Application of photometry for crops online diagnostics of the nitrogen nutrition of plants

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Abstract. The application efficiency of portable photometric nitrate tester “Spectrolyuks” produced domestically and «Yara» produced foreign for online diagnostics of nitrogen nutrition of agricultural crops in the link of field crop rotation reviewed. The results of a field test conducted in 2012-2015 in the Central Region of Non-Chernozem zone on spring grain crops (barley, triticale) and white mustard, shown the positive effect of a photometric devices application. The data photometric diagnostics obtained in the initial phase of crops development (stem elongation on the barley and triticale, budding on the white mustard) had a strong correlation dependency with crop yield of the link of the field crop rotation and stem diagnostics scores.

1. Introduction

Mineral nutrition plays an important role in the growth and development of plants and is one of the most accessible factors for regulating their vital activity [1-11]. Nitrogen is the most important and at the same time the most mobile element. When the main abiotic factors (light, heat, water) are found in the optimum, nitrogen will be the main element on which the yield of agricultural crops depends [9]. Timely, directed and correct impact on the processes of root and foliar nutrition affects the course of formation and the amount of the crop. The greatest success in growing high yields can be achieved only with a comprehensive diagnosis of plant nutrition. It involves a regular full agrochemical survey of fields, based on the results of which a plan of mineral nutrition of agricultural crops is drawn up, as well as operational diagnostics during the growing season to adjust the doses of fertilizing with nitrogen fertilizers. In modern technologies of agricultural crops cultivation, express diagnostics of nitrogen nutrition makes it possible to quickly establish a nitrogen deficiency in vegetative plants, thereby it becomes possible to control the yield and quality of plant products. The most promising way of rapid diagnostics is photometry [2-4; 7]. There is already some information about the tests of the N-tester "Yara" (Konica Minolta, Japan) in conditions of Russia, but recommendations for doses calculations of nitrogen fertilizers on specific crops and varieties in specific soil and climatic conditions based on its measurements can only be given by the regional agronomist of the manufacturing company [6]. On the foreign and Russian markets, there are analogues of this device (N-testers "Agrotester", Hydro) which do not have significant differences in appearance and principle
of operation. However, recommendations for doses calculations of nitrogen fertilizers based on the measurement results are also not publicly available by manufacturers [1]. A new device for diagnosing the level of nitrogen nutrition based on measuring the intensity of chlorophyll fluorescence, the light transmittance of leaf blades and the ratio of these indicators "Spectrolyuksk" was developed by a Russian company, specializing in the development of techniques, technologies and equipment based on spectrometry and fluorescence at the Scientific and Production Center for Medical and Industrial Biotechnology Spectrolyux [8].

The objective of research is to substantiate the effectiveness of the use of photometric devices of domestic production for the operational diagnosis of nitrogen nutrition of crops in the field crop rotation link in the conditions of the Moscow region.

The studies were carried out at the field experimental station of the FSBEI of Higher Education RGAU-Moscow Agricultural Academy named after K.A. Timiryazev in 2012-2015.

The results of the soil agrochemical analysis of the experimental site showed that it is well supplied with mobile forms of phosphorus - 361-483 mg/kg and potassium - 126-133 mg/kg (GOST 26207-91), increased content of easily hydrolysable nitrogen - 64-69 mg/kg (MU, 1985), the average humus content is 1.7-1.9% (GOST 26213-91). The link of the field crop rotation consisted of spring barley (variety Mikhailovsky), white mustard (variety Rapsodiya), spring triticale (variety Timiryazevskaya 42) and spring barley (variety TSKHA 4).

2. Materials and methods

The experiment scheme was specially developed to study the readings of photometric devices at different levels of fertilizing with nitrogen fertilizers and was as follows: for spring barley in 2012, four variants were used to introduce increasing doses of nitrogen fertilizers (ammonium nitrate) from $N_{30}$ to $N_{150}$ kg a.i./ha in the tillering phase, as well as two variants with fractional fertilizing: $N_{60}$ kg a.i./ha in the phase tillering plus $N_{60}$ kg a.i./ha in the stemming phase and $N_{90}$ kg a.i./ha in the tillering phase plus $N_{60}$ kg a.i./ha in the stemming phase. For white mustard (2013), spring triticale (2014) and spring barley (2015), increasing doses of fertilizers from $N_{30}$ to $N_{150}$ kg a.i./ha were also applied in the tillering phase, but the fractional application options were $N_{90}$ kg a.i./ha in the tillering phase, and in the phase of entering the tube $N_{30}$ in one version and $N_{60}$ kg a.i./ha in the other. Control were on all crops without fertilizing. Fertilizers were applied manually with an even distribution over the plot surface. The registered area of plots is 10 m$^2$, the repetition is fourfold, the placement of options in all years of research is randomized, agricultural technology is adopted for this zone. For diagnostics of nitrogen nutrition of plants, photometric devices of foreign "Yara" (Konica Minolta, Japan) and domestic production "Spectrolyux" (LLC "NPO Spectrolyux", Russia) were used. The records were carried out in different phases of plant development, but not earlier than 14 days after the last fertilization with nitrogen fertilizers. For taking readings with photometric devices, clean, undamaged, normally developed leaves of the upper tier were taken. Simultaneously with photometric diagnostics, plant (pedunculate, i.e. tissular) diagnostics were carried out according to the modified method of V.V. Zerling [10]. Statistical processing of the results of the field experiment was carried out by methods of variance and correlation analysis [5].

3. Results and Discussion

Adjustment of the doses of fertilizing with nitrogen fertilizers should be done in the early phases of plant development. So they will have a greater impact on the growth and development of crops. In our studies, measurements were carried out in the initial phases of development and to assess the effect of fertilizers in the middle of the growing season. However, the growth and development processes are also significantly influenced by weather conditions.

In 2012, the increased air temperature in combination with high precipitation rates exceeding the average annual values by two times in the first decades of May and June, in the second decade of July, in the second and third days of August, led to a significant lodging of barley crops in experimental plots using nitrogen fertilizers, which greatly complicated harvesting and affected the yield, which
ranged from 3.3 t/ha (control) to 4.41 t/ha (N60). The introduction of nitrogen fertilization in doses from 90 to 150 kg/ha of nitrogen did not have a statistically significant effect on the yield of barley due to significant lodging, reaching 90% in some plots, which began in the second half of the growing season.

The results of stem diagnostics obtained after applying top dressing with nitrogen fertilizers showed that plants in the phase of entering the tube on plots without top dressing or with small doses of nitrogen (N0, N30) needed additional top dressing in doses up to 60 kg/ha. When applying the main nitrogen fertilizers in doses from 60 to 90 kg/ha, it was necessary to apply another 30 kg/ha, and only in the variants with nitrogen doses of 120-150 kg/ha additional fertilizing was inappropriate (table 1).

The data of express diagnostics by the N-tester "Yara" in the same phase showed a rather strong correlation with the results of stem diagnostics (R = 0.70).

Table 1. Crop yield in the field crop rotation link t/ha.

| Option | Spring barley yield, t/ha | Option | White mustard yield, t/ha | Spring triticale yield, t/ha | Spring barley yield, t/ha |
|--------|--------------------------|--------|--------------------------|-----------------------------|--------------------------|
| Control | 3.31                     | Control | 0.36                     | 3.17                        | 5.23                     |
| N30    | 3.50                     | N30    | 0.38                     | 2.64                        | 6.91                     |
| N60    | 4.41                     | N60    | 0.57                     | 3.70                        | 7.60                     |
| N90    | 3.77                     | N90    | 0.61                     | 3.69                        | 7.27                     |
| N120   | 3.80                     | N120   | 0.54                     | 3.46                        | 7.43                     |
| N150   | 3.44                     | N150   | 0.49                     | 3.62                        | 6.32                     |
| N60+60 | 3.51                     | N90+30 | 0.50                     | 3.93                        | 6.56                     |
| N90+60 | 3.66                     | N90+60 | 0.58                     | 3.07                        | 7.39                     |
| HCP    | 0.54                     | HCP    | 0.13                     | 0.59                        | 0.92                     |

However, two further measurements, in the earing phase and in the milky ripeness phase, did not reveal close relationships with yield and with the indications of stem diagnostics. The readings of the Spectrolyux photometer in the phase of entering the tube and in the heading phase strongly correlated with the indications of stem diagnostics (R=0.82 and R=0.76, respectively) and with the readings of the Yara N-tester in the same phase (R=0.63 and R=0.70, respectively), but weakly with yield (R = 0.30 and R=0.33, respectively). The lowest indicators of measuring the ratio of the chlorophyll fluorescence intensity and the light transmittance of leaf blades were observed in the variants without nitrogen fertilization or with a low nitrogen dose of up to 60 kg/ha.

The winter of 2012-2013 was marked by heavy and prolonged snowfall, continuing into early spring. As a result, field work was started with a strong delay, and the sowing of white mustard was carried out on May 21 (the optimal time is the end of April – beginning of May), which greatly affected the further growth of mustard. It is quite sensitive to changes in the length of the day and blooms in the early stages, which prevents the use of pesticide treatments. In general, the temperature during the growing season slightly differed from the average annual data. Precipitation in some periods (third decade of May, second and third ones of July) exceeded the average long-term indicators twice.

According to the data for 2013, a statistically significant increase in yield was obtained for all variants, starting from the norm of 60 kg/ha, but a further increase in the rate of nitrogen fertilizers to 150 kg/ha did not bring significant success. Stem diagnostics carried out at the early stages of crop development showed that mustard, after fertilizing according to the experimental scheme, needed fertilizing in all variants, only in different doses. The correlation of the stem diagnostics readings with the yield was 0.71-0.77 in different phases. The data of photometric diagnostics using the Yara N-tester, obtained in the same phases of plant development, had a close correlation with productivity (R=0.62-0.87) and even closer with stem diagnostics. In the budding phase, the correlation coefficient was 0.88, in the phase of the end of flowering, 0.93, and in the phase of pod formation, 0.97. The
readings of the domestic photometric device "Spectrolyux" also had a fairly close correlation with the yield, stem diagnostics points and with the readings of the N-tester "Yara", however, they tended to decrease at the last measurement in the phase of pod formation. So, the correlation coefficients with the N-tester "Yara" in the budding phase was 0.83, in the phase of the end of flowering 0.90, in the phase of pod formation 0.71. The correlation coefficient with stem diagnostics was 0.92, 0.80 and 0.57, respectively, for the measurement phases.

The most extreme in terms of meteorological conditions for the entire period of research was 2014. In the first ten days of June and the first ten days of August, the temperature exceeded the average annual indicators by 6-7\(^\circ\) C, and in the second and third ten days of June, it was 3-4\(^\circ\) C lower than the average annual indicators. Such differences had a negative impact on the passage of almost all phases of the development of spring triticale and reduced the positive effect of fertilizing on yield. A statistically significant increase in yield was recorded only in one variant of the experiment (N90+30).

Because of the lack of moisture in mid-May, when triticale was in the tillering phase, the plants immediately moved into the tube exit phase, forming only one stem. Precipitation at the end of May and June, exceeding almost twice the annual average, affected the formation of an additional stem (afterspring), which made it difficult to choose the optimal harvesting time.

Nevertheless, the results of stem diagnostics showed the same tendency as in other crops of the field crop rotation link - the doses of top dressing of 30-60 kg / ha were too small to meet the plant's nitrogen needs on the sod-podzolic soils of the Central Black Earth Region. The coefficient of correlation between yield and stem diagnostics scores was 0.57 in the tube emergence phase, 0.67 in the earing phase, and 0.56 in the milky ripeness phase. The correlation between the readings of the N-testers "Yara" and "Spetrolyux" with the yield and stem diagnostics scores was the lowest over the entire observation period.

In 2015, the agrometeorological conditions of the growing season were most favorable for the growth and development of the next crop of the crop rotation link - barley.

The air temperature for decades was insignificantly (by 1-3 degrees) higher than the average annual indicators, and only in the second decade of July it was 2.6 degrees lower than the average annual indicators. A large amount of precipitation (up to 50 mm per decade) fell at the beginning and end of May, allowing plants without stress to transfer their almost complete absence (0.7 mm per decade) in early June. Due to the weather conditions that developed during the growing season, barley was able to realize its potential productivity and form a high yield, but due to heavy precipitation in June and July, lodging was observed (up to 70% of crops) in all variants, except for "Control", which made harvesting difficult. The results of stem diagnostics did not show a sufficiently close relationship with the yield. However, for the entire observation period, this was the only case when plants needed nitrogen fertilizers from 30 to 60 kg/ha on all variants of the experiment. When conducting further studies in the phase of grain formation, the need for top dressing only increased. The results of photometric diagnostics with the Yara N-tester, obtained in the phases of stemming and grain formation, showed an average correlation with yield – 0.59-0.66, but quite strong with stem diagnostics – 0.85-0.81, respectively. In general, the readings of the N-tester "Yara" were 10-15% higher than the readings taken in the same phases on barley in 2012, which may indicate more favorable conditions for growth and development that developed in 2015 [12-15].

The N-tester "Spetrolyux" showed approximately the same regularities in carrying out photometric diagnostics in the initial phases of development and the middle of the growing season as the N-tester "Yara". The correlation coefficient with the yield in the phase of entering the tube was 0.54, with stem diagnostics – 0.75, with a foreign photometer – 0.67.

4. Conclusion

Thus, field photometric experiments conducted in different meteorological conditions on crops of the field crop rotation link showed the prospects of using N-testers for rapid diagnostics of the state of crops. We consider it appropriate to conduct further research on the photometric diagnosis of nitrogen nutrition of plants and develop appropriate recommendations for specific soil and climatic conditions.
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References
[1] N-tester Retrieved from: https://n-tester.ru/
[2] Afanasiev R A 2007 Physical methods of plant diagnostics of nitrogen nutrition of agricultural crops (Reports of the Timiryazev agricultural academy Moscow) 353
[3] Afanasyev R A, Belousova K V, Litvinsky V A, Pugachev P M, Mochkova T V and Shchukina O A 2012 Photometric diagnostics of nitrogen nutrition of spring rapeseed and winter triticale in the conditions of the Central Non-Chernozem region. Fertility 32 51-52
[4] Belousova K A, Afanasyev R A and Berezovsky E V 2015 Photometric express diagnostics of nitrogen nutrition of plants. Agrochemistry 32 78-87
[5] Dospekhov B A 1976 Methods of field experience (Moscow: Ear) 416
[6] Yara Company Retrieved from: https://www.yara.ru/
[7] Sychev V G 2010 Method of photometric diagnostics of nitrogen nutrition of cereals and other crops (Moscow: IAP) 32
[8] LLC «SPC Spectrolux» Retrieved from: http://spectrolux.narod.ru/
[9] Pryanishnikov D N 1945 Nitrogen in plant life and agriculture of the USSR (Moscow AS USSR) 175
[10] Tserling V V 1990 Diagnostics of nutrition of agricultural crops (Moscow: Agropromizdat) 236
[11] Yagodin B A, Smirnov P M, Peterburgsky A V, Asarov Kh K, Demin V A and Reshetnikova N V 1989 Agrochemistry (Moscow: Agropromizdat ) 655
[12] Lakomiak A. and Zhichkin K A 2019 Photovoltaics in horticulture as an opportunity to reduce operating costs. A case study in Poland. Journal of Physics: Conference Series 1399 044088
[13] Zhichkin K, Nosov V, Zhichkina L, Grigoryeva O, Kondak V and Lysova T 2020 The impact of variety on the effectiveness of crop insurance with state support. IOP Conference Series: Earth and Environmental Science 433 012004
[14] Zhichkin K, Nosov V, Zhichkina L, Andreev V and Mahanova T 2020 Contracting repair young animals in personal subsidiary plots of the population. IOP Conference Series: Earth and Environmental Science 422 012054
[15] Nosov V V, Kozin M N, Andreev V I, Surzhanskaya I Y and Murzina E A 2016 Increasing The Efficiency of Land Resources Use for an Agricultural Enterprise Research. Journal of Pharmaceutical, Biological and Chemical Sciences 7(6) 382–385