Diagnostics of nitrogen nutrition of winter barley crops using spectral analysis

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Abstract. To increase crop productivity, improve quality and soil fertility, it is necessary to study the processes of nutrient transformation in the soil, their supply to plants and regulation of methods of influence on these processes. It is necessary to learn how to manage the cycle of chemical elements and maintain the unity of organism and habitat. The article deals with the method of spectral analysis: a method of determining the chemical composition and structure of substances by their spectrum.

Keywords: nitrogen fertilisers, diagnostics, spectral analysis

1 introduction

Diagnostics of mineral nutrition of plants as a priority area of agrochemical research has been known since the time of J. Liebich. J. Liebich formulated the law of minimum, according to which the development of plants is limited not by those elements of nutrition that are present in the soil in abundance, but by those that are very little. He studied the effect on plant growth of the content of various chemical elements in the soil and formulated the principle: "The substance in the minimum controls the yield and determines the magnitude and stability of the latter over time". This principle is known as the minimum rule or Liebich's law.

Determination of the need of agricultural crops in such basic nutrition elements as nitrogen, soil diagnostics, i.e. determination of mobile forms of these elements in soils, on the basis of which the doses of appropriate types and forms of fertilisers are specified, has been and is widely used [1].

In most studies, the optimal doses of mineral fertilisers for specific cultivation conditions are established on the basis of field experiments with fertilisers by an experimental method. But this method only establishes the final effect of fertilisers on the crop. Field experiments cannot cover all the diversity of soils, climatic peculiarities of zones and regions of the country, as well as each farm and specific field. A more progressive method in this respect is that of chemical analysis of soils and plants and establishment of fertiliser doses by calculation [2].

Deep agrochemical research is needed to find out the peculiarities of interaction between plants, soil, microorganisms and fertilisers. Methods of agrochemical analysis make it possible to study the processes of movement and transformation of nutrients in the soil, their entry into plants and participation in the synthesis of complex organic substances. One of the main ways of influence on plants and soil is the use of mineral and organic fertilisers. Fertilisers act as a powerful factor that can increase crop yields and improve their quality [3].

Fertiliser application is one of the main factors influencing both the size and quality of barley yield. A high nutrition level leads to early sowing, and fertilisers have a positive effect on the biochemical composition of the grain.

Nitrogen is one of the most important macronutrients present in every part of the plant. It is easily leached from the soil and providing it in sufficient quantities helps the plant to grow and develop fully.

If there is not enough nitrogen, the upper part of the old leaves and shoots begin to change colour, growth slows down and the fruits are small. That is why, it is extremely important to apply nitrogen fertiliser to the soil.

The main forms of nitrogen fertilisers are as follows.

Amide the soil is converted into ammonium and then into nitrate form, as plants are only able to assimilate these two forms in the soil. Easily and quickly assimilated through the leaf surface, it is considered the best nitrogen fertiliser for foliar application.

Ammonium is gradually assimilated by the plant even at low temperatures and can be partially transformed into nitrate. Owing to this type, the root system grows better and nutrients are assimilated.

The greatest need for nitrogen fertilisers in barley is during the vegetative growth period; when the plant emerges into the tube, this period ends.

Types of nitrogen fertilisers are the following:

- ammonium nitrate is an effective fertiliser of ammonium-nitrate content, has a positive effect and is applied to most types of soils;
- lime-ammonium nitrate is a fertiliser containing calcium in addition to nitrogen, which results in better soil acidification;

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- urea has high nitrogen content from solid nitrogen fertilisers;
- urea-ammonia mixture is a nitrogen fertiliser with high concentrations, used in areas with insufficient moisture [4, 8].

Soil diagnostics is also used to identify the need of plants for nitrogen fertilisers, mainly in the pre-sowing period or at the beginning of active vegetation of crops. But unlike the content of mobile forms of phosphorus and potassium, which is characterised by relative stability even within several years, the content of nitrogen compounds available for plant nutrition in soils requires constant monitoring during each vegetation period. This is due to the instability in time, dynamism of this indicator, on the one hand, and the special demand of plants for nitrogen almost throughout their vegetation, on the other. And if sufficient provision of plants with phosphorus and potassium can be achieved by applying fertilisers in advance, the case with nitrogen is much more complicated. Nitrogen fertilisers are applied to the soil in spring immediately before sowing spring crops or superficially at the beginning of the growing season of winter cereals, focusing on the data of agrochemical survey of soils, including operational diagnostics.

In critical periods of vegetation, for optimisation of nitrogen nutrition of cereals and other agricultural crops, vegetative fertilisers are fed with nitrogen fertilisers according to the data of chemical methods of plant diagnostics: stem and leaf diagnostics.

In recent decades, along with chemical methods, physical, namely photometric, methods of diagnostics of nitrogen nutrition of crops, based on the relationship between the intensity of green colouration of plants and their nitrogen supply, have become increasingly important. Photodetectors of diagnostic devices record either the concentration of chlorophyll in indicator organs of plants or the intensity of its fluorescence [2].

Diagnosis of plant fertiliser requirements is carried out by different methods: observation of plant morphological state, leaf or whole plant analysis, chemical analysis of soil and field experiments. Lack of nutrition elements is manifested visually: leaf colour changes, plant growth is retarded (Table 1) [3].

Table 1. Characteristic external signs of crops under nitrogen deficiency

Missing element	Nature of growth and development	Leaf colouring
Nitrogen	Suppressed growth, short and thin stems and shoots. Few lateral shoots. Small leaf size. Premature ripening.	Pale green, chlorotic, leaves turn yellow later on. Appearance of orange and red tints on leaves. In maize under nitrogen starvation, middle leaf veins and adjacent tissues turn yellow and die off

Insufficient amount of macro- and microelements in the soil can be compensated by applying the required amount of mineral fertilisers. When developing a fertiliser application system, a project is prepared, in which all necessary materials, calculations and justifications are reflected:

- characteristics of the farm land;
- peculiarities of meteorological conditions;
- agrochemical characteristics of soils;
- balance of nutrients in the soil;
- measures for chemical reclamation of soils;
- planned productivity of crops, taking into account the application of fertilisers and the need of agricultural crops in nutrients;
- planned yield and the average actual yield of each crop.

Spectral analysis is a physical method of determining the composition of a substance based on the study of emission, absorption, reflection and luminescence spectra. The atoms of each element emit radiation at specific wavelengths, which in turn makes it possible to determine which elements are part of a given substance. Spectra are determined by the properties of the electron shells of atoms and molecules and the effect of the structure and mass of atomic nuclei on the position of energy levels. Spectral analysis can detect elements in a complex substance even if their mass does not exceed 10 grams [1, 18]. There are atomic and molecular spectral analyses, the tasks of which are to determine the composition of matter. Spectral analysis is based on the decomposition of white light into its components. If a beam of light is put on the edge of a three-sided prism, then, refracting in the glass, the rays that make up white light will give a rainbow strip on the screen, called the spectrum. In the spectrum, all colours are in strict order. Each colour corresponds to a particular wavelength of that wavelength or frequency. The wavelength in the spectrum decreases from red rays to violet rays from 0.7 to 0.4 μm and the frequency increases from 390 THz to 750 THz [2].

Spectral analysis methods consist in determining the chemical composition and structure of substances by their spectrum. They are divided into two large groups [3]. Emission methods use absorption spectra of atoms and the most common methods of elementary analysis of a substance, based on registration of atomic spectra with the help of a special device: spectrograph. The purpose of practical emission analysis is qualitative detection of elements in a substance. A sample of the substance under study is introduced into a radiation source, where it is vaporised, molecules dissociate and the resulting ions (atoms) are excited. The latter emit radiation, which enters the recording device of the spectral instrument. In qualitative atomic emission spectral analysis, the spectra of samples are compared with the spectra of already known elements, and then the elemental composition of the analysed substance is established.

In quantitative analysis, the amount of a given element in the original substance is determined. Accuracy and sensitivity of atomic emission spectral analysis depend, first of all, on physical characteristics: temperature, concentration of electrons, residence time of atoms in the excitation zone. Emission analysis together with other analyses is used in methods that establish specific groups of objects (shot, glass, auto enamels, etc.), as well as organic objects and objects of biological origin. If specific impurities are found in the composition of objects, their specific volumes (masses) can be established. This analysis is also used in the study of gunshot products to establish the sequence and distance of gunshots, gunshot traces of the shooter on another person. Recently, the introduction of microscopic methods of emission analysis into forensic practice has increased the sensitivity of the method to ten-thousandths of a microgram. There is one disadvantage: when emission analysis is used, the substance to be examined is destroyed [4, 5, 6, 7, 20].

Spectral analysis is one of the most common methods for determining the elemental composition of matter. Depending on the objects to be analysed, the required detection limits and the accuracy of the results, different instruments and different sources of excitation of spectra are used in the practice of spectral analysis. Recently, spectrometers have been actively used in agriculture and food industry.

The use of spectral equipment in agriculture and food industry makes it possible to see what cannot be seen with the human eye: the features of crops and trees, differences between mined minerals, areas of contamination of water, soil and the environment in general. It is used to analyse grains, fodder, plants, food products for impurities of toxic elements and heavy metals, etc.

Monitoring crops for nutrient availability, adequate water, disease presence, insect attack, and overall plant health is an important aspect of successful agricultural operations.

Traditional food grading methods are most often based on the experience of workers who make a visual assessment of quality based on their own experience and vision. However, these methods can be subjective and are usually limited by the ability of the human eye [8–12, 18, 19].

2 Materials and methods

Diagnostics of nitrogen nutrition was carried out in the Novoukrainsky farm (Figure 1) on soils with deep arable layer, medium-bound loamy soils.

The schemes of field experiments included variants with increasing doses of nitrogen from 0 to 150-180 kg/ha. The research objects were zoned varieties of winter barley. A portable model N-tester "Spectrolux" was used as photometric instruments [21–23].

An n-tester "Spektrolux" is a portable device designed for on-line diagnostics of nitrogen nutrition of plants. It is used on vegetative plants by measuring photochemical properties of leaves: chlorophyll fluorescence intensity, light permeability of leaf plates and the ratio of these indicators. All three indicators are immediately displayed on the liquid crystal display of the instrument in conventional units. The third indicator, i.e. the ratio of the first two, is taken as the main indicator of plants' need for nitrogen. In order to obtain a statistically reliable indicator within a visually homogeneous sowing area (field, plantation, vegetable bed), it is necessary to measure at least 40 different plants. At the same time, it is recommended to select the places of plant diagnostics evenly within the diagnosed area, for example, after the same number of steps when moving along the diagonal of the field [1, 2, 4, 8, 9, 15–17].

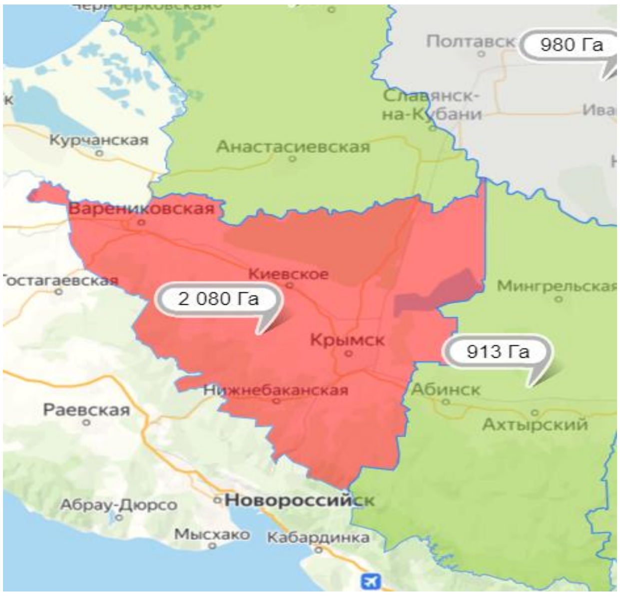

Fig. 1. Sown area of winter barley

During the experiments, the nature of crop dependence on increasing doses of nitrogen fertilisers was revealed, as it is this indicator that should be the basis for logical and statistical assessments of photometric diagnostics of nitrogen nutrition of plants. As a result of the research, the dependence of photometric indicators on increasing doses of nitrogen fertilisers applied to crops, the correlation with other diagnostic indicators studied in these field experiments, the relationship with crop yield and quality were established [24, 25].

3 Results and discussion

Studies in the diagnosis of winter barley revealed a positive correlation between the readings of the device and the doses of nitrogen fertilisers applied to this crop. The conjugacy of the location of points of the theoretical distribution curve and the actual reading of the device is characterised by the correlation coefficient r=0.99, i.e. they practically coincide with each other. The accuracy of determination of nitrogen fertiliser doses for plant feeding is on average n±10%, where n is the nitrogen dose kg/ha corresponding to the N-tester readings.

4 Conclusion

The results of studies on diagnostics of nitrogen nutrition of various crops have shown that photometric diagnostic methods allow estimating nitrogen nutrition availability of plants with a sufficiently high degree of probability.

In practice, these methods can replace more complex and difficult to perform and unsafe for performers methods of chemical diagnostics used earlier.

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