Biological Aspects of Economic Efficiency of Crop Farming

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Abstract. A robust increase in crop production has lately been associated with the government incentives to agricultural producers to comply with production technologies, which include the use of synthetic fertilizers in the required quantities. Heavy crop yields remove nutrients from the soil, thus, necessitating supplementary fertilizing, which affects the soil, it being a developed agricultural ecosystem. The plant nutrient uptake from the soil becomes difficult, phytotoxic effect may occur. Certain measures for soil rehabilitation should then be taken, the most important of which is the use of green manure and minor nutrients as a basis of the symbiotic relationship between organic and mineral constituents of the soil.

1. Introduction

The record crop of 2017, 134 million tons of grain, was raised due to a 17% increase in wheat harvest against the previous year, the total volume of which was 85.8 million tons. The growth in the yield is essentially associated with the policy of the RF Ministry of Agriculture designed to promote compliance with agricultural production technologies, including the application of synthetic fertilizers, using the mechanism of state support for their purchases by the growers of agricultural produce.

The RF Ministry of Agriculture is currently working out a comprehensive set of measures to build up the AIC produce export, with wheat grain being its centerpiece. In 2024, according to the projections of the RF Ministry of Agriculture, grain will hold the lead in the Russian export with a volume of over 11 billion dollars. Fat-and-oil and food and pharmaceutical industry products will be in joint second place with export figures of up to 8.6 billion dollars. Fish and seafood will take the third place with a total export volume of 8.5 billion dollars [1].

Already during the current year, according to the Ministry of Agriculture forecast, Russia can export 44 million tons of grain, including 36 million tons of wheat [2].

To fulfill the task of a fast-pace capacity building of agricultural crop export, it is necessary to work out the mechanism of R&D and technological support for agricultural production.

2. Rationale

Every year, with each grain yield, spring wheat removes the following nutrients from the soil: N – 25 kg/t, P₂O₅ – 9.5 kg/t, K₂O – 5.5 kg/t, S – 1.7 kg/t. The straw takes 12 kg/t of N, 2.7 kg/t of P₂O₅, 20 kg/t of K₂O, 2.3 kg/t of S [3]. Other nutrients are also removed with the increase in the crop yield, but this relation is not linear.
Estimates of plant-available nitrogen yield with the grain harvest in the anticipated export volume show that about 1 billion kg of bioavailable nitrogen is annually removed from the soil, which is more than two billion rubles, expressed in terms of the cost of nitrogenous fertilizer in gross weight. Here we should add the removal of phosphorus and potassium, minor nutrients necessary for normal plant growth and development, and the resulting value of the removed major and minor nutrients is approximately 10 billion rubles. With the revenue from grain exports of about 10 billion US dollars, the benefit is obvious. Besides, the export product is classified as a renewable raw material. Grain can be produced annually and it is in constant demand. Abroad and in Russia, the identified use of grain is becoming more and more varied, high-level processing and advanced technologies help manufacture products required for the feed and food industry, such as amino acids, glucose-fructose syrups, etc. Consequently, there is an increased demand for production and export of grain, and its quality is expected to be improved as well, which would allow for exporting the goods with higher added value. In this regard, there arises a problem of a well-timed and complete recovery of soil fertility and its repletion with the missing elements used for plant nutrition. This is achieved through the application of various synthetic fertilizers.

An increasing intensity of industrial manufacturing and agricultural production along with an escalating anthropogenic load on the environment lead to soil degradation. According to the Food and Agricultural Organization, globally, over 1.2 billion ha or 22% of the world’s agricultural lands have degraded and affected soils, 12% of the world’s soil resources are chemically degraded. In the Russian Federation, over 80% of cereal farming ecosystems contain phytopathogens [4].

3. Tasks, results and practical importance of the research

The initial stage of degradation of the artificially modified soil fertility is acidification of the subsurface layer across the agricultural background and the associated disruption of balance of soil characteristics due to their ill-proportioned change as affected by fertilizers. Consequently, a considerable amount of residual phosphorus from fertilizers becomes less available to plants, the root habitable layer diminishes and the soils lose an important ecological function – their ability to provide balanced feeding for plants, which should contain a large number of major and minor nutrients. As a result of an imbalanced plant nutrition, both manured and unmanured agricultural backgrounds fail to provide a satisfactory ecological quality of plant products after a long-term afterinfluence [5].

In this respect, a solution should be found to the following problems, which cause soil degradation as a complex process:

Accumulation of residual pesticides and other chemicals

Migration of pests and pathogenic organisms, spread of weed vegetation in the regions of the country that are located farther north

Production and use of new crop protection chemicals and, as a result, development of resistance to pesticides in weeds, pests and pathogens

Decline in the populations of entomophages, insect-pollinators and beneficial microorganisms.

Ever since the manufacturing became a private sector, land users have often made a big mistake, regarding the soil narrow-mindedly and ignoring, for various reasons, its living component. Microorganisms are a key factor in the soil-forming process. The soil is not a growing medium for plant roots, not a hydroponic support medium and certainly not a dead field used for construction of logistic and technical facilities!

Within the ecosystems conception, healthy soil is a complex biofactory with a continuous supply of energy and raw materials. It performs an infinite waste-free biotechnological production of unique biobased products that are constantly needed for geobionts and autotrophic organisms. Microbial activity provides for the formation and regeneration of humus, organic-matter degradation, as well as destruction and neoformation of soil minerals. The agricultural land yield largely depends on the intensity of microbiological process [6].
4. Research results

Despite the heterogeneity of ecological conditions in different types of soil, it remains a rather supportive environment for the biota. Marked temperature and humidity gradients allow soil organisms to migrate to optimal habitats. The soil, compared with other media, is the most densely populated with biota (Table 1) [4].

Table 1. A Number of Geobionts in 1-30 cm Horizon of Healthy Soil (on a per 1 m$^2$-basis).

| Group of Organisms     | Number of Individuals, ea |
|------------------------|---------------------------|
| Bacteria               | 60 000 000 000 000        |
| Fungi                  | 1 000 000 000             |
| Algae                  | 1 000 000                 |
| Single-celled animals  | 500 000 000               |
| Nematodes              | 10 000 000                |
| Acari                  | 150 000                   |
| Collembola             | 10 000                    |
| Enchytraeidae          | 25 000                    |
| Earthworms             | 200                       |
| Slugs                  | 50                        |
| Spiders                | 50                        |
| Isopoda                | 50                        |
| Myriapoda              | 150                       |
| Beetles                | 100                       |
| Fly pupae              | 200                       |
| Vertebrates            | 0.001                     |

Geobionts are characterized by stability and adaptability to environmental factors that is why many types of human intervention (e.g. plowing, fertilizing) do not destroy the integrity of soil microorganisms.

Adverse anthropogenic effect on the surrounding cultivated land evoke phytopathogen activity. A plant pathogen infecting potato tubers and causing skin spots (oosporosis) may serve as an example of the mechanism of focus expansion of a soil phytopathogen by means of seed grains. The pathogenic agent reproduces on potato tubers almost all year round (both in the field and in storage), circulating in the cultivated land as follows: mother tubers in the field – daughter tubers in the field – daughter tubers in the storage – mother tubers in the field. Thus, the pathogenic agent has acquired the traits of an r-strategist, reproducing, on the whole, asexually and expanding the pathogen foci in the soil.

Weed associated grass of spring wheat farming ecosystem is a reservoir of major root rot pathogenic agents affecting cultivated graminaceous plants. Soil phytotoxicity is most often caused by the residue of persistent herbicides and other xenobiotics, as well as fungi-decomposer products of Penicillium, Aspergillus, Fusarium. The phytotoxicity of unbroken soils was, beyond all doubt, lower (23-29%) than that of the cultivated soils, especially in terms of phytomass index of test plant seedlings. Particularly high phytotoxicity was registered in farms where an intensive crop growing technology is used, with the systematic and repeated application of herbicides (particularly graminicides and sulphonylurea) and synthetic fertilizers [7].

Synthetic fertilizers used in agricultural industry generally have an acidifying effect on the soil. Moreover, the anthropogenic activities result in emission of billions of tons of gas and aerosol acid agents into the atmosphere: chlorine and hydrochloric acid, hydrogen sulfide and sulfur dioxide, nitrogen oxides, aluminum compounds and carbon dioxide. In the agricultural regions of the Russian Federation, a strong acidic reaction of medium (pH 4.0-5.0) is often observed in humid climate and is typical for telopodzol and bog soils, yellow and red podzolic soils, with lime, potassium, boron, sulfur, zinc, cobalt and iodine extensively washed from them. The availability of phosphates, often shielded by iron, is lowered. Iron, aluminum and manganese are mobile and have a toxic effect on many plants.
The bacterial activity is suppressed, overactivity of fungi is observed. In addition, due to a quenched nitrification capacity, there is little nitrate in acidic soils, phosphate is fixed into trivalent forms of iron and aluminum that are unavailable to plants; there is a lack of calcium, magnesium and sulfur [8].

The use of unscientifically-based, extremely high doses of synthetic fertilizers leads to nitrate pollution of crop products and water, to the accumulation of adulterants or even dangerous pollutants coexisting with nutrients and contained in some fertilizers, and to a frequent distortion of optimal ratios of mineral elements, which inevitably leads to the disturbance in normal plant metabolism and product degeneration [9].

Natural organics play an important role in soil remediation and rehabilitation due to the widespread availability of raw materials and production technologies. Whenever there is a lack of manure, straw and green manure become the most important organic fertilizers. Due to the large C:N ratio in cereal straw, the lack of nitrogen (in it and other crop debris) should be compensated by urea nitrogen at ~10 kg N/t of straw. The main green manure crops adapted to most climatic zones of Russia are legumes (perennial and annotinous lupin, melilot, field pea, feed vetch, serradella) and oil radish, rape plant, summer rape, phacelia and amaranth [7].

In agricultural practices, there are many examples of green manure usage as an anti-phytopathogenic factor.

A contact of smut spores with germinating barley grains has led to their germination and infection of seedlings, and a plowdown of interplanted (self-sown) barley crop provided for a downsizing in smut number. The same enhanced germination of conidium Cercosporella (crown root agent) became a reason for burying of oil radish, peavines, white clover and rye grass as green manure. Incorporation of white goosefoot (Chenopodium album), chickweed (Stellaria media) and capsella (Capsella bursapastoris) helps to lessen the infestation of peas and flax by fusarial head blight. A well-timed plowdown of rape plants helps to reduce the number of turnip and cabbage gall weevil. However, if it remains on the field for too long, it will increase the number of pests [10].

Desorption of phosphorus, zinc, cuprum and iron from the soil substantially increases in case of the plant root system symbiosis with mycorrhizal fungi. Symbiotroph hyphae cover a larger amount of soil, thereby increasing the nutrient absorption area. The use of adequate doses and types of micronutrient fertilizers in most crop growing technologies leads to an improved efficiency of such basic fertilizers as nitrogenous, phosphatic, and potash.

One of the least known benefits of maintaining a sufficient level of minor nutrients is a reduction of the incidence of disease in plants. Microorganisms are sensitive to much lower concentrations of Cu, Mn, Zn than higher plants. Therefore, salts of these metals have been used in a variety of crop protection agents for a long time. Cuprum is used as a fungicide to halt the development of leaf pathogens, such as downy mildew. Foliar application of minor nutrients (B, Mn, Zn) can also reduce the disease manifestations on the aerial parts of plants, e.g. yellow spot (tan spot) of wheat. It has been proven that Zn down-regulates pathogens that cause root rot, damage by root-eelworm, and Ophiobolus graminis root infections. Boron treatments are efficient against a number of fungal infections. The cold rigor of crops depends on the level of boron supply, which is very important for managing boric nutrition during the critical growth and development phases, for example, after transplanting of seedlings or during early fruit formation [12].

5. Conclusion and suggestions

The application of scientifically defined doses of minor nutrients, which meet the needs of each particular crop, depending on the soil type, cultivation area and crop rotation used, will provide a synergetic symbiotic effect not only for crop capacity, but also for promotion of its resistance to biotic and abiotic stress factors and, therefore, for improvement of crop product quality.

A radical rehabilitation of farming ecosystem soils from pathogenic micromycetes, and minimization of damage caused by them are ensured by the following: a) introduction of crop rotation with discontinuation of amenable crop cultivation; b) inclusion of phytosanitary predecessors in the crop rotation, clearing the soil from pests; c) treatment of seeds with biologicals, treatment of crop
remains with fungous preparations combined with a mixture of carbamide and ammonium nitrate; d) 
sowing of green manure and systemic use of organic fertilizers (for individual crop rotation samples); e) 
introduction (based on soil fertilization level) of NPK fertilizers with fungistatic and/or antifungal 
effect. A systemic use of this set of techniques on the principle of complementarity (including clear-
ning the seed grain, weed (infection reservoir) control, etc.) ensures the elimination of the phytopathogens 
inoculum from the soil and a long-term improvement in its suppressivity. Such a strategy is a sound 
background for increasing stability and adaptability of farming ecosystems to biotic stress factors. It 
provides a sustainable and profitable production of environmentally friendly agricultural products and 
helps maintain health and effective soil fertility of farming ecosystems.

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