Development of mineral fertilization complex mechanization

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Abstract. The intensification of agriculture, its saturation with heavy machines, and the growth in the energy saturation of tractors put forward new tasks that cannot be solved without the development of theoretical and applied research in the field of soil mechanics. It became necessary to study the mechanical processes occurring in the soil when it interacts with the working bodies of tillage machines and the running systems of mobile agricultural machinery. Industrial technologies are based on the effective use of chemicals. The effectiveness of fertilization depends on the quality of their application (uniformity and place of delivery to the plant roots). In recent years, the annual volume of mechanized work per hectare has increased several times. Intensive industrial technologies are based on the effective use of chemicals. A successful increase in the efficiency of the use of all types of fertilizers and chemical plant protection products is possible only on the basis of an integrated quality management system for performing technological processes, including interrelated organizational and social measures. The article describes intensive and industrial technologies that are based on the effective use of chemical agents. A successful increase in efficiency, the use of all types of fertilizers and chemical plant protection products is possible only on the basis of an integrated quality management system for performing technological processes, including interrelated organizational, technological and social measures.

1. Introduction

One of the main directions in the development of agriculture is the widespread chemicalization of agriculture and animal husbandry. With the projected growth in the production of mineral fertilizers, the rates of their application will also increase. The existing system of machines does not correspond to such a scale of use of fertilizers and does not provide a comprehensive mechanization of all processes of their application. Development of a rational technology and a promising system of machines for applying fertilizers is one of the most important tasks of research and development organizations. At the same time, the main attention, as in solving the problems of mechanization of other agricultural processes, should be paid to the introduction of wide-cut and multi-row machines, increasing the working speeds of machine and tractor units, and creating universal machines.

The successful operation of the machine-tractor units for fertilizing during sowing and inter-row cultivation at high speeds depends to a large extent on the accuracy of the transport and handling operations. Technical means for their implementation should be created in parallel with the
introduction of high-speed and wide-cutting units. Further improvement of the system of fertilizing machines must follow the path of their all-round universalization.

2. Research methodology
The use of highly concentrated simple and complex fertilizers will reduce the volume of loading and unloading operations, which is especially important in connection with the planned expansion of the use of aviation for spreading fertilizers. Particular attention is paid to the production of non-washable forms of nitrogen fertilizers for their use in humid and irrigated areas [1,8,12]. The versatile and complex technical problems arising in solving the problems of the mechanization of mineral fertilizers urgently require the expansion and intensification of research work in this direction. In the long term, quality indicators such as uneven distribution of nutrients \( Q_{un} \), dose D and tolerances for them, in each case, should be determined as a result of maximizing net income from fertilization:

\[
P = MY(D, Q_{un}) - P_{re}(D, Q_{un}) - aD - U - F(D, Q_{un}),
\]

where \( M \) – unit price; \( Y(D, Q_{un}) \) – crop yield value; \( P_{re}(D, Q_{un}) \) – specific reduced costs for the preparation and application of fertilizers with a dose of D and distribution quality \( Q_{un} \); \( a \) – the cost of using fertilizers that do not depend on quality and methods of their application; \( I \) – expenses independent of indicators D and \( Q_{un} \); \( F(D, Q_{un}) \) – costs of low quality fertilization with a dose of D and unevenness \( Q_{un} \).

It is possible to optimize the entire technological process only after establishing the entire range of quality indicators that affect the formation of indicators \( Q_{un} \) and \( D \). It is possible to determine the indicators that affect their values only after drawing up a technological map of the process, in detail, describing its course in stages.

3. Main part
As a result of the analysis of technological maps developed in relation to specific conditions, a nomenclature of quality indicators for performing individual operations and the entire technological process is established [5-7].

Considering that the complete identification of the technological process is a complex task, in this work we will restrict ourselves to establishing functional links between the indicators of the second, third and fourth levels. The need to establish a connection between these levels is due, first of all, to the fact that the quality of the technological process of using fertilizers in production conditions is determined mainly by the operations of their preparation and application, which are amenable to control and management [2,13,15,16].

Let us denote a complex indicator of the quality of the distribution of nutrients over the field through \( Q_{nNPK} \), physical mass – \( Q_{nM} \) and nutrients in the mass of fertilizers – \( Q_{NPK} \). In accordance with the structure of quality indicators shown in the figure, the indicator \( Q_{nNPK} \) зависит от значений \( Q_{nM} \) and \( Q_{NPK} \), and those, in turn, - from parameters and indicators located at the fourth and fifth levels.

The need to establish such a relationship is also dictated by the fact that at present, as a rule, the coefficient of variation of the distribution of nutrients over the field is assumed to be identical to the coefficient of variation characterizing the distribution of the physical mass of fertilizers, i.e. \( Q_{nM} = Q_{nNPK} \).

This assumption is valid, for example, for single mineral fertilizers, but when using fertilizer mixtures, composts, working solutions, suspensions, it is invalid. So, when making composts, especially organic-mineral ones, in which there is a certain unevenness of nutrients, the quality of distribution of the latter over the surface of the field depends on their distribution in the fertilizers themselves, as well as on the uniformity of spreading over the field. [3,10,14].

As an example, consider the technological process of using peat mineral fertilizers. Let, after mixing the components, N nutrients (nitrogen) are contained in a fertilizer mass unit. Due to the poor
mixing quality, the value of $N$ will not be the same in different samples, i.e. is a random variable. If we assume that when fertilizing, a mass $m_{ij}$ falls on the site (baking sheet), then the amount of nutrients in it is

$$N_{ij} = Nm_{ij}.$$  \hspace{1cm} (2)

Hitch $m_{ij}$ also varies by site and is a random value. Therefore, the number $N_{ij}$ – is of random values. It is obvious that the nature of the distribution of the fertilizer mass over the field does not depend on the quality of the distribution of nutrients in this mass, i.e. random variables $N$ and $m_{ij}$ will be independent.

Taking into account formula (1), the indicator of the quality of the distribution of nutrients over the entire cultivated field can be found as follows:

$$Q_{nN} = 100D[Nm_{ij}]/M[Nm_{ij}].$$  \hspace{1cm} (3)

Considering that the mathematical expectation of the product of two independent random variables is equal to the product of their mathematical expectations, and the variance $D[x,y] = D[x]D[y] + M^2[x]D[y] + M^2[y]D[x]$, after simple transformations we get:

$$Q_{nN} = Q_NQ_{un} + Q_N^2 + Q_{un}^2,$$  \hspace{1cm} (4)

where $Q_N, Q_{un}$ – coefficients of variation of nutrients in the mass of fertilizers and the mass of the fertilizers themselves over the field.

By setting restrictions on $Q_{nN}$, you can set tolerances to $Q_N$ and $Q_{un}$.

Let’s establish the nomenclature of indicators related to the fourth and fifth levels. Analysis of technological schemes (the mechanism of quality formation) showed that all parameters, including quality indicators, on which complex indicators of the technological process depend ($Q_{nN}, Q_{un}$ and $Q_N$), can be subdivided into random, technological and managed.

As a result of studying the mechanism of the formation of the quality of the distribution of fertilizers throughout the cultivated field, it was found that the main reasons affecting the quality include:

- uneven distribution of fertilizers along the width of the aisle of the unit and along the length;
- dose instability along the length of the unit passage;
- instability of the overall working width.

The uneven distribution of fertilizers over the total and working widths of capture and along the length of the passage is due to the shape of the distribution density diagram of fertilizers during a single pass of the unit, which, in turn, depends on both design, technological parameters and random ones and, as a rule, is determined experimentally. Depending on the type of the distributing implement, the diagram can take the form of a two-peak curve with a depression in the middle (for machines for applying organic fertilizers), the shape of a parabola (for machines for applying solid mineral fertilizers). In most cases, fertilizer distribution plots are symmetrical about the longitudinal axis of the implement. Dose stability along the length of the unit passage depends on the type of the dosing working body and the constancy of the unit speed.

The main characteristics of the distribution of fertilizers with a single pass of the unit (intermediate quality indicators): average dose $q_{av}$, dose instability $\lambda_i$, $\lambda$, uneven distribution over the field $Q_{un}$, are found by the formulas

$$q_{av} = \frac{1}{B_0l} \int_{y_0}^{l} \int_{0}^{B_0} q(x,y) \, dx \, dy;$$  \hspace{1cm} (5)

$$\lambda_i = \frac{\|q(x,y)|_{y=y_0} - q(x,y)\|}{q(x,y)|_{y=y_0}} \times 100.$$  \hspace{1cm} (6)
where \( B_0 \) – the total working width after the machine has passed 10 m, i.e. at \( y_0 = 10 \) m; \( L \) – working stroke length, m.

Expressing in the formula (5) \( q(x, y) \) through \( \lambda_i \), we get

\[
q(x, y) = q_0(x, y)[1 - 0.01\lambda_i(y)],
\]

where \( q_0(x) = q(x, y)|_{y=y_0} = q(x, y_0) \).

Substituting expression (8) into formula (7), we obtain the dependence of the uneven distribution of fertilizers with a single passage of the unit:

\[
Q_{unm} = 100 \times \frac{1}{\sqrt{B_0}} \int_0^{B_0} \{ q_{av} - q_0(x)[1 - 0.01\lambda_i(y)] \} / q_{av}.
\]

4. Results and discussion

It is possible to reduce the uneven distribution of fertilizers along the working width and the length of the unit’s passage, and, accordingly, throughout the cultivated field to the level allowed by agricultural requirements, by overlapping the adjacent and longitudinal aisles of the unit. Therefore, the constancy of the working width, the way the machine moves across the field are important factors affecting the quality of fertilizer distribution.

In general, the functional dependence of the quality indicator of fertilizer distribution in a field area with a width \( B_0 \), processed by one unit, with two adjacent passes can be represented as follows:

\[
Q_{un} = 100 \sqrt{D[q(x, y), P(y), l/q_{av}[q(x, y), P(y)]]};
\]

\[
q_{av} = \frac{1}{(B_0-\rho)} \int_0^{B_0} q(x, y)dx + \int_{B_0-\rho}^{B_0} [q(x, y) + q(x - B_0 + P, 2l - y)]dx + \int_0^{l/2} q(x - B_0 + P, 2l - y)dy;
\]

\[
D[q(x, y)] = \frac{1}{(B_0-\rho)} \int_0^{B_0} [q_{av} - q(x, y)]^2 dx + \int_{B_0-\rho}^{B_0} [q_{av} - q(x, y) - q(x - B_0 + P, 2l - y)]^2 dx; \quad \text{(12)}
\]

where \( P(y) \) – overlapping adjacent aisles of the unit; \( B_0 = 2|x_1|, x_1 \) – equation solution \( q(x, y)|_{y=0} = 0 \).

Substituting into formula (11) instead of \( q(x, y) \) expression (6), we obtain the dependence \( Q_{un}(\lambda) \).

Analysis of expressions (4) – (13) shows that for calculating the generalized quality indicator \( Q_{un} \) it is needed to know the plot of fertilizer distribution \( q = q(x, y) \), total working width \( B_0 \), overlapping adjacent aisles \( P(y) \) or \( B_0(y) \), rutting length \( l \) (if \( l < L \)) and working stroke \( L \).

Knowing for each specific case the values \( Q_{unm}, \lambda, B_w, l, L \), you can define dependencies:

\[
Q_{un} = F(Q_{unm}, \lambda, B_w, l, L);
\]

\[
D = D(Q_{unm}, \lambda, B_w, l, L).
\]

From the analysis of formula (13) it follows that the uneven distribution of fertilizers over the field depends on a set of factors that are associated with a certain functional dependence. So, for the given values \( Q_{unm}, \lambda, L \) and limiting the value \( Q_{un add} \) working width of capture \( B_w \) depends on the length of the head \( l \), i.e. there must be a different working width for each headland. It may happen that starting from a certain length of the rut \( l_{add} \), it is impossible to find such an overlap in which the unevenness index would conditionally satisfy \( Q_{un} \leq Q_{un add} \). In order to ensure the required quality
of fertilization in this case, the machine must operate on races with a length that satisfies the condition \( l \leq l_{add} \) or it is necessary to set a limit on dose instability or \( Q_{unm} \), and, accordingly, on the design parameters of the working bodies of machines for fertilizing. This data is necessary to optimize the cooking operation and the entire technological process.

Having dependencies (14), (15) and knowing the reduced costs for the preparation of composts with the quality of distribution of nutrients \( Q_N \), it is possible to approach in a new way to optimizing the quality indicators of the distribution of nutrients in the mass of fertilizers and the mass itself over the field, and, accordingly, intermediate quality indicators \([4,9,11]\).

To simplify the task, let’s make some assumptions:

- second supply of compostable filler material and mineral fertilizers are constant \( q_{cm} = const, q_n = const, q_{mf} = const \);
- uneven distribution of nitrogen in the mixture \( Q_N \);
- unit reduced costs \( P_{re \, u}(Q_N) \) to obtain a unit mass of a mixture (compost) with unevenness \( Q_N \) are known;
- known unit reduced costs \( P_{re \, in}(Q_{un}) \) for the introduction of a unit mass of fertilizers with uneven distribution of physical mass \( Q_{un} \);

For these specific conditions, we found dependence (13) and substituted into it \( Q_{un}^*,we get:

\[
Q_{un}^* = F(Q_{unm}, \lambda, B_w, l, L). \tag{15}
\]

Considering that for specific conditions \( Q_{unm} = const, \lambda = const, l = const, h = const \), optimal working width \( B_w \) we find from the equation:

\[
Q_{un}^* = F(B_w). \tag{16}
\]

The optimal operating modes of the mixing plant are determined similarly if the dependence is known \( Q_N^* \), for example, on the speed of its rotor or the duration of mixing. Maintaining the working width of the spreader, the optimal operating mode of the mixer and the mixing time, provided that the remaining parameters and parameters are constant, ensure the required quality of fertilization.

5. Conclusion

For each crop and specific natural and climatic conditions, there is an optimal dose and quality of fertilizer distribution over the field, which maximizes their return on investment. The considered approach to the selection of quality criteria for the distribution of fertilizer allows a new approach to the substantiation of the parameters of the dosing and distributing working bodies of machines for local application. An important indicator of the quality of dry mineral fertilizers is the degree of flowability, which determines the uniformity of their supply to the scattering devices, and, consequently, their distribution in the soil. Data on optimal quality indicators and their tolerances is a necessary, but not sufficient condition for high-quality performance of the technological fertilization process. To achieve the required level of quality, it is necessary to develop standard technological processes for mechanized work, and practical guidelines for machine operators for their implementation. In addition, industry standards are required that regulate the quality of the main technological operations and the entire technological process as a whole. The standards should include requirements for technological operations and the quality of their performance, a nomenclature of quality indicators, methods for their assessment, a list of metrological equipment, control solutions, as well as instructions for their implementation.

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