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Differentiated application of nitrogen fertilizers based on optical sensor readings

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Abstract. The article considers the method of variable rate application of top dressing with nitrogen fertilizers in spring barley crops in the system of precise agriculture. The principle of is based on the in-process diagnosis of plants state in key phases of development and the introduction of necessary dose of top dressing in specific field areas. To assess the plants state, a GreenSeeker optical sensor, which measures the NDVI (Normalized Difference Vegetation Index). The tailored application of top dressing increases the yield of spring barley grain by 14.2% compared to the application of fertilizers with one calculated rate for the entire plot or field (Skudra, 2017, Hamann, 2020).

Key words: fertilizers, agriculture, nitrogen, top dressing, precision agriculture, ammonium nitrate, spring barley.

INTRODUCTION

Modern technologies in agriculture are aimed at obtaining high and stable yields with the rational use of energy and other resources. In agricultural production, attempts are being made to reduce the consumption of fuels and lubricants, heat energy, gas and electricity. Nevertheless, fertilizers, pesticides, and seeds are also a type of consumables. Rational approaches to their consumption can significantly reduce the cost of product unit manufacturing (Conway, 2019; Demestichas, 2020). The most successful experience was the use of fertilizers, pesticides and seeds in precision farming system, in which agricultural machinery manufacturers offer solutions for their differentiated application (Brisco, 1998; Afanacyev, 2012; Belousova, 2015; Monastyrskiy, 2019; Hernández-Clemente, 2019; Jelínek, 2020; Sychev, 2020). These include: Application of the main comples fertilizer with a rate differentiated by area. This method is used based on the results of pre-defined task maps based on the data of the agrochemical survey, taking into account the content of phosphorus (P_2O_5), kalium (K_2O), and nitrogen

(NO_3, NH_4) in the soil. Application of liquid and dry fertilizing with nitrogen fertilizers with a rate differentiated by area. Nitrogen fertilizers are one of the most expensive items of expenditure. But at the same time, top dressing of vegetative plants is a necessary stage for obtaining high yields and high-quality products. Therefore, their rational use is most relevant in agricultural production. Differentiated application of fertilizers can be carried out both in the off-line mode, which is most acceptable for the main application, according to pre-built maps, and in the on-line mode according to data obtained using sensor photo detectors installed on the sprayer or fertilizer spreader. In this case, the data is read and processed at the time of top-dressing.

The purpose of the research: to study the effectiveness of the method for obtaining data on the state of crops using the GreenSeeker optical sensor. Hypothesis: the possibility to use the data of the GreenSeeker optical sensor for the differentiated application of nitrogen fertilizers.

MATERIALS AND METHODS

Studies on various crops were carried out at the Field Experimental Station of the Russian State Agrarian University-Moscow Agricultural Academy named after K.A. Timiryazev (city of Moscow) and in the Department of remote hybridization of the Tsitsin Main Botanical Garden RAS (Moscow region) in 2009–2016. The soil of the experimental site is sod-podzolic medium loamy. To monitor the dynamics of fertilizer elements, an annual agrochemical survey of the soil was conducted, the results of which indicate that it is well provided with mobile forms of phosphorus (P_2O_5) - 183–304 mL kg of soil^{-1}; and exchangeable potassium (K_2O) - 102–148 mL kg of soil^{-1}; average humus content - 1.9–2.0%; and pH_{KCl} - 4.8’ The microrelief of the field is present. This field terrain makes it possible to differentiate the application of nitrogen fertilizers by experimental plots every year. The variability in the main elements of nutrition among plots was the following: for potassium - 13%, for phosphorus - 26.8%, for nitrogen - 46.7%.

The scheme of the experiment each year consisted of three treatments: without top-dressing with nitrogen fertilizers (Control); top-dressing with the recommended fixed dose; differentiated application of nitrogen fertilizers. The differentiated dose was calculated on the basis of data previously obtained from the Trimble GreenSeeker (Trimble; Sunnyvale; CA; USA) optical sensor (Shshuklina, 2017), with a dose varying from the average recommended dose. Top-dressing was carried out manually with ammonium nitrate (NH_4NO_3). The area of the accounting plot is 10 m^2. The repetition in the experiment is 4-fold with 8 repetitions in each variant, which was 32 plots for each of the three variants. A large number of repetitions was necessary to calculate the correlation dependencies of the experiment indicators.

The principle of the GreenSeeker system operation is based on the readings read by optical sensors that have independent light sources. This allows to read information at any time of the day, and regardless of weather conditions (fog, cloudy weather). GreenSeeker emits rays in the red and near-infrared (IR) spectrum, which are reflected from the surface of plants and fall on the photodiode located in the head of the sensor. The data obtained characterize the so-called vegetative index of biomass NDVI (Normalized Difference Vegetative Index). This indicator allows to effectively assess the condition of plants and their potential yield level (Barbosa, 2019). This is achieved by initializing the reflection in the red and infrared spectra. Simultaneously with taking

readings by GreenSeeker optical sensor, photometric diagnostics were performed with the portable N-tester 'Yara' (Konica Minolta, Japan), as well as plant (stem, tissue) diagnostics using the modified method of V.V. Tserling (Tserling, 1990) using 0.5 g of diphenylamine in 100 mL of concentrated H_2SO_4 on a 3-point scale. This method is used to detect the amount of NO_2, NO_3 ions in the juice of living plants directly in the field. All measurements were carried out in three phases of spring barley plant development: BBCH 32, BBCH 55, and BBCH 77. The application of fertilizers according to the results of the GreenSeeker measurement was carried out after the studies in the BBCH 32 phase. The differentiation consisted in the fluctuation of the dose of nitrogen fertilizers calculated by the coefficient of deviation from the average NDVI reading for the entire experimental site (Afanasyev, 2006). The fixed top-dressing was applied at a dose of 90 kg ha of nitrogen.The object of the study is spring barley variety TSHA4. The seeds were sown with an Amazon seeder within the time limits accepted for this zone. The seeding rate of spring barley is 5.0 million germinating seeds per 1 ha. Harvesting was carried out by the continuous method of the Sampo Rostov 2000 combine harvester with a working width of 1 m. Statistical processing was carried out according to the method of variance analysis, adopted in Russia when calculating the data of exploratory agricultural work. (Dospekhov, 1976). It is similar to the statistical methods developed by R.A. Fisher (1954). and statistical methods ANOVA.

RESULTS AND DISCUSSION

The indications for applying top-dressing were taken in the phase of stem elongation (BBCH 32) on all experimental plots Greenseeker optical system' In different parts of the field, the NDVI index was low (0.25–0.31) or high (0.68–0.71). It was noted that a low NDVI index was observed in erosion-hazardous areas of the field with a low content of nitrogen and phosphorus. On average, the NDVI index of spring barley crops was 0.49, which is a fairly low value, during the release phase. In most of the plots, the spring barley plants needed to be fed with nitrogen fertilizers. The differentiated dose of nitrogen fertilizers was calculated by deviation coefficient of the NDVI index from the average for all areas of the field wihh differentiated application . At the same time, the nitrogen dose ranged from 64 to 117 kg ha.

During the growth stage Inflorescence emergence (BBCH 55) of spring barley, readings were again taken from the entire experimental area with the GreenSeeker optical sensor. After top-dressing, the average field vegetation index of spring barley biomass was 0.62, which is 0.13 conventional units higher than before the introduction of nitrogen fertilizers. At the same time, it continued to vary widely from 0.27 to 0.68 on plots without top-dressing. Higher rates were recorded in terrain depressions with good water availability. In the variant with a fixed dose of top-dressing, the values ranged between 0.52 and 0' On plots with a fixed dose of nitrogen fertilizers, the biomass index was even higher and ranged from 0.55 to a maximum value of 0.79. This suggests that the application of fertilizers with rate differentiated by area favorably affected the general condition of spring barley plants.

Why no time-series data of GreenSeeker measurements is presented? It would be interesting to see how the NDVI values evolved during the duration of the experiment, and especially before and after fertilization. I suggest including such figure. It is very important that the figure will present standard error (or standard deviation) in order to

see the variability within replicates). Values of Yara measurements could also be presented in a time series plot.

Accounting for the yield in the experiment was carried out on a plot basis. At the same time, the average yield in the experiment was the following: on plots without top-dressing - 4.01 kg ha^{-1}, on plots with a fixed dose of top-dressing - 4.58 kg ha^{-1}, on plots with a differentiated dose of fertilizers - 5.21 kg ha^{-1} (Fig. 1). The increase in relation to the control for all variants, as well as between two variants with a different method of application, was statistically significant ($HSD_{.05}$ = 0.17).

The results of the correlation analysis between the yield and various indicators before and after fertilization are presented in Table 1. For this purpose, simultaneously with taking readings with the GreenSeeker optical sensor, stem (tissue) diagnostics according to Tserling (Tserling, 1990), measuring of plant height in the plot, and photometric diagnostics with the Yara N-tester were carried out. The scores of stem (tissue) diagnostics carried out in the phase of leaf-tube formation were most strongly correlated with the yield on plots without fertilization and with the application of their fixed dose.

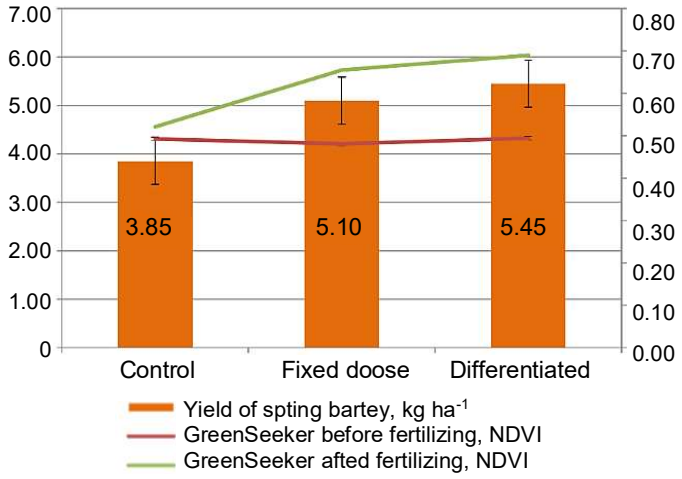

Figure 1. Barley yield for the different treatments, kg ha^{-1}.

The NDVI index recorded by the GreenSeeker optical sensor correlated most strongly with the grain yield of spring barley during filling phase on plots without fertilization (r = 0.70). This confirms the fact that the higher grain yield in this variant depended on the agrochemical composition of the soil of the site. The obtained readings in this phase reflect plant state and with a high degree of probability predict the value of the future yield on a particular plot.

Table 1. Correlation of photometric and stem (tissue) diagnostics data with spring barley grain yield (*: $p < 0.05$)

Indicator	Control (without top-dressing)	Fixed dose	Differentiated dose
Measurement of readings, before fertilization (BBCH 32)			
GreenSeeker, NDVI	-0.05	0.16	-0.15
Yara, c.u.	-0.09	0.06	-0.39
Tissue diagnostics, score	0.30	0.24	0.02
Plant height, cm	0.06	0.25	0.67
Measurement of readings, after fertilization (BBCH 53, 77)			
GreenSeeker, NDVI (BBCH 53)	0.70	0.12	0.37
GreenSeeker, NDVI (BBCH 77)	-0.14	-0.24	0.04
Yara, c.u. (BBCH 77)	0.70	0.51	0.36
Tissue diagnostics, score(BBCH77)	-0.01	0.01	-0.17
Plant height, cm (BBCH 77)	0.52	0.33	0.56

The scores of stem (tissue) diagnostics, as well as the readings of the GreenSeeker optical sensor recorded during milk-ripe phase, do not correlate with the grain yield of spring barley, since in this phase most plants have a high content of dry matter and a low content of chlorophyll, which complicates the romoval of measurement data. At the same time, the correlation coefficient between plant height in milk-ripe phase and yield had a weak bond ($r = 0.33$) in the variant with a fixed dose of fertilizer, and an average ($r = 0.56$) in the variant with a differentiated application of top-dressing. This suggests that taller plants in leveled crops, including in control crops, form a higher grain yield and vice versa.

Since with the help of the Yara N-tester, it is possible to approach the readings in different phases in more detail and find green leaves for manual measurements in the late vegetative phase, its data had the strongest correlation with the yield during the milk-ripe phase. This suggests that plants with a longer growing season, and therefore provided with nitrogen and moisture, gave a higher grain yield.

As I understand, some of the measurements were carried out before fertilization, and that fertilization was carried out for 'differenciated' treatments according to the values of the Greenseker measurements. In this case, the negative correlation between GreenSeeker NDVI and yield at early stages is logical. But it is important to clarify what measurements were carried out before fertilization (only leaf-tube formation phase?). This should be made clear in Table 1 too, maybe by adding an '*' to the measurements carried out before fertilization or a similar way.

CONCLUSIONS

It was found that the yield of spring barley obtained by applying differentiated top-dressing with nitrogen fertilizers was higher than on plots without fertilizers by 29.9%. And higher than the average yield on plots with a fixed dose of nitrogen fertilizers by 14.2%. It should be noted that the total amount of fertilizers applied with this method of calculation does not differ from the continuous application of the calculated dose, but allows to more efficiently apply top-dressing with nitrogen fertilizers, distributing it according to the plant needs, which has a favorable effect on grain yield. When calculating the physical mass of fertilizers used in the experiment, 9.2 kg of ammonium nitrate was used on plots with a fixed dose, and 9.7 kg of ammonium nitrate was used on plots with a differentiated dose.

The results of the readings of the GreenSeeker optical sensor and the Yara N-tester do not correlate with each other, both before and after fertilization. The GreenSeeker is a more user-friendly device. Since the results of its readings do not depend on the weather (cloudy or clear), and the device itself can be attached to the tractor. Readings are taken instantly. The N-tester Yara is a hand-held device that is used when you need to check the condition of plants at a certain point in the field. In order to get the result, it is necessary to take readings from 30 leaves of plants located nearby. This takes about 10–15 minutes

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