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Original Study Article

# Conceptual directions for the development of driverless agricultural mobile power units

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ABSTRACT

***BACKGROUND:*** Currently, major global developers and manufacturers in the field of mobile agricultural machinery are working on the development of agricultural robotic systems. Particular attention is paid to the development of universal driverless mobile power units (MPU) capable of performing various technological operations autonomously, without human intervention. In the future, this makes it possible to exclude the operator from the MPU control process and to reconsider approaches to the issue of increasing the efficiency of technological operations. The existing trend of productivity improvement by increasing the main parameters of the unit, such as operating width, operating velocities, load capacity, etc., may change to an alternative path consisting in the use of numerous autonomous small-sized units comparable in performance (a swarm of agricultural robots). Thus, the use of driverless control systems makes it possible to use conceptually new approaches to the development of agricultural MPUs. In this regard, it becomes relevant to conduct the study aimed at identifying promising conceptual directions for the development of driverless MPUs and evaluating the efficiency of their application.

***AIM:*** Identification of conceptual directions for the development of driverless driverless MPUs and a theoretical assessment of the efficiency of their application.

***METHODS:*** The study object was the MPU transformation in the context of the development of driverless control systems. The study was based on scientific publications on the development of robotic agricultural tools, informational data of manufacturers of agricultural tractors and control systems for agricultural machinery. In the course of the study, such methods as information analysis, synthesis, methods of performance analysis of agricultural units and analysis of present cost of performing technological operations, adapted for driverless MPUs by the Federal Scientific Agroengineering Center VIM, were used.

***RESULTS:*** The prospects for the introduction of driverless MPUs, the existing digital and intelligent control systems of MPUs and the main factors hindering their development are analyzed. A classification of agricultural MPUs according to automation levels is proposed. The main directions of development are identified and conceptual models of driverless MPUs are proposed: universal driverless MPUs (driverless tractors) with keeping the existing traction class and power classification, universal (multifunctional) low-power driverless MPUs of the only traction class, separate power modules capable of being combined into a single driverless unit based on the coupled agricultural machine. The method is proposed and the equivalent number of driverless MPUs of each conceptual model for each traction class is calculated. An assessment of the impact of the use of the proposed conceptual models of driverless MPUs on the arable unit performance and the present cost of arable operations has been carried out.

***CONCLUSIONS:*** Conceptual models for the advancing of driverless MPUs have been developed and comparative calculations of the efficiency of their application as part of arable units, helping to assess the possible prospects for their use, have been made.

**Keywords:** mobile power units; concept; driverless tractor; control system; automation level.

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Оригинальное исследование

# Концептуальные направления развития беспилотных мобильных энергетических средств сельскохозяйственного назначения

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АННОТАЦИЯ

**Обоснование.** В настоящее время крупные мировые разработчики и производители в области мобильных сельхозмашин ведут работы над созданием сельскохозяйственных роботизированных систем. Особое внимание уделяется разработке универсальных беспилотных мобильных энергетических средств (МЭС), позволяющих автономно выполнять различные технологические операции без участия человека. В перспективе это позволит исключить оператора непосредственно из процесса управления МЭС и пересмотреть подходы к вопросу повышения эффективности выполнения технологических операций. Существующий тренд повышения производительности за счёт увеличения основных параметров агрегата: ширины захвата, рабочих скоростей, грузоподъёмности и т. д. — может измениться на альтернативный путь, заключающийся в применении сопоставимого по производительности множества автономных малогабаритных агрегатов (рой сельскохозяйственных роботов). Таким образом, применение беспилотных систем управления позволяет использовать концептуально новые подходы к созданию МЭС сельскохозяйственного назначения. В связи с этим становится актуальным проведение исследований, направленных на выявление перспективных концептуальных направлений развития беспилотных МЭС и оценку эффективности их применения.

**Цель исследования** — выявление концептуальных направлений развития беспилотных МЭС сельскохозяйственного назначения и теоретическая оценка эффективности их применения.

**Методы.** Объектом исследования являлся процесс трансформации МЭС в условиях развития беспилотных систем управления. Основой исследования послужили научные публикации по вопросам развития роботизированных средств сельскохозяйственного назначения, информационные материалы предприятий-изготовителей сельскохозяйственных тракторов и систем управления сельскохозяйственной техникой. В процессе исследования использовались такие методы, как информационный анализ, синтез, методики расчёта производительности сельскохозяйственных агрегатов и приведённой себестоимости выполнения технологических операций, адаптированные ФГБНУ ФНАЦ ВИМ применительно к беспилотным МЭС.

**Результаты.** Проанализированы перспективы внедрения беспилотных МЭС, существующие цифровые и интеллектуальные системы управления МЭС и основные факторы, сдерживающие их развитие. Предложена классификация МЭС сельскохозяйственного назначения по уровням автоматизации. Выявлены основные направления развития и предложены концептуальные модели беспилотных МЭС: универсальные беспилотные МЭС (беспилотные тракторы) с сохранением существующей градации по тяговому классу и мощности, универсальные (многофункциональные) беспилотные МЭС малой мощности одного тягового класса, раздельные энергетические модули, объединяющиеся в единый беспилотный агрегат на базе агрегатируемой сельскохозяйственной машины. Предложена методика, и осуществлён расчёт эквивалентного количества беспилотных МЭС каждой концептуальной модели для каждого тягового класса. Осуществлена оценка влияния применения беспилотных МЭС предложенных концептуальных моделей на производительность пахотного агрегата и приведённую себестоимость выполнения пахотных работ.

**Заключение.** Разработаны концептуальные модели развития беспилотных МЭС и произведены сравнительные расчёты эффективности их применения в составе агрегатов для вспашки, позволяющие дать оценку возможным перспективам их использования.

**Ключевые слова:** мобильное энергетическое средство; концепция; беспилотный трактор; система управления; уровень автоматизации.

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## BACKGROUND

A key priority field of scientific and technological development of agriculture is the transition to highly productive, environmentally friendly agriculture. This transition involves adopting digital, intelligent, and robotic systems to enhance productivity and sustainability [1], [2]. This approach requires a fundamentally new approach to managing agricultural production processes [3].

Leading global major developers and manufacturers are increasingly focusing on agricultural robots and robotic systems [4]. A key area of focus is developing universal unmanned mobile power units (MPUs) that perform autonomously various technological operations without human participation [5].

Automation and robotization bring several advantages to the agricultural industry, including the following:

- enhancing labor productivity and eliminating manual labor;
- reducing or eliminating the influence of the human factor on production results;
- optimizing costs and reducing production costs;
- implementing the production potential of agricultural plants and animals and reducing product losses owing to strict adherence to agricultural technologies;
- increasing energy efficiency and environmental safety of agricultural machinery;
- increasing the safety of technological operations and reducing the impact of harmful production factors on humans;
- increasing the efficiency of using the agricultural machinery fleet.

Integrating digital technologies into MPUs transforms tractors and self-propelled combines into intelligent machines. These machines connect not only mechanically with mounted and trailed equipment (mounted system, trailer hitch, hydraulic system, power take-off shaft) but also integrate information (electronic) systems) [6]. Automation controls the depth of cultivation of tillage units, and ensures high accuracy of seed sowing and fertilizer application by using satellite navigation systems. It also allows remote configuration of machine settings via Internet connection,tailored to agroclimatic conditions and field geometric parameters [7], [8].

Modern tractors are equipped with intelligent engine control systems and drivetrain operating modes. Jointly, they develop an optimal operating mode depending on the load, which enables to use engine power most efficiently, cut down on fuel consumption, and reduce harmful emissions. The widespread use of automated control systems for controlling mounted systems, power take-off shafts, and hydraulic drives is becoming increasingly widespread. Automatic driving systems also facilitate the operation of wide-coverage vehicles, minimizing product and time losses and enhancing the quality of technological operations [9].

The advancement of unmanned control systems allows the use of conceptually new approaches for developing MPUs for agricultural purposes. InOngoing research aims to identify promising directions for the development of these systems and assess their theoretical effectiveness.

**The study sought to** identify conceptual directions for the development of unmanned MPUs for agricultural purposes and assess theoretically their effectiveness in agricultural applications.

## METHODS

The study focused on transforming MPU systems in the context of the development of unmanned control systems. The research was based on scientific publications about robotic agricultural equipment and information material from manufacturers of agricultural tractors and control systems. Methods included information analysis, synthesis, and productivity calculations for agricultural units. These methods were adapted by the Federal Scientific Agroengineering Center All-Russian Research Institute of Agricultural Mechanization specifically for unmanned MPUs.

## RESULTS

The transition to digital agriculture involves the use of MPUs with electronic control systems. Implementing these systems is an initial step toward fully unmanned MPUs, which will soon be capable of performing technological operations independently under the supervision of an operator in the cabin. In the long term, these MPUs are expected to operate autonomously in the field remote supervision from a control room, monitoringmultiple technical systems simultaneously [6].

Currently, significant progress has been made in developing MPUs with automatic control (autopilot) while keeping the operator in the cabin.

The initial stages of creating automatically controlled MPUs involves using parallel driving systems based on GPS/GLONASS navigation systems guided by a preloaded task map of a specific field. At their core, these systems function as electronic assistants, aiding the operator in controlling a tractor or self-propelled agricultural machine. There are several levels of parallel driving systems, namely course indicators (agronavigators), thrusters, and autopilot systems [9], [10].

Course indicators represent navigation systems for agricultural use. With these systems, the operator navigates the tractor or self-propelled agricultural machine based on course indicator signals. These systems are easy to install, relatively inexpensive, and can achieve accuracy up to 2 cm with a base RTK station, allowing minimal deviations from the set trajectory and ensuring a minimum overlap width of. However, the accuracy of movement of a unit with an agronavigator highly depends on the operator's qualifications and reaction speed. The operator must manage both the technological process flow and the tractor's directional compliance with the given course. Course indicators are most commonly used for operations that do not require high-precision, such as applying liquid and solid organic and mineral fertilizers and harrowing.

Thrusters function as advanced agricultural navigators equipped with mechanical steering devise that automatically adjust the movement direction of a tractor or self-propelled agricultural implement according to a given course. Typically, a thruster is either an additional steering wheel drive attached to the side or a replacement for the existing steering wheel. At its core, a thruster features an electronically controlled electric motor that transmits torque to the steering wheel or the steering shaft of the tractor mechanism. This system ensures driving accuracy in a stint without depending on the operator's skills or concentration level. However, it does rely on the technical condition and general technical capabilities of the steering system installed on the tractor. Thrusters are ideal for high-precision operations, including basic and presowing tillage, sowing and planting crops, spraying, and harvesting.

Autopilot systems take agricultural navigation further by incorporating a hydraulic unit installed into the hydraulic steering system, controlled electronically. Steering wheel rotation sensors improve driving accuracy. These systems enable autonomous driving not only in straight lines but also during U-turns, allowing the operator to concentrate on monitoring the progress of the technological process and the technical condition of the machine–tractor unit. Autopilot systems are versatile and can be used for almost all operations, from tillage to harvesting, excelling in high-precision crop care operations, in particular during interrow cultivation of row crops.

All parallel driving systems based on GPS/GLONASS navigation achieve increased positioning accuracy up to 2–3 cm using an RTK base station, although this coverage is usually limited to a few kilometers. Alternatively, paid paid adjustments can be connected to enhance accuracy [9].

Advancements in autopilot systems for agricultural tractors are focused on increasing automation and safety of operation of agricultural implements and units (Fig. 1). This is achieved through technical vision and artificial intelligence components.

Cognitive Pilot has developed the Agro Pilot unmanned driving system, leveraging artificial intelligence and deep learning technology of neural networks. The Cognitive Agro Pilot system includes a control unit with a neuroprocessor for autonomous driving, color video cameras, a control tablet, a digital hydraulic unit for steering control, and wheel turning angle sensors. This system allows a tractor or self-propelled agricultural machine to move autonomously on the field, guided by edges, windrows, or crop rows, while maintaining a specified speed. Driving accuracy is 1–2 cm using GPS/GLONASS navigation with an RTK base station and corrections, and speed control is within 1 km/h.

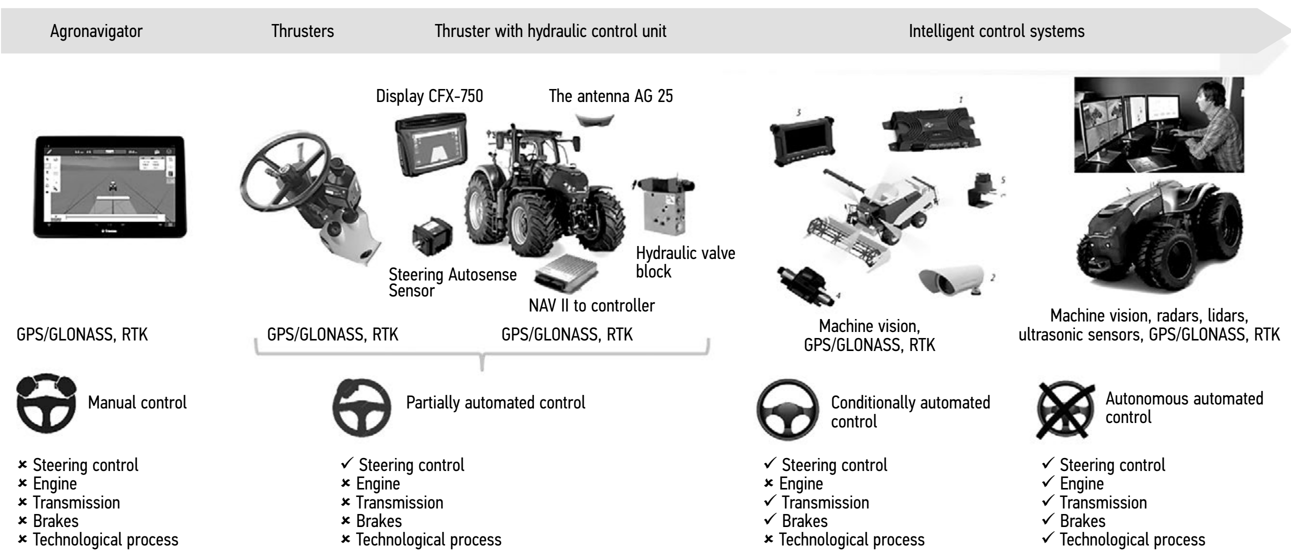


**Fig. 1.** Advancing of autonomous control systems of agricultural MPUs.
**Рис. 1.** Развитие автономных систем управления МЭС сельскохозяйственного назначения.

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The neural network, informed by the cameras, enables the combine to turn around automatically, change lanes to unharvested areas, stop before obstacles, or navigate around them [11].

The autopilot system under consideration can automate some functions, partially relieving the operator from directly controlling the tractor or self-propelled agricultural machine. This allows the operator to focus more on monitoring and managing the technological process. However, this system does not yet possess the full capability to make independent decisions in all nonstandard situations, requiring operator intervention in such cases. Consequently, the current autopilot systems cannot fully eliminate the need for an operator, making the creation of unmanned or autonomous robotic MPUs for agricultural purposes unattainable at this stage.

Several challenges hinder the further development and implementation of automated control systems. While these systems have high operational efficiency under operator supervision, they are not yet fully autonomous and struggle to generate optimal solutions in unexpected situations [12]. This limitation fosters distrust in these systems owing to the potential for material harm caused by system failures. Additionally, cybersecurity issues require elaboration, since attackers could potentially disable equipment, destroy crops, or cause other material damage. Comprehensive requirements for these systems must be elaborated and enshrined in the relevant regulations.

The use of unmanned MPUs requires seamless interaction among units. However, there is currently no specially allocated frequency for agricultural machinery that facilitates both remote control of MPUs and their contactless interaction. Compatibility issues also arise with existing software and hardware from different MPU and agricultural machine manufacturers, using a uniform data transfer protocol and standardized CAN buses. Although the international ISOBUS protocol exists, not all agricultural machine manufacturers, especially those producing in Russia, integrate elements of this system into their equipment. For the successful creation of unmanned MPUs, it is essential to establish legal requirements for the frequencies used, data transfer protocols, CAN buses, control units, and controllers.

Another significant hurdle hindering the development of Russian-made robotic agricultural machinery and, in particular, unmanned control systems, is the lack of a Russian-made component base, including microelectronics, neural computers, radars, lidars, cameras for machine vision technologies, RTK base stations, satellite communication systems, data reception and transmission units, and actuators for controlling electrical, mechanical, hydraulic and pneumatic components of agricultural machinery.

Given that MPUs operate in field conditions and traverse surfaces without hard coatings, it is crucial to ensure their passability in addition to geometric and technological cross-country ability. This requires the development of sensors and systems capable of determining the soil's bearing capacity and assessing the feasibility of MPU movement on such soil [13].

Technologies for unmanned control of various types of technical equipment are intensively developing across all industries. The trend is particularly evident in the fields ofh commercial and personal transportation, where many global automakers are developing unmanned vehicles. This rapid progress has prompted the creation of regulations that reflect levels of control automation. In 2018, the SAE J 3016-2018 standard, titled "Classification and systematization, as well as definitions of terms related to driving automation systems for road motor vehicles" was established by specialists from the international Society of Automotive Engineers (SAE) [14].

The standard provides a framework for classifying and defining terms related to driving automation systems. It emphasizes automation as part of vehicle systems rather than the vehicle itself. Specifically, SAE J 3016-2018 describes automated vehicle control systems that perform some or all of the dynamic driving tasks and involve three primary driving participants: a human driver, a driving automation system, and other vehicle systems and components.

According to SAE J3016, vehicles are classified into 6 levels of vehicle driving automation:

- Level 0: no driving automation
- Level 1: driver assistance
- Level 2: partial driving automation
- Level 3: conditional driving automation
- Level 4: high driving automation
- Level 5: full driving automation.

Level 0 vehicles lack any automation systems. However, levels 1 and 2 include systems that have been in use for some time, such as ABS, cruise control, and dynamic stability traction control.

By drawing an analogy to this classification, agricultural MPUs can also be classified based on their level of automation (Table 1).

Where M is manual control; MA is manual control with the ability to automate certain actions; AM defines automatic operations with the ability of manual control; AD refers to automatic control under remote supervision by a dispatch center operator; and A denotes automatic control under remote control of a central intelligent control system.

At level 0, there are no electronic control systems for any MPU functions; the operator exercises full control over all aspects of the MPU and the technological processes it implements.

**Table 1.** Automation levels of agricultural MPUs
**Таблица 1.** Уровни автоматизации МЭС сельскохозяйственного назначения

| **Automation level** | **Level 0** | **Level 1** | **Level 2** | **Level 3** | **Level 4** | **Level 5** |
|---|---|---|---|---|---|---|
| | **No electronic systems** | **Electronic assistants** | **Partial automation** | **Conditional automation** | **High automation** | **Full automation** |
| Engine control | M | M | MA | AM | AD | A |
| Transmission control | M | M | MA | AM | AD | A |
| Steering control | M | MA | MA | AM | AD | A |
| Brake system control | M | M | MA | AM | AD | A |
| Hydraulic system control | M | MA | MA | AM | AD | A |
| Control PTO shaft | M | MA | MA | AM | AD | A |
| Control with electric actuators | M | MA | MA | AM | AD | A |

*Note.* M — manual control; MA — manual control with the ability to automate certain actions; AM — automatic control with the ability to manual control; AD — automatic control under remote control of the dispatch center operator; A — automatic control under remote control of a central intelligent control system.
*Примечание.* Р — ручное управление; РА — ручное управление с возможностью автоматизации определённых действий; АР — автоматическое с возможностью ручного управления; АД — автоматическое управление под дистанционным контролем оператора диспетчерского центра; А — автоматическое управление под дистанционным контролем центральной интеллектуальной системы управления.

Level 1 involves the use of separate auxiliary systems, such as course indicators, agricultural navigators, steering correction systems, systems for turning the PTO shaft on and off. Other features include systems for lowering and lifting mounted equipment during turns, maintaining a set depth of cultivation, and adjusting the angle of inclination of the lift hitch. In this case, the operator is freed from performing simple, repetitive actions but must still monitor their implementation by electronic systems. This reduces the operator's load associated with guiding the MPU along the required trajectory and controlling some MPU systems, allowing greater focus on monitoring the technological process.

Level 2 involves partial automation of MPU control, which is associated with the use of automatic speed control and motion control with operator adjustments. The system can orient itself along rows of agricultural crops, mown swaths, edges of adjacent passages, field edges, and uncultivated parts. Autonomous safety systems a recognize obstacles on the way, stopping the MPU or navigating around them independently. When using such systems, the operator trusts most MPU movement-related functions to automation systems but intervenes when the system cannot make decisions independently.

Level 3 involves conditional automation of mobile devices, where all MPU control systems related to both motion control and technological process control are automated. The operator, located in the cabin, makes occasional adjustments or intervenes when the automatic system fails to make a decision independently.

Level 4 involves the use of unmanned control systems under remote operator supervision. The electronic system controls completely all functions of the unmanned MPU, but the operator located nearby or in the control room can remotely adjust operations or take over control if necessary.

Level 5 involves full automation, with an unmanned MPU controlled automatically under the remote supervision of a central intelligent control system and operator supervision.

According to experts, the automation level of mass-produced cars with automatic control functions reaches Level 3. By contrast, for agricultural MPUs, in accordance with the proposed division, some of the most advanced prototypes using automatic MPU control systems can be classified as Level 2, while commercially produced ones can be classified as Level 1.

Serially produced and widely used parallel and automatic driving systems based on GPS/GLONASS geopositioning and neural networks offer high functionality, accuracy, versatility, and accessibility. These systems already automate certain MPU control processes. The continued development of intelligent technologies in agriculture opens the door to new methods for managing agricultural machinery. Machine vision technologies, various types of detecting elements and sensors, electronic control systems, wireless data transmission technologies, and the Internet of Things make it possible to create unmanned vehicles that improve the quality of technological operations, ensure high accuracy and safety of driving, and achieve autonomy. This progress will eventually eliminate the need for an operator cabin, allowing remote control of unmanned MPUs from a centralized control center [15].

The transition to Level 4 automation removes the operator directly from the direct management of the MPU. This shift offers new approaches to increasing a main production indicator, labor productivity. In the future, with Level 4 and higher automation levels, a single operator can manage multiple units. Instead of focusing on increasing the cultivation width, operating speeds, and load capacity of individual units, this new approach could utilize a multitude of small, autonomous agricultural robots. This alternative strategy could match or even exceed current performance levels.

Moreover, the evolution toward higher technical level in tractors involves using the technological part of the unit as hitch weight. This would require extensive adaptive drivetrains in both the MPUs and agricultural machines, necessitating a transformation of both the MPUs themselves and the aggregated agricultural machines [16].

Thus, unmanned control systems allow for conceptually new approaches to creating MPUs for agricultural purposes. Research into robotic tools for agriculture [1] has identified three conceptual directions for developing unmanned MPUs (Fig. 2).

The conceptual direction 1 (conceptual model A) represents the development of unmanned universal MPUs based on mass-produced tractor models equipped with automation equipment and intelligent control systems. In most cases, the cabin and traditional manual controls may be retained or removed. This approach preserves existing trends in increasing the productivity of agricultural units by increasing the MPU power, the cultivation width of agricultural implements, working speeds, and other factors. These units typically operate individually or in small groups of 2–3 units and are often paired with commercially produced agricultural machines. Examples of this approach include the unmanned tractor concepts without cabins made from John Deere [17] and Case IH [18].

The conceptual direction 2 (conceptual model B) focuses on creating universal, unmanned low power MPUs that perform tasks primarily in groups. The idea is to develop universal machines of identical power that can collectively replace the entire range of existing tractors of different drawbar categories and power levels. All operational equipment would need to be standardized to match the traction force and power of

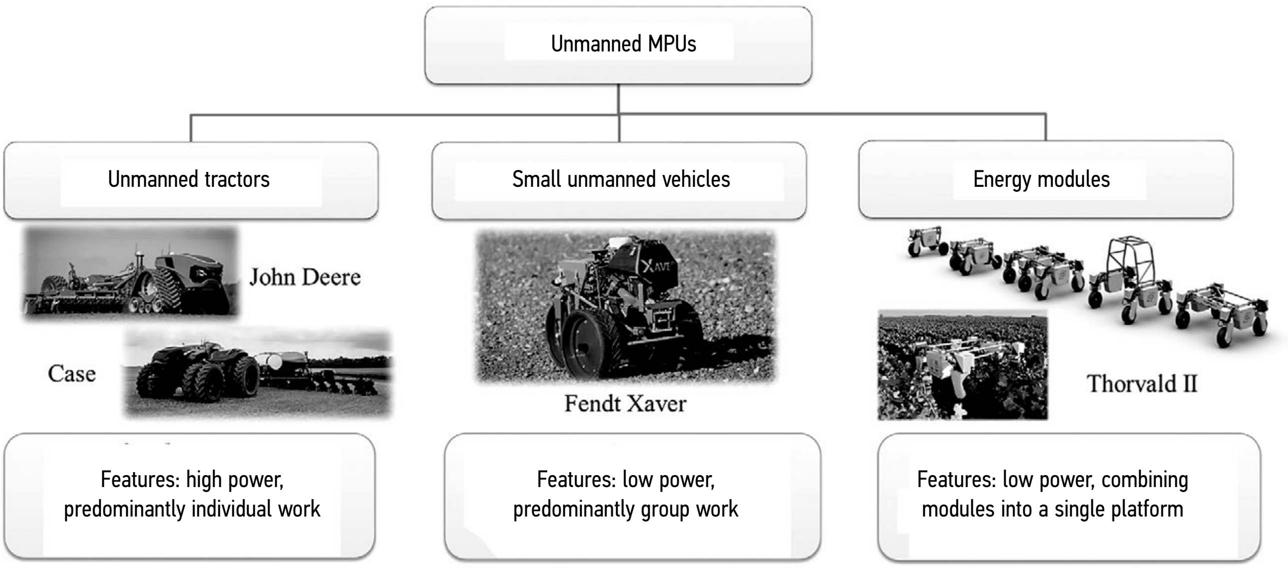


**Fig. 2.** Conceptual directions of development of driverless agricultural MPUs.
**Рис. 2.** Концептуальные направления развития беспилотных МЭС сельскохозяйственного назначения.

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these MPUs. An example of this approach is the Fendt Xaver sowing robots, which operate in groups controlled using cloud technologies. This reduces the number of installed sensors needed and simplifies the software and hardware installed on each robot [19].

The conceptual direction 3 involves using energy modules to develop unmanned MPUs for agricultural purposes (conceptual model C). This concept involves the creation of unmanned MPUs composed of several power modules, each of which includes all essential elements for performing as a traction-energy vehicle and for interacting with the external environment, other modules in the unit, and other units. By combining multiple power modules, it is possible to create unmanned MPUs of varying power levels and traction forces. Commercial agricultural machines with different parameters such as cultivation widths, operating speeds, power consumption, and hopper capacity can be adapted to work with these energy modules [20]. An example of this concept in action is the modular principle of constructing the Thorvald II robot system [21].

The abovedescribed conceptual models for the development of unmanned MPUs require sufficiently high levels of automation in agricultural unit control.

Figure 3 illustrates how unmanned MPUs from conceptual models A, B, and C can be aggregated with plows and cultivators for continuous and interrow tillage.

Currently, scientists and leading manufacturers of agricultural machinery are exploring all three concepts. To further determine the prospects for using the proposed conceptual models of unmanned MPUs, it is necessary to explore their comparative effectiveness.

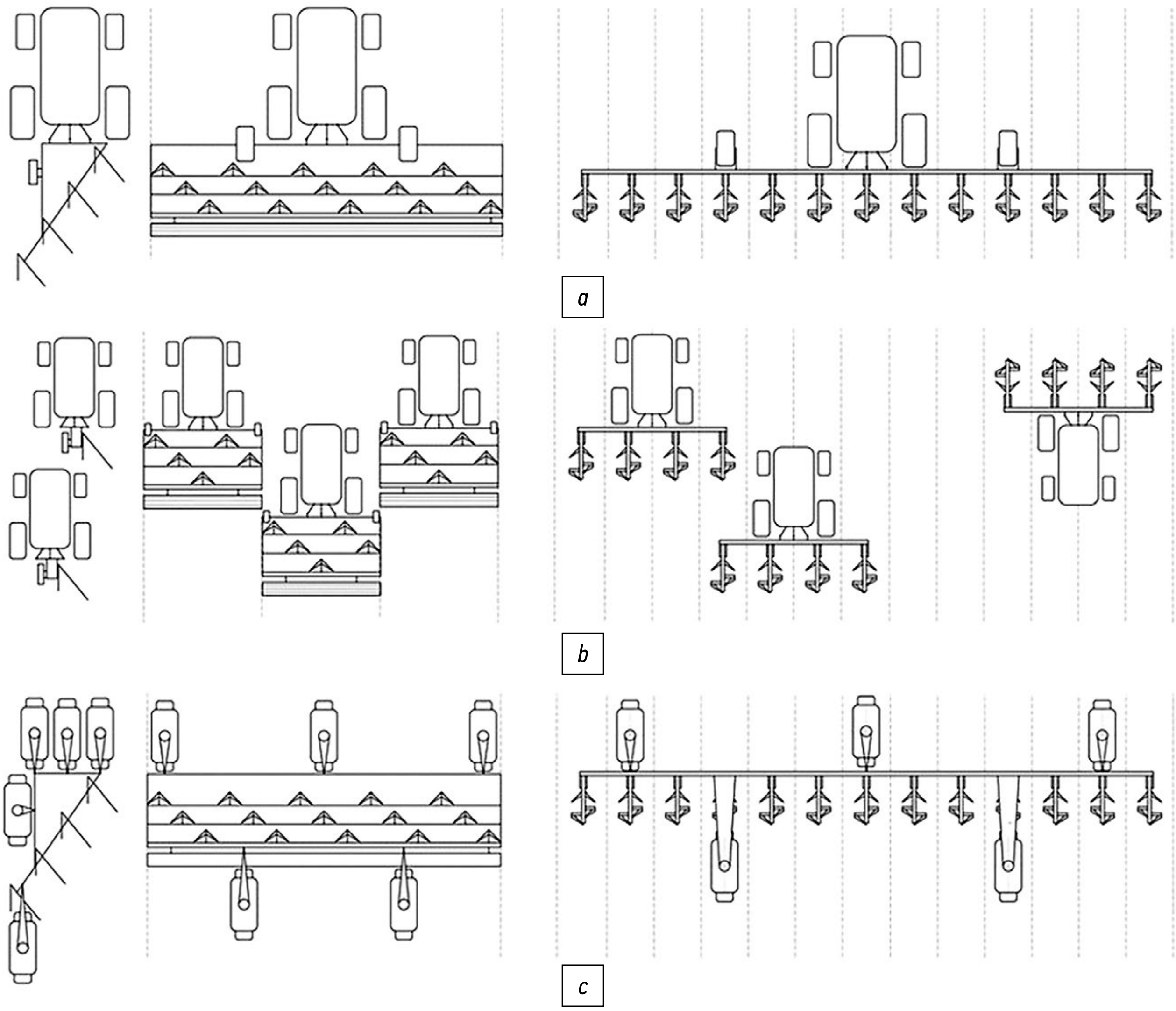


**Fig. 3.** Coupling of driverless MPUs with ploughs, unstriped and inter-row cultivators. *a* — conceptual model A; *b* — conceptual model B; *c* — conceptual model of C.

**Рис. 3.** Агрегатирование беспилотных МЭС с плугами, сплошными и междурядными культиваторами: *a* — концептуальная модель А; *b* — концептуальная модель В; *c* — концептуальная модель С.

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To compare different conceptual models, it is necessary to determine the equivalent number of unmanned MPUs relative to different conceptual models created by basic models (serial) of tractors across various drawbar categories. In theoretical studies, commercially produced agricultural tractors of drawbar categories ranging from 0.2 to 8 were taken as base models, according to GOST 27021-86 (ST SEV 628-85) "Agricultural and forestry tractors." Drawbar categories." In studies, it is assumed that in terms of traction force, unmanned MPUs of conceptual model B correspond to a tractor of drawbar category 0.6, while those of conceptual model C correspond to a tractor of drawbar category 0.2.

The use of unmanned MPUs of conceptual model A involves replacing the base tractor of the $i$-th drawbar category with an unmanned MPU of the same $i$-th drawbar category or converting the base tractor to unmanned operation. Each tractor in the $i$-th drawbar category is replaced by one unmanned MPU of the same category, i.e.:

$$n_{\text{A}}^{i} = n_{\text{б}}^{i}, \tag{1}$$

where is the drawbar category indicator according to GOST 27021-86; $n_{\text{A}}^{i}$ represents the estimated number of unmanned MPUs of the $i$-th drawbar category, model A, units; $n_{\text{б}}^{i}$ represents the number of basic tractors being replaced by unmanned MPUs..

In the case of using unmanned MPUs of conceptual models B and C (energy modules), one tractor of the $i$-th drawbar category was replaced by one or more unmanned MPUs of certain tract drawbar categories:

$$n_{\text{B}}^{i} \geq n_{\text{б}}^{i}, \tag{2}$$

$$n_{\text{C}}^{i} \geq n_{\text{б}}^{i}, \tag{3}$$

where $\text{n}_{\text{B}}^{\text{i}}$ is the estimated number of unmanned MPUs of conceptual model B, units; and $\text{n}_{\text{C}}^{\text{i}}$ denotes the estimated number of unmanned MPUs of conceptual model C (energy modules).

Since the traction force of unmanned MPUs of conceptual models B and C (energy modules) is initially accepted and remains constant, their equivalent number will directly depend on the traction force of the used base tractor of the $i$-th drawbar category.

The number of unmanned MPUs of conceptual model B, equivalent in traction force to a tractor of the $i$-th drawbar category, is determined by the following equation:

$$n_{\text{B}}^{i} = \frac{P_{\text{Kp b}}^{i}}{P_{\text{Kp B}}}, \tag{4}$$

where $P_{\text{Kp b}}^{i}$ is the maximum value of the rated traction force of the base tractor of the $i$-th drawbar

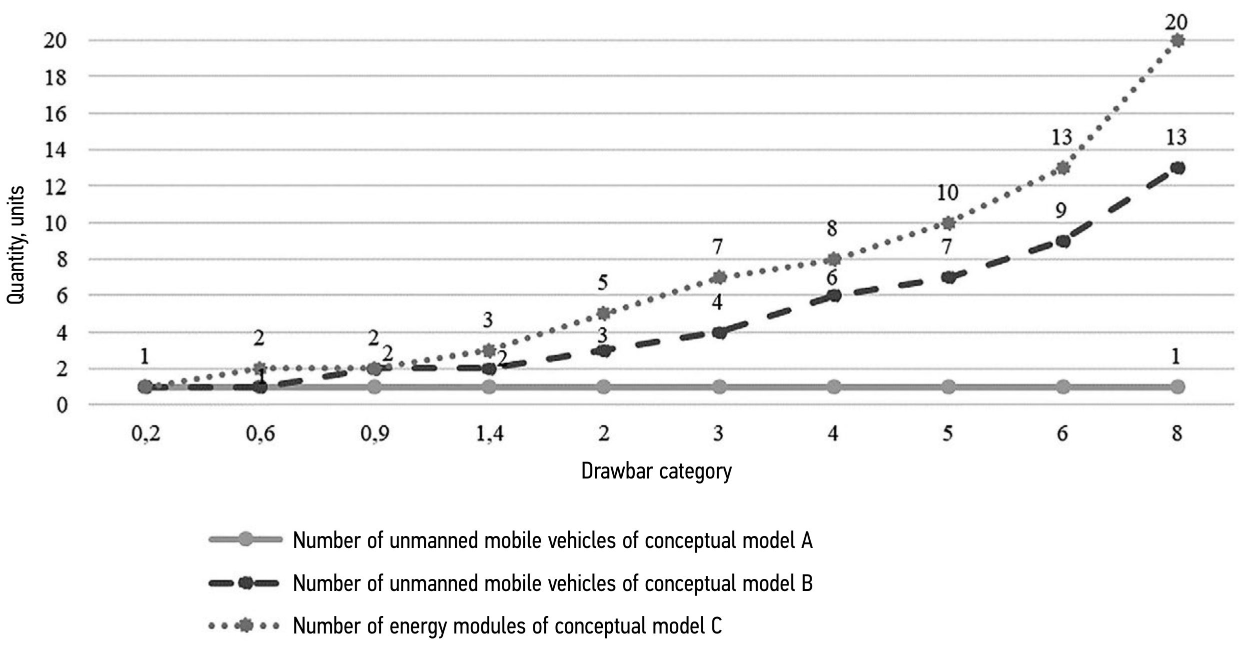


**Fig. 4.** Results of calculation of equivalent number of driverless MPUs of the conceptual models A, B and C depending on drawbar category of a basic tractor.

**Рис. 4.** Результаты расчёта эквивалентного количества беспилотных МЭС концептуальных моделей А, В и С в зависимости от тягового класса базового трактора.

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category according to GOST 27021-86, kN; $P_{\text{Kp B}}$ is the maximum value of the nominal traction force of an unmanned MPU of conceptual model B, kN. In our case, according to GOST 27021-86 for drawbar category 0.6, $P^{0,6}_{\text{Kp B}} =$ 8,1 kN.

The number of energy modules in conceptual model C, equivalent in traction force to a tractor of the $i$-th drawbar category, is determined using the following equation:

$$n^i_{\text{C}} = \frac{P^i_{\text{Kp b}}}{P_{\text{Kp C}}}, \tag{5}$$

where $P_{\text{Kp C}}$ is the maximum value of the rated traction force of the power module of the model C, kN. In our case, according to GOST 27021-86 for drawbar category 0,2 $P^{0,2}_{\text{Kp C}} =$ 5,4 kN.

In accordance with the outlined methodology, calculations were carried out, and a graph was plotted (Fig. 4) to indicate the dependence of the number of unmanned MPUs of conceptual models A, B, and C on the drawbar category of the base tractor. During the calculations, the equivalent number was rounded to integral numbers.

Conceptual model A assumes creating unmanned MPUs for each drawbar category. On the graph, this is represented as a straight line parallel to the x-axis, passing through the value of 1 of the y-axis.

To evaluate the potential of using the proposed conceptual models of unmanned MPUs, research was conducted to determine their impact on productivity and economic efficiency. This involved assessing the performance of units combined with unmanned MPUs from various conceptual models and evaluating cost reductions. The assessment relied on existing well-known methods [22], refined by the Federal Scientific Agroengineering Center Federal Scientific Agroengineering Center VIM.

A comparative assessment of the productivity of plowing units with reversible plows using unmanned MPUs from three conceptual models was performed.

The specific parameters used in the assessment included a run length of 1,000 m, tillage depth of 20–22 cm, specific traction resistance of the implement of 13.4 kN/m at a speed of 5 km/h, and a growth rate of traction resistance of the implement of 5% per 1 km/h increase in speed. The method for the unit movement was shuttle with loop bulb-shaped turns at the end of the run.

For calculating the shift time utilization coefficient, it was assumed that for basic tractors, 15 minutes per shift were spent on the operator's personal needs, with a rest time coefficient of 0.052. By contrast, for unmanned MPUs, the time spent on the operator's personal needs and rest was not considered.

The coefficient of time spent on turning the unit at the end of the headland was determined using the values of the kinematic length and the minimum turning radius of commercially produced agricultural tractors corresponding to the drawbar categories. Data on the kinematic length of agricultural implements were taken from the technical specifications provided by the manufacturers. A turning speed of 5 km/h was assumed for the unit.

For calculations, the shuttle method of the unit movement with loop bulb-shaped turns was adopted. For units with unmanned MPUs of conceptual model C, a loopless (trajectory along

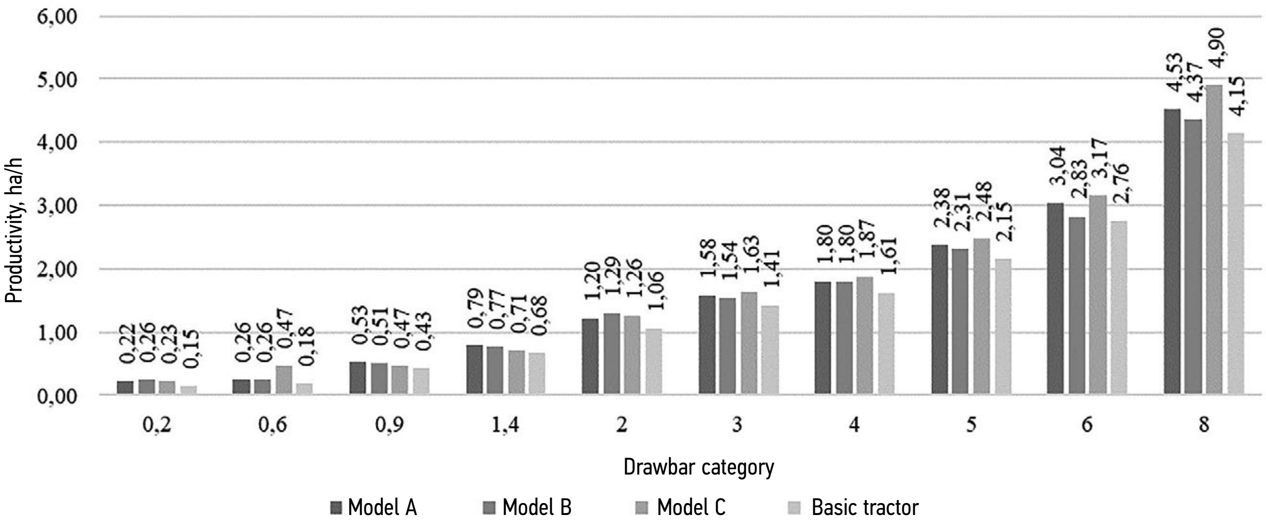


**Fig. 5.** Assessed hour performance of arable units including driverless MPUs of various conceptual models.
**Рис. 5.** Расчётная часовая производительность пахотных агрегатов в составе с беспилотными МЭС различных концептуальных моделей.

**Table 2.** Present cost of ploughing per hectare, rub/ha
**Таблица 2.** Себестоимость вспашки одного гектара, руб./га

| Drawbar category | Model A | Model B | Model C | Basic tractor |
|---|---|---|---|---|
| 0,2 | 3744,49 | 3054,24 | 2146,70 | 5835,98 |
| 0,6 | 3054,24 | 3054,24 | 1950,00 | 5250,71 |
| 0,9 | 1863,61 | 3054,24 | 1953,09 | 2677,13 |
| 1,4 | 1276,40 | 2036,16 | 1892,41 | 1850,66 |
| 2 | 1352,35 | 1832,54 | 1741,74 | 1746,01 |
| 3 | 1356,37 | 2036,16 | 1859,24 | 1675,90 |
| 4 | 1589,37 | 2617,92 | 1854,10 | 1898,02 |
| 5 | 1368,72 | 2375,52 | 1740,10 | 1617,49 |
| 6 | 1464,18 | 2498,92 | 1766,27 | 1685,94 |
| 8 | 1766,63 | 2335,59 | 1748,42 | 1979,64 |

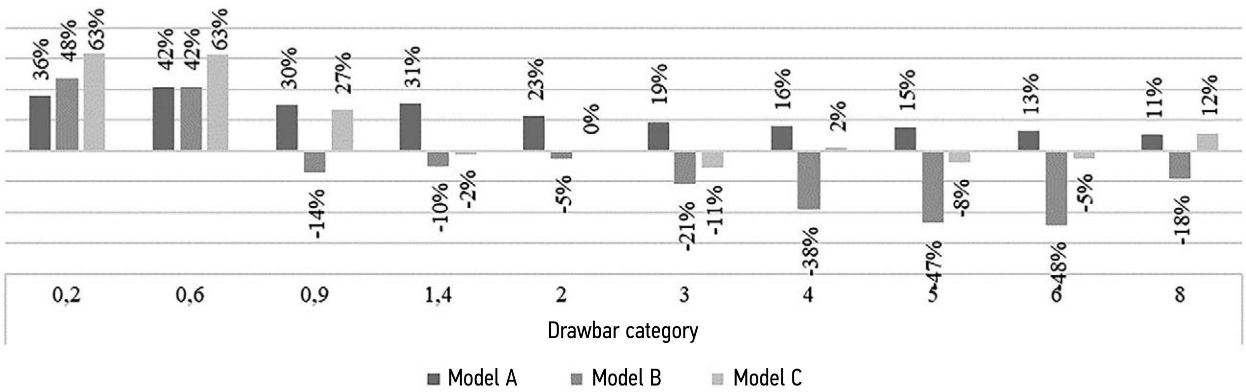


**Fig. 6.** Decreasing the present value of ploughing per hectare using driverless MPUs in comparison with basic tractors.
**Рис. 6.** Снижение себестоимости вспашки одного гектара при использовании беспилотных МЭС относительно базовых тракторов.

the minimum radius) turning method was adopted, where the turning radius equals the working width of the unit.

The results of calculating the hourly productivity of plowing units combined with basic tractors and unmanned MPUs from various conceptual models in their corresponding drawbar categories are presented in Fig. 5.

According to these calculations, the use of unmanned MPUs of the conceptual models under consideration can improve the plowing unit productivity.

The use of unmanned MPUs of conceptual model A can increase the plowing unit productivity across all drawbar categories. The use of unmanned MPUs of conceptual model B can increase the plowing unit productivity by 2%–42%, with significant gains achieved when using a group of these units compared to basic tractors of drawbar categories ranging from 0.6 to 4 (10–42%).

Conceptual model C, when compared to basic tractors of drawbar category over 0.6, can increase plowing unit productivity by 4–18%, with notable increases observed in drawbar categories from 2 to 8 (15–18%).

A comparative assessment of the reduced cost of plowing work using unmanned MPUs versus basic tractors was performed. The results for the cost of plowing one hectare are presented in Table 2.

Based on the data obtained, the reduction in the cost of plowing one hectare was calculated when using unmanned mobile vehicles relative to basic tractors in the corresponding drawbar categories (Fig. 6).

Fig. 6 shows that using unmanned MPUs of conceptual model A in all drawbar categories can

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reduce the cost of work by 11%–42%. The use of unmanned MPUs of conceptual model B is cost-effective compared to basic tractors only in drawbar categories 0.2–0.9. Cost reductions with conceptual model C can be achieved in drawbar categories 0.2–0.6 and 8. In other cases, employing MPUs of conceptual models B and C can lead to increased costs of plowmanship.

## DISCUSSION

Serially produced and widely used parallel and automatic driving systems based on geopositioning systems and neural networks now enable the automation of certain MPU control processes. The further development of these control systems is directly related to the integration of geopositioning systems, lidars, radars, machine vision, the Internet of Things, and other intelligent technologies. These advancements pave the way for autonomous control of all functionalities of agricultural MPUs, ultimately eliminating the need for an operator in the cabin and transitioning to fully unmanned MPUs.

Research has enabled the classification of agricultural MPUs according to automation levels. The transition to unmanned MPUs is possible upon reaching Level 4 automation, where the operator remotely controls the unit. The developed conceptual models reflect the main trends and promising directions for MPU development. The proposed methodology for calculating the equivalent number of unmanned MPUs helps determine the optimal number of unmanned MPUs included in an agricultural unit with each conceptual model for each drawbar category.

Calculations show that using unmanned MPUs of the conceptual models under consideration can improve plowing unit productivity. Specifically, conceptual model A can improve productivity and reduce costs across all drawbar categories. Conceptual model B can positively affect costs only within drawbar categories 0.2–0.9. Ultimately, conceptual model C shows cost benefits in drawbar categories 0.2–0.6, and 8. In other cases, conceptual models B and C can lead to increased plowing costs.

## CONCLUSION

Theoretical studies suggest that the proposed conceptual models of unmanned MPUs can improve the productivity of agricultural units. However, the results on the reduced cost of performing agricultural work with these models are ambiguous. For a more comprehensive and objective assessment of the effectiveness of the use of using unmanned MPUs, it is advisable to assess their performance across various agricultural operations.

## ADDITIONAL INFORMATION

**Authors' contribution.** I.A. Starostin — study management, conceptualization, methodology, project administration; A.V. Eshchin — formal analysis, conducting the study, writing the draft of the manuscript, visualization; T.Z. Godzhaev — conducting the study, writing the draft of the manuscript, writing and editing the final version of the manuscript; S.A. Davydova — formal analysis, conducting the study, writing the draft of the manuscript, writing and editing the final version of the manuscript. All authors made a substantial contribution to the conception of the work, acquisition, analysis, interpretation of data for the work, drafting and revising the work, final approval of the version to be published and agree to be accountable for all aspects of the work.

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## ДОПОЛНИТЕЛЬНАЯ ИНФОРМАЦИЯ

**Вклад авторов.** И.А. Старостин — руководство исследованием, концептуализация, методология, администрирование проекта; А.В. Ещин — формальный анализ, проведение исследования, создание черновика рукописи, визуализация; Т.З. Годжаев — проведение исследования, создание черновика рукописи, создание окончательной версии (доработка) рукописи и её редактирование; С.А. Давыдова — формальный анализ, проведение исследования, создание черновика рукописи, создание окончательной версии (доработка) рукописи и её редактирование. Авторы подтверждают соответствие своего авторства международным критериям *ICMJE* (все авторы внесли существенный вклад в разработку концепции, проведение исследования и подготовку статьи, прочли и одобрили финальную версию перед публикацией).

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## REFERENCES

**1.** Starostin IA, Eshchin AV, Davydova SA. Global trends in the development of agricultural robotics. *IOP Conf. Series: Earth Env. Sci.* 2023;1138:012042. doi: 10.1088/1755-1315/1138/1/012042

**2.** Lobachevskij JaP, Bejlis VM, Cench JuS. Aspekty cifrovizacii Sistemy tehnologij i mashin // *Jelektrotehnologii i jelektrooborudovanie v APK.* 2019;3(36):40–45. (In Russ). EDN RLCDHO

**3.** Aksenov A.G. Analiz intellektual'nyh sistem podderzhki prinjatija reshenij v sel'skom hozjajstve // *Jelektrotehnologii i jelektrooborudovanie v APK.* 2019;3(36):46–51. (In Russ). EDN CECDAH

**4.** Izmailov AYu, Godzhaev ZA, Grishin AP, et al. Digital agriculture (a review of digital technologies for agricultural purposes). Innovations in agriculture. 2019;2(31):41–52. (In Russ). EDN: JNIMAH

**5.** Lobachevskij JaP, Dorohov AS. Cifrovye tehnologii i robotizirovannye tehnicheskie sredstva dlja sel'skogo hozjajstva. *Sel'skohozjajstvennye mashiny i tehnologii.* 2021;15(4):6–10. (In Russ). EDN YFRZDV doi: 10.22314/2073-7599-2021-15-4-6-10

**6.** Starostin IA, Belyshkina ME, Chilingaryan NO, Alipichev AYu. Digital technologies in agricultural production: implementation background, current state and development trends. *Agricultural engineering.* 2021;3(103):4–10.

**7.** Fedorenko VF, Mishurov NP, Buklagin DS, et al. *Digital agriculture: state and development prospects.* M.: Rosinformagrotech; 2019. (In Russ)

**8.** Starovojtov SI, Cench JuS, Korotchenja VM, Lichman GI. Tehnicheskie sistemy cifrovogo kontrolja kachestva obrabotki pochvy. *Sel'skohozjajstvennye mashiny i tehnologii.* 2020;14(1):16–21. (In Russ). doi: 10.22314/2073-7599-2020-14-1-16-21

**9.** Goltyapin VYa. Systems of parallel driving of machine-tractor units. *Technique and equipment for the village.* 2013;11:12–14. (In Russ). EDN: RKAJJT

**10.** Matyuk NS, Zinchenko SI, Mazirov MA, et al. Resource-saving technologies of tillage in adaptive agriculture. Ivanovo: FGBNU Verkhnevolzhskiy FANTs; 2020. (In Russ). EDN: OXDIHN

**11.** Cognitive Agro Pilot Automatic driving system [internet]. accessed: 14.07.2023. Available from: https://www.tadviser.ru/index.php/

**12.** Sajapin AS, Petrishhev NA, Pestrjakov EV. Sovershenstvovanie upravlenija tehnicheskim sostojaniem mashin za schet ispol'zovanija cifrovyh sredstv monitoringa. *Tehnicheskij servis mashin.* 2023;61(4(153)):10–17. (In Russ). doi: 10.22314/2618-8287-2023-61-4-10-17

**13.** Godzhaev ZA, Lavrov AV, Shevtsov VG, Zubina VA. On the choice of the technological direction of development of the system of agricultural mobile power equipment. *Izvestiya MSTU MAMI.* 2020;1:35–41. (In Russ). EDN: WVVVVS doi: 10.31992/2074-0530-2020-43-1-35-41

**14.** *Taxonomy And Definitions For Terms Related To Driving Automation Systems For On-Road Motor Vehicles.* SAE J 3016. Washington: SAE, 2018.

**15.** Izmailov AYu, Lobachevsky YaP, Dorokhov AS. Modern technologies and equipment for agriculture — trends of the exhibition AGRITECHNIKA 2019. *Tractors and agricultural machinery.* 2020;6:28–40. (In Russ). EDN: OPALJD doi: 10.31992/0321-4443-2020-6-28-40

**16.** Kutkov GM. Development of the technical concept of the tractor. *Tractors and agricultural machinery.* 2019;1:27–35. (In Russ). EDN: ECZSAK doi: 10.31992/0321-4443-2019-1-27-35

**17.** New tracked and wheeled John Deere tractors [internet]. accessed: 14.07.2023. Available from: https://www.deere.ru/ru/tractors/

**18.** Case IH tractors [internet]. accessed: 14.07.2023. Available from: https://www.caseih.com/apac/ru–ru/products/tractors

**19.** Latest generation of seed sowing robots: The Fendt Xaver comes of age. Official website of AGCO GmbH. [internet]. accessed: 14.07.2023. Available from: https://www.fendt.com/int/2-fendt-xaver

**20.** Krestovnikov KD, Erashov AA, Vasjunina JuG, Savel'ev AI. Razrabotka ustrojstva soprjazhenija dlja modul'noj sel'skohozjajstvennoj robototehnicheskoj platformy. *Sel'skohozjajstvennye mashiny i tehnologii.* 2022;16(1):78–88. (In Russ) EDN MNHHSN doi: 10.22314/2073-7599-2022-16-1-78-88

**21.** Grimstad L, From PJ. The Thorvald II agricultural robotic system. *Robotics.* 2017;6:24.

**22.** Vereshchagin NI, Levshin AG, Skorokhodov AN. Organization and technology of mechanized work in crop production. Moscow: Akademiya; 2013. (In Russ).

## СПИСОК ЛИТЕРАТУРЫ

**1.** Starostin I.A., Eshchin A.V., Davydova S.A. Global trends in the development of agricultural robotics // IOP Conf. Ser.: Earth Environ. Sci. 2023. Vol. 1138. P. 012042. doi: 10.1088/1755-1315/1138/1/012042

**2.** Лобачевский Я.П., Бейлис В.М., Ценч Ю.С. Аспекты цифровизации Системы технологий и машин // Электротехнологии и электрооборудование в АПК. 2019. № 3(36). С. 40–45. EDN RLCDHO

**3.** Аксенов А.Г. Анализ интеллектуальных систем поддержки принятия решений в сельском хозяйстве // Электротехнологии и электрооборудование в АПК. 2019. № 3(36). С. 46–51. EDN CECDAH

**4.** Измайлов А.Ю., Годжаев З.А., Гришин А.П. и др. Цифровое сельское хозяйство (обзор цифровых технологий сельхозназначения) // Инновации в сельском хозяйстве. 2019. № 2 (31). С. 41–52. EDN: JNIMAH
**5.** Лобачевский Я.П., Дорохов А.С. Цифровые технологии и роботизированные технические средства для сельского хозяйства // Сельскохозяйственные машины и технологии. 2021. Т. 15, № 4. С. 6–10. EDN YFRZDV doi: 10.22314/2073-7599-2021-15-4-6-10
**6.** Starostin I.A., Belyshkina M.E., Chilingaryan N.O., Alipichev A.YU. Digital technologies in agricultural production: implementation background, current state and development trends // Agricultural engineering. No. 3 (103). 2021. P. 4–10.
**7.** Федоренко В.Ф., Мишуров Н.П., Буклагин Д.С. и др. Цифровое сельское хозяйство: состояние и перспективы развития. М.: Росинформагротех, 2019.
**8.** Старовойтов С.И., Ценч Ю.С., Коротченя В.М., Личман Г.И. Технические системы цифрового контроля качества обработки почвы // Сельскохозяйственные машины и технологии. 2020. Т. 14, № 1. С. 16–21. EDN HYFQAN doi: 10.22314/2073-7599-2020-14-1-16-21
**9.** Гольтяпин В.Я. Системы параллельного вождения машинно–тракторных агрегатов // Техника и оборудование для села. 2013. № 11. С. 12–14. EDN: RKAJJT
**10.** Матюк Н.С., Зинченко С.И., Мазиров М.А. и др. Ресурсосберегающие технологии обработки почвы в адаптивном земледелии. Иваново: ФГБНУ Верхневолжский ФАНЦ, 2020. EDN: OXDIHN
**11.** Cognitive Agro Pilot Система автоматического вождения [internet]. Дата обращения: 14.07.2023. Режим доступа: https://www.tadviser.ru/index.php/
**12.** Саяпин А.С. Петрищев Н.А., Пестряков Е.В. Совершенствование управления техническим состоянием машин за счет использования цифровых средств мониторинга // Технический сервис машин. 2023. Т. 61, № 4(153). С. 10–17. EDN MMBPZL doi: 10.22314/2618-8287-2023-61-4-10-17
**13.** Годжаев З.А., Лавров А.В., Шевцов В.Г., Зубина В.А. О выборе технологического направления развития системы сельскохозяйственных мобильных энергосредств // Известия МГТУ МАМИ. 2020. № 1. С. 35–41. EDN: WVVVVS doi: 10.31992/2074-0530-2020-43-1-35-41
**14.** Taxonomy And Definitions For Terms Related To Driving Automation Systems For On-Road Motor Vehicles. SAE J 3016. Washington: SAE, 2018.
**15.** Измайлов А.Ю., Лобачевский Я.П., Дорохов А.С. Современные технологии и техника для сельского хозяйства — тенденции выставки AGRITECHNIKA 2019 // Тракторы и сельхозмашины. 2020. № 6. С. 28–40. EDN: OPALJD doi: 10.31992/0321-4443-2020-6-28-40
**16.** Кутьков Г.М. Развитие технической концепции трактора // Тракторы и сельхозмашины. 2019. № 1. С. 27–35. EDN: ECZSAK doi: 10.31992/0321-4443-2019-1-27-35
**17.** Новые гусеничные и колесные тракторы John Deere [internet]. Дата обращения: 14.07.2023. Режим доступа: https://www.deere.ru/ru/тракторы/, свободный. – (Дата обращения: 12.07.2023).
**18.** Тракторы Case IH [internet]. Дата обращения: 14.07.2023. Режим доступа: https://www.caseih.com/apac/ru–ru/products/tractors
**19.** Latest generation of seed sowing robots: The Fendt Xaver comes of age. AGCO GmbH. [internet]. Дата обращения: 14.07.2023. Режим доступа: https://www.fendt.com/int/2–fendt–xaver
**20.** Крестовников К.Д., Ерашов А.А., Васюнина Ю.Г., Савельев А.И. Разработка устройства сопряжения для модульной сельскохозяйственной робототехнической платформы // Сельскохозяйственные машины и технологии. 2022. Т. 16, № 1. С. 78–88. EDN MNHHSN doi: 10.22314/2073-7599-2022-16-1-78-88
**21.** Grimstad L., From P.J. The Thorvald II agricultural robotic system // Robotics. 2017. Vol. 6. P. 24.
**22.** Верещагин Н.И., Левшин А.Г., Скороходов А.Н. Организация и технология механизированных работ в растениеводстве. М.: Академия, 2013.

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