Analysis of the use of a combine harvester equipped with a precision farming system in rice growing conditions

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Abstract. On the basis of the Federal State Budget Scientific Institution “Federal Scientific Rice Centre”, studies were conducted to evaluate the effectiveness of the use of the TUCANO 580 combine equipped for harvesting rice with the P420 pick-up. It was established that the combine successfully worked on threshing rice with a shift capacity of about 20 tons per hour. The performance indicators of the combine met the agro-technical requirements (ATT) and amounted to: the total grain loss for the combine 1.99%, including for the thresher 1.55% and for the pick-up 0.44%. Crushing and breaking of bunker grain amounted to 1.2%, which corresponds to the ATT standard - not more than 4.0%. The content of weed impurities was 0.8% (for ATT no more than 5.0%). Along with this, a technique was developed for processing data from a multispectral camera based on the results of surveying by an unmanned aerial vehicle (BVS) and the Sentinel-2A satellite. Based on spectral images, experimental fields, digital maps of the spatial distribution of the normalized relative vegetation index (NDVI) have been created. According to the CLAAS TELEMATICS system, yield maps were constructed. The digital topographic basis of the test ranges was adjusted with the addition of the necessary vector layers based on the results of processing the spectral survey. As a result of the work, a positive assessment of the efficiency of the combine is given, the basis for the creation of a geoinformation base in the information system for the application of precision technologies in agriculture is prepared.

1. Introduction
A combine harvester is a technical device that, like a tractor, affects the technological trends in the development of agriculture [1]. There are many well-known ways to select combine harvesters and design their fleet. The park can be developed analytically, taking into account the technical and technological parameters of the machines. For example, a mathematical model [2] was prepared to model a fleet of combines [2] in order to ensure the performance of all operations related to harvesting, in accordance with the structure of grown cereals, the optimal time for agricultural technology, acceptable material costs and working time. As a result of technological developments, the fleet of combines and tractors and, in particular, their capabilities have changed over the years [1, 3], but they have also changed due to the socio-economic development of countries over the years [4–7]. The general trend is that since 1965, when a record number of combine harvesters (more than 60,000 machines) were produced and put into operation in Western Europe, the engine power and performance of the combines have increased every year. The formation of the costs of harvesting...
combines has been studied by many authors [8-15]. Some of them focused on the characterization of specific machines from different manufacturers such as John Deere and New Holland [11, 12, 15]. For example, Prístavka and others studied harvesting costs for John Deere CTS 9780 and Z2264 combines in their work from 2010 to 2012 [10]. Prístavka and others also conducted research on the JD 9660 WTS combine for three years (2013–2015) and presented its performance, cleaning costs, main and additional, including fuel consumption [11]. All of these studies provide an overview of the total harvesting costs of various combines per season or year, but they do not indicate the efficiency of these machines. Based on the foregoing, it is necessary to conduct research aimed at studying the efficiency of the TUCSNO 580 combine modernized for harvesting rice.

Purpose of the work - To assess the efficiency of the combine TUCSNO 580 modernized for harvesting rice and to analyze the spatial distribution of yield.

2. Materials and Methods
To achieve this goal, the experimental fields were digitized using an unmanned aerial vehicle (UAV), maps with the spatial distribution of the NDVI index were created. In the CLAAS TELEMATICS information system, yield maps of the test fields were generated.

The object of the study was a TUCANO 580 grain harvester equipped for rice harvesting with the CLAAS TELEMATICS system, which is designed for direct and separate combination of cereals, legumes, oilseeds and other crops in all grain-producing regions of the Russian Federation. With the use of additional equipment, the harvester has the ability to harvest sunflower, corn for grain, and rice.

The harvester performs the following operations:

- cutting off the grain mass, threshing, separation and cleaning of grain, collection of grain and its accumulation in a bunker with subsequent unloading into a vehicle;
- placing the threshed stem mass into a swath;
- crushing of the threshed stem mass and spreading it over the field.

The harvester equipped for rice harvesting is equipped with special additional equipment, the main elements of which are: a pin threshing drum, a main concave with statically mounted pins, a reinforced grain conveying system, two caterpillar drives, bridge consoles, bridge struts and a ladder for the caterpillar drive with lifting mechanisms up.

3. Threshing technological process
The grain mass from the feeder chamber goes under the accelerating drum and from under it to the threshing drum, where the main threshing and primary separation of the threshed grain take place. The threshed stalk mass, reflected by the hammer beater, enters the separating rotor, the task of which is to separate the grain that was not separated in the threshing separating device.

The threshing process takes place during the passage of the working bodies (pins) along the panicle or as a result of their movement relative to each other, i.e. as a result of "combing".

The threshing device of the TUCANO 580 harvester of the APS system used for threshing rice (Figure 2) consists of an accelerator drum (1), a pre-concave (2), a main threshing drum (3), a main concave (4), an impact beater (5).

The diameter of the main threshing drum is 450 mm, the width of the thresher is 1580 mm (Figure 1).
Tests of the TUCANO-580 combine harvester, equipped for harvesting rice, were carried out on the picking and threshing of swaths of rice variety Favorit (experiment 1) in the fields of the Federal State Budgetary Scientific Institution "Federal Scientific Rice Centre" and variety Patriot (experiment 2) in the fields of the FSUE RPZ Krasnoarmeisky named after A.I. Maistrenko by specialists of the FSBI "Kuban MIS" in accordance with agrotechnical requirements (ATR).

For a comprehensive assessment of the efficiency of using the fleet of combine harvesters, the structural advance coefficient was calculated. It was determined by the ratio of the structural specific weight of grain threshed by each combine, or by a group of combines in the gross threshing, to the structural specific weight of the number of these combines in the entire operating combine fleet [16].

For the digitization of the experimental sites, a UAV was used, the autonomous flight of which was carried out at an altitude of about 300 m, which is optimal for solving the task.

The state of rice crops was monitored using data from the Sentinel-2A satellite, which covered the entire analyzed period (06/05/2019 - 08/29/2019).

Before rice harvesting, a vector layer of the contours of the test plots was loaded into the CLAAS TELEMATICS information system to create a raster with the spatial distribution of the yield.

The resulting yield maps were used for processing by geostatistical methods.

CLAAS TELEMATICS PROFESSIONAL with Automatic Documentation allows you to continuously query and document work data, trajectory and yield data from appropriately equipped grain and forage harvesters and tractors. All data is transferred via mobile communication from machines to a server, where they are processed and stored. Data from the server can be called up and analyzed on the TELEMATICS portal or in an application using a PC or smartphone with Internet access, as well as exported to any common agricultural management software for further processing (Figure 2).

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**Figure 1.** Threshing device of the TUCANO 580 combine APS system (rice threshing system).

**Figure 2.** How the TELEMATICS system works. 1. Geolocation based on satellite data; 2. Collecting data from agricultural machines; 3. Data transmission to the server via mobile communication; 4. Receiving data by the client; 5. Receiving data by the service.
The main functions of the TELEMATICS system are information, analysis, optimization and documentation. The functions of information include: information about the location of equipment, status of work, fuel level, etc. The analysis functions for working hours, productivity and diesel consumption allow accurate comparison of various performance characteristics. Using the analyzed data, you can identify ways to optimize and improve efficiency, or find the reason for underutilizing machine performance. At the same time, it will help to improve the work of the operator. Another function of the TELEMATICS system is documentation, which saves time by reducing paperwork, as well as reporting for a specified period (Figure 4).

The TELEMATICS Automatic Documentation function makes work much easier while increasing data security. The system automatically recognizes which field the machine is in and, based on the boundaries and recorded trajectories, generates site documentation for each job. In parallel, the operating data is automatically transferred to the TELEMATICS server. The files are exported in ISO-XML format, which can be used in farm management programs. Errors when entering or transferring data are excluded. Thanks to the automatic and at the same time fast data collection, office work is significantly reduced. The farmer receives accurate documentation to complete the field book (Figure 3).

![Figure 3. Scheme of functioning of TELEMATICS PROFESSIONAL and "Automatic Documentation". 1. Geolocation and vehicle data. 2. Time period. 3. Field boundaries. 4. Trajectory of machine movements. 5. Yield map. 6. Export of ISO-XML files. 7. Data recording.](image)

The combination of TELEMATICS PROFESSIONAL and Automatic Documentation allows automatic yield mapping as well as documented results from each field (Figure 4).

![Figure 4. TELEMATICS web page showing yield map.](image)
The sensors installed on the combine determine the moisture content and the amount of grain, measure the distance traveled and, taking into account the set working width of the header and other parameters, determine the yield. The received data are recorded by the on-board computer and supplemented with geographic coordinates (geolocation), then they are wirelessly fed into the TELEMATICS system from which they can be exported to various information systems for production management.

4. Results and Discussion
Analysis of operational and technological indicators. The test conditions in determining the operational and technological parameters of the TUCANO 580 combine equipped for rice harvesting were carried out on the rice irrigation system (RIS) of Federal Scientific Rice Centre (experiment 1), which were mostly typical and differed from the normative ones with a low grain moisture content of 11.8% (ATR 15.0 - 18.0%) and low straw moisture 20.0% (ATR 30.0-40.0%), which was due to weather conditions during the harvesting period (high air temperature). With an average operating speed of a combine with a pick-up of 6.31 km/h and a swath width (1.2 m) formed by a header ZhRK 5, the productivity of picking up and threshing swaths per hour of main time was 2.97 hectares (19.92 t), technological time - 2.34 hectares (15.68 tons). The productivity per hour of shift time was 1.95 hectares (13.067 tons). Specific fuel consumption during shift work was 10.93 kg/ha (1.63 kg/t).

Under operating conditions, the TUCANO 580 grain harvester, equipped for rice harvesting with a P420 pick-up, performed a technological process with a safety factor of 1.0. The performance indicators of the harvester corresponded to the requirements of ATR and amounted to: total grain losses behind the combine 1.99% (according to ATR not more than 3.0%), including 1.55% after the thresher (according to ATR not more than 2.0%) and behind the pick-up 0.44% (according to ATR not more than 1.0%). Crushing and hulling of bunker grain was 1.2%, which corresponds to the ATR standard - not more than 4.0%. The trash impurity content was 0.8% (according to ATR no more than 5.0%).

When determining the operational and technological indicators combine harvesters of "Krasnoarmeisky" on the picking and threshing of rice swaths (experiment 2), the test conditions were also mostly typical, but differed from the normative ones with low grain moisture content of 9.9% and low straw moisture content of 7.4%, which was due to agrotechnical and weather conditions during the harvesting period (the picking of rice swaths was carried out on the 7-8th day after mowing, during which a high air temperature was noted). With an average operating speed of a combine with a pick-up of 5.84 km/h and a swath width formed by a header ZhRK 5 (1.2 m), the productivity of picking up and threshing swaths per hour of main time was 2.63 ha (19.92 t). Productivity per hour of shift time - 1.70 hectares (12.91 t). Specific fuel consumption during shift work was 11.4 kg/ha (1.5 kg/t). Under operating conditions, the TUCANO 580 combine harvester, equipped for harvesting rice, with the P420 pick-up reliably performed the technological process, the reliability factor of the technological process was 1.0. The performance indicators of the harvester corresponded to the ATR requirements and amounted to: total grain losses behind the harvester 1.64%, including 1.33% behind the thresher and 0.31% behind the pick-up. Crushing and collapse of bunker grain amounted to 1.5%, which corresponds to the ATR standard. The trash content was 0.6%. In general, according to the results of the analysis of the obtained indicators, it can be concluded that the TUCANO 580 grain harvester, equipped for harvesting rice, with a pick-up P420 on the pick up and threshing of rice swaths reliably performs the technological process with operational, technological and agrotechnical performance indicators corresponding to ATR.

Based on the data obtained on the results of rice harvesting in 2019, the structural advance coefficients were calculated for all groups of combine harvesters in accordance with the achieved seasonal harvest, the value of which should be at least 1000 tons (table).
Table 1. - Structural Advance Coefficients for Characterizing Combine Harvesters.

| Seasonal harvester group, t | Structure, % | combine fleet | gross threshing yield | advance coefficient |
|----------------------------|--------------|---------------|------------------------|---------------------|
| 800-900                    | 14.3         | 6.07          | 0.424                  |
| 2000-2500                  | 28.6         | 29.13         | 1.018                  |
| 2500-3000                  | 28.5         | 37.50         | 1.316                  |
| 3000-4000                  | 14.3         | 22.74         | 1.590                  |
| Total:                     | 100          | 100           |                        |

The data in the table show that the structural advance coefficients for the combine harvester groups vary from 0.319 to 1.590. A differentiated assessment of the work of combine harvesters was carried out as follows: if the structural advance coefficients were below one, the use of machines was considered ineffective, with the coefficients close to one, the combines functioned at the minimum useful level. In those cases when the structural advance coefficients were significantly higher, the operation of the machines was assessed as highly efficient. This group included 5 combines, including the TUSANO 580.

Experts in the operation of grain harvesting equipment believe that in modern operating conditions, the optimal frontier providing a sufficiently high efficiency of the functioning of grain harvesters is seasonal harvesting, which is at least 1000 tons of rice per machine. As the obtained data show, the specified, seasonal threshing is really feasible: in the structure of the grain harvester fleet of the FSBSI "Federal Scientific Rice Centre" there were 71.43% of machines, including TUSANO 580, which threshed more than 1000 tons of rice in 2019. This strategic landmark should serve as a prospect not only in solving operational issues of using grain harvesters directly in agricultural organizations, but also in fulfilling tasks to improve the technical, technological and productive capabilities of promising models of grain harvesters used in the Russian Federation.

When performing a technical and operational assessment of the operation of a grain harvester, modernized for rice, verification of the optical and biological properties of plants was carried out at test sites (check card No. 7, 9, experimental plot of "Federal Scientific Rice Centre") to assess the state of rice crops (using data from the Sentinel satellite 2A) on the basis of which the raster data of the values of the vegetation index NDVI in 3 periods were created. The resulting raster has spatial zones of heterogeneity shown in Figure 6.

The obtained spectral data from the Sentinel-2A satellite were processed by geostatistical methods, as a result of which histograms of the frequency distribution of variables were constructed, reflecting the distribution of the vegetation index NDVI at the beginning of June, which had multimodality, which indicates the spatial heterogeneity of the studied areas.

When harvesting test polygons, maps of the spatial distribution of yield were obtained (Figure 5 d). A visual analysis of the yield distribution maps together with the vegetation index indicators clearly shows a pattern in the internal spatial structure of fields. NDVI values are spatially similar to yield indicators and completely repeat their structure. This allows us to talk about the possibility of planning agrotechnical measures, taking into account the characteristics of each field separately and the forecast of yield as a whole.

The obtained digital maps of the distribution of the vegetation and productivity indexes have a topographic reference, which makes it possible, using information technology, to plan agrotechnical measures taking into account the characteristics of each field.
Figure 5. Distribution of the normalized relative vegetation index NDVI and yield in fields 7 and 9: a) NDVI according to the Sentinel-2A satellite data on 06/05/2019; b) NDVI according to Sentinel-2A satellite data on July 20, 2019; c) NDVI according to the Sentinel-2A satellite on 08/29/2019; d) distribution of yield indicators (CLAAS TELEMATICS) 2019.

5. Conclusions
1. Combine harvester TUCANO 580, equipped for harvesting rice with a pick-up P420, corresponds to its purpose, reliably performs the technological process on picking and threshing of rice swaths with operational, technological and agrotechnical performance indicators that meet the technical requirements. The harvester has sufficient technical reliability, no failures were noted during the test period.

2. There is a large scatter of the structural advance coefficient by groups of combines: from the minimum (800-900 t) to the maximum (up to 4000 t) seasonal threshing. This is due to various reasons, the main of which is the insufficient replenishment of the fleet of combine harvesters, which requires updating with modern models.

3. The results of field digitization and the creation of yield maps on their basis are the basis of a geoinformation database for the formation of an information system for the use of precision technologies in agriculture.

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