Minimization of Water Erosion Degradation Processes on Chernozems in The Forest Steppe Zone of Ukraine

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Abstract

The most fertile soils named chernozems are dominant in the soil cover of Ukraine. The very great plowland of fertile soils under the modern farming conditions stimulate degradation processes; one of the most widespread is water erosion. According to the State Agency of Land Resources, the total area of eroded soils is 13.4 mln ha; environmental and economic damage of these processes equals approximately 2.5 billion dollars per year. The losses of grains yield calculated as 7-8 mln tons per year. The most intensively water erosion spread in slope lands of Forest Steppe zone of Ukraine; where part of arable land occupies above 80%. Purpose of the research was investigation of soil-saving tillage using V-blade treatment and soil cover mulching of chernozems to estimate effect of preventing water erosion.

Research was conducted in the stationary field experiment in Kyiv region on slope lands of the Southern-East exposure with the steepness 5–6º. Research results of 5-year field experiment show that V-blade treatment tillage had increased water infiltration to 0.85 mm/min. We considered, the main reason of this situation is a formation of a vertical pore space and more water stable soil aggregates in compare with traditional plowing.

Also, experimental results of sprinkling to simulate water erosion processes had been performed. The most erosion-preventing efficiency was noted on the typical chernozem after V-blade tillage cultivation on depth of 25–27 cm, where soil runoff include 57.5 m3/ha and soil losses were 0.78 t/ha, when after plowing – 125.6 m^3/ha and 9.88 t/ha accordingly. At the same time, using these measures will not save the soil cover upper layer, but will have a positive effect for increase of earthworms quantity and intensive root system formation of crops.

Keywords: Chernozems, water erosion, V-blade tillage, soil infiltration, soil ravine.

Introduction

Soils are one of the main components of the environment, which have an important biosphere functions for human life. The loss of soil fertility is a cause of land degradation. Poor Agroecological condition, which is characterized by much of the agricultural land in Ukraine, is largely a consequence of excessive development of agricultural and arable area. It was a main reason for poor environmental stability of landscapes and caused extensive degradation of soil. Therefore, recultivation of soil is restoring the environmental balance areas, which are destroyed by irrational human economic activity [1].

Land degradation is caused both natural and anthropogenic factors, which are in interaction with each others. Especially, these processes are characterized for countries with high level development of agriculture, which we can include Ukraine. Among the main factors of anthropogenic impact for the environment includes high level of agricultural development and cultivated land, a significant reduction of the area of forests, grasslands, meadows and pastures, etc. [2,3]. Also, to negative processes we may include a negative balance of humus. We refer also a negative balance of humus and nutrients in agriculture and wide spread using of environmentally non stable agricultural technologies too [4]. In this case, it is leads to deterioration water, agrophysical, biological and agrochemical soil properties, reduce their fertility, environmental sustainability and loss of agrobiodiversity [5].

The total area of lands in Ukraine is 60.355 mln. ha. and is one of the largest in Europe. According to the State Agency of Land Resources on 01.01.2010 year agricultural lands occupy 69% of total area of Ukraine. Agricultural lands consist of arable lands (78%), pastures (13%), hay lands (6%), perennial crops (2%) and fallow (1%). Forests and other forestry areas occupy almost 18% of the country, built-up lands – 4%, aquatic territories – 4% and wetlands – 2% [6].

It is known, that 60% of soil cover of Ukraine occupy chernozems, which have the unique structure, properties and potential fertility. However, in last time these soils are subjected to various types of degradation. In Ukraine, third parts of arable land area are eroded. These soils lost more than 30% organic matter [7]. Most of the arable land in the subsurface layer is compacted, which is resulting to reduced supply of nutrients.

The most fertile soils named chernozems are dominant in the soil cover of Ukraine. The very great plowland of fertile soils under the modern farming conditions stimulate of degradation processes. One of the most widespread is water erosion. According to the data of State Agency of Land Resources, the total area of eroded soils is 13.4 mln. ha approximately 32% of total area of Ukraine, including 10.6 mln ha of arable lands. Among depredated lands dominate moderately and heavy eroded soils. They occupy area above 4.5 mln ha, but 68 thousand ha of these soils lost a humus horizon [1]. In Ukraine are widespread developing processes of gully erosion and ravine formation. The total area of ravines is 140.3 thousand ha and their number exceeds 500 thousand [6].

Among the soil-climatic zones of Ukraine the most erosion processes are spread in the Steppe and Forest-steppe zones, where the proportion of eroded land is respectively 54.4 and 27.5% of the total area of farmland. The main reason for this phenomenon is the high level of plow lands, which in Steppe region occupies 62.5% and in Forest Steppe 58.1% of the total country area [8]. The characteristics of the soil erosion distribution of Forest Steppe area are presented in detail in Table 1.

After analysis we found, that the biggest area of eroded soils is spread in Kharkov region – 996.3 thousand ha or 41.2% of agricultural land. This index is very higher, than the national rate. The total eroded land area of Kyiv region is 157.9 thousand ha, accounting for 9.5% of the agricultural land [9]. However, there are areas in the Kyiv region, where the slope lands dominate in the structure of the land use. These lands have a high degree of erosion. In particular, this applies to the Obukhov area, in which have been conducted our research.

Water erosion are controlled by many physiographic, geologic, climatic, and other factors, such as topography, types and distribution of soils, vegetation cover, lithology, land use, etc. [10]. One of the named factors of erosion is climatic, which have both direct and indirect impact on these processes. Among the reasons of erosion formation are climatic variations, such as intensity of rainfall, the energy of falling drops, a depth of snow layer and the water content in it. The topography of the area plays an important role in creating a surface runoff and soil erosion formation.

It is known, that with increasing steepness of the slope increases the force of gravity, the speed and destructive power flow, which creates soil erosion. Also, the erosion hazard area affected by the length of slopes, their shape and exposure. The vegetation covers on the soil surface leads to dispersal the runoff into many small streams. In this way are creating better conditions for the absorption of water into the soil. The best anti-erosion effect is creates with available on the soil surface of legumes and grains, which have the well-developed root system

[11]. Low stable soil level to the outwash we observed under corn, sunflowers, sugar beets, etc [12]. The root system of plants contributes for soil cementation and structure formation. In this case, we observe the increasing its resistance to erosion and improving infiltration capacity.

Table 1. Areas of eroded land of the Forest Steppe region of Ukraine, thousand ha [6].

Region of Ukraine	Agri-cultural lands	Area of arable lands	Eroded lands		Including arable land	
			total area	% of agricultural land	total area	% of total area
Vinnitska	2017.1	1729	687.5	34.1	593.1	34.3
Kyivska	1668.4	1360.6	157.9	9.5	128.8	9.5
Poltavska	2175.7	1768.8	517.7	23.8	420.3	23.8
Sumska	1701.6	1232.8	305.1	17.9	176.3	14.3
Ternopilska	1049.7	854.0	244.0	23.2	239.7	28.1
Kharkivska	2418.7	1926.6	996.3	41.2	791.2	41.1
Khmelnitsky	1568.4	1254.8	628.4	40.1	501.9	40.0
Cherkaska	1451.4	1271.6	326.6	22.5	286.1	22.5
Chernivetska	471.2	333.9	124.2	26.4	88.5	26.5
Total area of the Forest-Steppe region of Ukraine	14522.2	11732.1	3987.7	27.5	3225.9	27.5

The soil erosion depends from most soil properties, such as particle size, infiltration rate, water stable aggregates and humus content, which together create their erosion resistance. The soil resistance to erosion is characterized as the ability of the soil surface to resist the damaging action of runoff and raindrops [12].

The water erosion occurs due to a great percentage of arable area, especially on slopes of the Right-bank Forest Steppe of Ukraine.

Study Area

Our research was dedicated to soil degradation, especially to formation of water erosion. They have been conducted during 2004-2010 years on the typical chernozems of two stationary experiments, which situated on different topography. The first objects of investigation were stationary plots of National Scientific Centre “Institute of Agriculture of National Agrarian Academy Sciences of Ukraine. Researches, on slope lands, were started in 1975 at experimental plots in Khalepie of Obukhiv district, Kyiv region. The soil is called as typical eroded chernozem, which characterized as light loam on loess with low humus content. The area, where we obtained a research are typical for landscapes of Right Bank Forest Steppe of Ukraine and refers to Rzhischiv ravine system with dissected topography and frequent signs of erosion processes. In stationary experiments we were studied the effect of different tillage technologies on intensity of water erosion of soil in the crop rotation: winter rape – barley sowing of alfalfa – alfalfa 2nd year of use.

The second object of our investigation was typical chernozem, which characterizes as medium loam on loess. These are stationary experiments of department of Soil Science and Soil Conservation of National University of Life and Environmental Sciences of Ukraine. Research activities for monitoring and changing properties of chernozem were started in 1998 at experimental farm of NUBiP of Ukraine called “Welikosnitinske” of Fastiv district, Kyiv region. In experiments studied the effects of different tillage technologies – plowing at 20–27 cm, V-blade tillage at 20–27 and 10–12 cm soil. Also, we studied an antierosion effect of organic fertilizers application, such as manure, straw and green manure combined them with mineral fertilizers in crop rotation: maize – corn silage – winter wheat.

Methods

The field experiments include the determination of soil permeability by Kachinsky method with using of filled water squares [13]. Biomass and roots capacity in the top soil layer were determined by Stankov method [14]. Number of earthworms in soil layers of 0–10 cm and 10–20 cm were obtained by Gilyarov method [15].

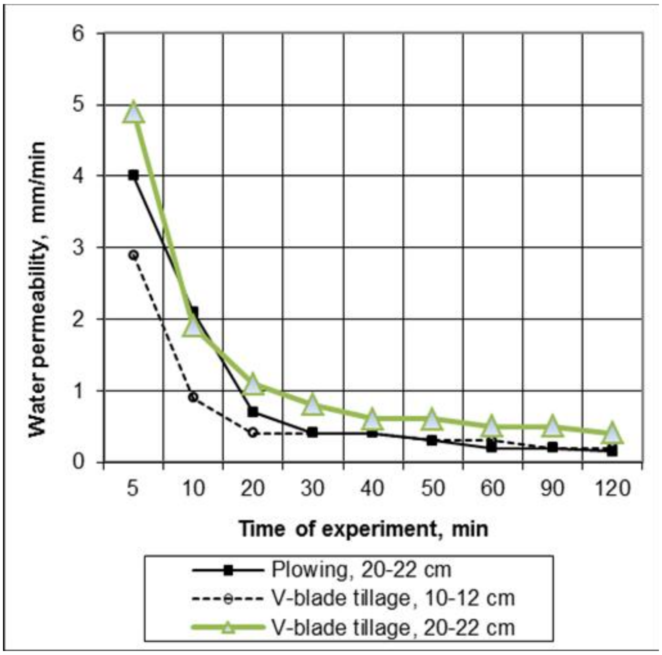
In the laboratory were determined the soil humus content by Turin method in modification of Simakov. The content of water stable aggregates were determined on Baksheyev device and with using Andrianov method, which based on maceration of soil aggregates in stagnant water [13]. In addition to field and laboratory studies we were obtained the model experiments – creating artificial rain by sprinkler installation (copyright certificate of V.I. Tarasov, 2003) [16]. The total time of experiment was 30 min, the height of falling drops – 2 m and the intensity rate of rain – 2.0 mm/min. Irrigation experiments were carried out on the slope lands of 6 and 3° after tillage application in autumn and in maize crops (phase of 5–6 leaves). The device of rain simulation ensures uniform rain drops to runoff site**.** The water, which is not infiltrated into the soil and loss of the fine earth, came with runoff to receiving vessel. In it was measured the volume of surface water runoff and losses of soil.

Results

It was found, that climatic conditions during the years of research were characterized by increasing precipitation, compared with middle long term resulting 507 mm. The sum of precipitation was formed in 2004 – 627 mm, in 2005 – 669 and 2006 – 611 mm. In the summer rain showers fell within the 40–79 mm per day, with an average intensity of 0.34–0.55 mm/min. Such rains, in the absence of vegetation cover on slopes, can cause to surface runoff and washing out of topsoil. Also, the volume of soil washing out depends from water infiltration. The high permeability of the soil promotes water absorption of rainfall and melting snow, reducing the intensity of washing out. The soil infiltration rate has a direct correlation with the flow of water and a lesser extent with the washing out of soil. So, the soil permeability of eroded chernozem characterized as low, in average (30 mm/hour) in the stationary plots with winter rape. The vegetation of alfalfa of second year growing contributed to increasing of infiltration to medium indexes of evaluation [17]. The highest figures were obtained in the field experiments after V-blade tillage application to a depth of 20-22 cm, which was on average 0.85 mm/min. (Fig. 1). We think it is related to the vertical orientation of the pore space and greater water resistance of soil aggregates compared with plowing, where soil permeability was 0.51 mm/min.

The water permeability of typical slightly eroded chernozem evaluated as average. Analyzing Fig. 1 we see, that the water saturation of soil lasted above 20 min with medium intensity of 1.0–3.0 mm/min after V-blade tillage application. The research results were shown, that on the stationary plots with plowing application the figures were 0.8–2.7 mm/min.

We believe that the torrential rainfall infiltration such a large amount of water can be absorbed by soil surface. Organic and mineral fertilizer application contributed to increasing of water permeability in maize field compared with control, because is improving roots saturation in top layer. We have seen the trend increase of waterstable aggregates was used as organic and mineral fertilizer in the experiment plots with all study tillage technologies.



The integrated water resistance index (average diameter of aggregates) was at control (without fertilizer) – 0.56–1.47 mm, with manure application – 0.78–1.81 mm, with straw and green manure using – 0.62–1.16 mm.

Fig. 1. The soil permeability of typical eroded chernozem under different tillage systems (growing of Alfalfa 2nd year using)

The great impact for the increasing content of waterstable aggregates was an alfalfa growing in the eroded chernozem. In this case, the average diameter of aggregates was 1.72 ± 0.14 in plots with V-blade tillage and 1.25 ± 0.07 mm in plowing area.

As noted earlier, significantly impede the movement of surface runoff and loss of soil available the vegetation cover on slopes. Also, have protective effect and plant residues, which reduce the ravages of the kinetic energy of raindrops and runoff too. Tendency to increasing their number was seen on typical slightly eroded chernozem, when were growing corn and winter wheat.

For example, the biomass of residues in crops of corn for silage in experiments of manure aftereffect in rate 40 t/ha and V-blade tillage at 25–27 cm was 0.54 t/ha, V-blade tillage at a depth of 10-12 cm – 0.77 t/ha and for plowing – 0.19 t/ha (Table 2). Thus, in the autumn the soil tillage contributes to the conservation of crop residues on the soil surface, whereas a large proportion of plowing, that reduces antierosion effect.

The root system of plants plays an important role in fixing of aggregates and reducing of erodible velocity of water flow. The root saturation of corn for silage was higher after fertilizer application, especially in experiments with V-blade tillage at 10–12 cm. In this condition we have the next results: at plots with manure application 1.06%, straw and green manure using – 1.13% and at control – 0.53% (Table 2). The root saturation of topsoil under winter wheat vegetation was higher with V-blade tillage application, approximately in 1.4–1.8 times compared with plowing. We found, that such treatment created better environmental conditions for the development of root growth in the topsoil and increases resistance to wash out [18].

A great impact for the reduction of soil erosion on slopes creates earth worms, which many scientists often called as “living matter for structure formation”. The calculation of number of earthworms at 0–20 cm layer of eroded chernozem showed greater their number in experiments under V-blade tillage application at a depth of 10–12 cm, where their quantity was 54 individuals/m^2 in 2004, 100 individuals/m^2 in 2005 and 41 individuals/m^2 in 2006, while in plowing plots – 39, 59 and 38 individuals/m^2 respectively (Fig. 2).

A similar trend is observed on the definition of vertical strokes of earthworms in the subsurface layer of the soil (0–20 cm soil layer). We was determined, that after plowing at 20–22 cm, their number was 33, 34 and 46 individuals/m^2, and under V-blade tillage application at 10–12 cm – 52, 51 and 54 individuals/m^2 respectively (Fig. 3).

Table 2. Effect of soil tillage and fertilizer application for root saturation and their mass in the 0–10-cm layer of typical slightly eroded chernozem, 2005–2006 years

Soil tillage	The biomass of plant residues, t/ha	he root mass < 1 mm, t/ha	The root saturation, %	The biomass of plant residues, t/ha	The root mass < 1 mm, t/ha	The root saturation, %
	Corn for silage			*Winter wheat*		
Without fertilizer (control)						
Plowing, 20–27 cm	0.04	0.29	0.43 ± 0.14	0.89	0.07	0.17 ± 0.02
V-blade tillage, 20–27 cm	0.19*	0.64*	0.66 ± 0.09	1.69*	1.20*	0.31* ± 0.02
V-blade tillage, 10–12 cm	0.72*	0.91*	0.53 ± 0.10	0.83	0.52*	0.31 ± 0.11
Manure 12 t/ha + 140 kg/ha + NPK						
Plowing, 20–27 cm	0.19	0.83+	1.09+ ± 0.10	0.61	0.29	0.24 ± 0.05
V-blade tillage, 20–27 cm	0.54*	0.50	0.66 ± 0.10	1.13*	0.65*	0.43* ± 0.03
V-blade tillage, 10–12 cm	0.77*	0.97	1.06+ ± 0.07	1.05*	0.97*	0.32 ± 0.03
Straw 1.2 t/ha + green manure + 140 kg/ha + NPK						
Plowing, 20–27 cm	0.47	0.83+	0.93+ ± 0.10	0.93	0.76	0.35 ± 0.08
V-blade tillage, 20–27 cm	0.46	0.54	0.91+ ± 0.05	1.79	1.65*	0.64* ± 0.12
V-blade tillage, 10–12 cm	0.42	1.53*+	1.13+ ± 0.11	1.36	1.88*	0.49 ± 0.15

** – effect of cultivation on the probability level of 0.95*   *+ – the impact of fertilizer*

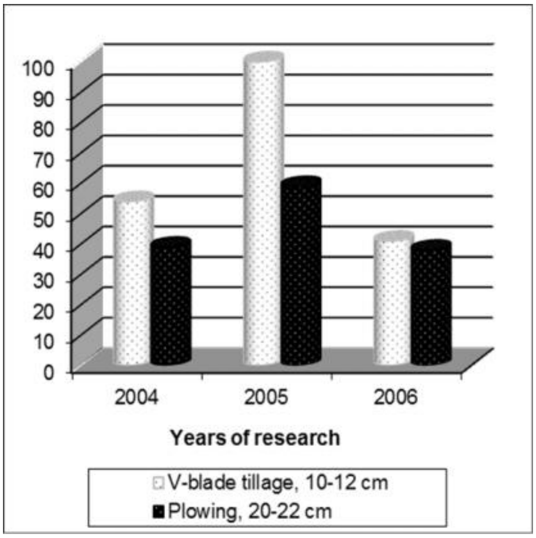


Fig. 2. The number of earthworms in the soil layer 0–20 cm of eroded chernozem, ind./m²

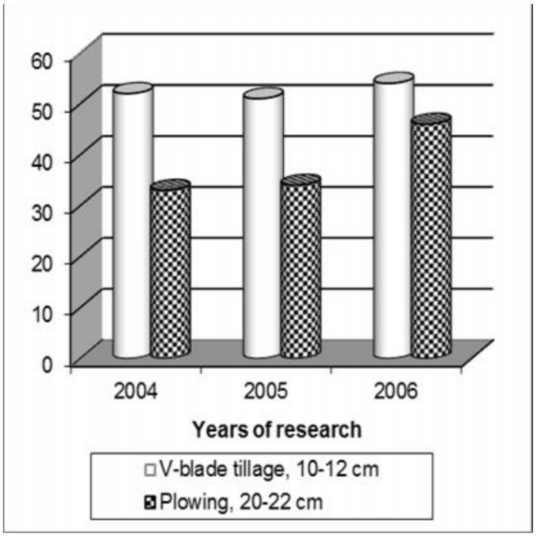


Fig. 3. The number of vertical pores in the layer in the soil layer 0–20 cm of eroded chernozem, ind./m²

In another object of investigation (Fastiv district) we was found, that number of earthworms of typical slightly eroded chernozem in corn field was higher, when straw and green manure applied, accounted under plowing 18 individuals/m^2 and V-blade tillage application 30 and 31 individuals/m^2. The number of vertical pores were 27, 72, and 30 sht./m^2 respectively. This is due to better water saturation of upper layer of soil and its mort mass saturation. Also, a similar pattern was observed in growing corn for silage. The number of earthworms under V-blade tillage was 42, under plowing aplication – 17 ind./m^2. The trend of increasing population worms in topsoil is found under V-blade tillage application both in the control and fertilizer application experiments. The increasing of number of worms and forming their vertical moves was due to the presence of organic residues on the top soil and creation a substrate for worms' nutrition (Fig. 4) [16]. Also, for increasing worm's population an important role plays better moisture conditions, when creating of mulching soil surface under V-blade tillage application.

Fig. 4. The creation of vertical movies by earthworms of eroded chernozem

It is known, that earthworm plays an important environmental role. They participate in soil structure formation, destroying of organic matter, providing additional vertical moves, which leading to improving of infiltration. Moreover, they are the main source formation of coprolites, which have a high water resistance and are more stable to outwashing processes.

In our research, we were compared both the water stable of soil aggregates and coprolites. It was determined, that coprolites are more stable compared with soil aggregates. The research results were shown, that waterstable of earthworm's coprolites of typical eroded chernozem, which were determined by Baksheyev device in soil layers at 0–10 cm and 10–20 am was 76.5 and 82.5% (Table 3). The waterstable of soil aggregates was lower – 62.5 and 66.9% respectively.

Table 3. The influence of earthworms on the water resistance of structural aggregates, 2006

Soil type	The waterstable aggregates content determined by Baksheyev device, %			
	above 1.0 mm	1.0–0.25mm	above 0.25 mm	under 0.25 mm
Coprolites of earthworms				
Eroded chernozem	31.8 ± 3.55	44.7 ± 2.78	76.5 ± 5.73	23.5
Typical chernozem	40.0 ± 3.77	42.5 ± 4.22	82.5 ± 4.67	17.5
Structural aggregates				
Eroded chernozem	17.3 ± 3,19	45.2 ± 4.81	62.5 ± 3.91	37.5
Typical chernozem	21.0 ± 3,60	45.9 ± 4.58	66.9 ± 4.21	33.1

$M \pm t_m,\ n = 4$

The research results were shown the highest antierosion efficiency of sprinkling of typical eroded chernozem under V-blade tillage at 25–27 cm., when surface runoff was 57.5 m^3/ha and soil loss – 0.78 t/ha [19]. We were found, that higher surface runoff and their losses were observed at plowing stationary plots, where surface runoff was 125 m^3/ha, losses of soil – 9.88 t/ha. Reducing of soil losses was observed in plots with fertilizer application, because manure, straw and green manure helped to better cementation of soil particles to aggregates. The lowest loses of soil after sprinkling were identified under B-blade tillage with straw and green manure application, where the losses of soil were 0.87 t/ha and water runoff 64.4 m^3/ha. The runoff and losses of soil under plowing were 2.53 t/ha and 178 m^3/ha.

Conclusions

So, in the paper we tried to review the main events, use of which in due to it's washed and improve their erosion resistance. We believe that the widespread application of soil V-blade tillage combined with organic fertilizer, especially using straw and green manure on slope lands of Right-Bank Forest-Steppe of Ukraine, will promote greater environmental sustainability of agricultural landscapes and gradually are minimized degradation processes of fertile soils of Ukraine.

References

Zubetz M.V., Balyuk S.A., Medvedev V.V., Grekov V.O. (2010). Current soil status of Ukraine and urgent measures for its protection: J. Agrochemistry and Soil Science, Special edition, 7–17 (in Ukrainian).

Bulygin S.Yu., Nearing M.A. (1999). Formation of Environmental Balanced Landscapes: The Problem of Erosion: Science Book. Soil Science and Agrochemistry Institute by A.N. Sokolovskiy, Kharkiv (in Russian).

Bulygin S.Yu. (2005). Formation of Environmental Stable Agrolandscapes: Monograph. Urozhay, Kyiv (in Russian).

Degtyarov V.V. (2011). Humus of Chernozems of Forest Steppe and Steppe Areas of Ukraine: Monograph. Maidan, Kharkiv (in Ukrainain).

Saiko V.F. (2000). Scientific approaches to sustainable land use in the implementation of agrarian reform: Journal of Agricultural Science, Volume 5, 5–10 (in Ukrainain).

Balyuk S.A., Medvedev V.V., Balayev A.D. (2010). The State Report of the Soil's Fertility of Ukraine: Report of National Academy of Agrarian Science of Ukraine, Kyiv (in Ukrainain).

Kanash O. (2005). Recent Developments in Land Use: Environmental Suitability of Land to Arable. J. Scientific Bulletin of National Agricultural University, Volume 81, 154–157 (in Ukrainain).

Bulygin S.Yu., Barvinskiy A.V., Achasova A.O., Achasov A.B. (2008). Assessment and Prediction of Land Quality: Tutorial. National Agricultural University of Kharkiv, Kharkiv (in Ukrainain).

Tretyak A.M., Bambindra D.I. (2003). Land Resources of Ukraine and their use: Tutorial. Edited by"ZSRU", Kyiv (in Ukrainain).

Shikula M.K., Gnatenko O.F., Petrenko L.R., Kapshtyk M.V. (2004). Soil Conservation: Tutorial. Znannya, Kyiv (in Ukrainain).

Tarariko O.G., Moskalenko V.M. (2002). Catalog Measures to Optimize the Structure of Agricultural Landscapes and Protect the Land from Erosion: Handbook. Phytosoziocentre, Kyiv (in Ukrainain).

Svitlichniy O.O., Chorniy S.G. (2007). Basics of Science about Erosion: Tutorial. University Book, Symi (in Ukrainain)..

Vadunina A.F., Korchagina Z.A., (1986). Methods of Investigation of the Physical Properties of Soil: Guidelines. Agropromizdat, Moskva (in Russian).

Stankov N.Z. (1964). The root system of field crops: Methodological Recommendations. Kolos, Moskva (in Russian).

Gilyarov M.S. (1975). Methods of soil and zoology of research: Accounting crayons arthropods and nematodes, pp. 30–45. Moskva: Nauka (in Russian).

Patent 63224, Ukraine, A01B13/16. Laboratory device to study the migration of substances in the soil for erosion and hydrological processes: Zubov O.R., Tarasov V.I., Mikhailov V.V. (Ukraine); Lugansk Institute of Agricultural Production; Request 06.03.2003; Published by 15.01.2004. Bulletin 1 (in Russian).

Medvedev V.V. (1988). Optimization of Agrophysical properties of chernozems: Monograph. Agropromizdat, Moskva (in Russian).

Berezhniak Iev.M. (2007). The role of biological factors in enhancing the stability of chernozems anti erosion: Journal of Agricultural Science, Volume 1, 65–68 (in Ukrainain).

Berezhniak M.F., Shevchenko I.P., Berezhniak Iev.M. (2007). The results of typical chernozem sprinkling under different agrotechnique measures: J. of Cherkassy Institute of Agricultural Production, Volume 7 (in Ukrainain).