Agro-Ecological Aspects of the Change of Sulphate Sulphur Content in Chernozem OF THE Buh-Dnipro Interstream Area in Ukraine

KOVALOV MYKOLA, VASYLKOVSKA KATERYNA, REZNICHENKO VITA, MOSTIPAN MYKOLA
Department of General Geoponics
Central Ukrainian National Technical University
Av. University, 8, Kropyvnytskyi
Ukraine
vasilkovskakv@ukr.net; http://www.kntu.kr.ua

Abstract: - The functional agro-ecological relation of hydrothermal coefficient ($HTCV_{V-IX}$) with the parameters of sulphate sulphur content, humus and nitrogen, soil density and total porosity in the most widespread soils of the region, which are typical and ordinary chernozems, were studied. In order to identify the difference between agrarian and natural ecosystems in the processes of sulphate accumulation, in accordance with the concept of V.V. Medvedev, we have made soil sections of land of various uses. All studies were conducted within the right bank of the Southern forest-steppe and northern steppe, as well as the transitional area of Ukraine. A close correlation between the content of sulphate sulphur and the total content of humus in the investigated soils of forest-steppe, steppe and transition zones of the Buh-Dnipro inter-stream of Ukraine was identified. Therefore, the studies showed that agricultural activities lead to soil compaction of agro-ecosystems and the reduction of sulphate sulphur content in them.

Key-Words: -typical and ordinary chernozems, soil density, sulphate sulphur, humus content, gross nitrogen

1 Introduction

Sulphur belongs to the group of the most important elements of plant nutrition despite the fact that its consumption is much less compared to nitrogen and phosphorus. It is in close connection with nitrogen, as both of these elements are necessary for the formation of proteins in plants. The main idea of the work is to study the processes of migration of sulphate sulfur into the lower parts of the soil profile of chernozem due to anthropogenic use. An additional factor in reducing sulphate sulfur content in soils is the use of environmentally friendly fuel. After all, in the mid-1990s Ukraine massively switched to more environmentally friendly natural gas of Russian origin. All industries, including processing factories which used local energy sources (brown coal, fuel oil, etc.) were converted to natural gas. As a result, emissions of sulfur-containing compounds have been significantly reduced. After 10-15 years chernozem needed additional application of sulfur-containing fertilizers.

In recent years, there has been an increase in the structure of crop areas that are more susceptible to the content of sulphur in the soil, its significant withdrawal to harvest, and the reduction of industrial emissions of sulphur into the atmosphere. As a result, the deficit of the so-called "fourth element", which is sulphur, has increased significantly. This is convincingly demonstrated by the results of the monitoring of field crops in agro-industrial formations. The field crops representatives of the cabbage family are particularly in need of sulphur. Sunflower needs mineral sulphur three times more than grain, and it reaches almost 50% of the needs of the rape, i.e. 25-35kg/ha [1]. Soybean, onion, garlic remove 45-85kg S/ha during harvesting [2].

2 Problem Formulation

The research was conducted within the territory of the right bank of southern forest-steppe and northern steppe of Ukraine where representative semi-stationary areas were selected. A group of soil sections were laid on those areas. To select semi-stationary areas, agrochemical maps of scale 1:25000 and 1:10000 were used. The materials of agrochemical research and seed-stock of Kirovohrad branch of the Institute of Soil Conservation of Ukraine and the Centre of Hydrometeorology of Kirovohrad region were also used. In order to find the difference between agricultural and natural ecosystems in the processes of accumulation of sulphate sulphur, in accordance with the concept of V.V. Medvedev [3], we studied the soil sections which were used differently. Therefore, sections 3 and 4 represent the forest-steppe zone (experimental area of Mala Vyska), sections 5 and 6 represent transition zone (experimental area of Kirovohrad), and sections 13 and 14 are the steppe zone (experimental area of Dolynka). Moreover, sections 3, 5 and 13 characterize natural ecosystems, and 4, 6 and 14 characterize agro-ecosystems. All experimental areas are located on plain territory. The selection of soil samples was carried out at the end of the vegetative period. The content of mineral sulphur was determined in accordance with All-Union State Standard (GOST) 26490-85 [4], humus was determined according to Tiuryn method (State Standard of Ukraine DSTU 4289-2004) [5]. Physical properties of the soil such as soil density (SD) and total porosity (TP) of the soil were determined by Kachinskyi method DSTU ISO 11272-2001 [6].

3 Problem Solution

As the research showed, the content of sulphate sulphur in soils of chernozem type of the Buh-Dnipro inter-stream of Ukraine depends on the conditions of humidification, soil type, amount of organic matter and the intensity of anthropogenic use of soil.

It has been established that the ratio among sulphate sulphur, humus and nitrogen contents has a rather wide interval and depends both on the conditions of soil formation and on the type of anthropogenic loading. According to our data, the mineral sulphur content in the soil profile of agro-ecosystems of the forest-steppe zone varies within the range of 3.2-5.0 mg/100g of soil, and in the natural ecosystems of this zone it is much higher– 12.4-22.4 mg/100g of soil. For the transition zone, these values are, respectively, 4.6-11.6 and 11.0-13.0 mg/100g of soil, and for the steppe zone they are 2.5-5.3 and 6.3-8.7 mg/100g of soil (Tab.1) [7]. Thus, in soils used in agro-industrial production, the amount of sulphate sulphur in all layers of soil is much smaller compared to natural ecosystems.

During the research, a close correlation between the content of sulphate sulphur and the total content of humus in the soil profiles of representative areas was revealed. The correlation coefficient for the forest-steppe zone is the following: natural ecosystems – 0.81, agro-ecosystems – 0.64; for the transition zone it equals 0.86 and 0.76, respectively; and for the steppe zone it is 0.86 and 0.84.

The obtained findings indicate that the humus layer of natural ecosystems for the content of sulphate sulphur for the forest-steppe zone and the transitional zone are identified as moderately-assured, and the steppe zone is poorly-assured. The humus horizon of agro-ecosystems in all research zones is identified as very poorly-assured. Despite the fact that the fungal micro-flora acidify the soil solution, contributing to the migration of sulphate sulphur into the profile, the presence of this element is sufficient to provide vegetation with nutrients. Agro-ecosystems do not have a naturally-balanced system for regulating the supply of nutrients.

Therefore, they are acutely in need of sulphur. This situation is aggravated by the fact that, against the background of unbalanced mineral fertilizers, the flow of sulphate-ion with industrial emissions dropped dramatically as a result of the introduction of the moratorium on limiting the presence of this element in emissions.

In all soil-climatic zones, regardless of the direction of the use of soils, the content of sulphate sulphur increases to the depth of the soil profile.

Table 1. The content of mineral sulphur and humus in the soils of the Buh-Dnipro inter-stream

Genetic horizon	Depth, cm	Ecosystem type	Research zone	Mineral sulphur content mg/100 g of soil	Total content of humus, %	pH (salt)
1	*2*	*3*	*4*	*5*	*6*	*7*
H	0-20	forest belt	Forest-steppe	12,4	7,30	5,2
H	30-40			13,2	4,94	5,7
H	50-60			13,5	4,41	5,9
Hp_k	90-100			14,9	2,22	6,8
PH_k	110-120			15,8	1,94	7,1
P_k	140-150			22,4	1,30	7,1
H_a	0-18	arable soil		3,2	4,91	7,0
H	30-40			3,6	3,27	7,1
Hp_k	50-60			4,3	3,23	7,1
PH_k	90-100			4,4	1,60	7,2
PH_k	110-120			4,7	1,26	7,3
P_k	140-150			5,0	0,69	7,3
H_k	0-20	grassland	Transition zone	11,0	5,36	7,4
H_k	30-40			11,2	3,65	7,5
HP_k	50-60			11,6	3,47	7,5
HP_k	90-100			11,8	2,16	7,5
Ph_k	110-120			12,6	1,94	7,6

P_k	140-150			13,0	1,32	7,6
$H_{a/k}$	0-20	arable soil		4,6	3,81	7,0
H_k	30-40			4,7	2,72	7,3
HP_k	50-60			10,8	1,95	7,5
Ph_k	90-100			10,9	1,2	7,5
P_k	110-120			11,2	1,04	7,6
P_k	140-150			11,6	0,77	7,6
H	0-20	forest	Steppe	6,3	5,34	5,5
H	30-40			6,8	3,65	6,2
HP	50-60			7,2	2,94	7,0
Ph_k	90-100			7,9	1,83	7,1
Ph_k	110-120			8,0	1,59	7,1
P_k	140-150			8,7	1,19	7,2
H_a	0-20	arable soil		2,5	4,12	7,0
H_k	30-40			2,4	2,7	7,1
HP_k	50-60			3	2,12	7,3
P_{hk}	80-90			3,5	1,62	7,3
P_k	110-120			4,9	1,35	7,4
P_k	140-150			5,3	0,79	7,4

Moreover, it should be noted that natural ecosystems with deeper layers of the soil and especially C-horizon contain a significantly higher amount of sulphate sulphur than agro-ecosystems. Natural ecosystems are more water-permeable due to the low SD and high TP. So, the content of sulphates in the C-horizon is slightly higher than in agro-ecosystems.

On the other hand, sulphates cause decalcification of the soil and its acidification. Under natural conditions, about 2% of organic sulphur is mineralized during the micro-biotic decay. The intensity of mineralization of sulphur depends on the content of humus and nitrogen in soil.

In agro-ecosystems, due to the alienation of plants beyond the boundaries of the field, the flow of organic matter to the soil is less, so the sulphur content is much smaller. Due to the fact that there is a direct relationship between the content of humus and nitrogen, and it is an opposite relationship between the content of humus and sulphur, the transformation of sulphur in the soil from the organic form to the mineral and in the opposite direction depends entirely on the mechanisms of self-regulation, that is, the presence of micro-organisms. Immobilization of sulphur in the soil is associated with humus, micro-organisms and by-products of microbial synthesis.

Losses of sulphur from the upper horizons occur due to leaching and anaerobic evaporation. Sulphur deficiency in the soil of agro-ecosystems weakens certain processes during the growth and development of plants, namely: photosynthesis (due to reduced chlorophyll content), fixation of nitrogen in legumes, conversion of ammonium nitrate into protein, formation of reserve proteins in formed seeds. At the same time, sulphur deficiency can intensify the process of accumulation of nitrates in plant products.

Thus, mineral sulphur has a significant role in plant nutrition, almost like nitrogen. Therefore, paying great attention to nitrogen nutrition without taking into account the needs of plants in sulphur, agricultural producers reduce its effectiveness. Sulphur and nitrogen are the "building blocks" of proteins, and therefore, without sufficient supply of plants with sulphur, it is impossible to achieve high productivity of field crops. The accumulation of zinc (Zn), selenium (Se), calcium (Ca), copper (Cu) and molybdenum (Mo) by plants also depends on the content of sulphur in the soil. Therefore, sulphur content in the soil should be sufficient [8].

Numerous scientific studies have shown that quantitative and qualitative humus content is subject to certain zonal peculiarities of soil genesis (climatic features, size of watering, plant type, etc.) [8-12]. The territory of the Buh-Dnipro inter-stream is also not an exception to this pattern.

The consistent level of humus and sulphur content in the soil completely depends on the dynamic equilibrium between the processes of humification and mineralization of organic matter. Under certain conditions, some processes predominate over others. As a result, there is either accumulation of humus or its loss (dehumidification). In natural soil formation, humification predominates over mineralization. Therefore, a gradual accumulation of organic matter of the soil occurs, the content of which under certain conditions stabilizes. In this regard, in the areas of natural ecosystems, humus, nitrogen and sulphur contents are slightly higher than in agro-ecosystems.

In addition to zonal subordination, our findings indicate a significant dependence of the content of humus, sulphur and nitrogen on a variety of other soil fertility indices. The most important role in the accumulation of sulphate sulphur and humus is played by indicators such as soil density (SD), total porosity (TP) and granulometric composition (GC). These indicators influence the process of immobilization of sulphate sulphur. This dependence is confirmed by our research results. Such spatial mosaic structure of chernozems is determined primarily by fluctuations in the humidity of the territory, as evidenced by fluctuations in the reduction of sulphate sulphur content of ecosystems. With a decrease in the depth of absorption, the variation of sulphate sulphur is reduced.

The SD index depends primarily on the humidity conditions and GC (Tab. 2.) [7].

For the southern forest-steppe zone they are №3-4 with hydrothermal $coefficient_{V\text{-}IX}$=1.13; transition zone are №5-6 with hydrothermal $coefficient_{V\text{-}IX}$=0.96; northern steppe zone are №13-14 with hydrothermal $coefficient_{V\text{-}IX}$=0,94. Taking into account these data, in steppe areas, the discrepancy in the parameters of steady-state soil density and the content of sulphate sulphur between natural and agro-ecosystems can only be traced to the depth of 40 cm. As precipitation increases, these differences can be traced in deeper layers of soil.

So, for the transition zone it is 60 cm deep and for the forest-steppe zone, it is 90 cm deep. The steady-state soil density for the natural analogue of the zones is higher, as opposed to the two previous researched zones (Tab. 1, 2) [7], due to the fact that the hydrothermal $coefficient_{V\text{-}IX}$ and the depth of soil soaking are higher.

In the natural ecosystems of the forest-steppe zone, the percentage of sand fraction is higher and the percentage of physical clay (PhC) is lower than in the agro-ecosystems. This dependence in combination with a low steady-state soil density, high total porosity and hydrothermal $coefficient_{V\text{-}IX}$>1, contributes to the migration of sulphate sulphur down the profile. The agro-ecosystems of this zone have much higher value of steady-state soil density and a lower index of total porosity, combined with a higher percentage of physical clay. Taking into account that the main and by-products are alienated outside the field, the content of sulphates in soils is considerably inferior to natural ecosystems. Such a combination of the above factors leads to the fact that the soils of agro-ecosystems, due to the consolidation and accumulation of moisture which is not accessible to plants, are less capable for leaching sulphates.

Table 2. Agro-ecological indicators of soils of experimental sites

Number of experimental area	Genetic horizon	Depth of sampling, cm	Granule-metric composition						Physical clay, %	Steady-state soil density, g/cm^3	Total porosity,%
			sand	heavy sand	coarse silt	medium silt	small silt	silt			
			<0,25 mm	0,25-0,05 mm	0,05-0,01 mm	0,01-0,005 mm	0,005-0,001 mm	>0,001 mm			
1	2	3	4	5	6	7	8	9	10	11	12
Forest-steppe, forest belt											
3	H	0-10	0,1	13,3	32,0	10,8	10,4	33,4	54,6	0,80	64
	H	30-40	0,0	9,8	31,6	9,4	17,1	32,1	58,6	1,02	58
	H	50-70	0,0	0,0	43,4	9,5	14,8	32,3	56,6	1,06	58
	Ph_k	90-100	0,0	4,4	36,4	7,5	13,6	38,1	59,2	1,31	49
	P_k	140-150	0,0	1,3	33,7	8,3	16,9	39,8	65,0	1,37	49
Forest-steppe, arable soil											
4	H_{ak}	0-20	2,0	5,4	34,0	9,0	13,0	36,6	58,6	1,21	50
	H_k	30-40	0,1	10,0	28,8	9,2	14,7	37,2	61,1	1,28	49
	Hp_k	50-70	0,0	6,6	32,5	9,6	13,9	37,4	60,9	1,3	51
	Ph_k	90-100	0,0	4,3	35,1	8,8	13,0	38,8	60,6	1,32	50
	P_k	140-150	0,0	3,4	26,8	12,3	15,3	41,9	69,8	1,39	49
Transition zone, grassland											
5	H_k	0-10	4,0	10,4	32,2	6,6	10,8	36,0	53,4	1,06	56
	H_k	30-40	0,4	3,2	37,6	5,7	13,1	40,0	58,8	1,07	56
	HP_k	50-70	0,5	4,9	34,3	7,0	13,3	40,0	60,3	1,13	55
	Ph_k	90-100	0,3	1,5	37,3	8,0	12,9	40,0	60,9	1,17	53
	P_k	140-150	0,4	3,2	37,2	9,8	13,4	36,0	59,2	1,19	53
Transition zone, arable soil											
6	H_{ak}	0-20	0,4	2,4	40,0	6,7	9,6	40,9	57,2	1,15	55
	H_k	30-40	0,4	1,0	40,9	5,6	11,7	40,4	57,7	1,30	49
	HP_k	50-70	0,3	3,5	38,1	7,7	11,0	39,4	58,1	1,14	56
	Ph_k	90-100	0,4	3,8	36,7	10,7	9,6	38,8	59,1	1,19	56
	P_k	140-150	0,5	2,0	40,5	3,2	10,7	43,1	57,0	1,20	56
Steppe, forest											
13	H	0-10	1,1	13,7	29,2	11,7	11,3	32,7	56,0	1,03	56
	H	30-40	0,9	8,0	34,2	9,3	14,1	33,5	56,9	1,14	55
	HP_k	50-70	1,1	1,7	42,4	8,2	11,2	35,4	54,9	1,19	55
	Ph_k	90-100	0,8	9,8	36,7	8,2	9,9	34,6	52,7	1,23	54
	P_k	140-150	1,0	4,1	37,0	6,3	15,1	36,5	57,9	1,26	53
Steppe, arable soil											
14	H_a	0-20	0,7	7,4	35,2	9,5	14,5	32,7	56,7	1,25	50
	H_k	30-40	0,4	4,3	30,6	10,1	15,1	39,5	64,7	1,15	54
	HP_k	50-70	0,3	1,0	27,5	10,0	17,8	43,4	71,2	1,21	54
	P_{hk}	90-100	0,4	3,3	30,7	8,0	16,6	41,0	65,6	1,26	53
	P_k	140-150	0,4	3,6	19,6	14,1	17,8	44,5	76,4	1,30	52

This dependence between the parameters of the granulometric composition, steady-state soil density and total porosity is characteristic for the transition zone as well as for the steppe zone. As the moisture of the area decreases, the volatility of sulphate sulphur content in the soils decreases.

The results of the tests carried out on the soils of the experimental zones indicate that the lowest values of the steady-state soil density are characteristic of the soil outside the limits of agricultural activity: for the forest-steppe zone it is 0.80 g/cm^3; for the transition zone it is 1.06 g/cm^3; and for the steppe zone it is 1.03 g/cm^3, respectively. At the same time, the highest levels of sulphate sulphur content are also characteristic of the soil of natural ecosystems.

Changes in sulphur and humus content in soils are a certain criterion, which reflects the course of soil formation and humus accumulation. In our opinion, there is a close relationship between sulphate sulphur, total content of humus and soil density. The higher the total humus indicator in the soil is, the lower the rate of steady-state soil density. And the total porosity is higher. On the other hand there is a reverse between sulphate sulphur and humus.

4 Conclusion

The content of sulphate sulphur in the soils of the Buh-Dnipro inter-streams of Ukraine depends on the characteristics of the water condition of soils, rainfall and intensity of anthropogenic loading. The soils of agro-ecosystems contain considerably less amount of sulphate sulphur than the same types of soils of natural ecosystems.

There is a direct correlation between the content of humus and sulphate sulphur in the soil profile. For natural ecosystems it varies within R=0.81-0.86 and for agro-ecosystems it is R=0.64-0.84.

When moving to west and north within the limits of the Buh-Dnipro inter-streams of Ukraine, the amount of sulphate sulphur increases in the soil of natural ecosystems. For agro-ecosystems, such regularity is not found.

The content of sulphate sulphur depends to a large extent on the value of the soil density and the depth of soil softening, namely there is alignment between the agro- and natural ecosystems at the same depths as well as soil density.

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