https://doi.org/10.26898/0370-8799-2024-11-14
УДК: 631.816.352
Тип статьи: оригинальная
Type of article: original

Обоснование технологической схемы технического средства для внесения в почву жидких минеральных удобрений

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В статье представлены результаты обоснования технологической схемы технического средства для внесения в почву жидких минеральных удобрений (ЖМУ) при возделывании сельскохозяйственных культур. Установлено, что формирование структуры данного технического средства основано на построении его функционально-структурной модели, базирующейся на определении состава функций и функциональной модели будущего изделия, поиске вариантов технических решений по функциям, построении структурной модели разрабатываемого технического средства, а на завершающем этапе – на оценке и выборе вариантов рабочих органов (технических решений) и перспективных технологических схем будущего технического средства. Благодаря выявлению причинно-следственных связей между конкретными технологическими операциями, которые должны выполняться техническим средством, а также технологическими и техническими решениями, определен состав его функций, включающий транспортирование запаса ЖМУ, обеспечение заданной нормы внесения, распределение ЖМУ по рабочим органам и в полосе внесения. Обоснована структурная схема технического средства для внутрипочвенного внесения ЖМУ на уровне моделей графов типа «дерево» с отображением контуров и конкретных взаимосвязей между элементами структуры. Перспективный вариант технологической схемы воспроизводится по комплексным показателям с использованием численных значений коэффициентов весомости (значимости) показателей качества выполнения технологических процессов. Данный вариант включает установленный на раме бак для ЖМУ, фильтрующие устройства, запорно-дозирующую аппаратуру (насос, регулятор давления, манометр), распределительную штангу, соединенные гидрокоммуникациями с устройством для создания газожидкостной смеси ЖМУ и многопоточным делителем жидкости, что в значительной степени предотвращает закупорку отверстий распылителей.

Ключевые слова: жидкие минеральные удобрения, внесение, техническое средство, функционально-структурная модель, состав функций, технологическая схема

Justification of a technological scheme of technical means for application of liquid mineral fertilizers into the soil

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The article presents the results of justification of a technological scheme of technical means for the application of liquid mineral fertilizers (LMF) into the soil during the cultivation of agricultural crops. It was found that the formation of the structure of this technical means is based on the construction of its functional-structural model which is based on the definition of the composition of functions and functional model of the future product, the search for variants of technical solutions for functions, the construction of the structural model of the developed technical means, and at the final stage on

the evaluation and selection of the variants of working bodies (technical solutions) and promising technological schemes of the future technical means. Due to the identification of cause-and-effect relations between specific technological operations to be performed by the technical means, as well as technological and technical solutions, the composition of its functions has been determined, including transportation of the LMF stock, ensuring the specified application rate, distribution of the LMF on the working bodies and in the application strip. The structural scheme of the technical means for in-soil application of the LMF at the level of graph models of the "tree" type with representation of contours and specific interrelationships between the elements of the structure is substantiated. The prospective variant of the technological scheme is reproduced by complex indicators using numerical values of weight coefficients (significance) of quality indicators of technological processes performance. This variant includes a frame-mounted LMF tank, filtering devices, shut-off and metering equipment (pump, pressure regulator, pressure gauge), distributing rod, connected by hydro-communications with the device for creation of the LMF gas-liquid mixture and a multiflow liquid divider, which largely prevents clogging of atomizer openings.

Keywords: liquid mineral fertilizers, application, technical means, functional and structural model, composition of functions, technological scheme

Для цитирования: *Назаров Н.Н., Иванников А.Б., Некрасова И.В.* Обоснование технологической схемы технического средства для внесения в почву жидких минеральных удобрений // Сибирский вестник сельскохозяйственной науки. 2024. Т. 54. № 11. С. 132–141. https://doi.org/10.26898/0370-8799-2024-11-14

For citation: Nazarov N.N., Ivannikov A.B., Nekrasova I.V. Justification of a technological scheme of technical means for application of liquid mineral fertilizers into the soil. *Sibirskii vestnik sel'skokhozyaistvennoi nauki = Siberian Herald of Agricultural Science*, 2024, vol. 54, no. 11, pp. 132–141. https://doi.org/10.26898/0370-8799-2024-11-14

Конфликт интересов
Авторы заявляют об отсутствии конфликта интересов.
Conflict of interest
The authors declare no conflict of interest.

Благодарность
Работа выполнена в рамках финансируемой научно-исследовательской работы № 0533-2021-0012.
Acknowledgements
The work was carried out within the framework of the funded research work No. 0533-2021-0012.

INTRODUCTION

One of the fundamental factors in the formation of high yields of grain crops is the introduction of liquid forms of mineral fertilizers (liquid complex fertilizers (LCF), urea ammonia nitrate solution (UAN)) into the root zone of vegetative plants [1–5]. To date, a significant number of technological and technical solutions have been developed to ensure the introduction of liquid mineral fertilizers in the zone of their consumption by the root system of the cultivated crops [6–15]. At the same time, despite the sufficient research in this area, there are still a number of unsolved problems associated with dosing small volumes of liquid forms of preparations, their transportation to the place of application, clogging of holes (tips) of sprayers with soil, rapid wear of supplying working fluid lines, which creates significant difficulties. For this reason, the issues of sustainability of the technological process of application of liquid forms of mineral fertilizers into the soil, associated with the formation of the technological scheme of the technical means used for these purposes, is an important and requiring solutions problem.

The purpose of the work is to substantiate the structure of the technical means for applying liquid forms of mineral fertilizers to the soil, ensuring the stability of its functioning in the presence of internal and external influences.

The objective is to develop methodological approaches to substantiation of technological scheme of technical means for introduction of liquid forms of mineral fertilizers into the soil.

МАТЕРИАЛ И МЕТОДЫ

As a methodological basis for the formation of the technological scheme of the technical

means for the introduction of liquid mineral fertilizers (LMF) into the soil, the graph of effects of the technical system under consideration, created using the combinatorial method, was adopted[1, 2] (see fig. 1).

Formation of the structure of a technical means for the introduction of LMF into soil is based on the construction of its functional-structural model (FSM) ((see fig. 2). This FSM should be based on the definition of the composition of functions of the future product and its functional model (FM), search for variants of technical solutions for functions and construction of the structural model of the developed technical means, and at the final stage - on the evaluation and selection of variants of working bodies (technical solutions) and prospective technological schemes of the future technical means[3-6].

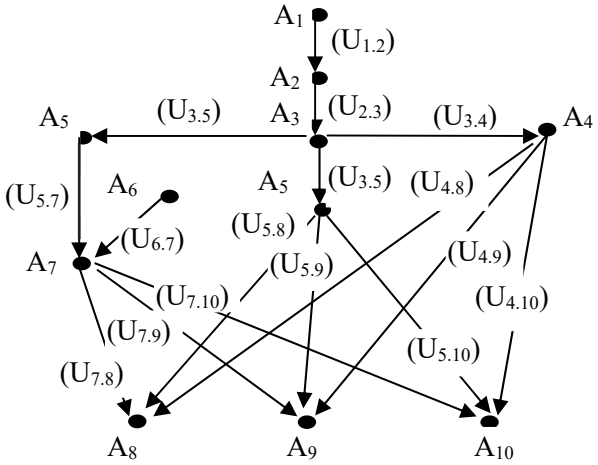

Рис. 1. Граф эффектов технической системы для внесения в почву ЖМУ:
A_1 – нахождение ЖМУ в емкости для хранения и транспортировки; A_2 – дозатор (насос-дозатор); A_3 – пускорегулирующая аппаратура; A_4 – распылители; A_5 – подача ЖМУ в многопоточный делитель жидкости; A_6 – источник сжатого воздуха; A_7 – устройство для формирования газожидкостной смеси ЖМУ; A_8 – распределение ЖМУ в полосе посева семян; A_9 – распределение ЖМУ в межполосную зону; A_{10} – распределение ЖМУ на подстилающую поверхность; $U_{1...n}$ – взаимосвязь между двумя явлениями (процессами)

Fig. 1. Effect graph of the technical system for the application of the LMF to the soil:
A_1 – LMF in storage and transportation tank; A_2 – metering unit (pump-dosing unit); A_3 – start-control devices; A_4 – atomizers; A_5 – feeding of LMF into multi-stream liquid divider; A_6 – compressed air source; A_7 – device for formation of the LMF gas-liquid mixture; A_8 – LMF distribution in the seed sowing strip; A_9 – LMF distribution to the interband zone; A_{10} – LMF distribution to the underlying surface; $U_{1...n}$ – interrelation between two phenomena (processes)

In determining the composition of functions of the future technical means, the cause-effect relations between specific technological operations, technological and technical solutions that should be performed both by the technical means as a whole (at the level of a single complex) and by its component parts were considered. The basic component in this case is the statement of two basic questions - why and how? They served as the basis for defining both the preceding and subsequent functions.

On the basis of the information obtained in this way, a graphical definition of the functional model of the technical means is made with the help of a visual representation of the functions and their subordination.

When searching for variants of technical solutions by functions and building a structural model of the developed technical means, the method of morphological analysis of systems was applied, which provides finding a promising technical solution on the basis of morphological maps. The criteria and limitations of the technological process functioning were used, which will be presented below.

RESULTS AND DISCUSSION

In accordance with the above methodological approaches, the composition of functions (dia-

[1]*Glazunov V.N.* Search for the principles of action of technical systems. Moscow: River Transport, 1990, 112 p.

[2]*Glazunov V.N.* Parametric method of solving contradictions in engineering. Moscow: River transport, 1990, 148 p.

[3]*Moiseeva N.K., Karpunin M.G.* Fundamentals of the theory and practice of functional-cost analysis. Moscow: Vysshaya shkola, 1988, 192 p.

[4]*Moiseeva N.K.* Choice of technical decisions at creation of new products. Moscow: Mashinostroenie, 1980, 181 p.

[5]*Golibardov E.I., Kudryavtsev A.V., Sinenko M.I.* Technique of functional-cost analysis. Kiev: Technics, 1989, 238 p.

[6]Fundamentals of functional-cost analysis: textbook / edited by M.G. Karpunin, B.I. Maidanchik. Moscow: Energy, 1980, 175 p.

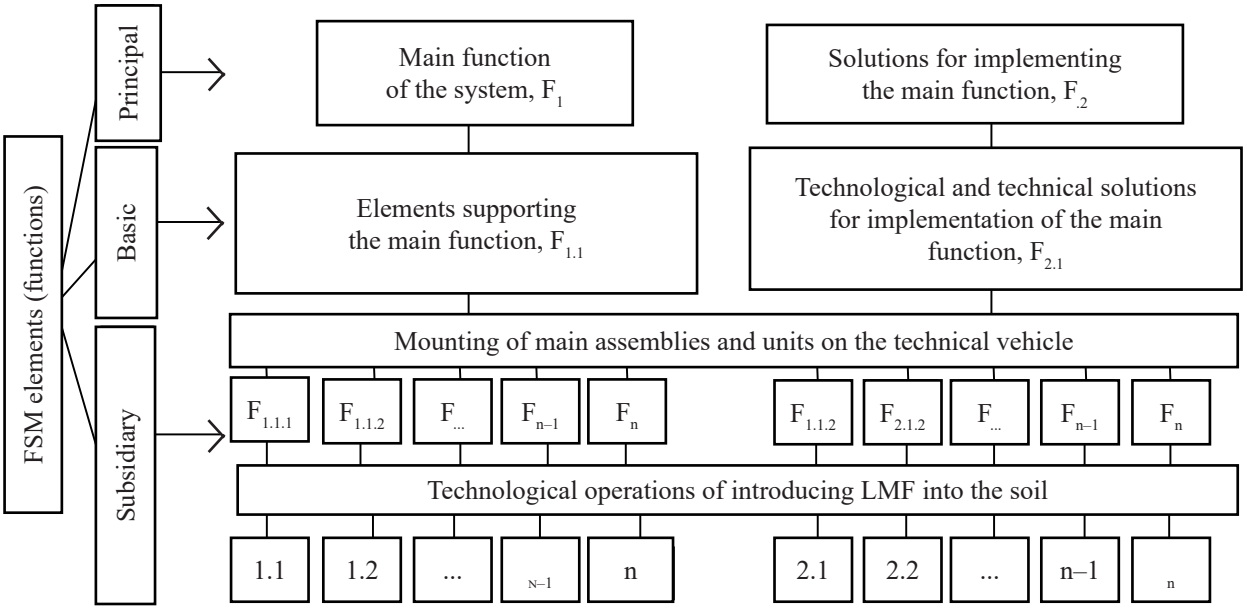

Рис. 2. Методический подход к формированию ФСМ технического средства для внесения в почву ЖМУ
Fig. 2. Methodological approach to formation of the FSM of technical means for application of LMF into the soil

gram) of the future technical means is defined, not only their number is presented, but also, to a certain extent, the executive mechanism realized through the components of the technical means (see fig. 3).

In general, the diagram of functions of the technical means for introducing liquid mineral fertilizers into the soil is as follows: transporting the stock of liquid mineral fertilizers → ensuring the specified rate of liquid mineral fertilizer application → distribution of liquid mineral fertilizers to working bodies → distribution of liquid mineral fertilizers in the application strip.

The composition of functions defined in this way is taken as the basis for forming the FM of the designed technical means. This model is formalized at the level of graphical representation with the display of the main functions realized

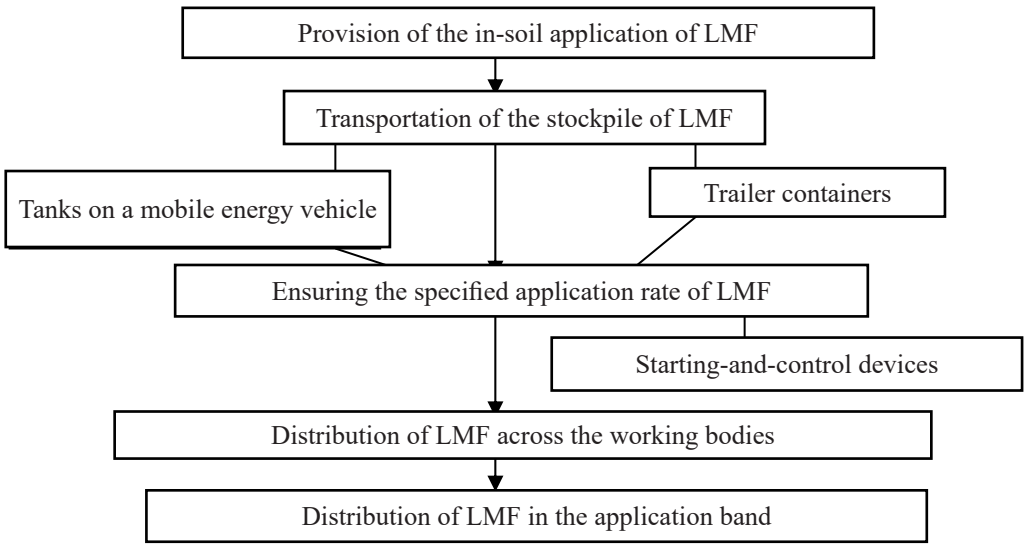

Рис. 3. Состав функций технического средства для внутрипочвенного внесения ЖМУ
Fig. 3. Composition of the functions of the technical means for in-soil application of the LMF

in the technical means and their subordination (see fig. 4).

Further substantiation of the technological scheme of the technical means for in-soil application of LMF is associated with its structural description, represented in graphical form and carrying information about the established static relations. This model refers to the "tree" type graphs and does not have contours and specific interrelations between the elements of the structure in its representation (see fig. 5).

Formation of the FSM of a technical means for in-soil application of LMF is based on the determination of the subordination of its functions in the following order: main, basic, auxiliary. The basic functions (transportation of the LMF stock, dosage and distribution of LMF by working bodies, feeding of LMF into the subcoulter zone, distribution of LMF over the width of the cultivated area) are realized in the technological process of the technical means and are subordinated to the main function (in-soil application of LMF), are obligatory for realization and are related to the placement of the equipment of the designed technical means on its structural basis. After defining the main and basic functions, a system of auxiliary functions is constructed, connected with the installation of

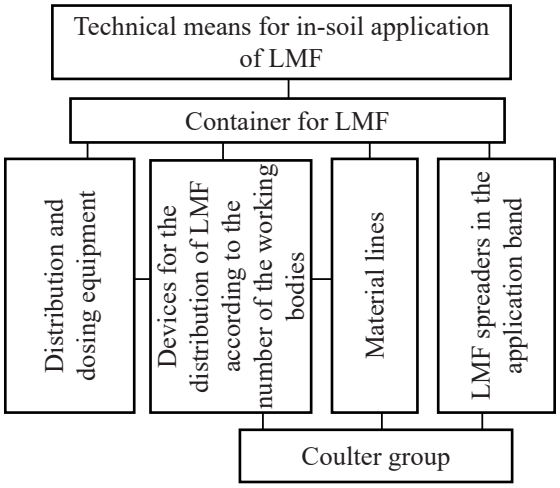

Рис. 5. Структурная схема технического средства для внутрипочвенного внесения ЖМУ

Fig. 5. Structural diagram of a technical tool for in-soil application of the LMF

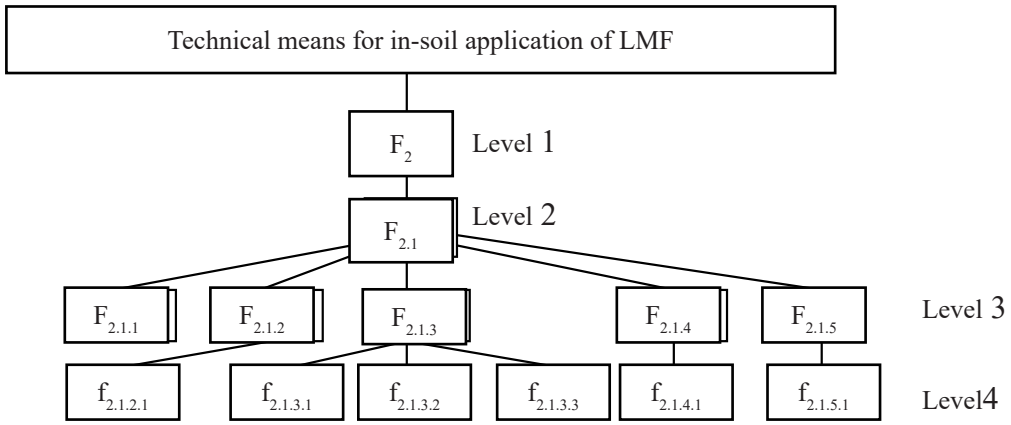

Рис. 4. ФМ технического средства для внутрипочвенного внесения ЖМУ:

F_2 – обеспечение внутрипочвенного внесения ЖМУ; $F_{2.1}$ – транспортирование запаса ЖМУ; $F_{2.1.1}$ – закрепление емкости на раме; $F_{2.1.2}$ – дозирование ЖМУ; $F_{2.1.3}$ – распределение ЖМУ по рабочим органам; $F_{2.1.4}$ – подача ЖМУ в подсошниковую зону; $F_{2.1.5}$ – распределение ЖМУ по ширине обрабатываемой площади; $f_{2.1.2.1}$ – установка распределительно-нагнетательной аппаратуры; $f_{2.1.3.1}$ – установка многопоточного делителя жидкости; $f_{2.1.3.2}$ – установка устройства для создания газожидкостной смеси ЖМУ; $f_{2.1.3.3}$ – установка распределительной штанги; $f_{2.1.4.1}$ – установка материалопроводов; $f_{2.1.5.1}$ – установка распределителей ЖМУ

Fig. 4. FM of the technical means for in-soil application of LMF:

F_2 – provision of in-soil application of LMF; $F_{2.1}$ – transportation of the LMF stock; $F_{2.1.1}$ – fixing of the tank on the frame; $F_{2.1.2}$ – dosing of LMF; $F_{2.1.3}$ – distribution of LMF to the working bodies; $F_{2.1.4}$ – feeding of LMF to the subsoil zone; $F_{2.1.5}$ – distribution of LMF over the width of the treated area; $f_{2.1.2.1}$ – installation of the distribution and injection equipment; $f_{2.1.3.1}$ – installation of a multiflow liquid splitter; $f_{2.1.3.2}$ – installation of a device for creation of gas-liquid mixture of LMF; $f_{2.1.3.3}$ – installation of a distributing rod; $f_{2.1.4.1}$ – installation of material lines; $f_{2.1.5.1}$ – installation of LMF distributors

distribution and discharge equipment, formation of the alternative variants of LMF distribution on the working bodies (the use of a multi-flow fluid divider, a device for creating an LMF gas-liquid mixture and the use of the spreader bar), which are necessary to realize the basic functions of the technical means (see fig. 6).

The promising variant of the technological scheme of the technical means for the application of LMF into the soil was determined taking into account the decision of the expert group established for this purpose[7]. The members of the expert group, consisting of 8 people, prioritized these indicators on a 5-point scale using complex indicators adopted to assess the quality of functioning of the process under consideration, based on the numerical values of the weight coefficients (significance) of these indicators. The following indicators are taken as comprehensive indicators: *A* – technological process performance quality (TP); *B* – technological process performance; *C* – stability of technological process operation; *D* – equipment installation costs; *E* – component price; *F* – complexity of manufacturing (labor costs for manufacturing); *G* – ease of maintenance (labor costs for maintenance); *H* – weight of working tools[8].

At the first stage the technological processes accepted for consideration were ranked (see footnote 8). The obtained data were processed using the methods of mathematical statistics (see the table).

Based on the results obtained, the second stage involved the selection of a promising technological scheme of a technical means for the application of LMF to soil according to the

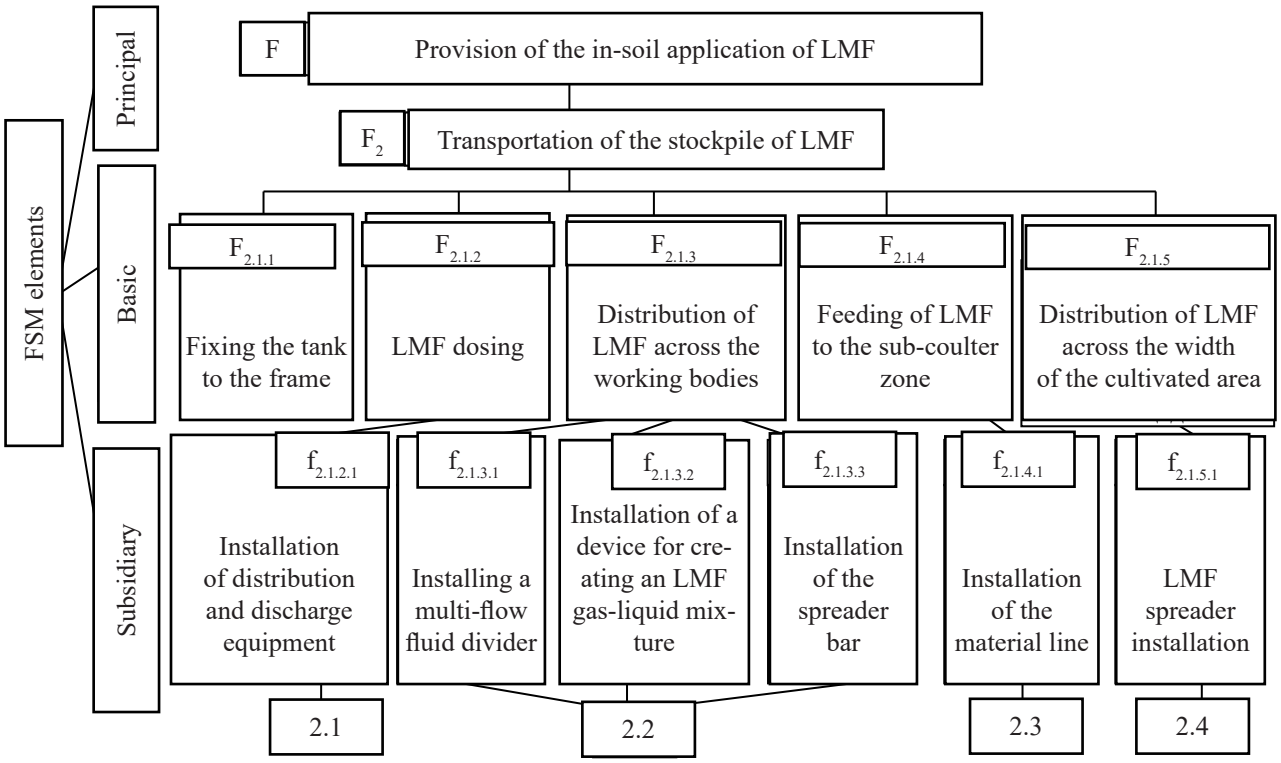

Рис. 6. ФСМ технического средства для внутрипочвенного внесения ЖМУ:

2.1 – дозирование ЖМУ; 2.2 – распределение ЖМУ по рабочим органам; 2.3 – транспортирование ЖМУ к рабочим органам; 2.4 – распределение ЖМУ в полосе внесения

Fig. 6. FSM of the technical means for in-soil application of LMF:

2.1 – dosing of LMF; 2.2 – distribution of LMF across the working bodies; 2.3 – transportation of LMF to the working bodies; 2.4 – distribution of LMF in the application strip

[7]*Litvak B.G. Expert information.* Methods of reception and analysis. Moscow: Radio and communication, 1982, 184 p.

[8]*Nazarov N.N.* Technological scheme of technical means for application of bacterial preparations suspension into the soil // Siberian Herald of Agricultural Science, 2010, vol. 40, N 2 (206), pp. 76–83.

Ранжирование показателей качества по результатам их балльной оценки экспертами
Results of quality indicators ranking according to the results of their scoring by the experts

Estimate	Quality index							
	A	*B*	*C*	*D*	*E*	*F*	*G*	*H*
Score	4,6	4,1	4,6	2,2	2,2	2,5	3,6	2,5
Occupied position	1	3	2	7	8	5	4	6

above quality indicators. The evaluation was carried out by the same group of experts.

It has been established that a potentially promising technological scheme of a technical means for in-soil application of liquid mineral fertilizers is a scheme including a tank for liquid mineral fertilizers mounted on a frame, filtering devices, shut-off and metering equipment (pump, pressure regulator, pressure gauge), distribution rod, connected by hydro-communications (see footnote 8). In addition, the presented technological scheme has a distinctive feature, expressed in the presence of two elements – a device for creating LMF gas-liquid mixture and multiple flow liquid divider (see fig. 7).

Both devices are mounted on the frame of the technical means and form a gas-liquid mixture or distribute the LMF mixture according to the number of ploughing working bodies outside the area of direct flow of liquid forms of fertilizers into the soil, which largely prevents clogging of sprayer openings.

CONCLUSIONS

1. The promising variant of the technological scheme of the technical means for in-soil application of LMF, including the tank for LMF, filtering devices, shut-off and dosing equipment (pump, pressure regulator, pressure gauge), distributing rod, connected by hydro-communications with the device for creation of gas-liquid mixture of LMF, multiflow liquid divider, which

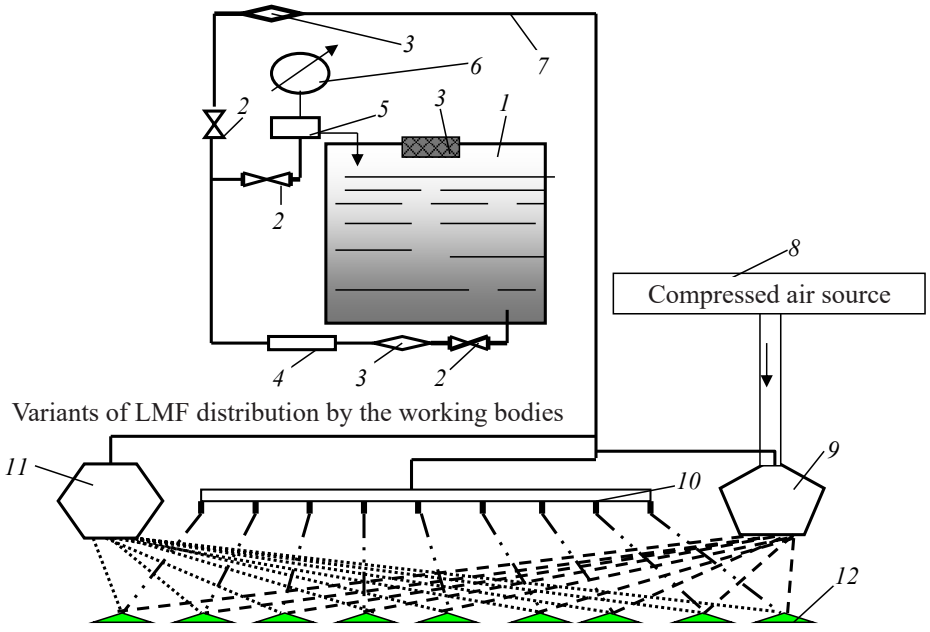

Рис. 7. Технологическая схема технического средства для внутрипочвенного внесения ЖМУ:
1 – бак для ЖМУ; *2* – запорная арматура; *3* – фильтрующие устройства; *4* – насос; *5* – регулятор давления; *6* – манометр; *7* – гидрокоммуникации; *8* – источник сжатого воздуха; *9* – устройство для создания газожидкостной смеси ЖМУ; *10* – распределительная штанга; *11* – многопоточный делитель жидкости; *12* – рабочие органы

Fig. 7. Technological scheme of the technical means for in-soil application of LMF:
1 – tank for LMF; *2* – stop valve; *3* – filtering devices; *4* – pump; *5* – pressure regulator; *6* – pressure gauge; *7* – hydraulic lines; *8* – compressed air source; *9* – device for creating gas-liquid mixture of LMF; *10* – distributing rod; *11* – multi-flow liquid divider; *12* – working bodies

largely prevents clogging of sprayer holes, is substantiated.

2. Methodical approaches of justification of technological scheme of technical means for in-soil application of liquid forms of mineral fertilizers are developed, which are realized through the formation of functions, determination of functional model of technical means, search for the variants of technical solutions on functions and construction of structural model of technical means, and at the final stage - through evaluation and selection of the variants of working bodies (technical solutions) and perspective technological schemes of future technical means.

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Дата поступления статьи / Received by the editors 27.05.2024
Дата принятия к публикации / Accepted for publication 31.07.2024
Дата публикации / Published 13.12.2024