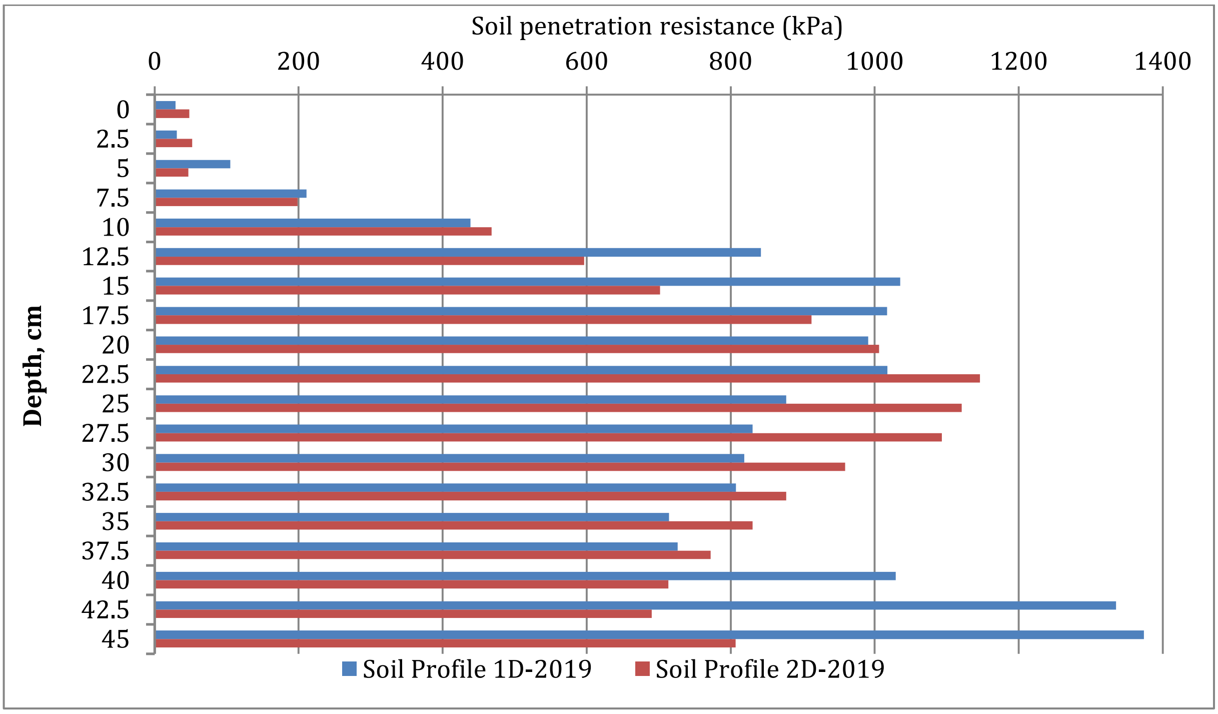


Figure 3. Vertical distribution of soils penetration resistance

More significant changes occurred in the chemical properties of the soil. At the post-hurricane site due to active form of the sod layer, there was an increase in the content of organic carbon in comparison with the site under the forest in the AY horizon by 1.1 times, alkaline hydrolyzable nitrogen by 1.6 times and available phosphorus by 1.2 times. At the same time, in the most sod horizon, the Corg content was 27,3 g kg^{-1} soil, alkaline hydrolyzable nitrogen – 252 and available phosphorus 46 mg kg–1 soil (Table 5).

Table 5. Chemical properties of soils

Horizon, depth, cm	pH $_{H2O}$	Total organic carbon	N alkaline hydrolyzable	P_2O_5 available
		g kg^{-1} soil	mg kg^{-1} soil	
		Soil Profile 1D-2019		
AY, 4-16	5.7±0.08	22.6±1.2	70±6.3	24±4.4
C, 16-50	6.0±0.09	12.7±0.8	28±3.4	28±2.2
		Soil Profile 2D-2019		
AO, 0-14	5.4±0.07	27.3±1.5	252±8.4	46±4.3
AY, 14-26	5.6±0.08	24.4±1.3	112±8.7	28±2.8
C, 26-60	6.2±0.09	10.4±1.8	14±3.3	57±2.4

mean ± standard deviation, n = 6

The value of specific electrical resistivity is an indicator that depends on various processes of soil formation and a wide range of soil properties (Pozdnyakov, 2008; Alekseev et al., 2017). Thereby, it is possible to assume that increase of this indicator in humus-accumulative horizons in the profile of post-hurricane soil in 5,2 times was influenced by an increase of organic matter and nutrients content.

Conclusion

The pine forest areas damaged by the hurricane are undergoing strong transformation processes. Currently, in this area, there is an active formation of highly productive herbaceous vegetation and the renewal of deciduous stands. This resulted in an increase in biomass, which is confirmed by the analysis of NDVI results. Active development of grass vegetation leads to the formation of the sod horizon, not characteristic of the soil botanical monument of nature with a capacity of approximately 14 cm, which contributes to the change and chemical properties of the soil. In humus-accumulation horizons, there is an increase in the content of organic carbon, alkaline hydrolyzable nitrogen and mobile phosphorus The electrical resistivity and acidification of the soil solution also increases.

Acknowledgement

This work was partly supported by the Russian Scientific Foundation: project № 17-16-01030 (laboratory study) and was performed within the framework of state assignment of the Ministry of Education and Science of the Russian Federation № 075-00326-19-00 on topic № AAAA-A18-118022190102-3.

References

Adamovich, T.A., Kantor, G.Ya., Ashikhmina, T.Ya., Savinykh, V.P. 2018. The analysis of seasonal and long-term dynamics of the vegetative NDVI index in the territory of the State Nature Reserve «Nurgush». *Theoretical and Applied Ecology* 1: 18–24. [in Russian].

Alekseev, I., Kostecki, J., Abakumov, E., 2017. Vertical electrical resistivity sounding (VERS) of tundra and forest tundra soils of Yamal region. *International Agrophysics* 31: 1–8.

Arinushkina, E.V., 1970. Soil chemical analysis guide. Moscow State University, Moscow, Russia. 488 p. [in Russian].

Baker, C., Sterling, M., Jesson, M., 2020. The lodging of crops by tornadoes. *Journal of Theoretical Biology* 500: 110309.

Barrett, B.S., Marin, J.C., Jacques-Coper, M., 2020. A multiscale analysis of the tornadoes of 30–31 May 2019 in south-central Chile. *Atmospheric Research* 236: 104811.

Beck, H.E., Zimmermann, N.E., McVicar, T.R., Vergopolan, N., Berg, A., Wood, E.F., 2018. Present and future Köppen-Geiger climate classification maps at 1-km resolution. *Scientific Data* 5: 180214.

Cadastral report on protected areas natural monument of regional importance «Pine forest near Venetsiya village», 2019. Information and analytical system «Specially Protected Natural Areas of Russia». Available at [Access date: 16.10.2020]: http://oopt.aari.ru [in Russian].

Chakraborty, A., Seshasai, M.V.R., Reddy, C.S., Dadhwal, V.K., 2018. Persistent negative changes in seasonal greenness over different forest types of India using MODIS time series NDVI data (2001–2014). *Ecological Indicators* 85: 887–903.

Chernetskiy, M., Pasko, I., Shevyrnogov, A., Slyusar, N., Khodyayev, A., 2011. A study of forest vegetation dynamics in the south of the Krasnoyarskii Krai in spring. *Advances in Space Research* 48: 819–825.

Chernokulsky, A., Shikhov, A., 2018. 1984 Ivanovo tornado outbreak: Determination of actual tornado tracks with satellite data. *Atmospheric Research* 207: 111–121.

Cui, W., Caracoglia, L., 2019. A new stochastic formulation for synthetic hurricane simulation over the North Atlantic Ocean. *Engineering Structures* 199: 109597.

Czerepanov, S.K., 1995. Vascular plants of Russia and adjacent states (within the limits of the former USSR). World and Family-95 Ltd, Moscow, Russia. 992 p. [in Russian].

De Beurs, K.M., McThompson, N.S., Owsley, B.C., Henebry, G.M., 2019. Hurricane damage detection on four major Caribbean islands. *Remote Sensing of Environment* 229: 1–13.

Diaz, J., Joseph, M.B., 2019. Predicting property damage from tornadoes with zero-inflated neural networks. *Weather and Climate Extremes* 25: 100216.
Ezer, T., 2020. The long-term and far-reaching impact of hurricane Dorian (2019) on the Gulf Stream and the coast. *Journal of Marine Systems* 208: 103370.
Fern, R.R., Foxley, E.A., Bruno, A., Morrison, M.L., 2018. Suitability of NDVI and OSAVI as estimators of green biomass and coverage in a semi-arid rangeland. *Ecological Indicators* 94: 16–21.
Hoffmann, P., Merker, C., Lengfeld, K., Ament, F., 2018. The Hamburg Tornado (7 June 2016) from the perspective of low-cost high-resolution radar data and weather forecast model. *Atmospheric Research* 211: 1–11.
Kadilnikov, I.P., 1964. Physiographic zoning of Bashkir ASSR. Bashkir State University, Ufa, Bashkortostan. 191p. [in Russian].
Kopecký, K., Hejný, S., 1974. A new approach to the classification of anthropogenic plant communities. *Vegetatio* 29: 17–20.
Long, J.A., Stoy, P.C., Gerken, T., 2018. Tornado seasonality in the southeastern United States. *Weather and Climate Extremes* 20: 81–91.
Majidzadeh, H., Uzun, H., Chen, H., Bao, S., Tsui, M.T.K., Karanfil, T., Chow, A.T., 2020. Hurricane resulted in releasing more nitrogenous than carbonaceous disinfection byproduct precursors in coastal watersheds. *Science of The Total Environment* 705: 135785.
Meixler, M.S., 2017. Assessment of Hurricane Sandy damage and resulting loss in ecosystem services in a coastal-urban setting. *Ecosystem Services* 24: 28–46.
Mo, Y., Kearney, M.S., Turner, R.E., 2020. The resilience of coastal marshes to hurricanes: The potential impact of excess nutrients. *Environment International* 138: 105409.
Moore, T.W., 2017. On the temporal and spatial characteristics of tornado days in the United States. *Atmospheric Research* 184: 56–65.
Novais, S., Sáyago, R., Cristóbal-Perez, E.J., Salguero-Hernández, G., Martén-Rodríguez, S., Lopezaraiza-Mikel, M., Quesada, M., 2020. Anthropogenic and hurricane disturbances had similar negative effects on epiphytic Tillandsia species in a tropical dry forest. *Forest Ecology and Management* 458: 117797.
Peng, W., Kuang, T., Tao, S., 2019. Quantifying influences of natural factors on vegetation NDVI changes based on geographical detector in Sichuan, western China. *Journal of Cleaner Production* 233: 353–367.
Pisek, J., Rautiainen, M., Nikopensius, M., Raabe, K., 2015. Estimation of seasonal dynamics of understory NDVI in northern forests using MODIS BRDF data: Semi-empirical versus physically-based approach. *Remote Sensing of Environment* 163: 42–47.
Pisman, T.I., Botvich, I.Yu., Shevyrnogov, A.P., 2018. Assessment of the state of forest vegetation in Krasnoyarsk Territory (Stolby Nature Reserve) according to satellite data. *Sovremennye Problemy Distantsionnogo Zondirovaniya Zemli Iz Kosmosa* 15: 130–140. [in Russian].
Pozdnyakov, A.I., 2008. Electrical parameters of soils and pedogenesis. *Eurasian Soil Science* 41: 1050–1058.
Riihimäki, H., Heiskanen, J., Luoto, M., 2017. The effect of topography on arctic-alpine aboveground biomass and NDVI patterns. *International Journal of Applied Earth Observation and Geoinformation* 56: 44–53.
Sahoo, B., Jose, F., Bhaskaran, P.K., 2019. Hydrodynamic response of Bahamas archipelago to storm surge and hurricane generated waves – A case study for Hurricane Joaquin. *Ocean Engineering* 184: 227–238.
Santoro, J.A., D'Amato, A.W., 2019. Structural, compositional, and functional responses to tornado and salvage logging disturbance in southern New England hemlock-hardwood forests. *Forest Ecology and Management* 444: 138–150.
Shikhov, A., Chernokulsky, A., 2018. A satellite-derived climatology of unreported tornadoes in forested regions of northeast Europe. *Remote Sensing of Environment* 204: 553–567.
Shirokikh, P.S., Suleymanov, R.R., Kotlugalyamova, E.Yu., Martynenko V.B., 2017. Changes in the vegetation and soil cover after the windfall in the broad-leaved forest of the National park «Bashkiria». *In: Proceedings of the RAS Ufa Scientific Centre* 3(1): 214–220. [in Russian].
Sokolov, A.V. (Ed.), 1975. Agrochemical Methods of Soil Studies. Nauka, Moscow, Russia. 656 p. [in Russian].
Strader, S.M., Ashley, W.S., Pingel, T.J., Krmenec, A.J., 2018. How land use alters the tornado disaster landscape. *Applied Geography* 94: 18–29.
The Red Book of the Republic of Bashkortostan, 2011. Media Print, Ufa, Bashkortostan. 384 p. [in Russian].
The Register of especially protected natural territories of republican importance of Bashkortostan Republic, 2016. Belaya reka, Ufa, Bashkortostan. 400 p. [in Russian].
Tucker, R., Callaham, J.A., Zeidler, C., Paul, A.-L., Ferl, R.J., 2020. NDVI imaging within space exploration plant growth modules – A case study from EDEN ISS Antarctica. *Life Sciences in Space Research* 26: 1–9.
Weber, H.E., Moravec, J., Theurillat, J.-P., 2000. International Code of Phytosociological Nomenclature. 3rd edition. *Journal of Vegetation Science* 11: 739–768.
Westhoff, V., Van Der Maarel, E., 1978. The Braun-Blanquet Approach. In: Classification of Plant Communities. Whittaker, R.H. (Ed.), Springer Netherlands, Dordrecht, pp. 287–399.
Zhu, X., Liu, D., 2015. Improving forest aboveground biomass estimation using seasonal Landsat NDVI time-series. *ISPRS Journal of Photogrammetry and Remote Sensing* 102: 222–231.

Eurasian Journal of Soil Science 2021, 10(3), 259 - 268

Eurasian Journal of Soil Science

Journal homepage : http://ejss.fesss.org

Compressibility behaviour and engineering properties of North Borneo Peat Soil

Habib M. Mohamad [a,*], Adnan Zainorabidin [b], Baba Musta [c], M. Nursyahrain Mustafa [a], Adriana Erica Amaludin [a], Mohamad Niizar Abdurahman [d]

[a] Faculty of Engineering, Universiti Malaysia Sabah, Malaysia
[b] Universiti Tun Hussein Onn Malaysia, 86400 Parit Raja, Batu Pahat, Johor, Malaysia
[c] Faculty of Science and Natural Resources, Universiti Malaysia Sabah, Malaysia
[d] Public Works Department Malaysia, Kuala Lumpur, Malaysia

Article Info

Received : 16.10.2020
Accepted : 24.04.2021
Available online : 30.04.2021

Author(s)

H.M. Mohamad *
A. Zainorabidin
B. Musta
M.N. Mustafa
A.E. Amaludin
M.N. Abdurahman

* Corresponding author

Abstract

It is known that peat soil is highly compressible. A constituent of peat soil from Klias, Sabah covering a wide range of index properties of fiber contents, specific gravity, organic contents and moisture contents were subjected to one-dimensional consolidation tests. This paper presents the engineering properties and compressibility behavior of sapric type of tropical peat soil. In this role, the high compressibility of Klias peat stands out as a most significant engineering property. With this intention, the purpose of this paper is to provide a simple and analytical means for predicting the consolidation settlement of sapric peat deposit under loading. The rate of primary compression, after a certain time. Increases with the logarithm of time. Loading applied from low stress to high stresses started from 2, 6.25, 12.5, 25, 50, 100 and 200 kPa resulting in high compression index, C_c and ratio, C'_c. The Klias peat soil represented sapric type of tropical peat with organic content is 98.43% and lower fiber content which is about 18% of the specimen. Compressibility index C_c, Coefficient of consolidation C_v, and Compression index, C_c, was identified as a crucial component of parameters in determination of settlements behaviour of peat soil. The coefficient of consolidation, C_v, was determined within the range of 1.264 to 12.911 cm²/min and requires special considerations in laboratory testing procedures and interpretation of results.

Keywords: One-dimensional, peat, soil, settlement, behaviour, coefficient of consolidation.

Introduction

Peat soil occur mainly in Southwest Sabah, or more precisely in northern part of Borneo island particularly on the Klias Peninsular, Lumadan, Bukau api-api and lower Kinabatangan area in west coast Sabah. Access into the area was by Kg. Luagan, Beaufort of or Lumadan agricultural area. The composition of peat soil consists of fragmented decayed plant material, organic matter and fibrous material. Peat is an organic soil which consists more than 70% of organic matters. Peat deposits are found where conditions are favorable for their formation and peat possess high organic content (Duraisamy et al., 2007; Zainorabidin and Mohamad, 2016b; Mohamad et al., 2020)

The high compressibility exists in unconsolidated state and cause an excessive settlement. The situation is also stressed (Jorat et al., 2013) where, the differential settlement or failure in structures built on such soils. Embankment technique to accelerate settlement by using granular material, clay or equivalent material that have high bearing capacities has been implemented in various method to enhance embankment stability

: https://doi.org/10.18393/ejss.930620
: http://ejss.fesss.org/10.18393/ejss.930620
Publisher : Federation of Eurasian Soil Science Societies
e-ISSN : 2147-4249

issues associated with embankment construction on peat soils. Under those circumstances, this study performed to investigate the plastic deformation void-ratio reduction or known as settlement behaviour with function of time.

General characteristics and intrinsic properties of peat soil which is soft and easily compressed (Zainorabidin and Mohamad, 2015) is essential to develop reliable method and assess the settlement coefficient when a load applied to a saturated peat soil. Settlement behaviour of peat soil in Sarawak, which is located in northwest Borneo Island, the average compression index, C_c was found for the undisturbed peat soil specimen test is 5.37 and ratio of C_α/C_c measured is 0.05 (Akeem et al., 2019). In particular, due to peat high compressibility properties and low shear strength material soil with known as heterogeneous behaviour, peat viewed as complexity geotechnical material (Mesri and Aljouni, 2007; De Guzman and Alfaro, 2018). In natural state, the fibrous peat exhibits large vertical strains and provides stiffness to stresses that are in an approximately vertical direction (Landva and Pheeney, 1980; Hendr et al., 2012).

The definition and method of testing mainly derived from peaty soils review in (BS 5930, 2015). Peat categories classified based on the extent and type of fibre content which are fibrous peat (>66% fiber), hemic (33-66% fiber) and Sapric (< 33% fiber) (Bujang, 2004). Oedometer test on peat were statistically analyzed for more than 2000 sets as a novel method for predicting the settlement of peaty grounds. The Noto method (Noto, 1991) was able to adequately reproduce the primary consolidation rate of peat. Due to the facts that they mainly cause large and primary long-term settlement, peat unsuitable for supporting structures (Mesri et al., 1997; Ajlouni, 2000; Munro and MacCulloch, 2006; Gofar and Sutejo, 2007). The α of peat was within the range of -0.55 to -0.9 (Oikawa et al., 1995). These values are smaller compared to Terzaghi's theory. From that, it is found that the primary consolidation rate of peat is higher in the early phase and lower in the later phase

With the aim of providing helpful information to geotechnical engineers for practical works and sufficient understanding on peaty grounds. This paper shows data on the settlement and compressibility behaviour of peat soil from Klias, Sabah, as well as analyses of the engineering parameters.

Material and Methods

Samples were collected from Klias, Beaufort, Sabah as shown in Figure 1, Location of Klias, Sabah in northern part of Borneo Island. in undisturbed form and carefully transported to laboratory located in Universiti Malaysia Sabah (UMS). A detail description on classification of peat soil is significant to describe the physical appearance of soil based on the Von Post classification. The results of peat soil consolidation test for Klias peat soil are very much helpful in adding to information and providing knowledge in general for Klias peat. Certainly, results of consolidation test for Klias peat soil will help designer or engineer learn the special considerations from Coefficient of consolidation (C_v) and Compression Index (C_c) in order to design of a specific need on peat soil such as embankment and design of foundations.

Figure 1. Location of Klias, Sabah in northern part of Borneo Island.

Experimental design and laboratory work

The process of sampling are divided into two general categories, disturbed and undisturbed sampling methods which uses different method. Since clearing and grubbing done, excavation work started from removing top soil and up to 0.5 m depth beneath ground level evenly. Disturbed sample used as sampling to determine the characterization of peat and description of peat. Visual observation on the peat soil are done after collecting disturbed sample as mentioned according to Von Post classification system. Undisturbed samples allow this study to identify the properties of compressibility, as well as the fracture patterns among others. In this study, the depth requirement is up to 0.5 m depth. Tube sampler using PVC with size 50 mm diameter and 160 mm height. Drive samplers are pushed into the soil without rotation, displacing the soil as they penetrate.

Figure 2 shows the natural condition as location of sampling site in Klias at agricultural land bordering gazetted forest reserves. The area of peatlands have been exploited for agriculture at the left side and remained forestry area. Figure 3 shows the peat profile at 1.0 m below ground level, excavated by using peat sampler. In general, it seems fiberless, extremely soft and loose. These physical characteristics are generally in line with the statement which is, in Lumadan, Sabah (Zainorabidin and Mohamad, 2016a), the peat was fibreless, very soft and succulent.

Figure 2. Klias peat soil sampling site at agricultural land bordering gazetted forest reserves.

Figure 3. Peat soil condition below 0.5 m from ground surface

Specific gravity, moisture content and pH test

In laboratory testing, the specimens of peat are workable with kerosene to determine the specific gravity rather than water. Water causes the particles of specimens floating and is difficult to determine the specific gravity. From the results, the specific gravity (G_s) observed that, Klias peat has 1.42. In this study, the moisture content determined using oven-dry method at 105°C from peat samples that was prepared from natural condition.

As seen in Table 1, the percentage of moisture content for Klias peat specimens is about 682%. While (Zolkefle, 2014) found peat can be reached up to 900%. In describing the salinity of peat soil, pH test are conducted. Klias peat has 4.25 at 1.0 m indicated as acidic. Due to different locations and natural activity decomposition matter, this is influenced the acidic factor of peat soil itself. When compared to other researchers, (Saadon et al., 2015) found that pH level of Sarawak peat ranges from 3.2 to 4.3 and acidic.

Liquid limit, organic content and fibre content test

The liquid limit of the soil is the moisture content corresponding to a cone penetration of 20mm and fitted with 35mm long cone of stainless steel with an angle of 300 ± 1 sinks exactly 20 mm into a cup of remolded soil in a 5s period. Table 1 shows the results of liquid limit test for Klias peat. Furthermore, the liquid limit was in the range of 200 % to 500 % as reported (Bujang, 2004) in West Malaysia. The organic content is the ratio, expressed as a percentage, of the mass of organic matter in a given mass of soil to the mass of the dry soil solids. The organic content in this study was determined by using the loss of ignition (LOI) test. From Table 1, it showed the percentage of organic content for Klias peat is about 98.43%. (Duraisamy and Bujang, 2008) proposed that the organic content for peat from 70% to 80%.

On the other hand (Boyland and Long, 2014), peats which are formed from the accumulation of organic materials over thousands of years, are characterized by its high-water content, compressibility and low shear stiffness and shear strength. However, in soil sciences, the soils that have organic content more than 35% are classified as peat. However, in soil sciences, the soils that have organic content more than 35% are classified as peat. In addition to that, the definition of peat according to the (ASTM D4427, 2013), peat is defined as soil that is naturally available with high organic substance that is derived primarily from plant materials.

Fibre content determined from dry weight of fibres retained on 0.15 mm as a percentage of oven-dried mass and being set in the oven at 105°C. This study led for determining the quantity of fibres in a peat sample and it's also a significant parameter in predicting or defining the samples. In this study, Klias peat has 18% fibre content. By means of this, all peat sample in this research are classified with sapric peat which are formed with moderately to well decompose organic materials with 1 – 33% of fibre content.

Table 1. Index properties of Klias, North Borneo Island peat soil.

No.	Parameters	Sample 1
1.	pH	4.250
2.	Specific gravity, G_s	1.420
3.	Area of specimen, cm^2	19.634
4.	Moisture content, %	682
5.	Fiber content, %	18
6.	Organic content, %	98.430
7.	Von Post classification	H4
8.	Peat type	Hemic

From observations, peat has a high uncertainty margin. Uncertainties and difficulties of testing of peat soil to determine the strength with very high compressibility, which presents significant challenge in developing peat behaviour in research. Peat contains high water content hence causing the material to be very sensitive and soft. This is why many researchers described peat as a challenging soil.

Oedometer test

The load transferred to the bottom pressure head is measured, and the friction in the oedometer ring is back-calculated (Michael et al., 2016). It was found that the friction has insignificant effect on the compression index, whereas swelling and recompression stiffness are influenced. Figure 4 shows the schematic drawing of floating-ring type which is employed in this study. The specimen size is about 20 mm thick and 50 mm in diameter. Specimen placed in a confining metal ring (19.63 cm^2).

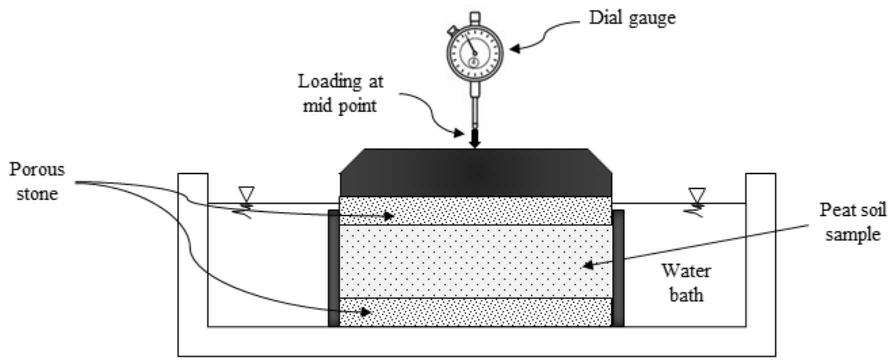


Figure 4. Schematic drawing of floating ring consolidometer setup for Klias peat soil.

Consolidation testing programs

The peat soil specimen was projected about 5 mm on both end side of metal ring and trimmed the excess soil content on top and bottom by using spatula. Porous stones that have been saturated by submerging 4 hours in distilled water then placed in bottom and top metal ring. The consolidation test was proceeded by applying loads in a geometric progression started from low stress applied to high moderate loading, 2, 6.25, 12.5, 25, 50, 100 and 200 kPa with a load ratio.

$$\frac{\Delta p}{p} = 1 \quad (1)$$

Low stress applied to the peat soil is essential method that significant to its natural state which is highly compressible. To avoid quick settlement and unreliable consolidation measurements, first load increment of 2 kPa is applied and watch immediately started. Against time, the specimen was reliable compared to immediate high loading applied. It appears that, if the increment ratio as shown in Equation 1 is not large enough, the peat soil specimen internal resistance built against the load. The total deformation tends to less than in Equation 1. For each load increment, the specimen is reached the primary consolidation within 24 hours, in general.

The total volume of peat soil sample is determined from the initial height H_i of the sample and the area A to the Equation 2 as follow.

$$V_t = V_s + V_w \qquad (2)$$

The changes in thickness at the end of each loading step used in determination of the Swelling Index (C_s), Compression Index (C_c) and the coefficient of consolidation (C_v). Figure 4 shows the consolidometer apparatus of Klias peat soil with incremental loading of oedometer test.

The unloading phase started once the 200 kPa loading completed and decremental of loading are set to be 50, 25, 12.5 and 6.25 kPa. Peat soil sample is carefully removed and its thickness and water content is measured when the test ended.

Subsequently, the height of the soil solids are computed after the oven-dried the soil cake. The total change in height of peat soil ΔH determined by using the Equation 3.

$$H_f = H_{Initial} - \Delta H \qquad (3)$$

Which the H_f, is initial sample height and use of dial gauge readings. From that formula, the height of solids, H_s (Equation 4) is

$$H_s = H_f - \frac{V_{wf}}{A} \qquad (4)$$

A is the area of consolidometer ring, while the initial height of voids are determined and computed by using Equation 5.

Figure 5. Laboratory testing of Klias peat soil with incremental loading of oedometer test.

$$H_v = H_{Initial} - H_s \qquad (5)$$

Consolidation test of peat soil obviously removed the void ratio and the thickness of the peat sample be reduced. The soil particle and fibrous material in peat rearrange to create a tighter or compacted coin shape with lower void ratio. Following the change in height, the initial void ratio, e_i determined with this Equation 6.

$$e_i = \frac{H_v}{H_s} \qquad (6)$$

Compression index, C_c determined from the straight-line part of the semilog plot of void ratio vs. log pressure as shown in the Equation 7. Accordingly, the swell index, C_s obtained from the curve of unload branch in Equation 8. On account of the compression ratio C'_c its defined as in Equation 9.

$$C_c = \frac{\Delta e}{\log p_2/p_1} \qquad (7)$$

$$C_s = \frac{\Delta e_s}{\log p_2/p_1} \qquad (8)$$

$$C'_c = \frac{\Delta \varepsilon}{\log p_2/p_1} \qquad (9)$$

Coefficient of consolidation C_v defined at the time 50 percent of consolidation, t_{50} as in the Equation 10 as follows.

$$C_v = \frac{TH^2}{t} \qquad (10)$$

Where T is the time factor for U = 50 percent (0.197), $t = t_{50}$, and the H is the average length of the longest drainage path during the increment of load application.

Results and Discussion

At the end of the consolidation test, the water content was calculated and the oven dry weight of peat soil, W_s is 13.21 g. The height of solids, H_s computed from Equation 5 is about 0.47381 cm. The sample cross sectional area, A computed is 19.634 cm^2. As the stress increased from 2 kPa to 200 kPa, the internal friction influenced the mean settlement of peat soil. The initial height of sample, H is 20 mm. The oedometer initial void ratio, e_o that calculated from the oedometer test was 3.221.

Coefficient of consolidation

Casagrande method were interpreted to this study (Casagrande, 1936) as shown in Figure 6. To identify the apparent coefficient of consolidation, C_v for Klias peat soil, the stress-strain dial reading-log time curves were analysed using the same theory (Casagrande, 1936) in Figure 7. As seen from the Figure 6, the maximum obtained coefficient of consolidation, C_v at various levels were very different. The highest C_v, was determined at lowest stress or at the beginning of loading stage, 2 kPa with 12.911 cm^2/min. Which was mainly due to the acceleration of stress and settlement. At this stage, the void ratio is considered high and the internal friction is still developed.

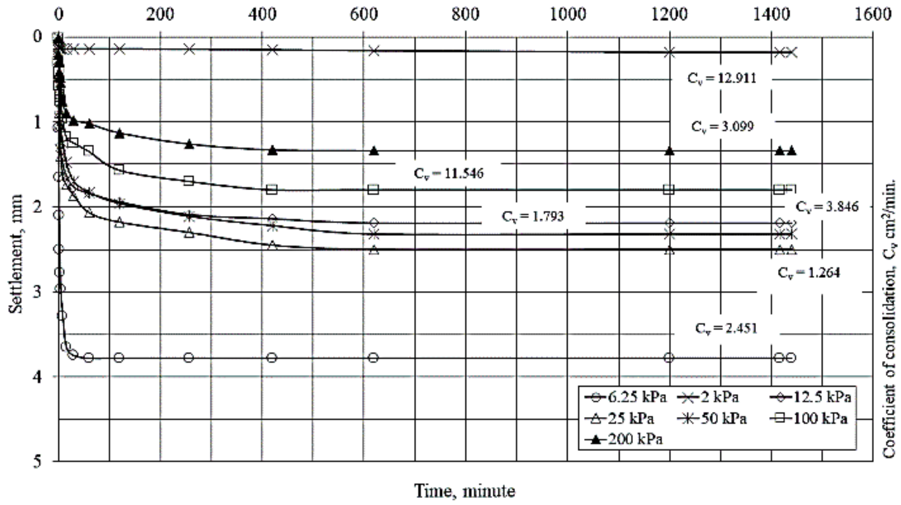


Figure 6. Coefficient of consolidation, C_v for Klias peat soil

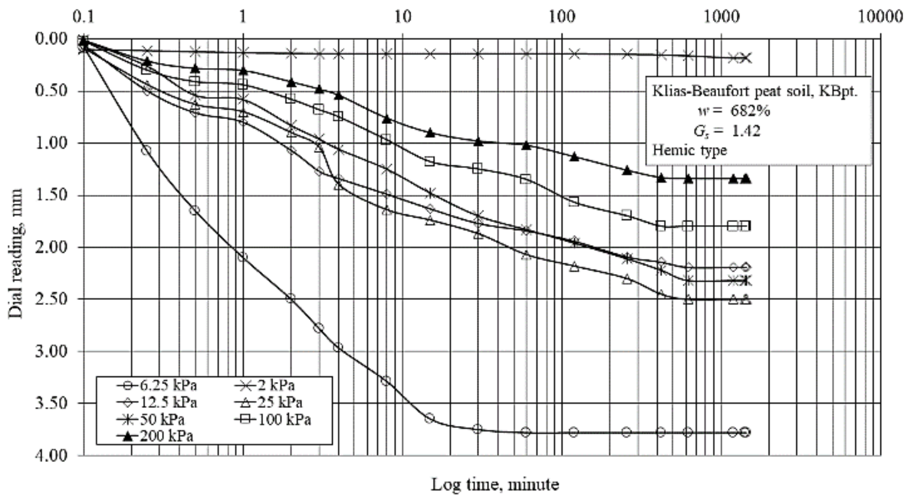


Figure 7. Dial reading versus time curves (log time, min.).

Prior loading stage, the initial void ratio is 3.221 and at the end of stress level 2 kPa, the void ratio decreased dramatically to 3.183, this is showing that, at even low and moderate loading, peat compressibility is high and void of ratio decreased simultaneously. This regime of void ratios decrement was continuously up to the 200 kPa. The internal friction acted on the first loading stepped causing the peat soil specimen getting dense or compressed. The loading was continued to 6.25 kPa and settlement was then recorded.

Obviously, due to the preloading process of 2 kPa, the void ratio continued stress with higher loading stress. Unfortunately, the void ratio value was less than previous loading. This is happened due to the loading and specimen reacted vertically compressed governed by the internal friction. The specimen was developed its internal friction due to the specimen has become denser and the particle was break from larger void, fall apart into small fragments, especially over a period of time as part of a process of settlement. The friction acted in the perpendicular direction of the applied load increment, which is contributed to the settlement and peat specimen compressed vertically. The stress at the bottom pressure was same when the specimen was in loading from top and vice versa when in unloading where sample swell accordingly. The individual specimens were then loaded up to 25 kPa, 50 kPa, 100 kPa and 200 kPa. The specimen dwindles against settlement. The increment of stress, (σ) kPa is in line with the contraction of coefficient of consolidation, C_v.

This situation is constant and settlement rates continue to be consistent with the removal of the void. Thus, peat has observably reacts toward loading in quick time and short time. The higher the load, the higher the settlement occurred. This is due to the restructuring of particles and fibers in peat soil that occurs with the removal of the void.

Dial reading versus time curves

The alternate loading reacts as stress applied to the peat soil specimen. At the end of primary consolidation test, the result compiled at plotted to time, t-log (min) vs dial reading (mm) as shown in Figure 7, where each loading plotted from 2, 6.25, 12.5, 25, 50, 100 and 200 kPa. The appearance of curve depending on stress applied and degree of consolidation for each loading stage. Obviously, the trendlines expressed as the corresponding to 50 percent, % consolidation, D_{50} at a given time within a soil mass under a given stress consolidation.

Thereupon, dial reading vs $\sqrt{time}$, were plotted to determine Do, where a straight line drew through the first several plotted points and the line extended until intersected in the ordinate. As shown in Figure 7 which is the intersection of the ordinate established, D_o. The coefficient of consolidation C_v defined at the time 50 percent of consolidation, t_{50} as in the Equation 10 and extracted from Figure 7. The $\sqrt{time}$, has a slight diminution with the increasing of stress applied, but it keeps in a range of 0.30 – 2.80. The ordinate value is arbitrarily taken as D_{90}. At 12.5 kPa, the C_v value is 11.546 cm²/min. The values of coefficient of consolidation C_v are slightly higher than the West Johor, Peninsular Malaysia peat (10.305 cm²/min) found (Johari et al., 2016). The compressibility of Klias peat and immediate settlement had been observed, the basic properties are shown significant in determination of peat settlement behaviour.

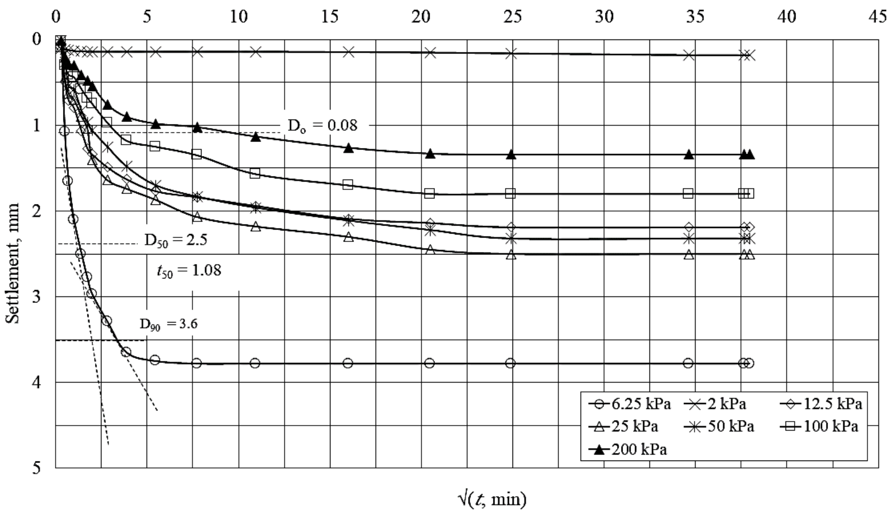


Figure 8. Settlement versus √time (min.)

Void ratio and compression index

The instantaneous void ratio appeared to be abstracted by plotted linear void ratio on e/log p, pressure, kPa given in Figure 9. The relationship of e and pressure, p (kPa) as a function of a_v, compression of compressibility as shown in Figure 10. The points in Figure 11 for the Plot of strain, ε versus log pressure, p (kPa) of the pressure applied.

However, subsequent to the void ratio, e versus log pressure, *log p* for Klias, peat soil, it drops to an average of 1.500. The initial void ratio, e_o was 3.221 and decreased to 0.256 at stress 200 kPa. Klias peats have the initial void ratio e_o value 3.221 from sapric peat type, whereas the amorphous granular peat in West Johor, Malaysia has an average the values for the initial void ratio 8.359 (Johari et al., 2016). Based on that void ratio results, the Klias peat soil was likely were very porous and the soil texture soft, spongy and fibreless. Given these points, due to the high organic content in Klias peat about 98.43% in the tested specimen.

Coupled with lower fibre content (18%) that concluded the specimen is organic dominants than fibre makes the peat sample frictionless (Zainorabidin and Mohamad, 2016a).

The p_c and C_c values was obtained from the graph, *e* vs log pressure as shown in Figure 9. The sample normally consolidated when $p = p_o$. Unfortunately, this study discovered $p > p_o$ which means the soil is preconsolidated and the value identified as p_c. The compression index, C_c value is 13.895. The first segment of compression index, C_c has a relatively steep slope and hence, a high compression index for Klias peat was discovered about C_c = 13.895.

The swelling index, C_s for Klias peat less than C_c value, obviously (C_s = 0.154). From an arithmetic plot of *e* v_s pressure, *p* (kPa), the coefficient of compressibility, a_v can be obtained as shown in Figure 10. The a_v value was 1.61 x 10^{-3}. The laboratory test results indicate the presence of a coefficient of compressibility for the peat sample. Compressibility and effective stress compressibility hold true at any time effective stress, and void ratio during consolidation.

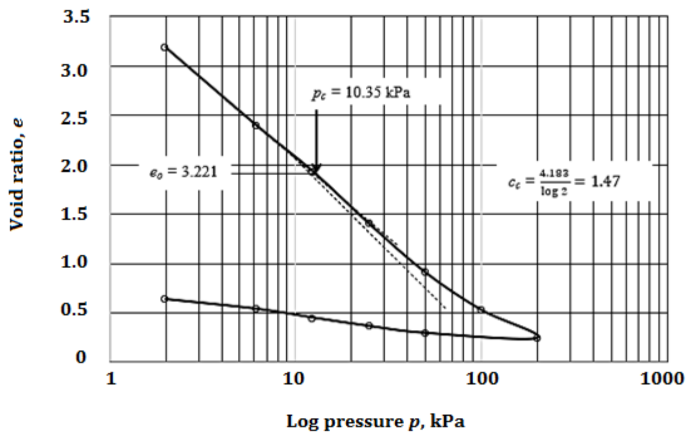


Figure 9. Void ratio, *e* versus log pressure, log *p* for Klias, peat soil.

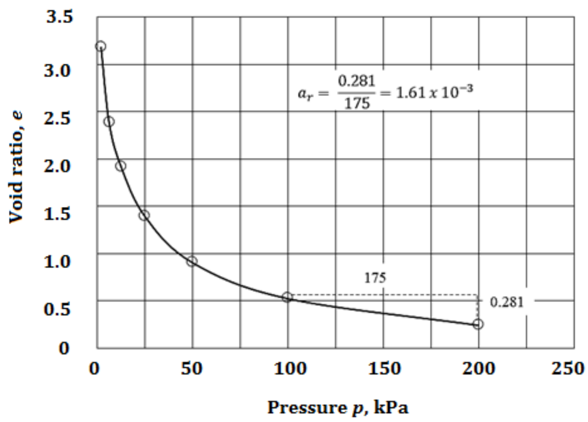


Figure 10. Void ratio, e versus pressure, *p*.

Consolidation behavior

The consolidation behaviour of peat soil designated for the one-dimensional time-dependent compression. Strain, *ε* and logarithm of pressure, *p* has relationship at first increment of loading for peat sample as shown in Figure 11. An instantaneous, strain, ε takes place immediately after the application of a stress or pressure from loading increment. The result of the compression of air voids and the elastic compression of the peat. The results of consolidation test have shown that peat soil has high settlement rate. From the results as stated in Table 2, the C_v value notched as high as 12.911 and classified as excessive towards the level of settlement.

Graph strain, *ε* vs *log pressure* was plotted. The typical plot is in Figure 11. From that graph, the identical in shape where the slope of the straight line drew in the curve and called the compression ratio, C'_c and defined as in the Equation 9. The compression ratio, C'_c value determined is about 3.194. (Duraisamy et al., 2007) have found the compression ratio using the formula, $C_C/1{+}e_o$ which is related to compression index of fibric, hemic and sapric are in the range of 0.2 to 0.4 and classified as very compressible. In this study, Klias peat has higher value 3.194 which is categorized as highly compressible.

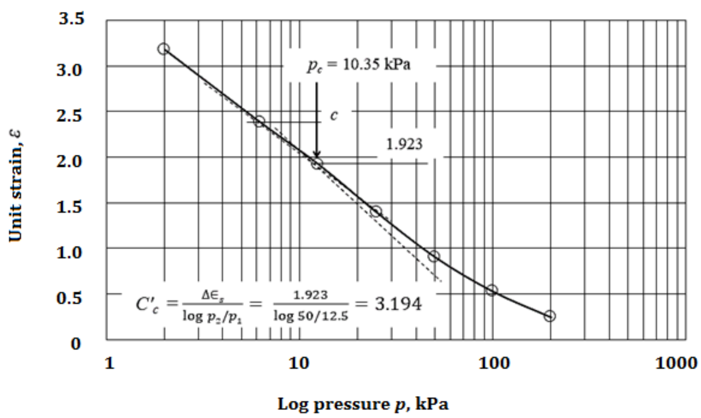


Figure 11. Plot of strain, ε versus log pressure, p (kPa).

The highly compression ratio characteristic of Klias peat soil contributed by high contains of organic in the specimens. The compression ratio for peat in the range in between 0.20 to 0.35 were very compressible (O'Loughlin and Lehane, 2003). Table 2 shows the computation of void ratio, *e* and compression index, C_v and related parameters in this study.

Table-2. Computation of void ratio, *e* and compression index, C_v.

Load Increment (σ, kPa)	Initial dial reading (mm)	Change in sample height, ΔH (mm)	Unit strain, ε	Average height for load, (mm)	Time for 50% consolidationt $_{50}$, min	Coefficient of consolidation, C_v, (cm²/min)
2	0.000	0.180	3.193	19.910	0.300	12.911
6.25	0.080	3.780	2.385	18.070	1.080	3.099
12.5	0.060	2.190	1.923	18.875	0.300	11.546
25	0.090	2.500	1.395	18.705	0.900	3.846
50	0.010	2.320	0.906	18.835	2.800	1.264
100	0.020	1.800	0.526	19.090	2.000	1.793
200	0.010	1.340	1.151	19.325	1.500	2.451

Conclusion

At the end of this analysis, the following are the main observations from the one dimensional-consolidation oedometer test and described in this paper; The index properties that obtained, the moisture content and specific gravity of North Borneo Island especially in Klias tropical peat correlate accordingly with the finding proposed (O'Loughlin and Lehane, 2003). The void ratio, *e* versus *log pressure*, *log p* for Klias, peat soil, it drops to an average of 1.500. The initial void ratio, e_o was 3.221 and decreased to 0.256 at stress 200 kPa. The highest C_v, was determined at lowest stress or at the beginning of loading stage, 2 kPa with 12.911 cm²/min. Which was mainly due to the acceleration of stress and settlement. The initial void ratio is 3.221 and at the end of stress level 2 kPa, the void ratio decreased dramatically to 3.183, this is showing that, at even low and moderate loading, peat compressibility is high and void of ratio decreased simultaneously. This study discovered p > po which means the soil is pre-consolidated and the value identified as pc. The compression index, Cc value is 13.895. The first segment of compression index, Cc has a relatively steep slope and hence, a high compression index for Klias peat was discovered about Cc = 13.895.

Acknowledgement

This publication resulted from research supported by the Universiti Malaysia Sabah for peat soil research grant, SGA0090-2019. The content is solely the responsibility of the authors.

References

Ajlouni, M.A., 2000. Geotechnical properties of peat and related engineering problems. PhD Thesis. Department of Civil Engineering, University of Illinois, Urbana-Champaign, USA.

Akeem, G.A., Alsidqi H., Dayang N.D.U., Siti, N.L., 2019. Strength and compressibility characteristics of amorphous tropical peat. *Journal of GeoEngineering* 14(2): 85-96.

ASTM D1997, 2013. Standard test method for laboratory determination of the fiber content of peat and organic soils by dry mass. Available at [Access date: 16.10.2020]: https://www.astm.org/search/fullsite-search.html?query=D1997&

ASTM D2974, 2013. Standard test methods for moisture, ash, and organic matter of peat and other organic soils. Available at [Access date: 16.10.2020]: https://www.astm.org/DATABASE.CART/HISTORICAL/D2974-13.htm

ASTM D4427, 2013. Standard classification of peat samples by laboratory testing. Available at [Access date: 16.10.2020]: https://www.astm.org/search/fullsite-search.html?query=D4427&

ASTM D4767, 2011. Standard test method for consolidated undrained triaxial compression test for cohesive soils. Available at [Access date: 16.10.2020]: https://www.astm.org/search/fullsite-search.html?query=D4767&

Boylan, N., Long, M., 2014. Evaluation of peat strength for stability assessments. *Geotechnical Engineering* 166(5): 421-430.

BS 5930, 2015. The Code of Practice for Site Investigations. British Standards Institute, Milton Keynes.

Bujang, B.K., 2004. Organic and peat soils engineering. Universiti Putra Malaysia Press, 146p.

Bujang, B.K.H., 2004. Behaviour of Soft Clay Foundation beneath an Embankment. *Pertanika Journal of Science & Technology* 2(2): 215-235.

Casagrande, A., 1936. Determination of the preconsolidation load and its practical significance. In: Proceedings of the 1st International Conference on Soil Mechanics and Foundation Engineering, Cambridge, Mass, 22–26 June 1936. Harvard Printing Office, Cambridge, Mass. Vol. 3, pp. 60–64.

De Guzman, E.M.B., Alfaro, M.C., 2018. Laboratory-scale model studies on corduroy-reinforced road embankments on peat foundations using transparent soil. *Transportation Geotechnics* 16: 1-10.

Duraisamy, Y., Bujang, B.K.H., 2008. Methods of utilizing cheap land for infrastructure development. ICCBT.

Duraisamy, Y., Bujang, B.K.H., Azlan, A.A., 2007. Engineering properties and compressibility behavior of tropical peat soil. *American Journal of Applied Sciences* 4 (10): 768-773

Gofar, N. and Y. Sutejo., 2007. Long term compression behavior of fibrous peat. *Malaysian Journal of Civil Engineering* 19(2) :104-116

Hendry, M.T., Sharma, J.S., Martin, C.D., and Barbour, S.L., 2012. Effect of fibre content and structure on anisotropic elastic stiffness and shear strength of peat. *Canadian Geotechnical Journal* 49(4): 403-415.

Johari, N.N., Bakar, I., Razali, S.N.M. Wahab., N. 2016. Fiber effects on compressibility of peat. *IOP Conference Series: Materials Science and Engineering* 136: 012036.

Jorat, M.E., Kreiter, S., Morz, T., Moon, V., de Lange, W., 2013. Strength and compressibility characteristics of peat stabilized with sand columns. *Geomechanics and Engineering* 5(6): 575–594.

Landva, A.O., Pheeney, P.E., 1980. Peat fabric and structure. *Canadian Geotechnical Journal* 17(3): 416-435.

Mesri, G., Ajlouni, M., 2007. Engineering properties of fibrous peats. *Journal of Geotechnical and Geoenvironmental Engineering* 133(7): 850-866.

Mesri, G., Stark, T.D., Ajlouni, M.A., Chen, C.S., 1997. Secondary compression of peat with or without surcharging. *Journal of Geotechnical and Geoenvironmental Engineering* 123(5): 411-421.

Michael, R.L., Kenny, K.S., Niels, M., Trankjær, H., 2016. Oedometer tests with measurement of internal friction between oedometer ring and clay specimen. In: Proceedings of the 17th Nordic Geotechnical Meeting Challenges in Nordic Geotechnic. 25-28 May 2016. Reykjavik, Iceland. pp 289-298.

Mohamad, H.M., Adnan, Z., Razali, S.N.M., Zolkefle, S.N.A., 2020. Assessment for applicability of microwave oven in rapid determination of moisture content in peat soil. *Journal of Engineering Science and Technology* 15(3): 2110-2118.

Munro, R., MacCulloch, F., 2004. Dealing with bearing capacity problems on low volume roads constructed on peat. (Executive Summary), Roadex III Northern Periphery Manual, Scotland. Available at [Access date: 16.10.2020]: http://www.roadex.org/wp-content/uploads/2014/01/Roads-on-Peat_English.pdf

Noto, S., 1991. Simplification of Modified Prediction method of Settlement for Peaty Soft Ground. Monthly Report of Civil Engineering Research Institute, No. 460, [in Japanese]. pp.37-41.

O'Loughlin, C.D., Lehane., B.M., 2003. A study of the link between composition and compressibility of peat and organic soils. In: Proceedings of the 2nd Conference on Advances in Soft Soil Engineering and Technology. Huat, B.B.K., Omar, H., Maail, S., Mahsun, E.,(Eds.). Universiti Putra Malaysia Press, Malaysia. pp.135-152.

Oikawa, H., Ishikawa, G., Vaid, Y.P., 1995. Settlement rates during one-dimensional consolidation of peat. In: Proceedings of the International Symposium on Compression and Consolidation of Clayey Soils. Yoshikuni, H., Kusakabe, O., (Eds.), A.A. Balkema, Brookfield, The Netherlands. Vol. 2, pp.149–154.

Sa'don, N.M., Abdul Karim, A.R., Jaol, W., Wan Lili., W.H., 2015. Sarawak peat characteristics and heat treatment. *Journal of Civil Engineering, Science and Technology* 5(3): 6-12.

Zainorabidin, A., Mohamad, H.M., 2015. Pre- and post-cyclic behavior on monotonic shear strength of Penor peat. *Electronic Journal of Geotechnical Engineering* 20(16): 6927-6935.

Zainorabidin, A., Mohamad, H.M., 2016a. Preliminary peat surveys in ecoregion delineation of North Borneo: Engineering perspective. *Electronic Journal of Geotechnical Engineering* 21(12): 4485–4493.

Zainorabidin, A., Mohamad, H.M., 2016b. A geotechnical exploration of Sabah peat soil: Engineering classifications and field surveys. *Electronic Journal of Geotechnical Engineering* 21(20): 6671–6687.

Zolkefle, S.N.A., 2014. The dynamic characteristic of Southwest Johor peat under different frequencies. Degree of Master in Civil Engineering Thesis. Universiti Teknologi Malaysia, Johor, Malaysia.