Justification of the rice harvester number in the main technological link, considering the accepted guarantee probability

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Abstract. This article substantiates the guaranteeing number of rice harvesters in the main technological link of the harvesting and transport complex, sets out the methodology and presents the calculated dependences of determining the rational number of rice harvesters, taking into account the accepted guarantee probability, which reduces the need for agricultural machinery and the cost of mechanized work. The article is recommended for agricultural specialists, scientists, teachers, graduate students, undergraduates and students of agricultural universities in the field of “Agricultural Engineering”.

1. Introduction

Krasnodar Territory is the main producer of rice grown in Russia. By 2020, in accordance with the country's agricultural development strategy, it is planned to receive more than 900 thousand gross rice harvest and expand sown areas to 150 thousand hectares. To implement the program, it is necessary to create new technologies and a highly efficient complex of machines for the production of this culture.

In 2019, in connection with the state and regional measures taken to support agricultural producers in Russia, it is possible to forecast the purchase of combines at the level of previous years.

Over the past three years, a significant share of combine harvesters purchased by farms in the Krasnodar Territory (73.3%) have been harvesters of Rostselmash Combine Plant LLC, which indicates the high competitiveness of combines of this manufacturer (Table 1).

There are many different publications on the topic of the use of domestic and foreign rice harvesters and other equipment [1, 2].

Certain experience has been accumulated in their operation. But at the same time, many scientists note that there are no clear methodological developments and recommendations, no comparative analysis to calculate the guaranteed number of rice harvesters in the main technological link of the harvesting and transport complex [3, 4].

Therefore, objectively, the need arises to continue further research in this area.
Table 1. Statistics on the acquisition of combine harvesters by farms of the Krasnodar Territory by producers.

| Harvester brand          | Harvesters purchased, % |
|-------------------------|-------------------------|
| Combine Plant Rostselmash LLC | 73.3                    |
| Gomselmash OJSC          | 16.1                    |
| Klaas LLC                | 2.7                     |
| “Laverda”                | 5.3                     |
| “New Holland”            | 1.3                     |
| Others                   | 1.3                     |
| **Total**                | **100**                 |

Rice, as you know, is a southern culture. The traditional region of its cultivation is Asia. However, rice is also grown in Russia. Moreover, most of the areas used for this culture are concentrated in the Krasnodar Territory. Rice is grown in this region using special technology.

Rice cultivation in the Kuban began in Soviet times. In the 20-30s in the Krasnodar Territory, large areas of floodplains overgrown with reeds were drained. It was these raw lands that were decided to use for planting rice. The area of the first experimental site allotted for this crop was 50 ha. Created by domestic farmers, a new exclusive method of growing rice was constantly improved in the following years. At first, the yields of this crop in the Krasnodar Territory amounted to only about 21-22 centners per hectare. Subsequently, these indicators steadily increased.

About 10 years after the start of rice cultivation in the Kuban, two reservoirs were built to create irrigation systems. They were designed in such a way that subsequently water resources were enough for 70 thousand hectares of rice fields.

A completely irrigation system for this crop was created in the USSR by the 80s of the last century. Until the 90s, the rice industry was considered in our country one of the most profitable. The total area of sown fields in Soviet times was about 300 thousand hectares.

With the collapse of the country, rice farms in the Krasnodar Territory fell into decline. In the 90s, the yield of this crop in Russia approached the first historical indicators and amounted to only 25 ha/c. At the same time, the sown area was reduced to 90 thousand hectares.

2. Materials and methods

In the course of the study, the monitoring results of the combine harvester operation in agricultural enterprises of the Slavyansk region of the Krasnodar Territory, performed by the author in 2016-2018, were used.

Investigations of combine harvesters were carried out under various economic conditions with the prevailing type of harvesting: selection of rolls formed by self-propelled modules of the GM-100 type with a ZhVN-5 roller header with a working width of 5 m and one version of direct rice combining with the “Torum-740” combine.

Today, the rice industry in the Krasnodar Territory is reviving. In 2014, the area allotted for this crop was already about 167 thousand hectares. But, unfortunately, the rice industry of the region still experiences some difficulties. So, for example, until 2016, not one new irrigation system was built in the region. All used in the fields were created in Soviet times.

This southern plant is cultivated in Russia by a special technology. The technique of cultivating it, of course, is similar to that used in Asian countries. However, in the technology of rice cultivation in the Kuban there are quite significant differences.

For example, Krasnodar rice is never cultivated in the same place from year to year for decades. Farms in the region must observe crop rotation. Every two to three years, wheat or soybeans are planted in a rice field. This can significantly increase crop yields and reduce the likelihood of damage by pests.

Rice is harvested in the Krasnodar Territory only after the fields are completely drained. This is also one of the features of the technology used in southern Russia. In Asian countries, in most cases not rich, the fields are usually not drained. Farmers often collect rice there by hand, right in the water.
Of course, work is very hard. Russian farmers use, of course, modern technology when cultivating and harvesting this crop.

In some areas of the region, and in particular, on the left bank of the Kuban, the thickness of the fertile soil layer in the fields is only about 15 cm. Therefore, when growing rice, local farms are forced to use quite a large amount of fertilizer. In order for the grains to be subsequently delivered to the food industry and to the stores of high quality, farmers carefully analyze the leaves of the plants before feeding them. In laboratory conditions, it is determined which particular substances are missing from the culture at a given specific time. In accordance with the data obtained, fertilizing is also carried out. The soil with this approach to business is not contaminated with any excess chemicals.

This culture is seeded in the Kuban on checks. It is so called small fields of 5 hectares. Rice is actually a very unusual plant. Unlike most other varieties of cereals, it is able to transfer oxygen from leaves to roots. That is, it can be grown, being almost completely immersed in water.

The main elements of the irrigation system in rice fields are [5, 6]:
- source;
- common distribution channel;
- irrigation canals.

The source of water supply to the fields can be either an artificial reservoir, the Kuban River or some nearby lake. The distribution channels are equipped with special injection equipment. Irrigation trenches are separated from them by valves. Shallow grooves are dug through the checks themselves. When the valves open, water begins to flow into the irrigation canals. Then it moves into the grooves on the checks and is distributed in all directions. Thus, flooding occurs. The water level rises to the required level during planting in about a day. Sometimes it takes a little longer time [7, 8].

In order to monitor the level of water rise, the Krasnodar rice producer installs special rails with a scale on the checks. Actually the control itself is performed by agronomists of farms when driving around fields. If necessary, watering workers later raise or lower the gate valves of the channels, thus adjusting the level [9, 10].

As already mentioned, the rice industry in the Krasnodar Territory continues to revive. Today, the yield of this crop in Russia is about 200 thousand tons of grain annually. To cover the domestic needs of the country, this is enough. Russia even has the opportunity to import about 50 thousand tons of cereals annually. Domestic Krasnodar rice is supplied mainly to neighboring countries.

In terms of productivity, Russian farms in 2016, according to statistics, even Italian ones caught up. Comparison in this case can be made, since there are domestic complexes and farms of this southern state at almost the same latitude. Italian rice varieties in Russia, thanks to the use of modern domestic cultivation technologies, grow faster, get sick less and give a larger grain.

According to many experts, rice growing in the region is a very promising industry. The modernization of farms, the purchase of new modern equipment, the increase in the general training of workers, all this, according to forecasts, can lead to an almost double increase in productivity.

The rice industry in our country is, unfortunately, quite expensive. According to estimates, farms spend up to 60 thousand rubles per season on growing only one hectare of this crop. But the profits from such agricultural complexes can be quite large. The quality of Krasnodar rice is simply excellent. And therefore, both domestic and foreign consumers buy it very willingly.

Thus, subject to cultivation technology, Krasnodar rice is very fruitful crop. How to grow it, we found out. Rice harvesting in the south of Russia is carried out after drainage using special combines. This modern technology is also responsible for threshing of grain.

Today, rice productivity in the Kuban is about 1 million tons per year. By 2017, 99 farms are engaged in the cultivation of this culture in the region. 23 of them are small businesses.

On sale, as known, rice does not come in ears of corn, but already in the form of cereals. Equipment intended for processing this crop, including combines, in Russia, unfortunately, is practically not produced. The same, that is, usually does not cope with loads during harvesting. Therefore, imported equipment is usually used to process rice in the Krasnodar Territory. It is bought more often in countries that are traditional rice producers - in China, Japan, South Korea, etc.
Of course, the rice industry in the Krasnodar Territory can develop not only subject to the use of new technologies and modern equipment. A lot in this regard also depends on what varieties of this crop will be grown in the fields. In the region, among other things, breeding is also carried out with rice. It is displayed at the stations both Krasnodar round-grain rice and long-grain rice.

To get a new variety of this culture of any variety, unfortunately, is quite difficult. It takes about 7 years for breeding. However, similar difficulties do not stop agrarians of the region. In the region, not only ordinary, but also elite varieties of culture are constantly being developed.

Both round-grain and long-grain rice is grown and, therefore, enters the store shelves in the region. Reviews this domestic crop among consumers earned just excellent. There are several reasons for this. Firstly, since Krasnodar rice is grown in compliance with crop rotation, it is an environmentally friendly product and the most beneficial for health. Secondly, the excellent quality of domestic cereals is also determined by the climate of the Krasnodar Territory. In the Kuban, it is not as hot as, for example, in Vietnam or China. Therefore, ears in this region are quite rarely infected with various kinds of pests that do not tolerate low temperatures too well.

The high quality of Kuban rice is evidenced even by the fact that the market today has, including counterfeit Asian products sold under the guise of Krasnodar. Such rice is grown in the worst conditions and, of course, does not have the same excellent taste as harvested in the south of Russia.

Rice is one of the most popular foods. Its production is in areas with a hot and humid climate. As a rule, rice is cultivated in tropical countries, but it can also be grown in subtropical countries. China, South America, India, Asia, Indonesia are the main distribution areas. In Asian countries, rice is planted manually. In America, it is sown on the fields directly from the plane. Great benefits lurk in rice husk. Nevertheless, it is cleaned and sent to livestock feed. White rice is used as food for people. In Japan, red rice is considered the best - it acquires a pinkish tint under the influence of bacteria. Such food was consumed by emperors.

Rice belongs to the herbal family. In appearance, it resembles a reed. Landing is peculiar. First, the field is moistened until it turns into dirt. Then you can start sowing. To maintain crop growth, it is necessary to establish a complex network of canals, dams and embankments. It will help maintain soil moisture in the desired state. The soil should be covered with a thin layer of water. In order to facilitate the work, often fields are arranged in the mountains.

When installing terraces in mountainous areas, water passes from one field to another. Watering is done using jugs or a special machine. Donkeys drive the irrigation device. Ready rice is different from what we see in the store, in color. It is brown in color, and not white, because it is covered with husk.

Weeds are usually removed manually. But for this it is necessary to drain the water. Its level is usually regulated by a gate. In order to grow 1 kilogram of rice, about 5 thousand liters of water are required.

In Russian Federation, rice is grow mainly in the Krasnodar Territory, where the main areas of crops are concentrated, and rice production is more than 80% of the total Russian production. The temperate continental climate of the region allows the cultivation of rice varieties with a grooving season of up to 125 days.

Now rice is used as a main course, as a side dish for mushrooms, meat, vegetables and for dessert. Most vitamins remain in unpolished rice. The thing is that it is not processed. Among other things, it has more fiber and minerals than white rice. Due to the fact that the plant contains a large amount of carbohydrates, it is very nutritious. In addition, rice is rich in proteins, minerals and vitamins, is easily digested and goes well with a large number of products. Growing a culture on your own is quite difficult.

Rice is the main cereal used by the population of Russia. In the practice of world rice growing, rice varieties are divided into long-grain, medium-grain and short-grain by the type of grain. The basis of this division is the shape of the grain, which is determined by the ratio of length and width. This is stable varietal trait that does not depend on growing conditions.

Most rice varieties cultivated in the Krasnodar Territory are included in the group of short-grain varieties.
Judging by the fact that in the shops are packages of rice with the inscription Krasnodar, it can be assumed that in the Krasnodar Territory is the rice granary.

In Primorye, there is Khankai rice for sale. It is grown near Lake Khanka. True, it often grows not of very good quality. Then it is processed into animal feed.

There are still paddy-fields in the Jewish Autonomous Republic, but there are very few of them and rice is also not very good.

Delicious rice is obtained in the Rostov and Astrakhan regions. Some rice is grown for their needs in Adygea, Kalmykia and Dagestan. There it is delicious. But he does not reach Primorye. Here they mainly eat Krasnodar, quite tasty, local and Chinese. It is of different quality. For Primorye, China is almost Russia.

Now it is much easier to meet domestic Kuban rice than imported rice in Russian supermarkets, which immediately catches your eye with the fact that it costs much more. The homeland of rice is Southeast Asia, in particular Indonesia, so it is not surprising that this region is the world leader in rice production. Most of it is grown in China, India and Indonesia. Russia is not even included in the 20 rice producing countries, but, nevertheless, this culture has been cultivated in Russia for a long time and quite successfully. Most of all, about 80% of the rice is grown in the Kuban, but in addition to this, another 8 regions have agricultural land planted with this crop. The total production of this crop varies from 160 to 360 thousand tons per year.

In this paper, based on studies conducted on the basis of agricultural enterprises of the agricultural complex of the Krasnodar Territory of various forms of ownership, an analysis of the seasonal operating time of domestic rice harvesters in order to justify the rational structure of the technological complex of rice cultivation machines, was made.

On the basis of the studies, scientifically based conclusions were made, practical recommendations for agricultural production were prepared.

The aim of this work is to increase the efficiency of the use of technological systems of machines for harvesting cereal crops in the agricultural enterprises of the Krasnodar Territory by substantiating the guaranteeing number of rice harvesters in the main technological link of the harvesting and transport complex. For this, it is necessary to analyze the theoretical and experimental results of this scientific task; receive and process the experimental information on the seasonal operating time of the RSM-181 “TORUM-740” rice harvesters; determine analytically and graphically the form of the seasonal distribution law and its parameters, and also check this distribution law by Pearson’s “chi-squared” criterion of consent.

According to the scientific hypothesis of the study, we assume that the seasonal operating time of the RSM-181 “Torum-740” rice harvester obeys the law of normal distribution.

The object of the study was the process of using technological complexes of machines for rice harvesting in the conditions of Krasnodar Territory farms.

The subject of the research was methods to increase the reliability and efficiency of using technological complexes of rice harvesting machines in agricultural enterprises of the Slavyansk region of the Krasnodar Territory by substantiating the rational structure of the technological complex of rice cultivation machines.

3. Results and discussion

This article substantiates the guaranteeing number of rice harvesters in the main technological link of the harvesting and transport complex using the developed mathematical model.

According to the results of previous studies in the Kuban State Agrarian University, it was noted that the structure of the harvesting and transport complex is its constituent parts, technological units, the main of which are the main harvesting unit and transport and service units.

Depending on the area of cultivated rice in the given agricultural sector of the Krasnodar Territory, there may be the following technological units (Figure 1):
1) the technological link for the preparation of paddy-fields for harvesting;
2) the main technological link;
3) the serving technological units (transport unit, maintenance unit and field repair unit, consumer services unit, etc.);
4) the technological link of mobile load carriers;
5) the technological unit of post-harvest tillage.

![Diagram of the structure of the technological complex of machines for rice harvesting using technological links.](image)

**Figure 1.** The structure of the technological complex of machines for rice harvesting using technological links.

In order to increase the efficiency of the use of technological complexes of machines for harvesting cereal crops in the agricultural enterprises of the Krasnodar Territory, on the basis of the obtained statistical data, the hypothesis was verified that the seasonal operating time of the RSM-181 “Torum-740” rice harvesters complies with the law of normal distribution.

Verification of this hypothesis was carried out under the conditions of ordinary operation of rice harvesters in typical farms of the Slavyansk region.

Based on the obtained experimental data, its theoretical and experimental analysis was carried out, experimental information was obtained and processed on the results of using RSM-181 “TORUM-740” combines for harvesting rice, the form of the law of the distribution of their seasonal operating time and its parameters was determined analytically and graphically, as well as checked this law of distribution according to Pearson's criterion of consent "chi-squared".

According to the above hypothesis of the study, the theoretical law of the distribution of the seasonal operating time of combines for the alignment of experimental information was selected. It was found that with a probability of \(P(\chi^2) > 0.88\), the seasonal operating time of the RSM-181 “TORUM-740” combine harvesters is subject to the law of normal distribution.

Moreover, the average seasonal operating time of one physical rice harvester was \(\bar{W} = 529\) ha, and the mean square deviation and coefficient of variation of this operating time were \(\sigma_\Omega = 159\) ha and \(v_\Omega = 0.3\), respectively.

Based on the research results, a graph of the theoretical and experimental distribution density of the seasonal operating time of RSM-181 “TORUM-740” combine harvesters was constructed, Figure 2.

An expression is obtained to justify the rational structure of the main harvesting link and the link for preparing paddy-fields for harvesting (the link mows edge strips and corrals), i.e. the total number of rice harvesters necessary to perform a given amount of harvesting work in a specified agricultural time:

\[
n_\beta = n_{av} + u_\alpha v_\Omega \left[0.5u_\alpha - \sqrt{n_{av} + 0.25(u_\alpha v_\Omega)^2}\right],
\]

where \(n_\beta\) is the rational number of combines in the technological link, pcs;
\(n_{av}\) is the average number of combines, pcs;
\(u_\alpha\) is the table argument;
\(v_\Omega\) is the coefficient of variation of the seasonal operating time of one combine.
The average number of rice harvesters in the main harvesting unit can be determined by the formula

$$n_{av} = \frac{F}{W_{ch} D},$$

(2)

where $n_{av}$ is the average number of combines, pcs;

$F$ is the rice harvesting area, ha;

$D$ is the duration of the harvesting;

$W_{ch}$ is the changeable rate of combine production, ha.

Provided that the average number of combines is $n_{av} > 4$ and the coefficient of variation of the seasonal operating time of one combine is $\nu_0 \leq 1.5$ with a sufficient degree of accuracy (the error will be $\delta \leq 5\%$) the following expression can be accepted for engineering calculations

$$n_\beta = n_{av} + u_\alpha \nu_0 (0.5 u_\alpha \nu_0 - \sqrt{n_{av}}),$$

(3)

In practical engineering calculations, the value of the specified warranty probability $\beta$ is taken equal to 0.95 or 0.90.

For the case if this probability value is $\beta = 0.95 \ u_\gamma = 1.64$, then we obtain the following expression

$$n_\beta = n_{av} + 1.64 \nu_0 (0.82 \nu_0 + \sqrt{n_{av}}),$$

(4)

For the case where the probability $\beta = 0.90 \ u_\gamma = 1.28$, we have the following expression

$$n_\beta = n_{av} + 1.28 \nu_0 (0.64 \nu_0 + \sqrt{n_{av}}),$$

(5)
When the required number of combines in the technological link is more than 4...5, then in expression (5) the first term (in brackets) can be neglected and the formula for calculating the rational number of rice harvesters in the main technological link $n_{av}$ will take the form

$$n_{av} = n_{av} + u_{av}v_{av}n_{av}.$$  \hfill (6)

Studies have found that for the “Torum-740” combines used in rice harvesting in the farms of the Krasnodar Territory, the coefficient of variation of seasonal production is in the range $v_{av} = 0.30...0.35$, therefore expression (6) for calculating the rational number of harvesters in the main technological link can be written as

$$n_{av} = n_{av} + 0.33u_{av}(0.17u_{av} - n_{av}), \hfill (7)$$

The calculated dependences of the rational number of combines $n_{av}$ on the average number of combines $n_{av}$ and the specified guarantee probability $\beta$, obtained by expression (7) are shown in Figure 3.

**Example.** Consider the example of how to use the nomogram.

Let us determine the rational number of “Torum-740’ rice harvesters working on the selection and threshing of rice rolls in one of the farms of the Krasnodar Territory.

The necessary data for the calculation:
- the rice harvesting area $F = 750$ ha,
- the duration of the harvesting work $D = 5$ days.,
- the long working shift $t_w = 10$ h,
- the hourly output of the combine $W_h = 3$ ha/h.

![Figure 3. Nomogram for determining the rational number of rice harvesters in the main technological link.](image)

**Decision:**
1. We calculate the average number of “Torum-740” rice harvesters in the main technological link

$$n_{av} = \frac{F}{Dt_wW_h} = \frac{750}{5\times10\times3} = 5$$ harvers.

2. We set the value of the guarantee probability $\beta = 0.90$. According to the nomogram shown in Figure 2, we determine the rational number of rice harvesters $n_{av} = 8$ pcs.

3. At the same time, the seasonal load on the “Torum-740” rice harvester will be:

$$W_s = \frac{750}{\beta} = 94$$ ha.

**4. Conclusion**

In conclusion, it can be noted that the main elements of the irrigation system in rice fields are: source, common distribution channel, irrigation canals.

The source of water supply to the fields can be either an artificial reservoir, a river or some nearby lake.

Russian rice is grown in the Primorsky Territory, Chechnya, the Astrakhan region, in Dagestan, Kalmykia. But almost 80% of domestic rice is grown in the Kuban (Krasnodar Territory), this is due to the fact that there is the longest summer.
Most of the rice is grown in the Kuban, but in addition to this, another 8 regions have agricultural land planted with this crop. The total production of this crop varies from 160 to 360 thousand tons per year.

To calculate the guaranteed number of rice harvesters in the main technological link of the harvesting and transport complex, the law of normal distribution can be used.

With an average number of combine harvesters \( n_\text{av} > 4 \) and a coefficient of variation of the seasonal operating time of one combine harvester \( v_\Omega \leq 1.5 \) with a sufficient degree of accuracy (error \( \delta \leq 5\% \)), the guarantee number of combine harvesters in the technological unit can be determined by the expression

\[
   n_\beta = n_\text{av} + u_\text{av} v_\Omega (0.5 u_\text{av} v_\Omega - \sqrt{n_\text{av}}).
\]

In practical engineering calculations, the value of the specified guarantee probability \( \beta \) can be taken equal to 0.95 or 0.90.

References
[1] Kireenkov A, Nushtaev D, Zhavoronok S 2018 MATEC 211 08003 doi.org/10.1051/matecconf/201821108003
[2] Kirsanov M, Tinkov D 2018 MATEC 193 03015 doi.org/10.1051/matecconf/201819303015
[3] Swapan B, Chapter V 2019 Velocity and Force Type Flow Meter Plant Flow Measurement and Control Handbook pp 395-539
[4] Govaerts R 2014 World Checklist of Cyperaceae (London, UK: Royal Botanic Gardens, Kew) p 726
[5] A Merotto, M Jassieniuk, M Osuna, F Vidotto, A Fererro, A Fisher 2009 J. Agric. Food Chem. pp 1389 -1398
[6] Pedroso R, Al-Khatib K, Alarcon-Reverte R, Fischer A 2016 Pest manag. Sci. pp 1673-1680
[7] Tietema R 2014 Large-Scale Industrial Coating Applications and Systems Comprehensive Materials Processing 4 pp 519-561
[8] Tehranchian P, Riar D, Norsworthy J, Nandula V 2015 Weed Science pp 561 – 568
[9] Valverde B, Boddy L, Pedroso R, Eckert J, Fischer A 2014 Crop Protect pp 16 – 22
[10] Qianfan X 2013 Diesel Engine System Design pp 3-112