

REGULAR ARTICLE

Mathematical modeling as a tool for determination of tendencies in changes of humus concentration in soil of arable lands

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ABSTRACT

Level of sustainability of agricultural production is characterized by balance of nutrients in soil. Using monitoring data, conducted by the State Institution "Institute of Soil of Ukraine", nitrogen balance is calculated for two Ukrainian regions – Ternopil and Kirovograd Adding nutrients and removal of them with the harvest was taken into account. Particular attention has been given to nitrogen. Intensity of nitrogen balance in Kirovograd region was 64.5%, which indicates loss of humus – soil organic matter. Intensity of nitrogen balance in agricultural soil of Ternopil region was satisfactory – 108.1%. With the aim of soil humus state evaluation, a prognosis mathematical model was developed in Wolfram Mathematica 9 to estimate humus change in both regions.

Keywords: Nitrogen balance; Humus; Dehumification; Mathematical modeling; Prognosis

INTRODUCTION

During recent years, environmental pollution with reactive nitrogen compounds is alarming the global community. Nitrogen compounds - nitrates, ammonia, nitrogen oxides and many other nitrogen derivatives are widely used in industry and agriculture. The main consumer of nitrogen compounds is the agriculture, and also the source of its emissions in the production of both crop and livestock production. (Sutton at al., 2011a). In agriculture, nitrogen compounds are used as a part of organic and mineral fertilizers, food products and animal feed. Reactive nitrogen is the collective term for all nitrogen forms except for unreactive dinitrogen (N₂) (Sutton at al., 2014).

Soil humic substances are the storage of main nutrients, which contain 40-60 % of carbon, 3-5 % of nitrogen, 3-5% of hydrogen, 33-37 % of oxygen (Orlov, 1990). Only part of all amount of nitrogen that comes from nutrition is digested by living organisms. Some undigested nitrogen is excreted in waste, stored and used as fertilizer, but other

part is lost vaporization to the atmosphere and goes to the water sources. (Sutton at al., 2009).

Concentration increase of different reactive nitrogen compounds can lead to the unbalance in various environmental media (air, soil, water, plants, animals, humans). This phenomenon is called the nitrogen cascade (Galloway at al., 2003). Nitrogen compounds are transferred by air, flows over long distances and cause negative consequences for environment and humans. Nitrogen compounds that are emitted to the biosphere cause a number of negative consequences in planetary scale: acidification of lakes, rivers and soil, pollution of surface and underground waters, eutrophication of surface waters, loss of biodiversity of flora and fauna (Sutton et al., 2012).

Precipitation of reactive nitrogen can cause active growth of nitrophilous plants and crowding out of other plant species. Increase of reactive nitrogen precipitation is one of five main threats to the biodiversity throughout the world. Besides direct influence, increase of nitrogen availability

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can also have indirect influence on many plant species, increasing their sensibility to other stress factors – frost, drought or resistance. (Bobbink *et al.*, 2010).

Nitrogen in the form of nitrates can migrate deep in the soil profile and pollute groundwater. Research of the quality of groundwater in different parts of Ukraine indicated high nitrates concentration (Palapa and Kolesnyk, 2009). Surface waters are also exposed to pollution, as the result of income of large quantities of nutrients. Among the consequences of anthropogenic influence, eutrophication is the most significant one. Eutrophication is the main reason why rivers and sea coastal waters cannot pretend to receive “Good ecological status” grade according to the Water Framework Directive (Borja, 2006). Ecosystems of Black and Azov Sea during recent decades were subjected to significant anthropogenic load. In the middle of 90th the eutrophication level and the amount of incoming contaminants greatly exceeded the assimilative capacity of sea environment. Recent years, with the decrease of industrial production levels, the ecological situation has slightly improved. A trend of biodiversity restoration and increase of quantities of many aquatic life species has formed; however the level of eutrophication of Black and Azov Sea basin has decreased, but had not reached the safe level yet. (Alexandrov and Zaitsev, 1998.).

Researches, conducted from 1972 to 1977 confirmed that air pollutants can transfer over several thousand km before precipitation, causing damage to environment. This fact highlights one more time the necessity of international cooperation on these problems. With this problem in mind, High-Level Meeting on environmental protection in the framework of the UN European Economic Commission was held in November, 1979 in Geneva (Switzerland). As the result of this meeting, representatives of governments of 34 countries and EU signed the Convention on Long-Range Transboundary Air Pollution (CLRTAP; Sutton, 2011b).

According to the Convention, Ukrainian government has developed measures plans on decrease of air pollutants emissions which lead to acidification, eutrophication and formation of ground-level ozone for 2005–2015. Also, according to EU Association Agreement Ukraine has to fulfill a series of directives in the field of water use, directed on acceleration of drinking water quality increase, increase of effectively of urban wastewater treatment, prevention of pollution of water bodies with agricultural nitrates. (Libanova and Hvesyk, 2014).

With the aim of approach of Ukrainian legislation to EU legislation, to aid the problem of prevention of ground and surface waters pollution with agricultural nitrates by

promotion of the codices of better ways of agricultural activities, plan of implementation of Council Directive 91/676/EEC on water protection from pollution with nitrates from agricultural sources is developed. Ukraine has signed the Convention on biodiversity in 1992, ratified it in 1994. 192 countries and EU are parties to the Convention. Ukraine has also ratified UN Framework Convention on Climate Change, including Kyoto Protocol (UN FCCC) and is a party of this Convention and Kyoto Protocol. In Ukraine, part of “Agriculture” sector in total greenhouse gas emission (not including “Land use, land-use change and forestry” sector) was 9% in 2010. Main waste emission sources are agriculture is animal enteric fermentation and agricultural lands, 26% and 58% of emissions accordingly. Emissions in this sector have decreased on 67% compared to 1990. Drastic reduction of emissions during this period is caused primarily by decrease of livestock numbers in agricultural enterprises, amount of implemented fertilizers, and change of approach to manure management as the result of Soviet Union collapse and following economic crisis. Main factor that determined increase of emissions in 2010 compared to the previous years is increase of quantities of implemented nitrogen fertilizers from 634,9 to 774,7 thousand tons (by 22%). To a lesser degree, increase of emissions is caused by increase in numbers of pigs (by 10%), poultry (by 7%) in all farm categories. Sector of land use, land-use change and forestry includes both emission and absorption of carbon dioxide. This sector causes emissions of CO₂, CH₄ and, in minor amounts, N₂O (MENR, 2015).

MATERIALS AND METHODS

In this paper, are presented data from ecological and agrochemical certification of agricultural land of two regions – Kirovograd and Ternopil, situated in western and central parts of Ukraine.

Kirovograd region is situated in the central part of Ukraine and covers the area of 24,6 thousand square kilometers. Territory of the region is situated between rivers Dnipro and Southern Bug, in the southern part of Dnipro Upland in forest steppe and northern steppe zones, different by natural conditions. The plow of the region, i.e. proportion of area of its arable lands and total area, is 71,7%. Arable lands are average 86,4% of total agricultural lands, including 87,1% in forest steppe lands, 85,5% in transition zone between forest steppe and steppe, and 86,5% in steppe zone.

Water and wind erosion are dangerous for lands of Kirovograd region. In current region, erosion processes

are classified into next categories: planar washout, gully formation and river erosion. (OECD, 2008).

Ternopil region is situated in the western part of Ukraine, area of the region – 13,8 thousand square kilometers. Territory of the region belongs to forest steppe zone, in western part of right-bank steppe and has fertile lands with enough humidification, which assists development of agriculture. High proportion of fertile soil and plainness of the territory determine the structure and specialization of agricultural complex of the region. The plow of the region is 64%, arable lands have 84,2% in total agricultural lands, this proportion in current region is one of the highest in Ukraine. (Zastavetska, 2009).

During the work on ecological and agrochemical certification of agricultural land, standard methods were used (Sozinov and Prister, 1994; Sozinov, 1996; Ryzhuk *et al.*, 2003). Field agrochemical investigation of agricultural land, sampling and laboratory testing of soil samples were performed according to the State Standards of Ukraine (DSTU) and acting in Ukraine International Standards (GOST, ISO). In selected samples, agrochemical indexes were determined. Analysis of soil samples was performed on an Automated line “ASVA-P(k)” according to Existing Standards in Ukraine: determination of pH was carried out according to GOST 26483-85 by method, for pH determining of salt extraction in soils; determination of mobile compounds of phosphorus and potassium was conducted on the following methods: Kirsanov method (DSTU 4405:2005) and Machyhin method (DSTU 4114-2002); samples of carbonate soils were determined by the Machigin’s method, using extraction with 1% $(\text{NH}_4)_2\text{CO}_3$ solution. Alkali hydrolysed nitrogen was determined by Guidelines, on determination of the alkali hydrolysed nitrogen, in the soil, by the Kornfeld method (Gorodny *et al.*, 2005), based on hydrolysis of organic compounds of soil solution, using sodium hydroxide; evaporated ammonia is absorbed with boric acid in Conway glassware and is titrated with sulfuric acid. Determination of humus was performed by the Tyurin method (DSTU 4289:2004) by oxidation of humus in soil with potassium dichromate in sulfuric acid media using heating and photolorimetric measuring.

To develop humus level prognosis in the soil mathematical modeling were used – a method of study of different processes and phenomena by creating their mathematical models and study these models. This method is based on identity of model equation forms and relations between real world values.

In this paper, with the goal of mathematical model construction, data on ecological and agrochemical

certification of agricultural land on humus concentration in Kirovohrad and Ternopil regions of Ukraine was analyzed. Using mathematical models, dynamics of change of weighted average humus level in 2001 – 2010 was studied; prognosis of humus concentration for the period 2011-2020 and selected Ukrainian regions was built.

RESULTS AND DISCUSSION

Ukrainian land resources cause high potential productivity of crops. This potential is implemented through soil fertility and improvement of their functional properties. However, long-term non-rational exploitation of land resources without consideration of landscape, soil and climate characteristics, intensive tillage lead to development of progressive degradation processes. Agricultural lands are the basis of agricultural production. These lands cover 69,1% of total Ukrainian land fund; 77,8% of agricultural lands are arable lands. (Agriculture of Ukraine, 2014). Researches of Ukrainian scientists indicate that such proportion of land categories violates principles of sustainable agriculture and leads to deterioration of ecological situation in the country. (Kucher, 2006; Shevchenko, 2013; Furdychko, 2013). Main requirement to lands in agriculture is the ability of soils to produce high yield of crops. This factor depends on concentration of nutrients in soil and use of organic and mineral fertilizers. Nitrogen is the mandatory element in soil humus (Bittman *et al.*, 2014). As the result of a large of different biochemical processes, nitrogen can be transformed to compounds with varying mobility and oxidation factor that vary from -3 to +4. The least mobile compound is organic nitrogen in amide forms, which is a part of humic compounds.

Incoming soil nitrogen flows are: application of mineral nitrogen fertilizers, fixation of atmospheric nitrogen with rhizobia of leguminous plants, crop residues, green plants plowing, aerosols sedimentation etc. Outgoing soil nitrogen flows are: removal with harvested crops, losses during all nitrogen cycle in soil-plant system.

Besides, nitrogen cycle is tightly connected to carbon cycle, and also to cycles of other nutrients. (Bacon and Freney, 1989). That’s why N-flow control can cause carbon circuit, total CO₂ emissions to the atmosphere and carbon sequestration in soil. Usually, a system that has nitrogen leaks has also carbon leaks, and vice versa. This fact once again confirms the importance of N-flow control from point of view of complete agriculture. Depending on the type of agricultural company, N-flow control has to include a number of complex management actions, such as (Oenema *et al.*, 2014):

- a) Application of fertilizers for crops;
- b) Organization of crops growing and harvesting, including recycling of residues;
- c) Growing of crops for soil protection or cover;
- d) Care of meadows and pastures;
- e) Tillage, drainage and irrigation;
- f) Animal feeding;
- g) Cattle maintenance (including animal well-being), including stabling;
- h) Management of manure, including storage and application;
- i) Ammonia emissions decrease measures;
- j) Measures to decrease nitrates leaching and prevent pollution of soil runoff;
- k) Measures on N₂O emissions decrease;
- l) Measures on denitrification decrease.

To achieve high-yield agricultural production with minimal N losses and other unintended environmental consequences, all measures have to be complex and balanced.

Sustainable state in agricultural production is characterized by balance in nutrients. State Institution “Institute of Soil of Ukraine” has conducted the research on ecological and agrochemical certification of agricultural land at the regional level. Using the results of this research, a balance of nutrients in agriculture was calculated for Ternopil and Kirovograd regions in 2012 as example. Nutrients balance calculation was conducted using data on main nutrients income – nitrogen, phosphorus and potassium, and their takeaway in crop rotations while growing different crops. Nitrogen loss was not taken into account for balance calculation.

Nutrients balance in agriculture of Kirovograd region

As it is shown in Table 1, majority of nitrogen, phosphorous and potassium comes to agricultural soils with mineral fertilizers. Organic fertilizers are used in minor quantities, although it is known that maximum productivity can only be reached using both organic and mineral fertilizers, when quantity of nutrients that came from mineral and organic fertilizers is close (Pannikov and Mineev, 1977). Maximum quantity of mineral nitrogen are applied to sugar and fodder beets – 94 kg/ha, canola and mustard – 60 kg/ha, grain corn – 51 kg/ha and winter crops – 47 kg/ha. Minor quantities of nitrogen were applied to legumes –15 kg/ha, however, taking into account other sources, mainly symbiotic nitrogen fixation, soil under a mixture of legumes (alfalfa, clover, sainfoin) received 98.9 kg/ha of nitrogen, and soil under peas, soybean and vetch – 38.5 kg/ha of nitrogen. Nitrogen fertilizers were not applied to soil under green forage, barley, oats, millet, sorghum, buckwheat, herbal legumes, and fallow. Such nutrients as phosphorous and potassium were also applied in non-balanced quantities (Table 1).

Calculation of nutrients balance (Table 2) indicated that the greatest nutrients deficit (of nitrogen, phosphorous and potassium) was observed in soil under grain corn – 233 kg/ha, sugar and fodder beet –130.8 kg/ha, canola and mustard – 126.8 kg/ha. Nitrogen deficit was observed in soil after cultivation of all agricultural crops except herbal legumes. Maximum nitrogen deficit was observed in soil after cultivation of: grain corn – 82.7 kg/ha, winter crops for green fodder– 46.9 kg/ha, canola and mustard – 39.4 kg/ha, sugar and fodder beet – 37.6 kg/ha. Altogether, most soil grueling cultures are grain corn, sugar and fodder beet with deficit of nitrogen, phosphorous and potassium

Table 1: Nutrients income in soils of Kirovograd region, 2012

| Agriculture crop or crops group | Area under selected crop or crops group, ha | Manure applied, t/ha | Income of nutrients in soil, kg/ha | | | | | | | | | | | | | | | | | | | |
|--|---|----------------------|------------------------------------|-----|------|-------|--------------------------|------|------|-------|--------------------|-----|-----|-------|--------------|------|------|-------|-------|------|------|-------|
| | | | With organic fertilizers | | | | With mineral fertilizers | | | | From other sources | | | | Total income | | | | | | | |
| | | | N | P | K | Total | N | P | K | Total | N | P | K | Total | N | P | K | Total | | | | |
| Winter crops for green fodder | 20 371 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 8.5 | 1.0 | 1.2 | 10.7 | 8.5 | 1.0 | 1.2 | 10.7 | |
| Winter grain crops | 413 217 | 0.12 | 0.5 | 0.2 | 0.6 | 1.4 | 47.0 | 5.0 | 3.0 | 55.0 | 8.5 | 1.0 | 1.2 | 10.7 | 56.0 | 6.2 | 4.8 | 67.1 | 56.0 | 6.2 | 4.8 | 67.1 |
| Peas, soybeans, vetch | 131 728 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 15.0 | 6.0 | 4.0 | 25.0 | 38.5 | 1.0 | 1.2 | 40.7 | 53.5 | 7.0 | 5.2 | 65.7 | 53.5 | 7.0 | 5.2 | 65.7 |
| Grain corn | 181 705 | 0.07 | 0.3 | 0.1 | 0.3 | 0.8 | 51.0 | 11.0 | 7.0 | 69.0 | 8.5 | 1.0 | 1.2 | 10.7 | 59.8 | 12.1 | 8.5 | 80.5 | 59.8 | 12.1 | 8.5 | 80.5 |
| Barley, oats, millet, sorghum, buckwheat | 208 318 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 8.5 | 1.0 | 1.2 | 10.7 | 8.5 | 1.0 | 1.2 | 10.7 | 8.5 | 1.0 | 1.2 | 10.7 |
| Annual herbs, vetch with oats | 23 377 | 0.06 | 0.3 | 0.1 | 0.3 | 0.7 | 7.0 | 0.5 | 0.5 | 8.0 | 23.5 | 1.0 | 1.2 | 25.7 | 30.8 | 1.6 | 2.0 | 34.4 | 30.8 | 1.6 | 2.0 | 34.4 |
| Alfalfa, clover, sainfoin | 22 675 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 98.9 | 1.0 | 1.2 | 101.1 | 98.9 | 1.0 | 1.2 | 101.1 | 98.9 | 1.0 | 1.2 | 101.1 |
| Silage corn | 20 776 | 0.31 | 1.2 | 0.6 | 1.5 | 3.4 | 14.0 | 2.0 | 2.0 | 18.0 | 8.5 | 1.0 | 1.2 | 10.7 | 23.7 | 3.6 | 4.7 | 32.1 | 23.7 | 3.6 | 4.7 | 32.1 |
| Sugar and fodder beet | 24 290 | 0.09 | 0.3 | 0.2 | 0.4 | 1.0 | 94.0 | 39.0 | 42.0 | 175.0 | 8.5 | 1.0 | 1.2 | 10.7 | 102.8 | 40.2 | 43.6 | 186.7 | 102.8 | 40.2 | 43.6 | 186.7 |
| Potatoes, vegetables, melons and gourds | 69 473 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 26.0 | 2.0 | 1.0 | 29.0 | 8.5 | 1.0 | 1.2 | 10.7 | 34.5 | 3.0 | 2.2 | 39.7 | 34.5 | 3.0 | 2.2 | 39.7 |
| Rapeseed and mustard | 80 439 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 60.0 | 11.0 | 9.0 | 80.0 | 8.5 | 1.0 | 1.2 | 10.7 | 68.5 | 12.0 | 10.2 | 90.7 | 68.5 | 12.0 | 10.2 | 90.7 |
| Sunflower | 417 370 | 3.27 | 13.1 | 6.5 | 16.3 | 36.0 | 13.0 | 6.0 | 4.0 | 23.0 | 8.5 | 1.0 | 1.2 | 10.7 | 34.6 | 13.5 | 21.5 | 69.7 | 34.6 | 13.5 | 21.5 | 69.7 |
| Fallow | 106 956 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 7.0 | 0.0 | 0.0 | 7.0 | 7.0 | 0.0 | 0.0 | 7.0 | 7.0 | 0.0 | 0.0 | 7.0 |

Table 2: Nutrients balance in agricultural soils of Kirovograd region in 2012

| Agriculture crop or crops group | Area under selected crop or crops group, ha | Takeaway, kg/ha | | | | Balance, kg/ha (+/-) | | | | Balance, % before takeaway | | | | Balance intensity, % | | | |
|--|---|-----------------|------|-------|-------|----------------------|-------|--------|--------|----------------------------|------|------|-------|----------------------|-------|-------|-------|
| | | N | P | K | Total | N | P | K | Total | N | P | K | Total | N | P | K | Total |
| Winter crops for green fodder | 20 371 | 55.4 | 19.1 | 27.7 | 102.2 | -46.9 | -18.1 | -26.5 | -91.5 | 84.7 | 94.8 | 95.7 | 89.5 | 15.3 | 5.2 | 4.3 | 10.5 |
| Winter grain crops | 413 217 | 80.9 | 30.7 | 53.0 | 164.6 | -24.9 | -24.4 | -48.2 | -97.6 | 30.8 | 79.8 | 90.9 | 59.2 | 69.2 | 20.2 | 9.1 | 40.8 |
| Peas, soybeans, vetch | 131 728 | 90.9 | 19.9 | 24.1 | 134.9 | -37.4 | -12.9 | -18.9 | -69.2 | 41.1 | 64.8 | 78.4 | 51.3 | 58.9 | 35.2 | 21.6 | 48.7 |
| Grain corn | 181 705 | 142.5 | 47.5 | 123.5 | 313.5 | -82.7 | -35.4 | -115.0 | -233.0 | 58.0 | 74.5 | 93.1 | 74.3 | 42.0 | 25.5 | 6.9 | 25.7 |
| Barley, oats, millet, sorghum, buckwheat | 208 318 | 49.9 | 18.7 | 39.0 | 107.6 | -41.4 | -17.7 | -37.8 | -96.9 | 83.0 | 94.7 | 96.9 | 90.1 | 17.0 | 5.3 | 3.1 | 9.9 |
| Annual herbs, vetch with oats | 23 377 | 40.3 | 17.6 | 60.5 | 118.4 | -9.5 | -16 | -58.4 | -84.0 | 23.6 | 90.9 | 96.7 | 70.9 | 76.4 | 9.1 | 3.3 | 29.1 |
| Alfalfa, clover, sainfoin | 22 675 | 60.3 | 17.7 | 53.2 | 131.1 | 38.6 | -16.7 | -52.0 | -30.0 | 64.0 | 94.4 | 97.7 | 22.9 | 164.0 | 5.6 | 2.3 | 77.1 |
| Silage corn | 20 776 | 47.0 | 18.8 | 65.8 | 131.7 | -23.3 | -15.2 | -61.1 | -99.6 | 49.6 | 80.9 | 92.9 | 75.6 | 50.4 | 19.1 | 7.1 | 24.4 |
| Sugar and fodder beet | 24 290 | 140.5 | 36.5 | 140.5 | 317.4 | -37.6 | +3.7 | -96.8 | -130.8 | 26.8 | 10.1 | 69.0 | 41.2 | 73.2 | 110.1 | 31.0 | 58.8 |
| Potatoes, vegetables, melons and gourds | 69 473 | 52.2 | 23.0 | 83.5 | 158.7 | -17.7 | -20.0 | -81.3 | -119.0 | 33.9 | 87.0 | 97.4 | 75.0 | 66.1 | 13.0 | 2.6 | 25.0 |
| Rapeseed and mustard | 80 439 | 107.9 | 39.8 | 69.7 | 217.5 | -39.4 | -27.8 | -59.5 | -126.8 | 36.5 | 69.8 | 85.4 | 58.3 | 63.5 | 30.2 | 14.6 | 41.7 |
| Sunflower | 417 370 | 44.5 | 23.9 | 17.1 | 85.5 | -9.9 | -10.4 | 4.4 | -15.8 | 22.2 | 43.5 | 25.7 | 18.5 | 77.8 | 56.5 | 125.7 | 81.5 |
| Fallow | 106 956 | 0.0 | 0.0 | 0.0 | 0.0 | +7.0 | 0.0 | 0.0 | +7.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |

Table 3: Nutrients income in soils of Ternopil region in 2012

| Agriculture crop or crops group | Area under selected crop or crops group, ha | Income of nutrients in soil, kg/ha | | | | | | | | | | | | | | | |
|-----------------------------------|---|------------------------------------|-----|------|-------|--------------------------|------|------|-------|--------------------|-----|------|-------|--------------|------|-------|-------|
| | | With organic fertilizers | | | | With mineral fertilizers | | | | From other sources | | | | Total income | | | |
| | | N | P | K | Total | N | P | K | Total | N | P | K | Total | N | P | K | Total |
| Spring grain crops (without corn) | 256961 | 1,0 | 0,5 | 1,2 | 2,7 | 71,6 | 16,4 | 14,4 | 102,3 | 3,8 | 1,5 | 1,2 | 6,4 | 76,3 | 18,4 | 16,8 | 111,5 |
| Winter wheat | 180987 | 1,0 | 0,5 | 1,2 | 2,7 | 81,6 | 18,5 | 16,3 | 116,4 | 4,1 | 1,5 | 1,0 | 6,6 | 86,7 | 20,5 | 18,5 | 125,7 |
| Grain corn | 106948 | 3,0 | 1,5 | 3,6 | 8,0 | 89,5 | 13,6 | 13,4 | 116,5 | 0,3 | 0,1 | 0,1 | 0,6 | 92,8 | 15,2 | 17,1 | 125,1 |
| Soybean | 37590,5 | 0,2 | 0,1 | 0,2 | 0,5 | 31,9 | 13,6 | 12,9 | 58,4 | 3,4 | 0,7 | 2,0 | 6,1 | 35,5 | 14,4 | 15,1 | 64,9 |
| Sunflower | 14131,1 | 0,0 | 0,0 | 0,0 | 0,0 | 57,2 | 15,8 | 14,7 | 87,7 | 0,6 | 0,3 | 1,6 | 2,5 | 57,9 | 16,0 | 16,3 | 90,2 |
| Sugar beet | 40076,9 | 12,1 | 6,0 | 14,5 | 32,6 | 138,6 | 48,2 | 94,9 | 281,6 | 0,8 | 0,2 | 0,3 | 1,4 | 151,5 | 54,4 | 109,7 | 315,6 |
| Rapeseed | 44561,8 | 0,0 | 0,0 | 0,0 | 0,0 | 117,3 | 25,2 | 29,1 | 171,6 | 0,2 | 0,1 | 0,1 | 0,4 | 117,5 | 25,3 | 29,2 | 172,0 |
| Potatoes | 5171,62 | 2,0 | 1,0 | 2,4 | 5,4 | 94,9 | 18,1 | 53,1 | 166,1 | 10,8 | 3,0 | 15,9 | 29,7 | 107,7 | 22,1 | 71,4 | 201,2 |
| Vegetables | 1100,13 | 0,2 | 0,1 | 0,2 | 0,5 | 40,5 | 34,7 | 35,3 | 110,4 | 0,1 | 0,0 | 0,2 | 0,3 | 40,7 | 34,9 | 35,7 | 111,3 |
| Silage corn | 6515,93 | 3,1 | 1,5 | 3,7 | 8,3 | 56,7 | 4,6 | 4,0 | 65,2 | 1,9 | 0,7 | 0,5 | 3,2 | 61,6 | 6,9 | 8,2 | 76,7 |
| Forage grass | 9869,05 | 0,5 | 0,3 | 0,6 | 1,4 | 32,3 | 0,8 | 0,7 | 33,7 | 2,1 | 0,7 | 0,9 | 3,7 | 34,9 | 1,7 | 2,2 | 38,8 |

(NPK) of 233 kg/ha and deficit of nitrogen of 130.8 kg/ha. Intensity of nutrients balance, a value which characterizes sustainability of agriculture, is calculated. When intensity factor is less than 100%, it means that nutrients are in deficit; when nutrients are balanced, this factor equals 100%; when nutrients balance is positive, this value is over 100%. (Petersburgsky, 1979). For agriculture of Kirovograd region, nitrogen balance intensity equals 64.5%. Therefore, we can conclude that crops provision with nitrogen in Kirovograd region in 2012 was unsatisfactory.

Nutrients balance in agriculture of Ternopil region

Nutrients balance calculation for agricultural lands of Ternopil region in 2012 was conducted using data on nitrogen, phosphorous and potassium income (Table 3). As we see from Table 3, organic fertilizers were not used

for growth of sunflower, rapeseed and other industrial crops. Maximal amount of nitrogen in the form of organic fertilizers was applied when growing sugar beets – 12.1 kg/ha, other crops received from 0.2 to 3 mg/ha with organic fertilizers. Main nitrogen quantity and potassium comes to soil with mineral fertilizers. Maximal amount of nitrogen in the form of mineral fertilizers was applied to sugar and fodder beets – 138.6 kg/ha, canola and other industrial crops – 117.3 kg/ha, potatoes – 94.9 kg/ha, grain corn – 89.5 kg/ha and winter wheat – 81.6 kg/ha. Other sources of soil nitrogen income provided minor amounts from 0.1 to 10.8 kg/ha.

Calculation of nutrients balance (Table 4) indicated that nitrogen balance in agriculture of Ternopil region in 2012 was positive in agricultural soils under canola, sugar beets,

Table 4: Nutrients balance in agricultural soils of Ternopil region in 2012

| Agriculture crop or crops group | Area under selected crop or crops group, ha | Takeaway, kg/ha | | | | Balance, kg/ha (+/-) | | | | Balance, % before takeaway | | | | Balance intensity, % | | | |
|-----------------------------------|---|-----------------|------|-------|-------|----------------------|-------|-------|--------|----------------------------|------|------|-------|----------------------|-------|-------|-------|
| | | N | P | K | Total | N | P | K | Total | N | P | K | Total | N | P | K | Total |
| Spring grain crops (without corn) | 256961 | 106.8 | 27.8 | 52.7 | 187.3 | -30.0 | -9.0 | -36.0 | -75.0 | 28.5 | 33.9 | 68.2 | 40.5 | 71.5 | 66.1 | 31.8 | 59.5 |
| Winter wheat | 180987 | 128.7 | 40.2 | 83.3 | 252.2 | -42.0 | -20.0 | -65.0 | -127.0 | 32.6 | 49.0 | 77.8 | 50.2 | 67.4 | 51.0 | 22.2 | 49.8 |
| Grain corn | 106948 | 110.9 | 42.8 | 30.4 | 184.1 | -18.0 | -28.0 | -13.0 | -59.0 | 16.3 | 64.4 | 43.9 | 32.0 | 83.7 | 35.6 | 56.1 | 68.0 |
| Soybean | 37590.5 | 48.2 | 21.2 | 17.1 | 86.5 | -13.0 | -7.0 | -2.0 | -22.0 | 26.4 | 32.0 | 11.8 | 24.9 | 73.6 | 68.0 | 88.2 | 75.1 |
| Sunflower | 14131.1 | 42.5 | 18.6 | 15.1 | 76.1 | +15.0 | -3.0 | +1.0 | +13.0 | 36.3 | 14.1 | 8.2 | 18.4 | 136.3 | 85.9 | 108.2 | 118.4 |
| Sugar beet | 40076.9 | 89.3 | 34.0 | 93.6 | 217.0 | +62.0 | +20.0 | +16.0 | +98.0 | 69.5 | 59.9 | 17.2 | 45.4 | 169.5 | 159.9 | 117.2 | 145.4 |
| Rapeseed | 44561.8 | 80.0 | 41.2 | 22.9 | 144.1 | +37.0 | -16.0 | +6.0 | +27.0 | 46.8 | 38.4 | 27.6 | 19.4 | 146.8 | 61.6 | 127.6 | 119.4 |
| Potatoes | 5171.62 | 88.0 | 26.2 | 130.8 | 244.9 | +20.0 | -4.0 | -59.0 | -43.0 | 22.4 | 15.3 | 45.4 | 17.8 | 122.4 | 84.7 | 54.6 | 82.2 |
| Vegetables | 1100.13 | 44.0 | 17.6 | 55.0 | 116.6 | -3.0 | +17.0 | -19.0 | -5.0 | 7.4 | 98.1 | 35.1 | 4.5 | 92.6 | 198.1 | 64.9 | 95.5 |
| Silage corn | 6515.93 | 94.2 | 31.4 | 87.9 | 213.6 | -33.0 | -25.0 | -80.0 | -138.0 | 34.6 | 78.2 | 90.7 | 64.1 | 65.4 | 21.8 | 9.3 | 35.9 |
| Forage grass | 9869.05 | 21.9 | 6.6 | 22.7 | 51.1 | +13.0 | -5.0 | -20.0 | -12.0 | 59.4 | 74.4 | 90.3 | 24.1 | 159.4 | 25.6 | 9.7 | 75.9 |

Table 5: Weighted average humus levels in soil of districts of Kirovograd region (2001–2010), %

| District | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 |
|-----------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| Bobrynets | 4.448 | 4.434 | 4.42 | 4.406 | 4.392 | 4.378 | 4.364 | 4.35 | 4.336 | 4.322 |
| Vilshany | 4.516 | 4.504 | 4.492 | 4.48 | 4.468 | 4.456 | 4.444 | 4.432 | 4.42 | 4.408 |
| Gayvoron | 3.762 | 3.744 | 3.726 | 3.708 | 3.69 | 3.672 | 3.654 | 3.636 | 3.618 | 3.6 |
| Golovanivsk | 3.708 | 3.736 | 3.764 | 3.792 | 3.82 | 3.848 | 3.876 | 3.904 | 3.932 | 3.96 |
| Dobrovelyckovka | 4.848 | 4.792 | 4.736 | 4.68 | 4.624 | 4.568 | 4.512 | 4.456 | 4.4 | 4.344 |
| Dolyna | 4.778 | 4.714 | 4.65 | 4.586 | 4.522 | 4.458 | 4.394 | 4.33 | 4.266 | 4.202 |
| Znamiianka | 3.97 | 3.91 | 3.85 | 3.79 | 3.73 | 3.67 | 3.61 | 3.55 | 3.49 | 3.43 |
| Kirovograd | 4.43 | 4.41 | 4.39 | 4.37 | 4.35 | 4.33 | 4.31 | 4.29 | 4.27 | 4.25 |
| Kompaniivka | 4.67 | 4.638 | 4.606 | 4.574 | 4.542 | 4.51 | 4.478 | 4.446 | 4.414 | 4.382 |
| Mala Vyska | 4.984 | 4.958 | 4.932 | 4.906 | 4.88 | 4.854 | 4.828 | 4.802 | 4.776 | 4.75 |
| Novgorodka | 4.29 | 4.238 | 4.186 | 4.134 | 4.082 | 4.03 | 3.978 | 3.926 | 3.874 | 3.822 |
| Novoarhangelsk | 3.872 | 3.908 | 3.944 | 3.98 | 4.016 | 4.052 | 4.088 | 4.124 | 4.16 | 4.196 |
| Novomyrhorod | 4.262 | 4.264 | 4.266 | 4.268 | 4.27 | 4.272 | 4.274 | 4.276 | 4.278 | 4.28 |
| Novoukrainka | 4.554 | 4.546 | 4.538 | 4.53 | 4.522 | 4.514 | 4.506 | 4.498 | 4.49 | 4.482 |
| Oleksandrivka | 3.476 | 3.44 | 3.404 | 3.368 | 3.332 | 3.296 | 3.26 | 3.224 | 3.188 | 3.152 |
| Oleksandriia | 4.044 | 3.99 | 3.936 | 3.882 | 3.828 | 3.774 | 3.72 | 3.666 | 3.612 | 3.558 |
| Onufriivka | 3.102 | 3.09 | 3.078 | 3.066 | 3.054 | 3.042 | 3.03 | 3.018 | 3.006 | 2.994 |
| Petrove | 4.302 | 4.26 | 4.218 | 4.176 | 4.134 | 4.092 | 4.05 | 4.008 | 3.966 | 3.924 |
| Svitlovodsk | 2.974 | 2.972 | 2.97 | 2.968 | 2.966 | 2.964 | 2.962 | 2.96 | 2.958 | 2.956 |
| Ulianovka | 4.424 | 4.408 | 4.392 | 4.376 | 4.36 | 4.344 | 4.328 | 4.312 | 4.296 | 4.28 |
| Ustinovka | 4.348 | 4.324 | 4.3 | 4.276 | 4.252 | 4.228 | 4.204 | 4.18 | 4.156 | 4.132 |

potatoes, fodder grass and sunflowers. Soils under spring crops, winter wheat, grain corn, soybean, vegetables and silage corn had negative nutrients balance. Compared to 2011, nitrogen losses decreased on 1 kg/ha phosphorous losses on 2kr/ha, potassium losses on 2kg/ha.

In general, greatest losses of nutrients were in soils under silage corn, green forage, potatoes and winter wheat. Thus, losses in soils under silage corn were the greatest and reached 138 kg/ha, including 80 kg/ha of potassium. Loss of potassium in total balance also happened when growing winter wheat – 65 kg/ha and potatoes – 59 kg/ha. Significant losses of nutrients were also observed for soils under grain corn – 59 kg/ha, soybean – 22 kg/ha and

green forage – 12 kg/ha. Calculated intensity indicator for nitrogen balance equals 108.1% for Ternopil region.

Using obtained data, we can conclude that nitrogen supply of agricultural corps for Ternopil region in 2012 was satisfactory. However, insufficient and unbalanced income of other main nutrients – potassium and phosphorous – took place.

Because nitrogen is fixed in soil as a component of humic compounds, unbalanced agricultural production leads to loss of main organic soil compound – humus. Soil humus is the main source of nutrients for plants. With insufficient income of fertilizers while intensive farming,

Table 6: Weighted average humus levels in soil of districts of Ternopil region (2001–2010), %

| District | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 | 2010 |
|--------------|------|------|------|------|------|------|------|------|------|------|
| Berejani | 2.48 | 2.48 | 2.49 | 2.50 | 2.50 | 2.51 | 2.51 | 2.52 | 2.53 | 2.53 |
| Borshchiv | 2.33 | 2.33 | 2.34 | 2.34 | 2.34 | 2.35 | 2.35 | 2.36 | 2.36 | 2.36 |
| Buchach | 3.10 | 3.11 | 3.11 | 3.12 | 3.13 | 3.13 | 3.14 | 3.14 | 3.15 | 3.16 |
| Husiatyn | 3.27 | 3.26 | 3.25 | 3.24 | 3.23 | 3.21 | 3.20 | 3.19 | 3.18 | 3.17 |
| Zalishchyky | 2.98 | 2.98 | 2.98 | 2.98 | 2.98 | 2.98 | 2.98 | 2.98 | 2.98 | 2.98 |
| Zbarazh | 2.88 | 2.92 | 2.96 | 2.99 | 3.03 | 3.06 | 3.10 | 3.14 | 3.17 | 3.21 |
| Zboriv | 3.30 | 3.29 | 3.29 | 3.28 | 3.28 | 3.27 | 3.26 | 3.26 | 3.25 | 3.25 |
| Kozova | 3.51 | 3.51 | 3.51 | 3.51 | 3.51 | 3.51 | 3.51 | 3.51 | 3.51 | 3.51 |
| Kremenets | 2.70 | 2.69 | 2.68 | 2.68 | 2.67 | 2.66 | 2.65 | 2.65 | 2.64 | 2.63 |
| Lanivtsi | 3.32 | 3.31 | 3.31 | 3.30 | 3.29 | 3.28 | 3.27 | 3.27 | 3.26 | 3.25 |
| Monastyrська | 2.24 | 2.24 | 2.24 | 2.24 | 2.25 | 2.25 | 2.25 | 2.25 | 2.25 | 2.26 |
| Pidvolochysk | 3.72 | 3.73 | 3.75 | 3.76 | 3.78 | 3.80 | 3.81 | 3.83 | 3.84 | 3.86 |
| Pidhaitsi | 3.24 | 3.20 | 3.16 | 3.12 | 3.08 | 3.04 | 3.00 | 2.96 | 2.92 | 2.88 |
| Terebovlia | 3.61 | 3.60 | 3.60 | 3.60 | 3.59 | 3.59 | 3.58 | 3.58 | 3.58 | 3.57 |
| Ternopil | 3.42 | 3.43 | 3.44 | 3.45 | 3.46 | 3.47 | 3.48 | 3.49 | 3.50 | 3.51 |
| Chortkiv | 3.01 | 3.01 | 3.00 | 3.00 | 3.00 | 2.99 | 2.99 | 2.98 | 2.98 | 2.98 |
| Shumsk | 2.75 | 2.76 | 2.77 | 2.78 | 2.80 | 2.81 | 2.82 | 2.83 | 2.84 | 2.86 |

Table 7: Prognosis of weighted average humus concentration in agricultural lands of Kirovograd region, 2011–2020

| Year | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|--------------------------------------|------|------|------|------|------|------|------|------|------|------|
| Weighted average humus concentration | 3.95 | 3.93 | 3.9 | 3.88 | 3.86 | 3.83 | 3.81 | 3.79 | 3.77 | 3.74 |

Table 8: Prognosis of weighted average humus concentration in agricultural lands of Ternopil region, 2011–2020

| Year | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 | 2017 | 2018 | 2019 | 2020 |
|--------------------------------------|-------|-------|-------|-------|--------|-------|-------|------|------|-------|
| Weighted average humus concentration | 3.055 | 3.056 | 3.056 | 3.057 | 3.0578 | 3.058 | 3.059 | 3.06 | 3.06 | 3.061 |

plants irreversibly absorb nitrogen, accumulated in soil humic compounds. This leads to decomposition of humic compounds and degradation of soil.

With the aim of humus state evaluation in agricultural soils, research on dynamics of humus content in soils of two studied regions – Ternopil and Kirovograd – was conducted.

Processes of dehumification of Ukrainian soils are highly intensive during latest 25 years. This problem is widely and relevantly covered in many scientific papers. According to these researches, change of ownership and management had negative influence on soil fertility, causing loss of a significant part of humus (Ukraine National Report, 2010). According to the results of agrochemical certification of agricultural lands during recent 5 tours of inspection (1986–2010), humus content in Ukrainian soils has decreased by 0,5%. Total area of agricultural lands, affected by dehumification, is 39 million hectares.

The most significant losses happened when amounts of applied organic fertilizers were drastically reduced, and crop formation was the result of soil potential fertility (Medvedev and Lisovy, 2001; Lisovy and Nikitiuk, 2006). However, according to the data of Regional State Design and Technology Centers of soil fertility and production quality

protection, humus levels in some Ukrainian regions begun to stabilize in recent years. This was caused by termination of stubble and straw burning practices, switching to minimum soil tillage and usage of biologization methods (Ukraine National Report, 2010). Usage of byproducts as organic fertilizers and introducing green manure plants to crop rotation promotes the stabilization of humus balance and replenishment of soil nutrients, which positively affect soil fertility. Thereby, one of tasks of this article was development of prognosis mathematical model and evaluation of general tendency in weighted average humus level in agricultural lands of Ukraine.

Prognosis mathematical model for humus dynamics in agricultural soils of Kirovograd and Ternopil regions *Building a program for experimental data processing in Embacadero Delphi XE 5*

To build a prognosis model, it is required to have data on weighted average humus level for each year. However, during 2001–2010 only two selected years have data on measurements of humus levels for each district. To find values of weighted average humus levels for other years, method of linear extrapolation was used. This method is widely used in computational mathematics to find unknown values using existing discrete data. (Gulin and Samarsky, 1989). We form a series $a = \{a_n, n \in N\}$, where a_i is the value of weighted average humus level measured in the year

i . If we have some given values a_i and a_j , where $i < j$, we can find other elements of this series using linear extrapolation polynomial in the form

$$a_k = a_i + \frac{a_j - a_i}{j - i}(i - k) \tag{1}$$

where a_k is extrapolated value; a_i, a_j – elements of the series $i < j$. Using this formula, weighted average humus level for 2001-2010 can be calculated with some precision.

Using the software Embacadero Delphi XE 5 was built a program that reads data from Microsoft Excel file, process them, builds linear extrapolation polynomial calculates data on each district for 2001-2010, and outputs the result as a new Excel file.

Development of prognosis mathematical model of humus concentration dynamics in Wolfram Mathematica 9 using linear regression methods

To evaluate the behavior of weighted average humus concentration and to make a prognosis, the classical model of linear regression was used. Linear regression is a method of finding a relationship between vector and scalar data (Maiboroda, 2007). While using linear regression, a relationship between data is built using linear functions, coefficients of functions were calculated using input data. General linear regression model has the form

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \dots + \beta_k x_k + u, \tag{2}$$

where y is dependent value, (x_1, x_2, \dots, x_k) – independent values, u – statistical error. Using experimental data, we estimated values $(\beta_0, \beta_1, \dots, \beta_k)$ and distribution of random variable u .

Depending on the objects which are studied using linear regression, different methods of unknown parameters estimation can be used. Such methods are: least modules method, maximum likelihood method etc. The most used one is the least square method. According to this method, a value is used as the meaning of the parameter, if this value minimizes sum of squares of residual for all observations, i.e.

$$\hat{\beta} = \arg \min_{\beta} \sum_{i=1}^n \left| y_i - \beta_0 - \sum_{j=1}^k X_{ij} \beta_j \right|^2, \tag{3}$$

where $\hat{\beta}$ is the vector of estimated values for parameters $(\beta_0, \beta_1, \dots, \beta_k)$, y_i – estimated data, X_{ij} – input data (Maiboroda, 2007).

In our calculations we use the methods of least squares, because this method gives the best unbiased consistent linear estimation.

Using Wolfram Mathematica 9, a program was created to build a prognosis and evaluate tendencies of humus levels in soil. This program utilizes mathematical method of classical linear regression and use experimental data to build a prognosis. Program output has the form of linear polynomial $G(x) = A + xB$ (4)

where x means year, $G(x)$ – weighted average humus level in year x , A and B – regression coefficients, obtained using the least squares method.

Prognosis of weighted average humus level in the soil of Kirovograd and Ternopil regions of Ukraine

Using the described above program of data processing and data on weighted average humus levels for Kirovograd and Ternopil regions, the extrapolation of this data is made for 2001 – 2010. Tables 5 and 6 contain extrapolated data for each district of Kirovograd (Table 5) and Ternopil (Table 6) regions.

Using mentioned above mathematical model, a general tendency in humus concentration is agricultural soil of Ternopil and Kirovograd regions for 2001-2010 is determined (Figs. 1 and 2).

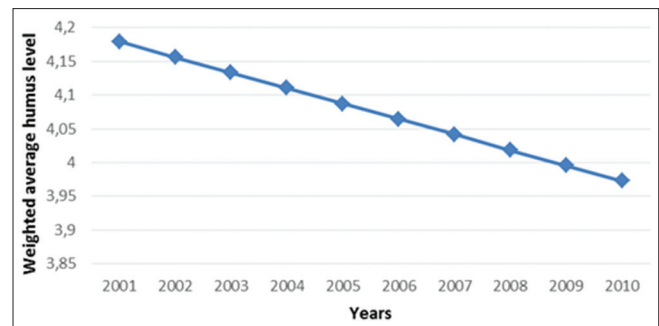


Fig 1. Dynamics of humus concentration (%) in soil of Kirovograd region in 2001–2010.

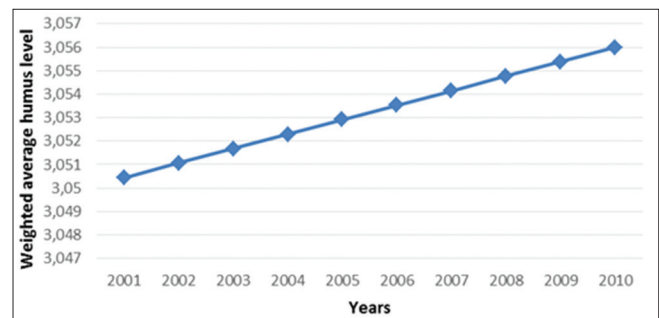


Fig 2. Dynamics of humus concentration (%) in soil of Ternopil region, 2001–2010.

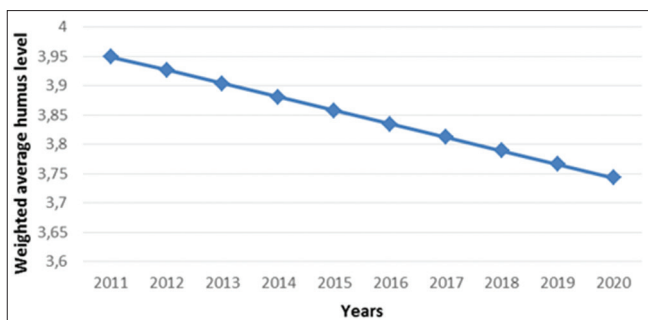


Fig 3. Prognosis of weighted average humus concentration (%) in agricultural lands of Kirovograd region, 2011-2020.

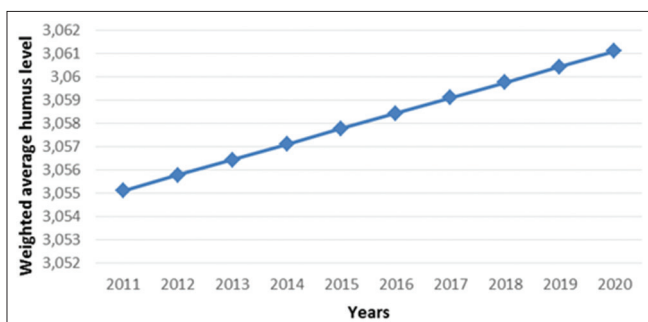


Fig 4. Prognosis of weighted average humus concentration (%) in agricultural lands of Ternopil region, 2011-2020.

As it is shown in Fig. 1, weighted average humus level in the soil of agricultural lands of Kirovograd region is decreasing during 2001-2010. Fig. 2 indicates slow positive increase of humus concentration in soils of agricultural lands of Ternopil region.

Using programming methods mentioned above, we have built linear regression model and obtained regression polynomials in the form $G(x)=19,237-0,00825x$ for Kirovograd region and $G(x)= 3.05437 + 0.00065x$ for Ternopil region. Using this model these polynomials, a prognosis of humus concentration was built in agricultural lands of Ternopil and Kirovograd regions for 2011-2020. (Figs. 3 and 4). Results of this prognosis are shown in Tables 7 and 8.

Using received models and data, we can predict that in case of use of current agricultural technologies, weighted average humus level in Kirovograd region can reach its critical value in 2183 (Fig. 3).

CONCLUSIONS

- Using data by State Institution “Institute of Soil of Ukraine” on quantities of income and takeaway with harvest nitrogen, phosphorus and potassium in 2012, balance of nutrients in agriculture is calculated on the regional level. Two regions – Kirovograd and

Ternopil – are taken for example.

- Intensivity of nitrogen balance in agricultural lands of Kirovograd region was unsatisfactory and was equal 64.5%, which means loss of humus – soil organic matter. Intensivity of nitrogen balance in Ternopil region was satisfactory and was equal 108.1%. Application of phosphorus and potassium in agriculture of both regions is unbalanced.
- Because nitrogen is accumulated in soil as a component of organic matter – humus, a program was built using Embacadero Delphi XE 5 to evaluate humus dynamics to in agricultural soils. This program builds linear extrapolation polynom and calculates extrapolated values of weighted average humus level in soil, using input data, for each year in the period 2001-2010.
- Using Wolfram Mathematica 9, a program was built that processes input data and, using method of linear regression, builds prognosis model of dynamics of weighted average humus level and allows detection of trends of humus levels change.
- Using prognosis mathematical model, tendencies in the dynamics of weighted average humus level change were evaluated for agricultural lands of Ternopil and Kirovograd regions. Prognoses for humus level tendencies display rather fast rates of soil dehumification in Kirovograd region. Prognosis for Ternopil region, however, does not show signs of humus destruction.

Author contributions

L. M. planned the article, evaluated, analyzed and interpreted the experimental data and corrected the article. I. Y. planned and designed the Monitoring study of soil, collected the data. O.M. searched literature, built mathematical models and wrote the article. L.P. calculated the nutrient balance.

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