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Article

Sahara Desert dust as soil forming factor in Central Balkans

Anton Sotirov [1]

[1] Institute of Agriculture, Kyustendil, Agricultural Academy, Bulgaria

Abstract

The airborne transfer of dust fraction from the Sahara Desert plays an essential soil forming role. To the description of reference soil IT008 Chromic Luvisols should be added the mixed origin of this soil between autochthonous soil formation factors and external exogenous soil formation factors such as transfer of desert dust from nearer and distant deserts. Due to a number of physical factors, these particles settle in the lower parts of these areas. Desert dust plays a significant influence on plants in the Kyustendil valley, located in Central Balkan Peninsula. It reduces the acidity of more acidic soils, which is why it affects crops that develop better at lower values of pH=4.5-5.5. In general, it can be expected that desert dust in certain quantities can have a positive effect on soil formation and plant development due to the enrichment of the soil with silt, clay minerals that are still in the process of degradation, introducing calcium, potassium, silicon, and other beneficial elements, this being a light fraction that is devoid of heavy metals and other harmful components. But in high amounts may cause desertification of the soil. This fraction physics-chemical is very mobile, facilitates cation exchange in the soil, also introduces the necessary organic substance in the form of polen and other biological material intercepted by the air. Silt in certain quantities improves soil structure, drainage properties, plasticity and soil evaporation. The dust increase the phosphorus content, low size particles and mechanical and chemical composition of the soil.

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Keywords
Sahara Desert; dust; soil forming; plants; Chromic Luvisols

Introduction

Location. Town of Kyustendil is located in South-West Bulgaria (Central Balkan Peninsula), Lat.: 42°16'N / Lon.: 22°41'E / Altitude: 527 m, Timezone: Europe/Sofia (UTC+2). It is settled in the Kyustendil Pliocene Valley, which is fenced by the mountains Osogovo from the South, Lisets and Chudinska from West and North-West, Zemenska from the North, and Konyavska from the North-East and East. It is connected to the neighboring valleys by gorges. It is drained by the Struma River and its tributaries, that flows into the Mediterranean Sea (Fig. 1).

Climate. The climate of the town of Kyustendil is transitional continental to Mediterranean. Rainfalls usually are not heavy. Their average annual amount is about to 589 mm. There is a tendency to alternate dry with wet years or periods (Fig. 2). By seasons they are distributed fairly evenly. Snowfall is mainly from November to March, with snow cover up to 30 cm thick and lasting for up to 15 days. However, the water wealth of Kyustendil and its surroundings is not small. There are many rivers, springs, dams, mineral and ground waters (Ivanchev, 1996). The climate is mild, transitional continental with Mediterranean influence, and is

Corresponding Author Anton Sotirov ✉ Institute of Agriculture, Kyustendil, Agricultural Academy, Bulgaria

determined by the entry of warm air masses along the Struma River and the protection from the entry of cold air from the North (Zahariev, 1963).

Figure 1. Location of the studied area

Soils. At the vicinity of the valley of Kyustendil can be indicated four main soil types – Arenic Fluvisols, Haplic Chernozems-Vertisols, Chromic Luvisols, and Cambisols, according to World reference base for soil resources (Teoharov et al., 2009). All of them are distributed only in the form of small spots in the Northwestern part of the Kyustendil valley. Cambisols covers the belt from 800 m to 1900 m above sea level, and Chromic Luvisols occupy the peripheral parts of the valley and slopes up to 800 m altitude (Fig. 3). The most common are the Arenic Fluvisols, which occupy the bottom of the Kyustendil valley and the floodplain and overflow terraces of the rivers – Struma, Dragovishtitsa, Bistritsa and Banshtitsa (Ivanchev, 1996).

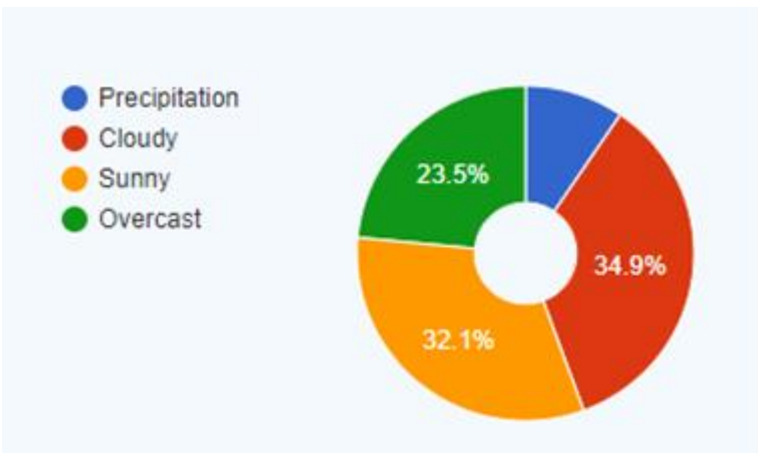

Figure 2. Weather characteristics-chance of precipitations during the year (World weather.com)

Description of reference soil IT008 Chromic Luvisols: A very deep, moderately well drained, dark red, clayey profile. The A-horizon dark reddish brown to yellowish red sandy clay overlies a deep homogeneous B2t-horizon of textural clay; throughout this horizon are Mn-mottles prominent. The bulk of roots is confined to the topmost horizon. The pH (method Hellige) is mildly alkiline in the topsoil and neutral in the subsoil. No evidence of groundwater is found within 300 cm. This type of soil is generally underlain by wheathered fine gravel or clayey texture and massive structure. Continuous clay layers are common, and generally the clay content increases with depth (average 56%). These soils occurs frequently on remnants of marine terraces at intermediate altitude (90 to 120 m), often situated on interfluves. Under a mediterranean climate the soils support a natural vegetation of oak forest, often degenerated to low shrub. The soil is encountered in Calabria, but is believed to occur commonly in the mediterranean region, although individual bodies of the soil are supposedly not very large. An appreciable acreage of this soil is in use for cereal production. Associated soils are red and reddish brown soils, because of the redder colour in the B-horizon, as well as rankers and alluvial soils. Marine terraces of Middle Pleistocene calcerous sands; locally fine bands of coarse gravel. (Benayas, 1970; Bruin, 1970; Heilmann, 1972).

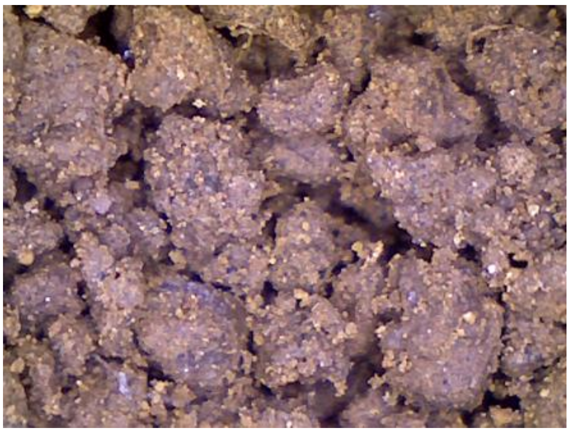

Figure 3. The soil of the studied area, digital microscopy, reflective light, air x100, some of the small particles are dust from Sahara-clay minerals and feldspar silt

Method

Meteorological data is measured by meteo-station “Meteobot” ver. 1.6 of Institute of Agriculture, Kyustendil, Agricultural Academy, Sofia, Bulgaria (Fig. 4). Additional information on air quality was obtained through the computer application "Ventusky.com", with the air in the area monitored for pollution for the following parameters: AQI - air quality index (ranking level between 0 and 400), Dust-Desert particulate matter (μg/m^3), PM10 minor particulate matter (μg/m^3), PM2,5-coarse particulate matter (μg/m^3), NO_2 (μg/m^3), CO (ppbvμg/m^3), SO_2 (μg/m^3), O_3 (μg/m^3).

Mineral study was executed in laboratory as the measurements were done by using binocular reflective microscope “Carl Zeiss Jena” and a digital microscope with a computer program “Micro Viewer ver. 2.2.d”. with reflective white LED light. The uppermost soil ploughing horizon with depth up to 30 cm was sampled in 6 profiles. Total number of the samples are 30. The studied parameters and chemical elements of soil with an aqueous extract in a ratio of 1:1. For this purpose, rain was simulated by adding 100 g of distilled water in 100 g of soil to activate the exchange of cations and the formation of electrolytes necessary for the measurement (Bell, F.G., 1998).

Figure 4. "Meteobot" meteo-station's satellite picture of the studied fields (white contour) ("Meteobot").

The Sahara dust was collected in a special cylinder - dust and water collector of the regular meteorological station of the Institute of Agriculture-Kyustendil, Bulgaria. The quantity accumulated for the last week of May 2024 was about 2 mm. The soil and collected Sahara dust at the meteorological station were studied for the chemical elements Fe, Cu, Zn, and Pb through X-ray spectral fluorescent analyses ("BARS-3" instrument). Three soil samples and three dust samples were studied with the most accurate instrument program with 16 consecutive measurements for 16 seconds done, which the machine automatically averages to achieve statistical reliability of the measurement.

Results or Findings

Wind action in arid zones usually cause soil erosion, but winds in Kyustendil valley, which is at temperate zone - moderate between semi-arid and semi-humid area, usually the winds have low speed 0.1-10 km/h, because of the mountain fences. The valley represents a place for deposition of eolic sediments rather than wind abrasion. But in both cases, wind affects agriculture in this regard. By itself, wind can remove uncemented debris up to a certain size, which it can perform more effectively if the debris is dry rather than wet. However, once armed with rock particles, the wind becomes a noteworthy agent of abrasion. The size of individual particles which the wind can transport depends on the strength of the wind, and on particle shape and density. The distance which the wind, given that its velocity remains constant, can carry particles depends principally upon their size. Fine grained particles on the ground surface are subjected to increasing stress, so that they ultimately begin to move.

At first, particles are moved by saltation, that is, in a series of jumps. The impact of saltating particles on others may cause them to move by creep, saltation or suspension. Saltation accounts for up to three-quarters of the grains transported by wind, most of the remainder being carried in suspension; the rest are moved by creep or traction. Particles removed by the wind primarily are of sand and dust size (Bell, 1988).

Figure 5. Dust from Sahara Desert in the air around the Kyustendil Valley on 27 March 2024.

Figure 5 is a picture made in a sunny day of the dusty clouds, the highest value detected for the last one and a half year, respectively 179 μg/m^3, reported on March 27, 2024 at 17.00 local time.

Table 1 shows the data by the meteo-station "Meteobot" for the same period. The meteo system shows that during past year 2023 the summary dust content was about 2008 μg/m^3 or about 0.002008 mg/kg (2.008 kg/t). The valley has the shape of an irregular ellipse, whose long axis is oriented from the Northwest to Southeast direction and has a length of about 20 km, and its width varies from 7 to 10 km or its surface is about 170 sq. km, but surface of the Kyustendil municipality, including the villages at the mountain slopes is about 959.40 sq. km (Yearbook of Municipalities in Bulgaria, 2002). Thus, it can be estimated that only in a one-meter air layer above the territory of the municipality of Kyustendil during 2023 there were about 1926.4752 kg of dust from the Sahara Desert, and with an air layer of 100 m, the amount becomes 192647.52 kg.

As it is seen the sensible dust layer might be accumulated in the soil at Kyustendil valley. Typically, warm dusty air from the Sahara mixes with cooler air in spring or autumn, and the dust cloud in many cases, falls in the form of rain on the valley. Sand and dust have the property of liquids, i.e. they take the form of the vessel in which they are placed, can be poured from it, flow along the lines of liquids, and finally for them also the rule of Friedrich Heinrich Alexander von Humboldt is valid, sediments, whether carried by water or wind are deposited and accumulate before and around bariers, and in some cases behind them, depending on the shape and size of the partcles of the dust. Therefore, much of this dust falls on the ground and is deposited in the foothills and slopes of mountains or hills that block the path of the dust-bearing wind, or in smaller barriers is deposited behind them in the form of sand hair, similar to gold-bearing deposits. Particulate matter is also deposited when the wind speed decreases, for example, when entering valleys enclosed by mountains or the weather conditions that led to the appearance of this wind change sharply, for example, a change in atmospheric pressure, temperature, humidity, etc. In a word, the closed valleys where the path of the warm Saharan air ends along the Struma River valley are suitable for the accumulation of the dust fraction in the air.

Table 1. Sahara dust content in the air (μg/m³) (by "Ventusky") and wind speed (m/s) (by "Meteobot")

Date	Sahara dust content in air, mg/m³	Wind speed, m/s	Date	Sahara dust content in air, mg/m³	Wind speed, m/s	Date	Sahara dust content in air, mg/m³	Wind speed, m/s
12.3.2024	20	1.40	22.10.2023	67	1.20	12.5.2023	20	0.30
15.3.2024	20	0.30	23.10.2023	80	0.20	14.5.2023	20	2.30
02.2.2024	8	2.00	24.10.2023	20	0.20	15.5.2023	87	0.50
12.2.2024	47	2.10	25.10.2023	20	0.10	16.5.2023	40	0.30
26.1.2024	20	4.70	26.10.2023	47	0.40	17.5.2023	21	0.50
27.1.2024	20	2.80	27.10.2023	9	1.00	01.4.2023	20	1.50
28.1.2024	9	3.60	14.9.2023	21	0.60	01.3.2023	20	0.50
29.1.2024	9	3.30	15.9.2023	20	0.50	02.3.2023	20	0.20
07.1.2024	27	1.00	24.9.2023	60	0.10	03.3.2023	12	0.20
08.1.2024	21	0.40	25.9.2023	20	0.90	25.2.2023	20	1.40
16.1.2024	20	1.00	26.9.2023	20	1.80	26.2.2023	40	3.50
17.1.2024	20	0.60	27.9.2023	20	2.10	27.2.2023	21	1.20
18.1.2024	20	2.50	28.9.2023	20	1.30	28.2.2023	20	0.40
19.1.2024	19	0.40	29.9.2023	20	1.10	17.1.2023	20	4.20
02.12.2023	20	2.50	30.9.2023	20	1.10	18.1.2023	20	4.30
03.12.2023	59	0.80	15.8.2023	20	1.40	19.1.2023	40	3.20
05.12.2023	9	0.20	18.8.2023	8	0.70	20.1.2023	13	1.10
06.12.2023	20	0.00	19.8.2023	19	0.70	22.1.2023	20	0.10
07.12.2023	20	1.00	21.8.2023	20	1.20	23.1.2023	1	0.10
01.11.2023	20	0.40	22.8.2023	20	0.70	27.1.2023	7	0.20
04.11.2023	62	0.80	26.8.2023	20	0.50	10.12.2022	20	4.10
08.11.2023	40	0.30	27.8.2023	20	0.50	11.12.2022	20	2.30
11.11.2023	20	1.50	28.8.2023	20	0.50	17.12.2022	11	2.10
24.11.2023	20	0.10	14.7.2023	20	0.50	01.11.2022	39	0.20
25.11.2023	40	1.70	15.7.2023	28	0.50	02.11.2022	20	0.10
29.11.2023	20	0.60	16.7.2023	20	0.30	04.11.2022	20	0.30
30.11.2023	13	0.20	17.7.2023	20	0.40	05.11.2022	20	0.70
10.10.2023	39	1.10	18.7.2023	20	0.90	06.11.2022	20	0.10
11.10.2023	20	0.40	20.7.2023	20	0.80	17.11.2022	20	0.40
12.10.2023	19	0.40	21.7.2023	20	0.70	21.11.2022	1	1.30
13.10.2023	8	0.30	22.7.2023	40	0.60	23.11.2022	20	0.40
14.10.2023	20	0.30	23.7.2023	20	0.90	24.10.2022	20	0.20
15.10.2023	20	0.30	25.7.2023	40	0.50	25.10.2022	20	0.10
20.10.2023	67	1.10	26.7.2023	60	1.30	26.10.2022	20	0.50
21.10.2023	40	1.60	24.6.2023	11	0.50	31.10.2022	20	0.80

Figure 6 is a distribution map of the main soil types in Bulgaria. Low areas South of the Stara Planina (Balkan) Mountain are soils of the Chromic Luvisols type. These are also the areas with the most intense transfer of dust from the Sahara Desert over Bulgaria, with the difference that the deposited dust particles above the hills and mountains are moved by rains and rivers to the lower parts of the terrains. Obviously, dust from the Sahara Desert plays an important role in the soil formation not only of the Kyustendil valley, but also for the formation of soils of the type Chromic Luvisols elsewhere in Bulgaria and Central Balkan Peninsula. In Figures 7 and 8 a great resemblance is seen between the wind-brought desert dust-silt and the dust fraction of the soils Chromic Luvisols of the Kyustendil valley. Microscopic observations found that the dust from Sahara Desert has much more complicated composition. Firstly the pH of the fresh wet dust fell with moisture on the ground has pH~6, as it was expected to be much more alkaline, because of the feldspar content. There were observed also clays, mainly saponites and their representative montmorillonite are products formed at the expense of aluminosilicate minerals of the group of mica, feldspars or magnesium silicates. There are some crystals, which were determined as quartz, muscovite, biotite, calcite. There are dark particles and crystals, which are non-magnetic. Some of the particles are probably contamination by the air as ash, soot, polen or other pollutant as textile, fuzz and etc.

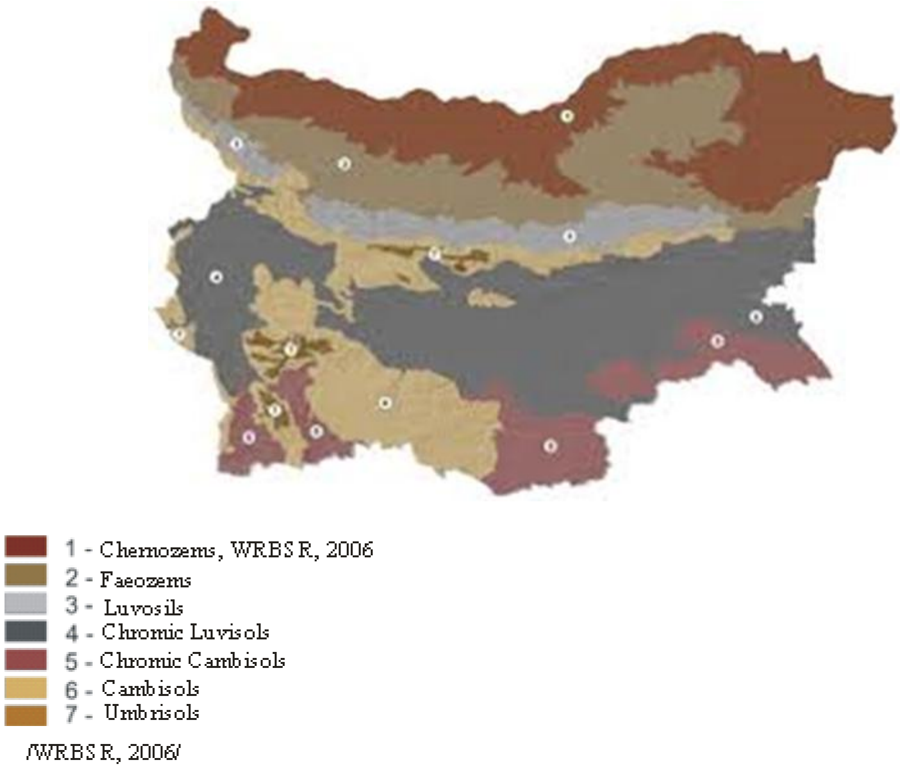

Figure 6. Soil map of Bulgaria National Soil Survey, https://en.nationalsoils.com/

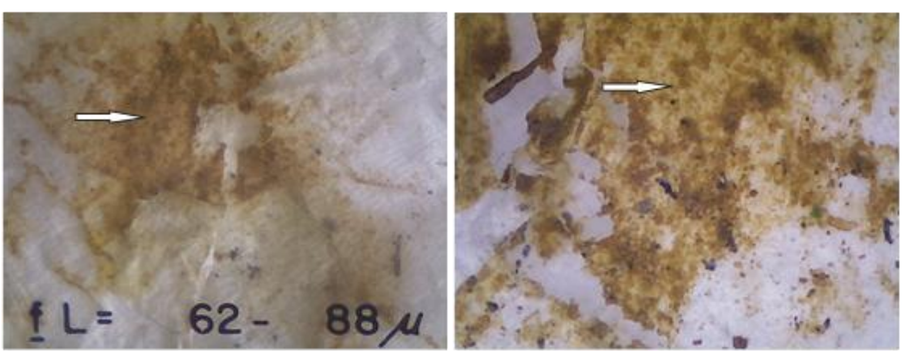

Figure 7. Microscopic view of the Sahara Dust, accumulated on 28 March 2024 at Kyustendil Valley, digital microscope, air environment, reflective white light, magnification x200

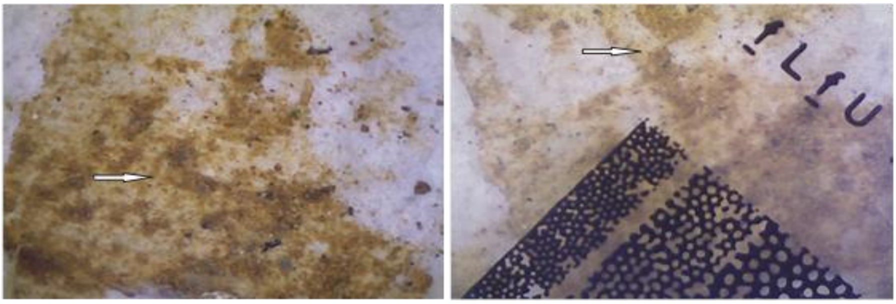

Figure 8. Microscopic view of the soil Chromic Luvisols at the Kyustendil Valley, digital microscope, air environment, reflective white LED light, magnification x200

Because of the resemblance of the Sahara Desert dust and dust-silty fraction of the Chromic Luvisols soil in mineral content and microscopic components and also, because of the match between Word's distribution of the Chromic Luvisols soil map (Reference soil Italy 08: Chromic Luvisol ISRIC, World Soil Museum and Worlds distribution of the desert dust by Alsharif Wiam et al. (2020) (Figs. 9 and 10). There is full almost cover of the territories with distribution of the worlds desert dust content and the Chromic Luvisols soil, including the studied area Kyustendil Valley (Figs. 11 and 12), Bulgaria, Europe and the World.

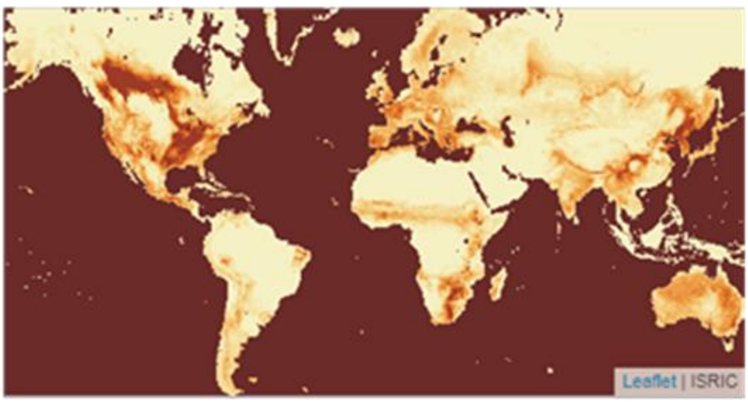

Figure 9. Word's distribution of the Chromic Luvisols soil map (Reference soil Italy 08: Chromic Luvisol ISRIC, World Soil Museum)

Figure 10. Worlds distribution of the desert dust (Alsharif Wiam et al., 2020).

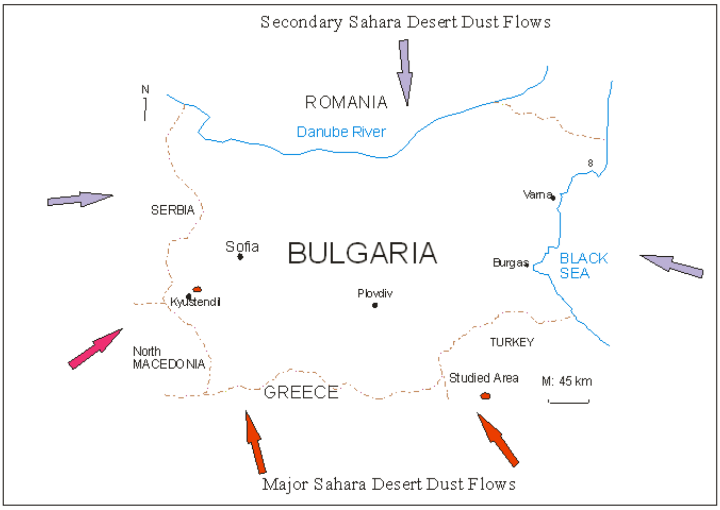

Figure 11. Major and secondary air flows carrying dust from the Sahara Desert

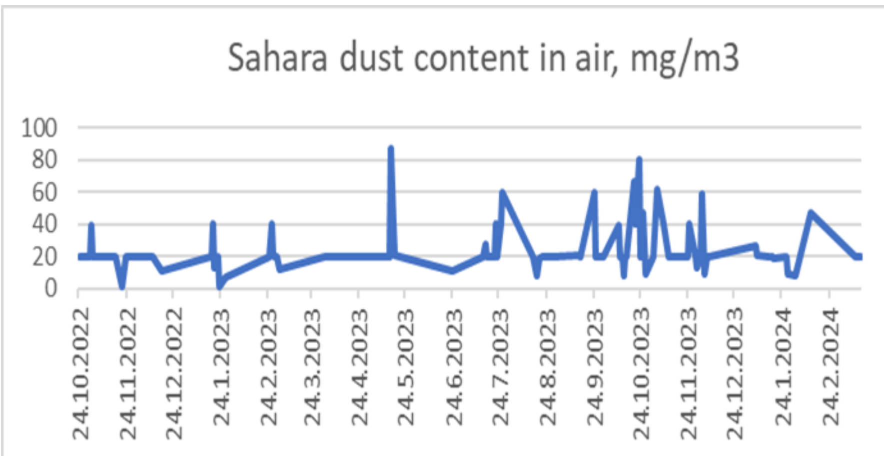

Figure 12. Sahara dust content in the air over Kyustendil Valley during last 1.5 years.

On Figure 11 the pulsatile sinusoidal character of alternating air masses with higher and then with lower contents of desert particulate matter is seen.

Table 2 presents the data from the X-ray spectral fluorescence study of the Sahara dust collected and the upper 5 cm layer of the soil next to the collector of the dust. It might be seen that the content of siderophie element Iron Fe in the Sahara dust and studied soil are very close, but their amout is 2 times more than the data published by Guieu et al. (2002). Chalcophile element Copper Cu also is almost equal in the dust and in the soil, but Zink Zn is about 10 times more in the Sahara dust than in the soil studied, and Lead Pb is about 100 times less in the soil tnan in the dust. Guieu et al. (2002) take attention of high content of Lead Pb in the Sahara dust, which is much less in the Saharan soils. They link Pb content in the dust with anthropogene genesis. They also related the similar ratios between some elements and common genesis of the dust and the soil. Table 2 shows also equal ratio between studied major siderophile and chalcophile elements Cu/Fe. The Lead Pb and Zink Zn contents are sensitive high in the studied Sahara dust, but it is difficult from the present study to determinate anthgropogene or natural is their genesis. Te concentration in the studied soil of the Zn is not high, which is typical for the soils, because of the very complicated phenomenon and combination of processes influence on the element content in the soil and its adsorbtion by the plants (Ganev, 1990). According to Bouska (1981) Pb usually in the nature is a part of galena or pyrite mineralization, Fe is connected with pyrite or differend oxydes and it is a part of the plants, Cu usualy is accummuated in the plants and it is connected with Cu mineralizations also, Zink is related with different natural mineralizations as enrichment of the elements in the Earch's crust and in the major anthropogene polutant coal ash are given in the Table 3 below.

Table 2. Results from the X-ray spectral fluorescent analyses. Mean concentrations of Fe, Cu, Zn, Pb in Sahara dust and Chromic Luvisols soil, Kyustendil valley, Bulgaria (n.d.-no data)

Element, %	Sahara dust, collected in the local meteo-station during the last week of May 2024	Chromic Luvisols soil of the surface 10 cm layer of Kyustendil valley, Bulgaria	Sahara dust, data pulished by Guieu et al. (2002)	Saharan soils, data published by Guieu et al. (2002)
Iron (Fe)	8.72%	7.14%	4.45%	3.94%
Copper (Cu)	0.50%	0.40%	n.d.	n.d.
Zink (Zn)	5.98%	0.41%	n.d.	n.d.
Lead (Pb)	3.3%	0.026%	0.0048%	0.0024%
Iron (Fe)	87200 ppm	71400 ppm	44500 ppm	39400 ppm
Copper (Cu)	5000 ppm	4000 ppm	n.d.	n.d.
Zink (Zn)	59800 ppm	4100 ppm	n.d.	n.d.
Lead (Pb)	33000 ppm	260 ppm	48 ppm	24 ppm
Ratio Cu/Fe	0.057	0.056	n.d.	n.d.
Ratio Zn/Fe	0.68	0.057	n.d.	n.d.
Ratio Pb/Fe	0.38	0.0036	n.d.	n.d.

Table 3. Enrichment of elements in Earth's crust, pelitic sediments and coal ash (ppm) by Krejci-Graf (1972).

Element	Eartch's crust (Average)	Pelitic sediments	Max contents in the coal ash
Cu	70 ppm	192 ppm	4000 ppm
Zn	40 ppm	200-1000 ppm	10000 ppm
Pb	16 ppm	20 ppm	1000 ppm

Discussion

According to Warren and Maizels (1977) the wind erosion cause slight severity – rippled surfaces, fluting and small-scale erosion, moderate severity – wind mounts and wind sheeting, severe pavements, and very severe extensive active dunes (Bell, 1998). Stancheva (2000) described the influence on the physical properties of the soil on the plants or the "heavy" soils has small mineral grains, which ensure good moisture content of the soil, but low level of aeration, because of the higher density and cause reduction of the growing of the roots. Soils with small soil particles, the absorption capacity of the soil is higher and it retains nutrients around the root zone for a longer period. In addition, due to the increased active surface, the possibilities of contact between roots and soil particles are increased. Again, according to the same author, the reduced size of mineral particles in clay soils as the soils of the studied area, causes an increase in their water-holding capacity. In such soils, the development of the root system is most often superficial. To warm these fine particulate matter, more heat is needed and are known as "cold soils". In the conditions of an arid climate, due to the high capillarity, the so-called "heavy" soils quickly lose their moisture, which is why they are poor in vegetation. At the same time, they are prone to salinization due to their low drainage capacity Ganev, S. (1990). For the first time, a NASA satellite has quantified in three dimensions how much dust makes this trans-Atlantic journey. Scientists have not only measured the volume of dust, they have also calculated how much phosphorus – remnant in Saharan sands from part of the desert's past as a lake bed – gets carried across the ocean from one of the planet's most desolate places to one of its most fertile (www.nasa.gov). According to Stancheva (2000), phosphorus is very important for the development of plants, as it is contained in them not only in organic but also in inorganic form, but even with a strong phosphorus deficiency, part of the phosphates remain in inorganic form, therefore they should not be considered as a source of reserve phosphorus, but can cause eutrophication of the ecosystem.

Conclusion and Implications

The airborne transfer of dust fraction from the Sahara Desert plays an essential soil forming role. To the description of reference soil IT008 Chromic Luvisols should be added the mixed origin of this soil between autochthonous soil formation factors and external exogenous soil formation factors such as transfer of desert dust from nearer and distant deserts. Due to a number of physical factors, these particles settle in the lower parts of these areas. Desert dust plays a significant role in agriculture in the Kyustendil valley. It reduces the acidity of more acidic soils, which is why it affects crops that develop better at lower values pH = 4.5-5.5, such as apple plantations negatively, and those that develop better at lower soil acidity such as cherries can have a positive effect. In general, it can be expected that desert dust in certain quantities can have a positive effect on soil formation and plant development due to the enrichment of the soil with silt, clay minerals that are still in the process of degradation, introducing calcium, potassium, silicon, and other beneficial elements, this being a light fraction that is devoid of heavy metals and other harmful components. But in high amounts may cause desertification of the soil. This fraction physics-chemical is very mobile, facilitates cation exchange in the soil, also introduces the necessary organic substance in the form of polen and other biological material intercepted by the air. Silt in certain quantities improves soil structure, drainage properties, plasticity and soil evaporation.

Declarations

Competing interests: The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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Orcid ID

Anton Sotirov https://orcid.org/0000-0001-5893-8374

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