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Forecast for the Adaptive Tillage System

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ABSTRACT: Precision tillage has great potential. The result of tillage operations can be improved depending on the optimal solution of construction working bodies and technological parameters of cultivating, which, in addition, can be adapted to the tillage technology depending on the local agro-climatic conditions.

The article presents the results of the synthesis of the system of adaptive control of soil cultivation by creating a complex technological system with modeling of the structural-matrix schemes and on-stream technological influences of working bodies of machines and external agro-climatic conditions on the agrophysical state of the soil.

The research methods are matrix methods of analysis of structural schemes of technological process control systems; system-analog modeling of tillage control systems; structural analysis and synthesis of technological changes in agrophysical indicators of soil tillage.

The main results are the structural diagram of the on-stream adaptive control system of the tillage unit for the requirements of precise agriculture; matrix diagram of the imaging and generalized system of equations of on-stream adaptive control of working bodies of tillage machines; system-analog model of the machine-tractor unit with the adaptive control system of working bodies.

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KEYWORDS: tillage control machines, adaptive control, matrix modeling, matrix imaging, structural modeling.

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INTRODUCTION

It is generally known that one of the significant disadvantages of the development of modern technological processes is the aspect of thinking associated with the use of construction positions that have already been used. Modern concepts in the development of tillage technologies are the processes of implementing control of the modes of operation of tillage machines and till bodies in conditions of risk and uncertainty of functional loads from the surrounding environment (Laurentiu, V., *et al.*, 2017). The methodology for solving diverse problems of quality and efficiency in tillage should take into account a significant number of factors and be presented in an accessible form for the response of working bodies of tillage machines.

In generally mechanical tillage is changing the ratio of solid part, which subsequently affects physico-chemical, biological and heat-mass conversion processes (Voytyuk D.G., *et al.*, 2012; Lobb D.A., *et al.*, 2008). The main soil quality indicators of tillage are bulk density and coefficient of structure (DSTU 4362:2004, 2005). Crushing of soil depends on the granulometric composition, water content, constructions parameters of working bodies cultivating, as well as the speed (Lobb D.A., et al., 2008).

Local innovation, in such cases would be an adaptive control system aimed at implementing compromise solution have been proposed in particular: obtaining high quality tillage according to Agro Technological Electronic Requirements (ATER), support the estimated yield level; optimal costs of materials and funds for the process of soil preparation achieved transitional and atypical modes of operation; minimum deviation from ATER requirements due to unforeseen and accidental violations of operating conditions of tillage machines.

It is also known (Kravchuk V.I., 2005; Techen, Anja-Kristina & Helming, K. 2017; Zavhorodnii A.F. *et al.*, 2004; Kravchuk V.I. Baranov G.L. 2001; Kravchuk V.I. Baranov G.L. 2002) that in the development and calculation of automated tillage control systems, there is a specific task for manipulating the working bodies of machines. The main difficulties are associated with the lack of necessary on-stream information about the state of agrophysical soil parameters. The main information for the adaptive control system must be obtained dynamically in the process of tillage of the entire adaptive system in on-stream cultivation, which is not well studied.

The purpose of the study: is the development of on-stream adaptive control of the processes of tillage machines on the basis of the synthesis of a complex technological system with subsequent modeling of flow changes and their dynamic effect on working bodies.

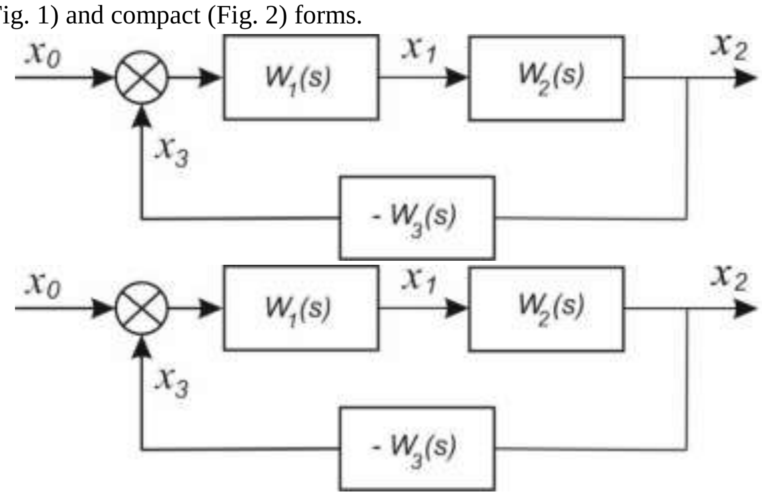
Task of the study: is develop an algorithm, system-analog model, matrix structure and a generalized system of equations of on-stream adaptive control system of the working bodies of the machine-tractor unit.

MATERIALS AND METHODS

Empirical studies, generalization and classification of technologically significant agrophysical parameters of soil condition.

Analog and structural modeling based on the similarity of physical nature phenomena to obtain a block diagram, structural matrix and a mathematical equation for the on-stream tillage control system.

The development of the adaptive control system of the working bodies of tillage machines can be based on methods of automatic change of the phase state of the soil. The development of theories of automatic regulation (TAR) led to the display of systems in the form of structural diagrams with the designation of transfer functions characterizing links or their groups. By default, the views are in expanded (Fig. 1) and compact (Fig. 2) forms.



x_0 – input parameters; x_1 – control parameters; x_2 – output parameters;
x_3 – deviation parameters; W_1 – control body; W_2 – control object;
W_3 – computing means.

Fig. 1 - Structural diagram of an automatic control system in expanded form (Shatikhin L.G., 1991).

Transfer functions for direct W1, W2, and reverse object W3 characterize the conversion of input parameters x_0 to output values x_2 passing in on-stream and can be written as the ratio of two operator polynomials (Shatikhin L.G., 1991):

$$\frac{x_2(s)}{x_0(s)} = W(s) = \frac{R(s)}{Q(s)}, \qquad (1)$$

where, Q (s) – native dynamic object operator; R(s) – operator of communication between dynamic objects; s – Laplace complex variable.

The equation for the transfer function:

$$\Phi(s) = \frac{W_1 \cdot W_2}{1 - W_1 \cdot W_2 \cdot (-W_3)}, \qquad (2)$$

According to control systems and their internal processes for dynamic objects are closed, it is advisable to use in compact forms (Fig. 2).

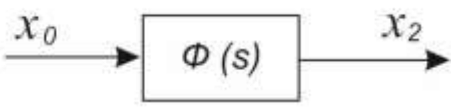


Fig. 2 - Diagram of an automatic control system in folded form (Shatikhin L.G., 1991).

The equation for x_2 output parameters determined by x_1 input is:

$$x_2 = \Phi(s) \cdot x_0, \qquad (3)$$

or:

$$x_2 = \frac{W_1 W_2}{1 + W_1 W_2 W_3} \cdot x_0 . \qquad (4)$$

For a transfer function with dynamic object operators:

$$W\ (s) = \frac{R(s)}{Q(s)}, \qquad (5)$$

Without taking into account the Laplace transform operators, the equation of the initial parameters:

$$x_2 = \frac{\frac{R_1}{Q_1} \cdot \frac{R_2}{Q_2}}{1 + \frac{R_1}{Q_1} \cdot \frac{R_2}{Q_2} \cdot \frac{R_3}{Q_3}}, \qquad (6)$$

or

$$x_2 = \frac{R_1 \cdot R_2 \cdot Q_3}{Q_1 \cdot Q_2 \cdot Q_3 + R_1 \cdot R_2 \cdot R_3}. \qquad (7)$$

In the expanded form of the record, the independent parameters of the adaptive control system (Fig. 1) could be represented by a system of equations:

$$\left.\begin{aligned} x_1 &= W_1(x_0 + x_3); \\ x_2 &= W_2 \cdot x_1; \\ x_3 &= -W_3 \cdot x_2; \end{aligned}\right\} \qquad (8)$$

The structure diagram (Fig. 1) can be depicted as a structural matrix in which the signs of diagonal coefficients on the left side will be opposite to the signs of coefficients of a conventional matrix or main determinant (Steven H., 2011).

The first step to creating a structural matrix is to build a rectangular grid with the quantity of segments n^2 when n – is the number of equations in the system. On the right side, set independent variables (in this case, one). Variables are marked in writing order above each column (in this case, one). Variables are marked in writing order above each column, (in this case, x_1, x_2, x_3). On the main diagonal on the left are the coefficients of independent variables (in this case, units). In each row in segments, the coefficients of equations from the right side of the system are indicated under the corresponding variables. Coefficients are written with such signs as they have in the system of equations. To form a structural matrix, transfer functions are first written, which can be further converted into link and link operators with corresponding indices (Fig. 3).

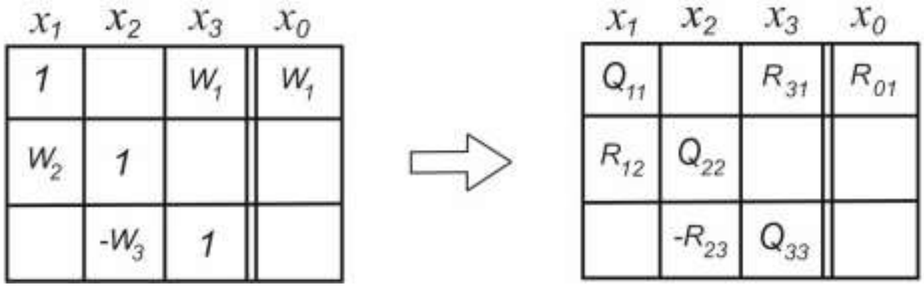


Fig. 3 - Structure Matrix Transformation diagram.

For determining variable x_2 we are using the Kramer equation. System of equations (8) in ordered form:

$$\left.\begin{aligned} 1 \cdot x_1 + 0 \cdot\ x_2 - W_1 \cdot x_3 &= W_1 x_0; \\ -W_2 \cdot x_1 + 1 \cdot\ x_2 + 0\ \cdot\ x_3 &= 0; \\ 0 \cdot x_1 + W_3 \cdot x_2\ + 1\ \cdot x_3 &= 0; \end{aligned}\right\} \qquad (9)$$

Provided that the main determinant of the system is not equal to zero, the system has the following solutions:

$$x_2 = \frac{\Delta_2}{\Delta} \cdot x_0, \qquad (10)$$

$$\Delta = \begin{vmatrix} 1 & 0 & -W_1 \\ -W_2 & 1 & 0 \\ 0 & W_3 & 1 \end{vmatrix} = 1 + W_1 W_2 W_3\ ; \qquad (11)$$

$$\Delta_2 = \begin{vmatrix} 1 & W_1 & -W_1 \\ -W_2 & 0 & 0 \\ 0 & 0 & 1 \end{vmatrix} = W_1 W_2\,. \qquad (12)$$

Solution for x_2 which coincides with equation (4):

$$x_2 = \frac{W_1 W_2}{1 + W_1\ W_2 W_3} \cdot x_0. \qquad (13)$$

The method of constructing an adaptive soil treatment system by synthesizing a structural diagram allows you to perform conceptual design on a matrix field, which can be basic for writing a cybernetic and mathematical model depending on the level of detail.

The coordination of patterns of functioning of working bodies of agricultural machines, for technological processes of changing the phase state of the soil, is the basis for the construction of high-quality systems for adaptive control of tillage processes.

RESULTS

The development of the adaptive processing control system was carried out by synthesizing technological processes for changing the phase state of the soil through the coordination of elementary actions of the working organs on the soil.

The basis for structuring the system is a complex idea of the corresponding number of typical tasks, between which there are no or no relationships established (Walsham, Geoff and Han, Chun-Kwong, 1990; Zolghadri Marc *at all*, 2013). The complexity of structuring can be reduced by analyzing the problem, evaluating it and developing an algorithmic complex with subsequent decision-making on the synthesis of adaptive systems.

The study of the on-stream adaptation of tillage machines in order to solve the problems of qualitative and effective tillage was carried out on the basis of the development of aspects of technological changes, system analysis, and modeling by the method of structural matrix (Shatikhin L.G. 1990).

The sequence of elementary actions is formed in the form of a control algorithm (Fig. 4) based on an agro-technological electronic map (ATER) with a determined sequence of operations.

There are also confirmations (Ivanuita M.V., 2015; Lobb D.A., 2008; Zavhorodnii A.F. *at all* 2004, Saleh A. At all, 1997) that the main requirements for the development of modern tillage machines, regardless of the conditions of a priori uncertainty and operating conditions, should provide high-quality indicators of tillage. The conditions of a priori uncertainty refer to the change in the grain size distribution of the soil, bulk density, and structure as input parameters depending on the agro-climatic location of the treated area.

Obviously, that improving the quality of tillage can be improved by a streaming system for adapting tillage machines based on the ATER task. (Kravchuk V.I. Baranov G.L. 2001; Lobb D.A., 2008; Zavhorodnii A.F., *at all* 2004; Semyonov A. *at all* 2021).

The flow adaptation algorithm of the machine-tractor unit can be formalized under the influence of a set of control actions on the actuators, taking into account the signals of external sensors and commands coming from the measuring devices.

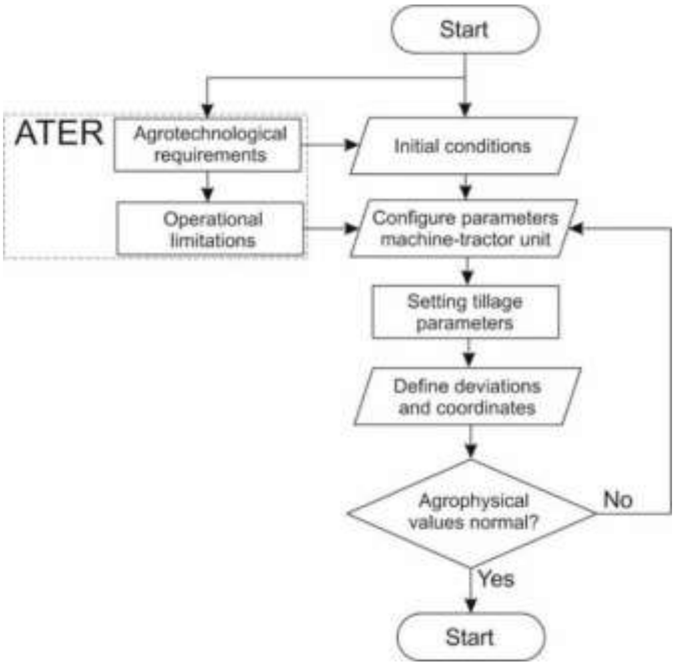
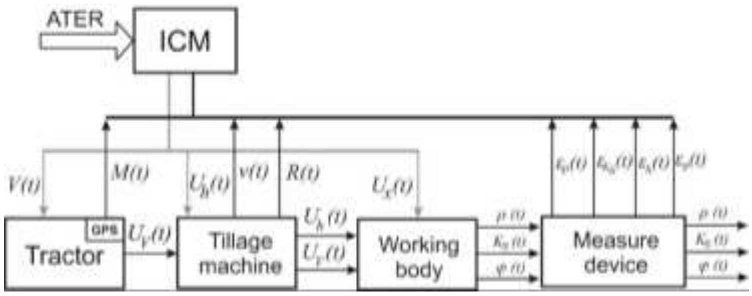


Fig. 4 - Algorithm of the tillage adaptation.

Therefore, the main component of the adaptive multifactor system is the system-analog model of the machine-tractor unit with elements of on-stream adaptation of the working bodies of tillage machines (Fig. 5). This model can be typical for agricultural units in the diagram "ATER - Information Control Means (ICM) - Tractor - Soil Processing Unit - Working Body - Control Means - ICM" taking into account the control actions of U and the values of deviations ε in agrophysical parameters.



U (t) - control parameter data (*V(t)* – specified tractor speed; *h(t)* – cultivation depth);

V_a *(t)*– operating speed; $\varepsilon(t)$ - values of deviations of agrophysical parameters; *R(t)* - traction resistance of the unit; $\varphi(t)$ – soil water content; $\rho(t)$ – bulk density of soil; K_S *(t)* - soil structural coefficient; *M (t)* - GPS coordinates; $\upsilon(t)$ - actual speed of the unit.

Fig. 5 - System-analog model of a machine-tractor unit with tillage machines adaptation.

Detail of the on-stream adaptive control system of the working elements of the unit is determined by structural diagrams (Fig. 6), modeling the control process of soil agrophysical indicators.

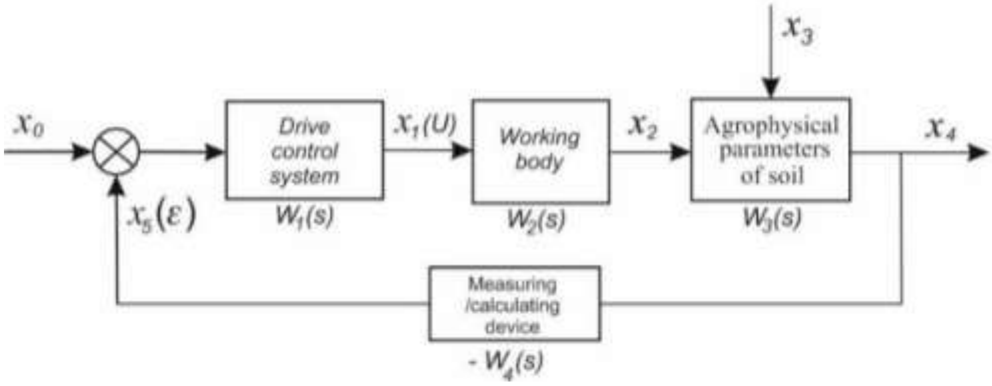


Figure 6 - Block diagram of adaptive control system (unfolded form).

Before starting operation, the system sets the process parameters for tillage specified in ATER x_0 (ρ_0, $K_{S.0}$, *V*, h_0, φ) and GPS coordinates are necessary to determine the type of soil. During processing, the system analyzes the currently defined parameters x_4 (bulk density ρ, soil structural coefficient K_S, actual speed of the unit υ, cultivation depth h and soil water content φ), calculate deviations ε, sets and set control parameters *U* which form initial soil agrophysical parameters x_4. External disturbances x_3 are physical composition, water content, and actual speed (Fig.7).

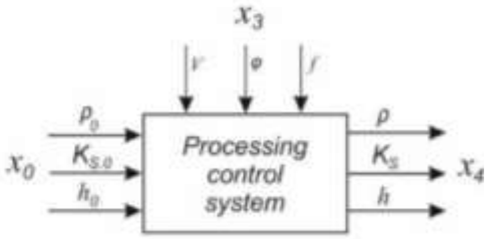


Fig. 7 - Schematic of the multi-dimensional tillage control system (compact form).

To develop a structural matrix, the studied set is composed of objects expressed by the matrix coefficients of a system of linear equations. The names of such objects are identified as a sequence of indexes reflecting the topological properties of matrix elements (Shatikhin L.G., 2010).

The angular arrows in the blocks show the links between the regulators in accordance with the block diagram of the closed control cycle. Double arrows - control actions requiring energy impact on actuators.

By replacing the angular arrows with the corresponding coefficients of the coordinate matrix (Fig. 8) the flow control system can be expressed by matrix equations:

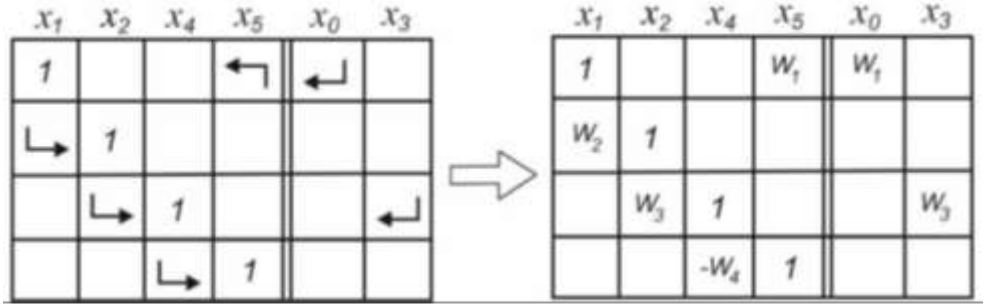


Fig. 8 - Diagram of structural matrix transformations

In the expanded recording form, independent parameters of the adaptive control system (Fig. 8) can be represented by a system of equations:

$$\left.\begin{aligned} x_1 &= W_1(x_0 + x_5); \\ x_2 &= W_2 \cdot x_1; \\ x_4 &= W_3(x_2 + x_3); \\ x_5 &= -W_4 \cdot x_4. \end{aligned}\right\} \qquad (14)$$

A system of equations (14) in ordered form for applying Cramer's method:

$$\left.\begin{aligned} 1 \cdot x_1 + 0 \cdot x_2 + 0 \cdot x_4 + W_1 \cdot x_5 &= W_1 x_0; \\ W_2 \cdot x_1 + 1 \cdot x_2 + 0 \cdot x_4 + 0 \cdot x_5 &= 0; \\ 0 \cdot x_1 + W_3 \cdot x_2 + 1 \cdot x_4 + 0 \cdot x_5 &= W_3 \cdot x_3; \\ 0 \cdot x_1 + 0 \cdot x_2 - W_4 \cdot x_4 + 1 \cdot x_5 &= 0. \end{aligned}\right\} \qquad (15)$$

Main determinant:

$$\Delta = \begin{vmatrix} 1 & 0 & 0 & W_1 \\ W_2 & 1 & 0 & 0 \\ 0 & W_3 & 1 & 0 \\ 0 & 0 & -W_4 & 1 \end{vmatrix} = 1 + W_1 W_2 W_3 W_4; \qquad (16)$$

Provided that if the main determinant of the system is non-zero, the system has the following solutions:

$$x_4 = \frac{\Delta_4}{\Delta} \cdot x_0, \qquad (17)$$

Determinant Δ_4:

$$\Delta_4 = \begin{vmatrix} 1 & 0 & W_1 & W_1 \\ W_2 & 1 & 0 & 0 \\ 0 & W_3 & W_3 & 0 \\ 0 & 0 & 0 & 1 \end{vmatrix} = W_3(1 - W_1 W_2); \qquad (18)$$

The solved equation for the coordinates of problem x_4 will be:

$$x_4 = \frac{W_3(1 - W_1 W_2)}{1 + W_1 W_2 W_3} \cdot x_0. \qquad (19)$$

To study the mathematical model, it is necessary to investigate the functions and parameters of control and external conditions that can describe the technological processes of tillage. Methods of such studies should be based on research for invariant systems the main task of which is to establish dependencies for the existing ways of adaptation of the systems depending on coordinates and external conditions x_3.

DISCUSSION

Research noted that one of the significant drawbacks of the development of modern technological processes is the defined traditional way of thinking associated with the use of design schemes that have already been used. Modern ways of developing tillage technologies are processes of implementation of progressive directions by modes of operation of tillage machines and working bodies in conditions of risks and uncertainty of functional loads from the surrounding environment (Walsham *at all,* 1990; Zolghadri Marc *at all* 2013; Williams, P John., 2000; Ucgul M, Chang C-L. 2023).

Coordination of the patterns of functioning of the working bodies of agricultural machines, which are characteristic for technological processes of changing the soil phase, makes it possible to build high-quality control systems and develop systems for on-stream adaptive control of soil processing (Zybarev, Y.N., Fomin, D.S. 2020).

There are also confirmations (Voytyuk D.G. *at all*, 2015; Lobb D.A. 2008, Ivanuita M.V. 2015) that the main requirements for the development of modern tillage machines, regardless of the conditions of unspecified uncertainty and operating conditions, should provide high-quality indicators of tillage. The conditions of unspecified uncertainty refer to the change in the grain size distribution of the soil, density, and structure as input parameters depending on the agro-climatic location of the treated area.

Obviously, (Kravchuk V.I. Baranov G.L., 2001; Semyonov Aleksey 2021; Qu Y, Pan C, Guo H., 2021; Han Q, Siddique KHM, Li F 2018) improving the quality of tillage can be improved by the flow system of guaranteed adaptive control of the working processes of tillage machines based on the ATER task. The proposed model of cultivation is based on the use of synthesized matrix control forms with on-stream determination of grain size distribution, soil water content, and density.

The method of matrix images made it possible to depict the system of guaranteed adaptive control in the form of block matrices and made it possible to establish connections between the agrophysical and structural parameters of the process of tillage.

CONCLUSIONS

The development of a system of on-stream adaptive control of a machine-tractor unit using the methods of automatic control theories made it possible to coordinate an algorithm, a system-analog model, a matrix diagram, and a generalized system of equations with the agro-technical requirements of tillage.

The matrix image method allows you to display the adaptation system in the form of block matrices and establish models of connections between the agrophysical, structural, and technological parameters of the working organs of tillage machines.

REFERENCES

1. Laurentiu, V., Cardei, P., Vladut, V., & Lucian, F. Modern trends in designing and selecting the machine/equipment for deep soil tillage. Engineering for Rural Development. 2017. https://doi.org/10.22616/ERDEV2017.16.N320
2. Voytyuk D.G., Aniskevich L.V., Ishchenko V.V. Agricultural machines. Kyiv: "Agroeducation" 2015.
3. Lobb D.A., Soil Movement by Tillage and Other Agricultural Activities, Editor(s): Sven Erik Jørgensen, Brian D. Fath, Encyclopedia of Ecology, Academic Press, Pages 3295-3303, 2008 https://doi.org/10.1016/B978-008045405-4.00832-6.
4. DSTU 4362:2004. Soil quality. Indicators of soil fertility. [Valid from 2006-01-01] Kyiv: "State Consumer Standard of Ukraine". 2005. 17 p.
5. Kravchuk V.I. Theoretical foundations of adaptation of agricultural machines. Kyiv. National Agrarian University. 2005.
6. Techen, Anja-Kristina & Helming, K. Pressures on soil functions from soil management in Germany. A foresight review. Agronomy for Sustainable Development. 2017. https://doi.org/10.1007/s13593-017-0473-3.
7. Zavhorodnii A.F. Kravchuk V.I. Yurchuk V.P. Geometric design of working bodies of root harvesting machines. Kyiv: Agrarian Sience, 2004.
8. Kravchuk V.I. Baranov G.L. Methodology for building discrete models of agricultural machinery operating modes. Agrarian science and education. Volume 2. - 2001 No. 1-2. - P. 45-52.
9. Kravchuk V.I. Baranov G.L. The method of calculating optimal software controls based on discrete models and the synthesis of closed-loop control laws for agricultural machinery and aggregates. Mechanization of production processes of fish farming, industrial and agricultural enterprises. Coll. Science Proceedings of Kerch Technol. etc. – 2002. Issue 3. Kerch: KMTI. - P. 34-40.
10. Shatikhin L.G. Structural matrices and their application to the study of systems. / L.G. Shatikhin. Moscow, Mechanical engineering. 1991.
11. Steven H. Weintraub. A Guide to Advanced Linear Algebra. *Lehigh University*. Dolciani Mathematical Expositions. Volume 44. 2011. [Epub ahead of print] https://doi.org/10.5948/UPO9780883859674.
12. Walsham, Geoff and Han, Chun-Kwong, "STRUCTURATION THEORY AND INFORMATION SYSTEMS RESEARCH". *ICIS 1990 Proceedings*. https://aisel.aisnet.org/icis1990/7.
13. Zolghadri Marc, Florent Couffin, Vincent Cheutet, Caroline Bourcier, Roberta Costa Affonso, Patrice Leclaire, Structuring systems and related research challenges, IFAC Proceedings Volumes, Volume 46, Issue 24, 2013 P. 190-197, https://doi.org/10.3182/20130911-3-BR-3021.00017.
14. Ivanuita M.V. Numerical study of the process of interaction between the surface of a smooth roller and the soil. Bulletin of the Vinnytsia Polytechnic Inst. Vinnytsia, No. 5. P.128-133. 2015.
15. Kravchuk V. Targonya V. Haydai T. Golub G. Kukharets S. Ivanuita M. Methodology and model of ecological and economic management of agricultural technologies. "Technical and technological aspects of the development and testing of new equipment and technologies for the agriculture in Ukraine". UkrNDIPVT im L. Pogorily. Doslidnytske, 2020. – V. 27 (41). Pages 142-152. https://doi.org/10.31473/2305-5987-2020-2-27(41)-13.
16. Saleh A. Al-Suhaibani, Abdulrahman Al-Janobi, Draught Requirements of Tillage Implements Operating on Sandy Loam Soil, Journal of Agricultural Engineering Research, Volume 66, Issue 3, 1997, Pages 177-182. https://doi.org/10.1006/jaer.1996.0130.
17. Semyonov Aleksey & Sabiev, U & Golovin, A & Prokopov, Sergey & Abdylmanova, R. The Ways to Improve the Efficiency of Agricultural Enterprises. IOP Conference Series: Earth and Environmental Science. 2021. https://doi.org/10.1088/1755-1315/937/3/032105.
18. Williams, P John. Design: The Only Methodology of Technology?. Journal of Technology Education. Vol 11. 2000. Pages 48-60. https://doi.org/10.21061/jte.v11i2.a.4.
19. Ucgul M, Chang C-L. Design and Application of Agricultural Equipment in Tillage Systems. *Agriculture*. 2023; 13(4):790. https://doi.org/10.3390/agriculture13040790
20. Zybarev, Y.N. & Fomin, D.S.. Modern approaches to adaptive tillage complexes in crop rotation and intensive land use in the Middle Urals. E3S Web of Conferences. 2020 https://doi.org/10.1051/e3sconf/202022202058.
21. Qu Y, Pan C, Guo H. Factors Affecting the Promotion of Conservation Tillage in Black Soil The Case of Northeast China. Sustainability. 2021; 13(17):9563. https://doi.org/10.3390/su13179563.
22. Han Q, Siddique KHM, Li F. Adoption of Conservation Tillage on the Semi-Arid Loess Plateau of Northwest China. *Sustainability*. 2018; 10(8):2621. https://doi. org/10.3390/su10082621.