International Journal of Science and Research Archive
eISSN: 2582-8185
Cross Ref DOI: 10.30574/ijsra
Journal homepage: https://ijsra.net/

(RESEARCH ARTICLE)

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Efficiency of using resource-saving technologies for harvesting grain (head) crops on the example of Georgia

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International Journal of Science and Research Archive, 2025, 17(02), 1066-1071

Publication history: Received 18 October 2025; revised on 25 November 2025; accepted on 27 November 2025

Article DOI: https://doi.org/10.30574/ijsra.2025.17.2.3147

Abstract

The article presents the results of the operational, technical, and economic research on traditional and two different resource-saving technologies for harvesting grain crops: grain harvesting was carried out using a standard Deutz-Fahr C6205 combine, and the same Deutz-Fahr C6205 combine, which was equipped with a special high-cutting comb-type reaper. Studies have shown that compared to traditional grain harvesting technologies, the use of resource-saving technologies reduces operating costs by 1.26...1.57 USD / t, adjusted by 2...2.4 USD / t; Increases combine harvester productivity by 70–80%, reduces harvesting time by 1.7–1.8 times, and significantly reduces technological and grain self-seeding losses.

Keywords: Cutting; Threshing; Heads; Reaper; Combine; Technology; Costs and Operation

1. Introduction

In a small land country like Georgia, where the average yield reaches a maximum of 4 tons per hectare, reducing grain losses during harvesting is particularly important. According to Geostat, by 2025, grain crops were sown on 78 thousand hectares [1], as confirmed by existing studies [2], losses during grain harvesting in Georgia using traditional technologies amount to 5-6% per hectare, which amounts to total of about 20,000 tons of grain per year, which is quite a large amount for such a small-land country as Georgia.

The most critical operation in grain production is harvesting within optimal agronomic terms (7–12 days); therefore, preventing losses due to self-shattering of grain and lodging of the field during this period is very important. As shown in our 2023-2024 study [2], grain losses due to self-shattering in winter wheat and barley are: 5% 10 days after maturity, 9% after 15 days [2], 18.4 to 20.2% after 20 days of full maturity, and up to 50% after 26 days.

Harvesting with minimal losses within optimal agronomic terms is possible primarily only if grain producers have a sufficient number of high-quality grain harvesters [3]. The number of grain harvesters in the Republic of Georgia has increased sharply over the past 5 years. Although 1,500 grain harvesters were operating in collective and state farms in Georgia in 1992, by 2024, only 300 combines were involved in harvesting, of which about 200 were more than 15 years old. With such a number of machines, harvesting 57 thousand hectares of grain in Georgia takes more than a month, which inevitably leads to significant grain losses and a decline in grain quality.

Therefore, the agricultural engineering services of countries with small land areas and low per-hectare yields of grain crops are faced with a very important task:

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Increasing the number and productivity of existing grain harvesting equipment and implementing modern resource-saving technologies and equipment.

1.1. Justification

As practice shows, the productivity of grain harvesting combines is limited by the throughput of the threshing machine, which in modern combines ranges from 5 to 12 kg of grain per second. The total harvested mass during low cutting of stalks (10-15 cm) is, on average, 40% grain and 60% straw. Thus, when harvesting one hectare with a yield of 40 quintals, the threshing machine processes approximately 4 tons of grain and 6 tons of straw. Accordingly, if the harvesting method allows for the complete or partial separation of straw from the threshing mass and its entry into the threshing machine, this significantly (by 20-70%) increases the productivity of the combine and reduces its energy consumption by 25-30% [4]. The idea of harvesting grain without straw entering the threshing machine was described in the first century of the last millennium in an article about the work of the Gallic reaper. [7] The Roman writer and historian Gaius Palladius described the reaper in the article. During harvesting, it combed the stalks with a metal comb, removed the ears, and threw them into a transport cart, which performed the main processes of harvesting with minimal resources and energy consumption. That is, only the ears were taken from the field, while the straw remained in the field. In all other technologies (cutting, transporting, crushing and processing of straw), energy and labor costs were 3-5 times higher [7]. According to Professor P. A. Shabanov's research, the mass harvested by the combing method (by weight) consists of: 60–80% free grain, 10–20% grain remaining in the ears, and 20–30% straw and chaff [6].

A number of scientists have worked on the combing method of harvesting grain and its threshing [3,4,5,6, etc.]. Their studies examine the structural and technological parameters of the working bodies of the combing-type threshing device, which made it possible to introduce this method into practice.

Currently, the combing-type threshing device is used in Russia, Ukraine, the United Kingdom, and other European countries.

1.2. Straight field Sloping field

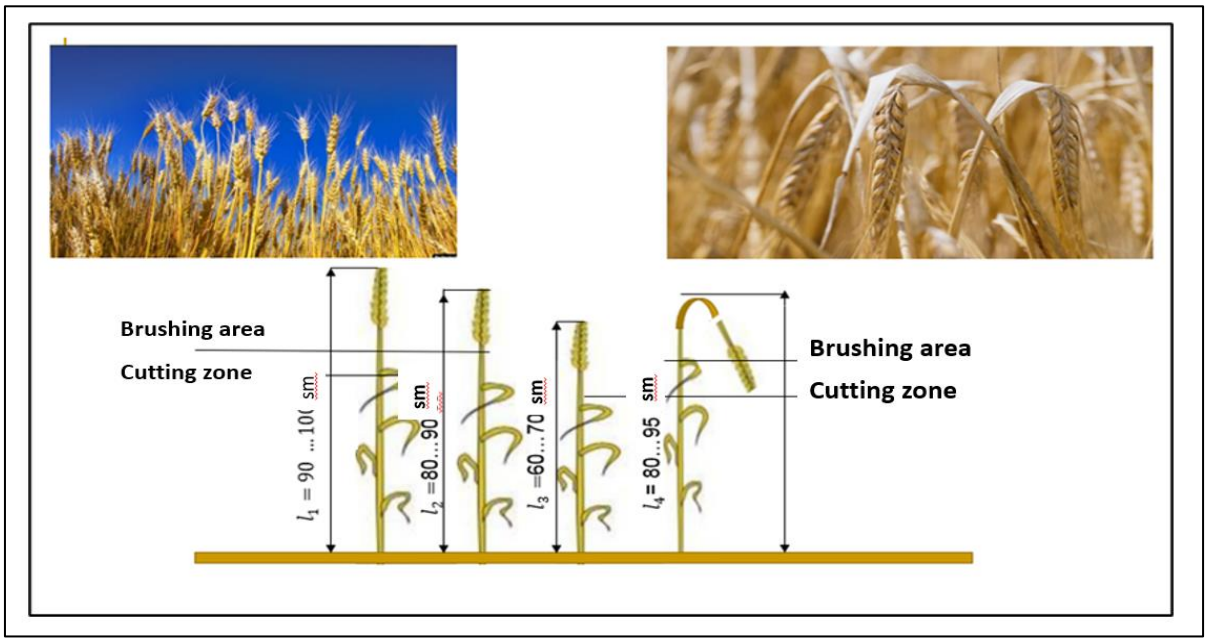

Figure 1 Dimensions of the height of the wheat stalk and cutting zones

When a combing-type cutting device is installed on a combine, broken grains and partially unthreshed heads enter the threshing unit. In this case, one component must be cleaned. At the same time, the other must be thoroughly threshed. Unfortunately, combines do not have devices that would divide the mass supplied to the threshing machine into grain and heads, so that they can be broken and further processed on separate devices. In order to achieve high-quality results, it is necessary to redesign and adjust the existing components according to the standard scheme.

The proposed method involves harvesting grain using a combine equipped to cut the heads at a high level above the stalks. In this harvesting method, the height of the sickle from the soil surface is adjusted to minimise the risk of losing or damaging tilted heads (Fig. 1).

The technological scheme of the comb-type sickle is presented in (Fig. 2) - The height of the head cutting is adjusted according to the varietal and dimensional characteristics of the harvested wheat. In any case, the mass entering the threshing machine contains straw.

The amount is significantly reduced, which will increase the speed (productivity) of the combine.

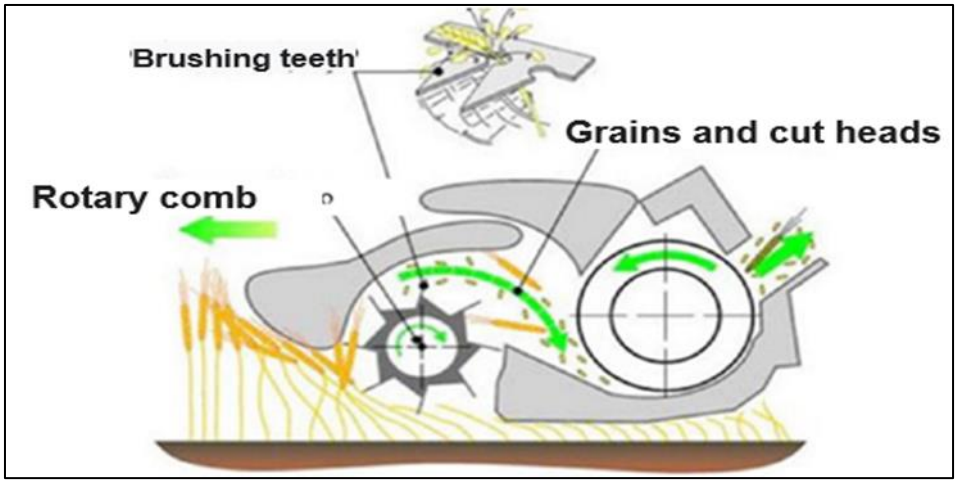

Figure 2 Technological scheme of a comb-type sickle

1.3. Research goals and objectives

The purpose of the research was to conduct a technical-operational and technical-economic assessment of the technologies discussed above. To achieve this objective, it is necessary to solve the following tasks:

- Determination of the mass of grain, straw and ears that enter the threshing machine when cutting the ears at a high height.
- Determination of the relationship between the working speed of the combine, productivity and grain mass;
- Calculation of technological losses of grain and losses resulting from self-thinning during harvesting of overripe grain;
- –Comparison and generalization of the results obtained using modernized grain harvesters and energy-saving technology in Georgian conditions with the results obtained using the existing harvesting method using a standard combine.– Determination of the economic efficiency of resource-saving technologies.

2. Research materials and methods

The study was conducted on a 300-hectare area of winter wheat and barley owned by Agroconsulting LLC, a leading company equipped with modern technical equipment and management methods, located in the Dedoplistskaro municipality of Georgia.

The operating and adjusted costs of harvesting wheat and barley were calculated using a generally accepted methodology [3]. The following data were used to calculate the operating and adjusted costs for all options: yield per hectare, 40 centners of grain and straw in a ratio of 1:1.5. The following indicators were sourced from Agroconsulting LLC: wages, production standards, and fuel consumption for all technological operations. The cost of tractors, combines, and agricultural machinery was obtained from the company's financial statements, along with the operational technical characteristics of the used combine, Deutz-Fahr C6205, and the prices available at that time.

The depreciation period of the combine was also taken into account, which was 15 years. The cost of diesel fuel was - 2.5 GEL/litre. The annual charge for repair of combines (MR) and annual charge for maintenance (TM) - 5% of their cost.

The coefficient of use for the combined shift is -0.7. The coefficient of use of the width of the threshing machine is 0.98. The coefficient of use of the speed is 0.95. The interest rate on the bank deposit is 10%. Social contributions on the salary are 42%.

The annual working time of the combine is 500 engine hours, with a combing threshing machine – 300 engine hours.

To calculate the number of grains entering the threshing machine of the combine from one hectare of wheat crop during harvesting and cutting the heads, it was necessary to determine the average weight of 1 cm of straw stalk and the weight of the head (without grains).

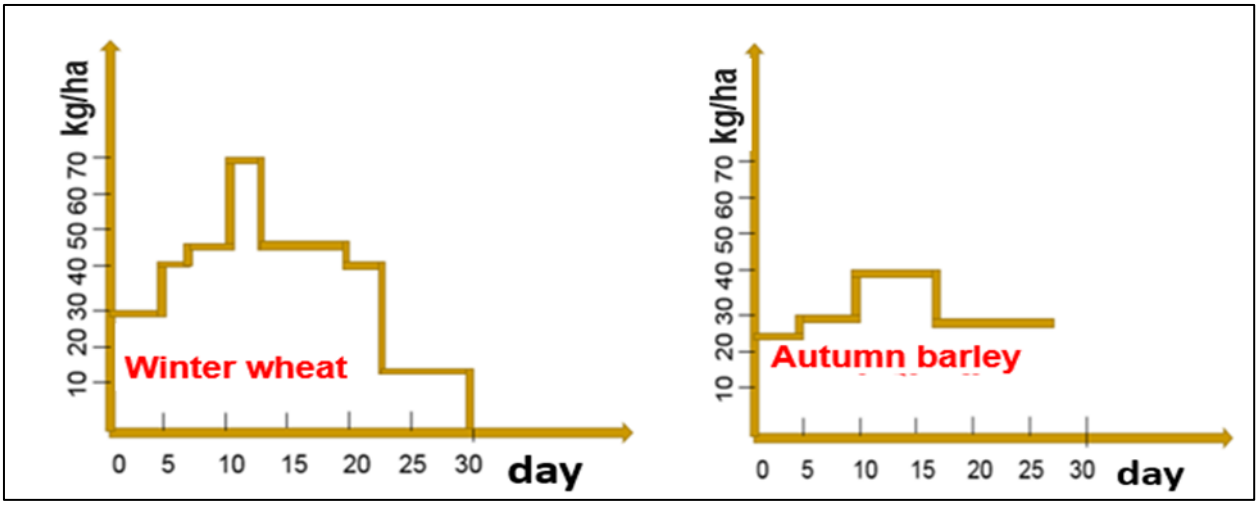

Figure 3 Dynamics of daily natural grain losses

The conducted research showed that in the case of threshed wheat, the average weight of the head without grains is 10–14% of the grain weight in the head, and the average weight of 1 cm of wheat stalk (straw) is 0.015–0.016 grams. The speed of the combine harvester was determined by taking into account the throughput of the threshing machine and the number of grains entering the threshing machine per second. It was determined by the formula: 〖V〗_к= (3.6·q)/(Y_(m^2)·B) km/h, where q is the throughput of the threshing machine of the combine, kg/s. Y_(m^2) – the amount of grain yield per square meter of field, kg/m2; B – the width of the collector, m. Fuel consumption per hectare (1 ton) was determined on the basis of hourly consumption, with a specific consumption of 0.162 kg/tph (0.2 l/tph). The engine power of the Deutz-Fahr C6205 combine is 280 hp. The estimated hourly consumption at 100% power is 45.4 l/h. According to the company's records, the actual consumption was 41 litres per hour. Therefore, on average, under production conditions, the engine is loaded to 90% of its capacity. Grain losses during wheat harvesting by the combine were calculated using a well-known method used in practice [3]. Using this method, we have shown that self-seeding of grain begins on the 5th day after full ripening of wheat, reaches 5% of the initial yield after 10 days, and reaches 9% of the initial yield, or peak, after 15 days (Fig. 3). While self-seeding of barley begins on the 5th day after ripening and reaches its peak on the 17th day. If it is assumed that wheat harvesting starts on the first day of full ripening, then the 5% loss level is reached on the 8th-10th day.

Our calculations take into account the rate of grain loss caused by self-seeding of crops: 0.5% on the third day of harvesting, 1.0% on the fourth day, 1.5% on the fifth day, and 0.5% on each subsequent day of harvesting. A total of 12 days of harvesting is taken into account. According to the formula for calculating losses proposed by A. N. Sukharev and N. G. Ignatieva, a 5% loss is reached on the sixth day of harvesting, and 12% on the tenth day. Obviously, this formula is designed for wheat varieties that are prone to self-shattering. Along with the ripening of wheat grains, technological losses also increase (in the threshing and threshing machine). After 10 days of full ripening, they reach 4–5%; therefore, according to our calculations, losses during the process increase daily by 0.2% of the daily yield. Results and discussion. Option 1. Traditional winter wheat harvesting technology: Harvesting using a Deutz-Fahr C6205 combine with a 6-meter-wide combine, with a grain yield of 40 c/ha and a grain to straw ratio of 1:1.5. The technological operations performed by the combine are: Threshing the grain with a low cut (12–15 cm) at a height, threshing in a threshing machine, separation on a straw baler, grain cleaning, unloading the grain into a truck, crushing the straw and scattering it on the field. When calculating the combine's operating speed, the amount of grain mass entering the threshing machine per hectare was determined: when harvesting using traditional technology (stem height 10-15 cm), which was equal to 2.5% of the grain mass, when the grain yield is 40 c/ha and the grain to straw ratio is 1:1.5, the grain mass is

equal to 100 c/ha or 1 kg/m^2. 4,000 kg of grain and 6,000 kg of straw and chaff are fed into the threshing machine of the combine per hectare. In the case of a threshing machine with a throughput of 10.5 kg/s and a load of 95%, the calculated (theoretical) speed of the combine is 6 km/h (1.67 m/s); the theoretical hourly productivity is 3.6 ha/h. Technical productivity is 2.3 ha/h (9.2 t/h). Actual fuel consumption 13.6 l/ha (3.3–3.4 l/t). Option 2 - The grain is harvested by a Deutz-Fahr C6205 combine, only instead of the standard reaper, a ZHON-6 "brand (Fig. 2) combing-type reaper with a working width of 6 m is installed. In this case, the harvesting unit performs the following operations: the combing device removes 70% of the grain from the heads of the stalks, cuts the heads with grain (30%) and 10% of the straw stalks (by weight of the grain); The threshing device of the combine crushes the grain remaining in the delivered heads. At this time, both heads with grain and free (combed) grains enter the threshing device; it also separates the coarse mass on the straw screen, cleans the grain from chaff and impurities, and removes the grain from the combine bunker and loaded into a transport vehicle; the straw is crushed and thrown onto the field. When harvesting grain with this type of threshing machine, the weight of the mass (grain + straw) entering the threshing machine per hectare is: grain - 4000 kg, chaff - 560 kg and straw - 1440 kg. Total - 5900 kg/ha (0.59 kg/m2). With such a load of this threshing machine, the theoretical working speed of the combine is 10.2 km/h. The theoretical productivity of the combine is 5.6 ha/h; technical productivity - 4.2 ha/h; fuel consumption - 2.0 l/t (8 l/ha). The threshing machine is loaded at 96%. Option 3. - The Deutz-Fahr C6205 grain harvester with a standard 6-meter-wide cutterbar harvests a straight-standing field with a high cut so that the heads are followed by a 15-20 cm long straw. The delivered mass is crushed and separated, and the straw crusher separates the remaining grain from the coarse chaff, which is then crushed and scattered on the field. The grain is loaded from the bunker into a truck. When harvesting a field with a 100 cm stalk, the combine cutterbar should cut the stalk and 20 cm of the stalk (below the head). Then the mass entering the threshing machine is equal to the mass of the head and grain - 4,600 kg (mass of straw - 1,600 kg). Total - 6,200 ha/ha or 0.62 kg/m2 (the ratio of the mass of grain, straw and chaff is 1:0.55). The working speed of the combine is 10 km/h, and the hourly productivity (technical) is 4.0 ha/h. Diesel fuel consumption is 2.1 l/t. When harvesting a field of winter wheat with lodged ("tilted") heads: the sickle cuts the stalks 10-15 cm below the lodged heads, as a result of which straw (45-50 cm high) remains. In this case, the threshing machine is fed 4,000 kg of grain per hectare, 2,350 kg of straw and boxwood stalks, a total of 6,350 kg/ha (0.635 kg/m2). Under these conditions, the theoretical working speed of the combine is 9.4 km/h (2.6 m/s). Theoretical productivity is 5.64 ha/h. Technical productivity is 3.7 ha/h (14.8 t/h). Fuel consumption is 10 l/ha (2.5 l/t). If we compare the technical and operational characteristics of the above-mentioned grain harvesting technologies, it can be noted that the resource-saving technology, compared to traditional technology, increases the productivity of the combine harvester: when harvesting a straight field, when the heads are straight, by 1.7–1.8 times (combing method) and by 55% when the heads are tilted. At the same time, fuel consumption is reduced by 42% in the first case and by 42–27% in the second case, respectively. Calculations of the operating and adjusted costs of wheat harvesting were performed using the aforementioned technical and operational indicators. The calculation results are presented in Table 1

Table 1 The calculation results are presented

Expenses	**Unit of measurement**	**Capture technologies**			
		Traditional method	**The method of introduction**	**High cut (20 cm. below the head)**	
				A straight field	**Inclined head field**
		.....	.....	.....	.....
		Wheat.....			Barley
Productivity	Ha/h	1,8	2,5	3,0	3,7
Broken mass	t/h	7,5	9,5	10,2	6,8
Fuel consumption	Dollar/ha	8	7,2	7,3	7.5
Fuel cost	Dollar/ton	280,0	280,0	280,0	280,0
Salary	Dollar/ton	0,8	0,8	0,8	0,8
Depreciation	Dollar/ton	3,48	2,48	2,0	2,16
Operating costs	Dollar/ton	12,24	8,81	7,98	8,8
Reduced costs	Dollar/ton	17,45	12,04	10,98	11,88
Productivity growth	%	--------	45	54	70

Reducing fuel consumption	%	----------	58	57	60
Savings in operating costs	Dollar/ton	----	3,41	4,22	3,59
Reduced cost savings	Dollar/ton		5,41	6,47	5,56

3. Conclusions

Analyzing the data in Table 1, it can be noted that the lowest operating costs were achieved when harvesting with the high-cut method - 3.5 USD/t, and when harvesting grain using the ZHON-6 harvester - 3.58 USD/t. Compared to harvesting grain using the traditional method (5.35 USD/t), harvesting with the high-cut method leads to a saving of operating costs of 1.87 USD/t (35%), and harvesting with the brushing method - 1.5 USD/t (34%). This saving is mainly achieved by reducing fuel consumption from 3.3 to 2.0 l/t (40%).

The lowest reduced costs are achieved when harvesting with the high-cut method - 4.80 USD/t, and harvesting with the brushing method - 5.26 USD/t. The total savings in reduced costs are 2.37 and 2.83 USD/t, respectively.

It is important that the use of resource-saving technologies significantly increases the efficiency of grain harvesting machines by 70-80%. This will reduce grain losses due to self-seeding and minimize technological losses associated with stable crops.

The additional income from reducing grain losses (both technological losses and self-seeding) ranges from $6.70 to $9.60 per ton, depending on the harvested area and grain yield. This additional income ensures the completion of harvesting operations for high stubble and straw left on the field. Most importantly, the proposed technologies allow the grain harvesting process to be completed within the specified agrotechnical deadlines.

Compliance with ethical standards

Disclosure of conflict of interest

The authors declare that there is no conflict of interest to be disclosed.

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