TECHNOLOGICAL AND TECHNICAL SOLUTIONS OF THE PROBLEM OF VARIABLE RATE APPLICATION OF MINERAL FERTILIZERS IN CONDITIONS OF NORTHERN KAZAKHSTAN

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Abstract: Article presents theoretical and practical grounds of technological and technical solutions of a problem of variable rate subsurface application of mineral fertilizers in the conditions of Northern Kazakhstan. Research results are implemented in pre-production models, validated in laboratory and field conditions. Variable rate application of mineral fertilizers, taking into account key parameters of soil fertility will allow raising of recoupment of phosphoric fertilizers to 18,5 kg of grain for 1 kg of active substance of fertilizers, with a standard recoupment being 8-10 kg, saving 25-30% of mineral fertilizers. Annual economic benefit of implementation of the developed machines system makes more than 25 thousand USD.

Keywords: FERTILIZER, SUBSURFACE APPLICATION, VARIABLE RATE

1. Introduction

Efficiency of mineral fertilizers application substantially decreases due to insufficient uniformity of their distribution on the area, caused not only by constructive and technological imperfections of fertilizer machines, but also by the method of application of an average dose of fertilizers through the field disregarding variability of parameters of their initial distribution in different field sites. Solution of this problem requires development of a new technology and creation of automated means for variable rate application of mineral fertilizers within the system of precision agriculture, ensuring preservation of soil fertility and productivity increase at high efficiency and recoupment of fertilizers, which is the major scientific and technical problem demanding solution in the shortest terms [1].

2. Theoretical grounds

Considering average productivity $Y$ as function of random argument, irrespective of the distribution pattern of fertilizers across the field, and taking into account that responsiveness function of the given agricultural crop to fertilizers and density of their distribution across the field are known, we receive [2]:

$$Y = M \left[ Y(D) \right] = a_0 + a_1 D + a_2 \left( \sigma_2^2 + D^2 \right) = a_0 + a_1 D + a_2 D^3 \left[ 1 + 1/104V^2 \right]$$

Where $\sigma_2$ - standard deviation of random variable $D$, $D$ - expected value of random variable $D$, $a_0$, $a_1$, $a_2$ - empirical factors characterizing function of responsiveness of the given culture to fertilizers; $V_{ap}$ - variation factor of a dose of fertilizer application.

Analysis of (1) shows that for finding average productivity at square-law dependence of productivity on a dose of fertilizers there is no necessity to establish the pattern of distribution of fertilizers across the field, it is enough to know application dose $D$ and it standard deviation $\sigma_2$. Values $D$ and $\sigma_2$ can be defined through mathematical treatment of agro technical estimation of machines data.

From (1) it also follows that increasing non-uniformity of fertilizers application in soil leads to considerable decrease in responsiveness of plants to fertilizers. Existing technologies and machines for subsurface application of mineral fertilizers cannot provide quality performance of technological process. One of the reasons for this is an insufficient level of scrutiny of interaction process of mineral fertilizers with working parts of machines.

Quality of performance of technological process of mineral fertilizers application ($V_{ap}$) can be estimated using efficiency indicators. Quality of fertilizers application can be used as an efficiency indicator for the considered process provided that expenses do not exceed the set limit. Assuming that responsiveness function of a particular agricultural crop to mineral fertilizer is known, the effect (KZT /hectare) of fertilizer application, taking into account expenses for application, costs of an productivity increase and expenses for its transportation, is represented as:

$$E = \left( A - \lambda \right) \left[ a_0 + a_1 D + a_2 D^3 \left( 1 + 1/104V^2 \right) \right] - C_{ap} - C_{p},$$

where $\lambda$ is the price of a unit of product, KZT/t; $T$ - expenses for transportation of a unit of product, KZT/t; $C_{ap}$ - expenses for application of physical mass of fertilizers, KZT/hectare; $C_{f}$ - cost of mineral fertilizers, KZT/hectare.

Assume in (2) condition of minimal non-uniformity of fertilizer application

$$\phi(V_{ap}) = 0.$$  (3)

Then optimum indicators of quality of fertilizer application across the field can be found as a result of maximization of effect, for that the conditional maximum of function (2) is defined, i.e.

$$\max E \text{ at } \phi(V_{ap}) = 0.$$  (4)

3. Algorithm of optimization of quality indicators

Search for a conditional maximum can be reduced to finding usual maxima of Lagrangian function $L = E + \lambda \cdot \phi$. Necessary conditions of an extremum:

$$\phi(V_{ap}) = 0; \quad \frac{\partial E}{\partial V_{ap}} + \lambda \cdot \frac{\partial \phi}{\partial V_{ap}} = 0$$

Found as a result of solution of this problem value of variation factor of fertilizers application $V^*_{ap}$ will be optimum for the given technology of mineral fertilizers application.

Knowing $V^*_{ap}$ enables new approaches to the problem of control and quality management of fertilizers application technological process and formulation of requirements to perspective technical means for mineral fertilizers application.

For the synthesis of mineral fertilizer application control system, technological process of subsurface application by cultivators with fertilizers, according to Fig. 1 is presented as a number of consistently proceeding operations: movement of the machine across the field ($D_m$), supply of fertilizer devices ($P$), dispensing of fertilizers ($D$), transportation of fertilizers through fertilizer hoses to working parts (T), subsurface distribution of fertilizers (R).
Determining actions in the process of subsurface application of mineral fertilizers are: supply of fertilizers to fertilizer device $U_Q(t)$, required dose of fertilizers $q_i(t)$ and width of application line $L_i$.

Output streams $Q_i(t)$ are influenced by disturbing actions $Z_Q(t)$, $Z_H(t)$ and $Z_L(t)$, including physical and mechanical properties of fertilizers, unevenness of a surface of a field, technical and technological characteristics of fertilizer machines.

Target parameters are the following functions: $q(t)$ - dose of fertilizers applied, $V_i(t)$ - non-uniformity of seeding between devices and instability of seeding, $L_i(t)$ - working width application line, $V_i(t)$ - non-uniformity of fertilizer distribution within the width of application line.

The task of management of subsurface application of mineral fertilizers process lies in changing the dose of fertilizer application $q(t)$ with regard to demand of the given elementary field site for a kind and dose of fertilizer. Proceeding from it, the function chart of technological process automatic control is presented as a control system over executive mechanisms of application dose changing.

Cultivators with fertilizers have been developed for field testing of variable rate subsurface application of mineral fertilizers and technical solutions for its realisation [3, 4]. Fig. 2.

To obtain information on spatial variability of fertility parameters of an experimental field soil samples were taken and analyzed. Results of agrochemical analysis testify to presence of considerable non-uniformity of nutrients distribution in soil.

Subsurface variable rate application of starting and major doses of fertilizers is carried out with regard to nutritive elements content; transitive characteristics and quality of technological process performance are defined.

4. Conclusions

Laboratory and field tests have shown that:
- Cultivator with fertilizer based on SZS-2.0 seeder allows differentiation of application dose from 12 to 408 kg/ha and increase of application width of mineral fertilizers by more than 3 times, and depth up to 8 cm in comparison with base machine;
- Cultivator with fertilizer with CSS allows differentiation of application dose from 50 to 450 kg/ha with a transition period 3-3.5 seconds, reduce of non-uniformity of application within application width by 20-22 % in comparison with feed and fertilizer seeder with centralized seeding «BARS-1000», raising width of application line by 30-35 %;
- Chisel fertilizer provides soil processing on depth 32...35 cm and application of fertilizers with width of an inclined tape 25...29 cm, with non-uniformity of fertilizer distribution within its width of 7,8-22,7 %.

Results of the technical and economic analysis have shown that variable rate application of mineral fertilizers with regard to initial non-uniformity of nutrients distribution in soil will allow raising recoupment of phosphoric fertilizers to 18,5 kg of grain on 1 kg of active substance of fertilizer, with standard recoupment being 8-10 kg, and save up to 25-30 % of mineral fertilizers, and consequently decrease agrochemical pressure on environment. Annual economic benefit of implementation of the developed means for variable rate subsurface application of mineral fertilizers makes more than 25000 USD.

5. References