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Corresponding author ORCID: 0009-0006-8542-708X

THE CALIBRATION PROCESS OF THE “TRIMBLE - YIELD MONITORING” SYSTEM FOR THE PURPOSE OF YIELD MAPPING DURING THE TECHNOLOGICAL OPERATION OF BARLEY AND WHEAT HARVESTING

Šunjevarić, V., Milan[1*], Dražić, S., Milan[*1], Gligorević, B., Kosta[*1], Pajić, B., Miloš[*1], Bošković, D., Biljana[*1], Zlatanović, J., Ivan[*2]

[1]Univesity of Belgrade, Faculty of Agriculture, Beograd – Zemun
[2]University of Belgrade, Faculty of Mechanical Engineering

*Corresponding author: m.sunjevaric@agrif.bg.ac.rs

Abstract. The integration of various technologies such as sensors, GPS, drones, collection, analysis and management of data obtained during agricultural production is the standard when it comes to precision agriculture. Yield, as the main goal of production, is not just the value after harvest, but says much more when yield data is appropriately collected and later analyzed in the right way. Mapping involves collecting yield data from different locations on the plot and creating a map or spatial representation of yield variations. This provides an insight into the heterogeneity of the plots is obtained and the right decisions can be made and activities on the plots can be planned appropriately. The experiment was carried out in the technological operation of harvesting barley and wheat at the sites Progar and Padinska Skela, owned by the company “Al Dahra”. A combine harvester “New Holland CR 7.90” was used for harvesting with a “Trimble Yield Monitoring System” to monitor and map yields. The system is equipped with an optical sensor to monitor the applied mass and a moisture sensor “Ag Leader”. During the work, the following parameters were monitored: moisture, amount of mass harvested, hectoliter mass, and a calibration of the entire system was performed to minimize the possibility of errors.

Keywords: precision agriculture, GPS, mapping, yield, harvest, harvester, calibration.

1. INTRODUCTION

Harvesting is the last technological operation in the cycle of agricultural production, during which information about the quantity and quality of the threshed grain can be obtained. Timely harvesting and the use of appropriate technical means are essential for the implementation of the entire process, i.e. for maximizing productivity and minimizing losses of threshed grain. The technological aspect of harvesting has reached a fairly high level, the technical means used produce minimal losses, the operator’s work is based on the use of various technical systems. As in other production segments, the term precision farming is often heard in this area. The advantages of using this technology do not stop at harvesting, so that many of the new technologies can also be used in this process [2, 5].

Tractors can be equipped with autopilot systems with RTK signals for sowing, feeding and crop protection, and combine harvesters are equipped with the same systems. With an accuracy of 2.5 cm and the ability to monitor the work process in real time, an enviable level of production was achieved. With the eternal pursuit of higher yields and better working conditions, man has created some systems that greatly facilitate the work of the agricultural producer. One of the applied systems in agricultural production technology is the ability for the operator to monitor the crop yield in real time during harvest. If we combine systems such as yield monitoring during harvesting and GPS technology, we get the possibility to record the yield quantities per certain unit of area [1, 9, 11].

Trimble has developed a standardized system for monitoring and mapping yields - the "Yield Monitoring System". It enables us to create a separate yield map for each plot on which we harvest. By mapping the entire process from sowing to feeding, protection and harvesting, we can carry out a detailed analysis that allows us to make better decisions throughout the process. By using this system, we can achieve considerable savings in the use of the various inputs. The savings are reflected in the fact that, based on the analysis of the yield maps, vegetation indices and soil analysis, the standards for sowing and top dressing have been reduced and thus savings have been made, as well as in the database on the quality of the soil we have [4, 7, 8].

To achieve accurate results, the system must be properly calibrated and its accuracy must be monitored during operation. The aim of the study is to monitor the calibration process of the yield mapping system, its accuracy and the possibilities we have with the collected crop data. During the test, the entire process was followed, from the installation of the system itself to its commissioning and calibration, i.e. achieving the highest possible accuracy.

2. MATERIAL AND WORKING METHODS

The calibration of the yield mapping system was carried out on combine harvesters of the manufacturer "New Holland", model "CR 7.90", during the technological operation of the barley and wheat harvest. The site where the calibration process was carried out is located near Progar (44.708889, 20.156944) and Padinska Skela (44.939722, 20.424444), on plots belonging to the company "Al Dahra". The test was carried out on several plots with a total area of 50 ha.

The mapping system tested is a system from the American manufacturer Trimble "Yield Monitoring", which can optionally be added to the existing autopilot system with the navigator "TMX 2050" (Fig. 2.a) (Tab 1.) from the same manufacturer. The hardware part consists of an optical sensor (Fig. 1.a), which measures the grain level on the threshing unit, and the moisture sensor "Ag Leader" (Fig. 1.b), as well as the software application "FmX Plus" (Fig. 2.b), also developed by Trimble [6, 9].

Figure 1. (a) Optical sensor that measures the fill level at the blades of the mass elevator (b) Ag Leader moisture sensor

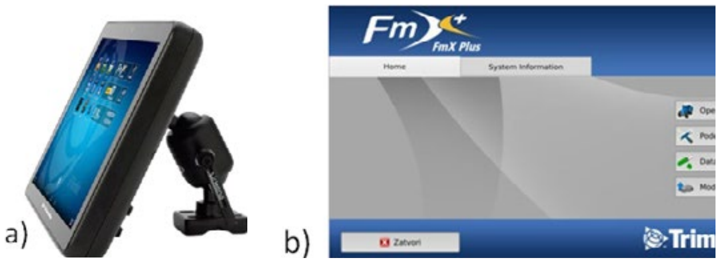

Figure 2. (a) Trimble TMX 2050 navigator (b) FmX Plus software for use with the Yield Monitoring system, [9]

Table 1. Technical characteristics and functionalities of Trimble TMX 2050 navigator

Technical features	
Display	Touchscreen, 30.8 cm diagonal, high resolution
Operating system	Android operating system
Internal memory/RAM	16 Gb/ 1Gb
Navigation software	FmX Plus / Precision IQ
GNSS receiver	Dual frequency
ISOBUS compatibility	Yes
Optional camera output	Yes
Storage of	users / properties / packages / handlers / operations
USB port	Yes

Functionalities	
Automatic steering	Trimble Autopilot/EZ-Pilot/EZ-Steer/TrueTracker/TrueGuide
NextSwath (headland turning)	Yes
AutoSync (wireless data exchange)	Yes
Precise application of nitrogen fertilizer	Yes
Yield and moisture monitoring	Yes
Checking the leveling of plots	Yes
Mapping of boundaries and objects on plots	Yes

In this research, the yield monitoring and mapping system used in a New Holland combine harvester was powered by an 8.7-litre inline six-cylinder engine with a "common rail" fuel injection system controlled by an electronic control unit (ECU). The transmission is hydrostatic, 4 gears (forward and reverse). During the test, the combine harvester was mounted with a wheat header.

Table 2. Technical features of the harvester

	Paremeters	Units	
1.	Number of cylinders / charging	/	6 / turbo
2.	Engine power	KW	338
3.	Nominal engine speed	rpm	2000
4.	Engine displacement	ccm3	8709
5.	Max. speed	km/h	30
6.	Type of transmission	/	Hydrostatic 4+4
7.	Weight of vehicle	kg	18000
8.	Dimensions	m	3,25/9,97/3,97
9.	Type of movement system	/	Wheel
10.	Grain tank size	l	9500
11.	Emission class	/	V

As part of this research, an additional "Yield Monitoring" system was installed on the existing Trimble TMX 2050 Autopilot system to monitor data on the amount of mass harvested and the moisture level at the time of harvest. The harvester's navigation device is equipped with software for yield mapping and real-time monitoring of harvesting parameters during harvesting. The application used during harvesting is FmX Plus.

The system consists of the following components:

- Moisture sensor (Figure 1b): It generates an electric field, detects disturbances due to changes and changes the capacitance in the dielectric material around the sensor. Changes in capacitance result in changes in the output voltage signal that is sent to the yield monitor.
- Proximity switch (Figure 1a): Controls the level of grains in the sensor housing. It reacts to the presence of grains in a certain zone and sends a signal to a DC motor that drives the elevator to empty the moisture measurement system housing. It works on the principle of changing the value of the dielectric constant, which is 1 for air, compared to grain, whose constant value is between 10 and 30.
- Header height sensor (Figure 3c): Provides information about the height of the crop header based on which cover detection is turned on or off, i.e. whether or not to harvest at a given time.
- Spiral conveyor (Figure 4c): It is used to empty the cover; when the proximity sensor sends a signal to it, it is activated and the mass that was in the sensor is conveyed further to the elevator and the bunker, freeing up space for receiving new grain and for repeated measurements.
- DC motor (Figure 4b): It drives the spiral conveyor and is activated by the signal from the proximity sensor.

Figure 3. (a) Moisture measurement system (b) moisture sensor (c) header height sensor

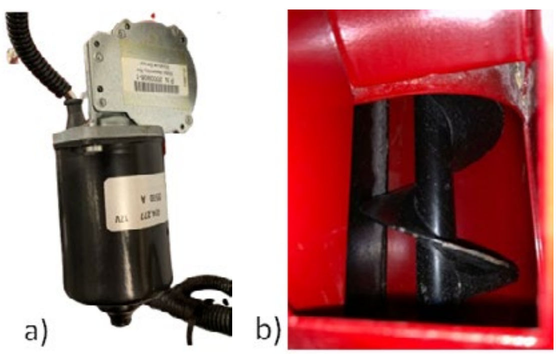

Figure 4. (a) DC motor (b) spiral conveyor

The Ag Leader system for moisture measurement is installed on the outside of the tunnel through which the blades of the threshed grain elevator move. The installed system has two openings on the tunnel through which the mass enters the space where the moisture sensor is located and through which the spiral conveyor returns the mass on which the moisture was measured back to the mass conveyor. The second part of this system is an optical sensor. It is also located on the outside of the tunnel through which the threshed grain elevator moves and its task is to provide us with data on the amount of yield. The operating principle of this sensor is based on changing the parameters of the optical signal, i.e. each time the knife passes over, the sensor reads the size of the husk formed by the driven mass (Fig. 5). Based on the hectoliter mass and the size of the cup, the software calculates the yield and displays it on the screen of the navigation device in the cab [9].

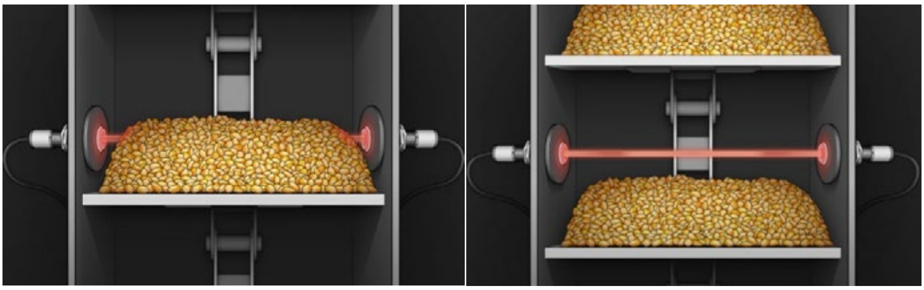

Figure 5. Functional principle of the optical sensor for monitoring the amount of threshing mass [9]

3. SYSTEM ADJUSTMENT AND CALIBRATION PROCESS

In order for the Trimble Yield Monitoring and Mapping System to perform its function properly, it is important that all system components are correctly connected and adjusted on the harvester. The entire process is controlled via the FmX plus application on the Trimble TMX 2050 navigator. In the application, the crop being harvested and the combine's work input must be set and the function of all sensors must be checked so that the further process of calibration and adjustment can begin [9].

Figure 6. (a) Home page of the FmX plus application (b) Configuration of the header

The first setting option is the “Implement” item (Fig. 2 (b)), in which we define the operation we are performing, the working handle of the header and its position in relation to the navigator’s receiver. This item (Fig. 7) is very important for the accuracy of the mapping, so the correct measurements, i.e. the physical dimensions of the cutting unit and the dimensions of the application itself, must be entered so that the navigation system can form the correct navigation lines.

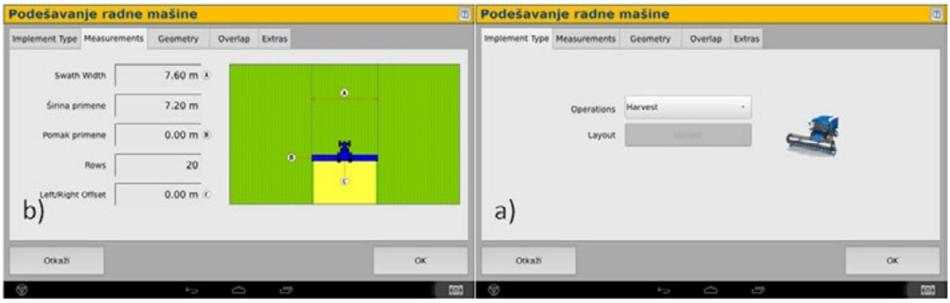

Figure 7. (a) Selection of the operation (b) Settings of the working machine

After setting up the implement in the navigator, the next step is to select the Yield Monitoring module, which has several options in its menu, such as settings, calibration or diagnostics. In the basic settings (Fig. 8) for yield monitoring, the requirements for the system to function must be met, i.e. the following must be selected: the manufacturer of the combine harvester, its series, the type of yield monitoring and the type of moisture sensor. The next step is the “Advanced settings” option (Fig. 9), where the dimensions of the blades of the pure grain elevator must be entered, which pass the previously installed optical sensor, which is placed in a suitable position.

Figure 8. Yield tracking settings with advanced options

To obtain accurate readings, it is necessary, after entering the dimensions of the blades, to enter the angle of the elevator and its compensation, if any. The compensation refers to the position of the buckets left-right or front-rear. If some of these parameters are not entered correctly, precise yield data cannot be obtained and there is also a possibility that an error will be reported during the initial calibration.

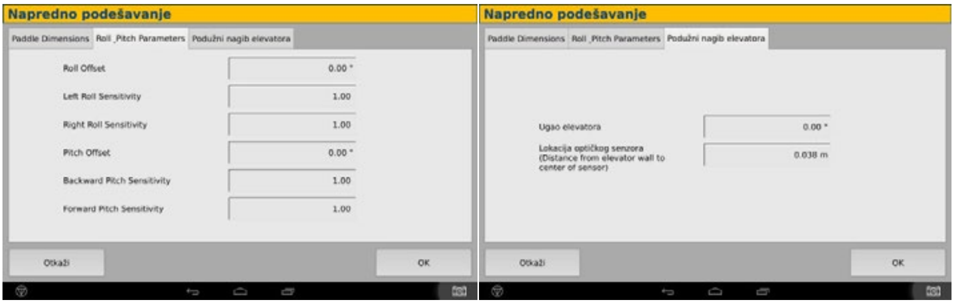

Figure 9. Entering the value of the elevator angle and its compensation

After entering data within the basic settings required for yield control (Fig. 10), it is necessary to adjust the height of the adapter (header). The setup can only be run if the height sensor is active, for which there is an indicator in the setup menu. After checking the activity, the highest and lowest position of the adapter is read and the distance between them is displayed as a percentage, 0% - the lowest, 100% - the highest position. During harvesting, these values are always visible on the navigator screen, depending on the position of the header. The next setting is of the time type and consists in measuring and then entering the time between the moment when the adapter mows the crop and the moment when the first grain falls into the combine's hopper. The following settings must also be entered: type of crop to be harvested, unit of measure, storage moisture and upper moisture limit.

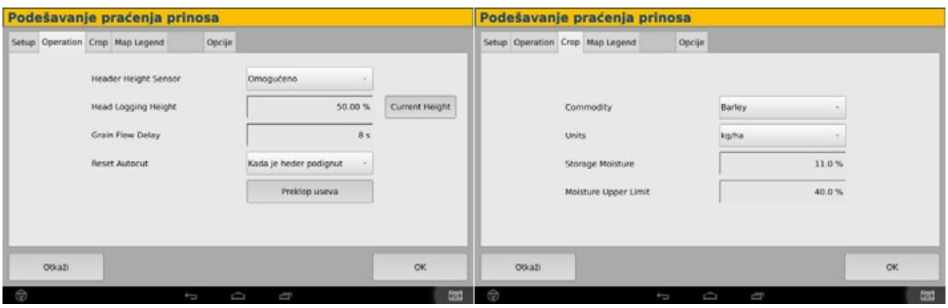

Figure 10. Header height setting, grain transit time from mowing to bunker, input of crop type, moisture values

To obtain accurate readings, it is necessary, after entering the dimensions of the blades, to enter the angle of the elevator and its compensation, if any. The compensation refers to the position of the buckets left-right or front-rear. If some of these parameters are not entered correctly, precise yield data cannot be obtained and there is also a possibility that an error will be reported during the initial calibration.

In the working view on the navigator's screen, the yield map is displayed according to the traffic light principle, with a good yield on a certain part of the bar cell being displayed in green and a poor yield in red, while the values between the upper and lower limits are displayed in yellow (Fig. 15). Accordingly, we adjust the upper and lower expected values of moisture and yield to accurately represent the coverage detection, i.e. the state of the yield on the plot.

Figure 11. Setting the coverage record on the working view

The next step is to calibrate the height of the adapter (header) and the yield sensor. Calibrating the height of the adapter (header) is necessary due to the voltage range in which the sensor operates, because if it is set to a mowing height that is outside the voltage range, the system will detect an error. Yield sensor calibration is performed to determine if there are certain deviations in the clean grain elevator mechanism, such as defects in the chain that carries the blades, missing or damaged blades themselves.

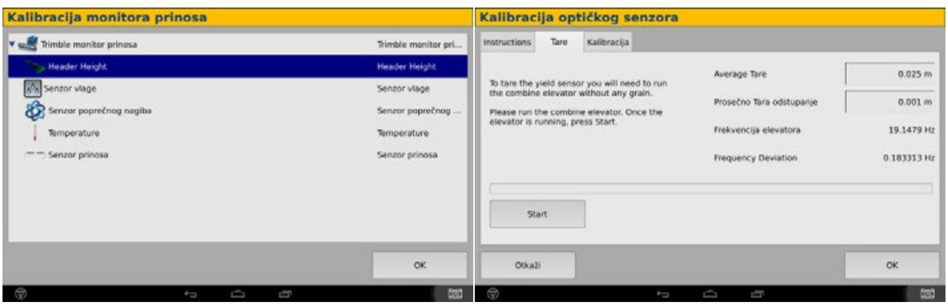

Figure 12. Selecting the settings in the yield monitor and calibrating the optical sensor

Calibration of the optical sensor (Fig. 12) is carried out by switching on the threshing unit according to the settings previously made, setting the number of revolutions to the maximum value and then obtaining data on the deviation and frequency of the elevator are obtained. The process is repeated three or more times, if the obtained (first and second decimal places) are not extremely different, the calibration is successful, and if the values differ by a whole number or more than 0.3 after each start, it is necessary to check the combine or elevator system.

Header height calibration (Fig. 13) is performed by pressing the "Start" button, after which the adapter is raised to the top position and 100% is entered in the first field, which represents the maximum height of the adapter. The adapter is then lowered to the lowest position, i.e. to the ground, and 0% is entered in the second field.

Figure 13. Header height calibration

The yield monitoring diagnostics (Fig. 14.) is used to check the yield monitoring status, header height, elevator angle, moisture percentage and other parameters during operation. The activity of the optical sensors can also be monitored, such as the percentage of darkness, which lets us know if the sensor is placed correctly, as well as the activity of the moisture sensor.

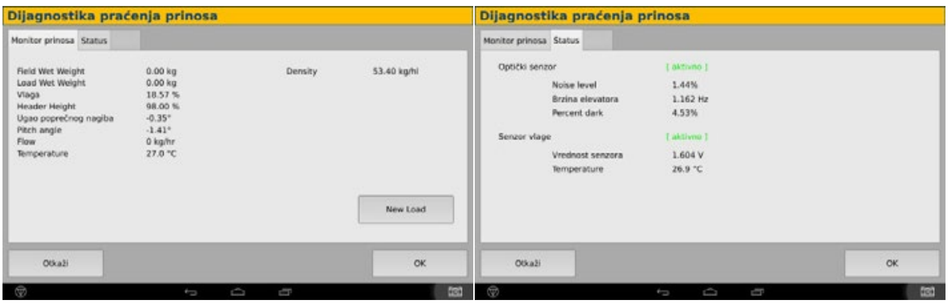

Figure 14. Yield monitoring diagnostics

The working view is used to monitor all parameters during operation, in it a new measurement called "load___" can be started (Fig. 15 (a)), in the same window the percentage moisture content as well as the average yield per hectare and the amount of harvested crop in a particular measurement can be monitored. In the "loads and calibration" option (Fig. 15 (b)), you can enter the density (hectoliter weight) and thus calibrate the yield sensor, and by entering data on the moisture percentage, you can calibrate the moisture sensor and thus obtain precise results for subsequent measurements.

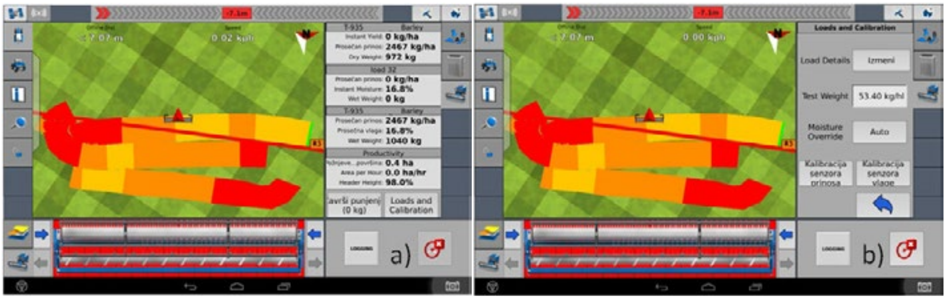

Figure 15. (a) Working view (b) Entering the correct values after checking in the precision measuring probe

Once the bunker for the crushed mass has been filled, it is transferred to a transport vehicle in which the grain is sent for inspection, i.e. for remeasurement with calibrated equipment. The harvester continues the harvest, i.e. with a new measurement of "load___", and one waits for the results of the accurate measurements, which are entered into the system as "load __ __" measurement data. If accurate measurement data is available, pressing the "Calibrate yield sensor" button (Fig. 15) opens the menu for entering values (Fig. 16). Under the "Calibration type" option, "Multiload" is selected, i.e. when calibrating multiple loads, the measurement results are checked by the mapping system and compared with the actual measured values. The measured value from the display is entered in the "Recorded Weight" field and the measured value from the calibrated scales is entered in the "Current weight" field, according to which the calibration is updated; it is also important to enter the hectoliter mass measured on the reference device in the "Test Weight" field in kg/hl. The system applies the updated calibration retroactively to both the previous and the next measurement.

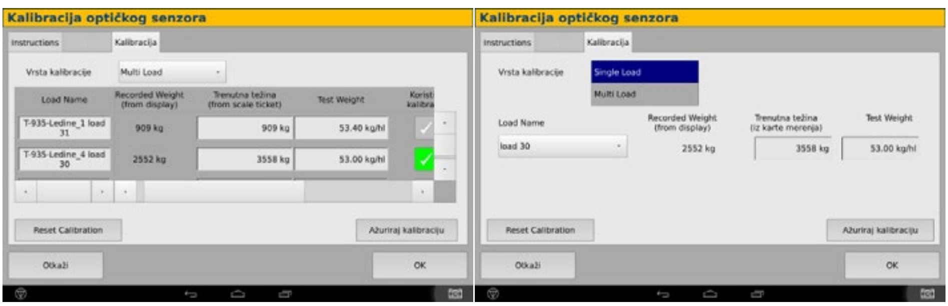

Figure 16. Yield sensor calibration menu

Calibration of the humidity sensor is started by pressing the "Calibrate humidity sensor" button (Fig. 17), which opens the calibration menu. The principle is the same as for the yield sensor, the "Multiple load" option is selected, in the field "Current moisture offset" the value of the measurement performed by the system on the combine harvester is read in the "Current moisture offset " field, and we enter the current value of the calibrated moisture meter in the "Moisture difference (%)" field below. After updating the calibration, the values are applied retroactively to both previous and subsequent measurements.

Figure 17. Moisture sensor calibration menu

4. RESEARCH RESULTS AND DISCUSSIONS

In the technical-technological process of barley harvesting, the first measurement ("Load 1B") shows from the results presented (Table No. 3) that the difference between the mass measured by the combine harvester and the mass measured by the calibrated scales is about 23%, i.e. that the device on the combine harvester weighed 743 kg less than the scales. After three measurements were entered into the calibration menu of the yield sensor, the last, fourth measurement ("Load 4B") was carried out, in which error values of 2% were obtained, i.e. the device on the combine weighed 62 kg less than the calibrated scale, which is a more accurate result than the first measurement. From the values obtained, it can be concluded that the yield sensor is sufficiently calibrated so that it can continue to work without additional measurements. As part of the same measurements, the moisture content of the threshed grain was measured using the same principle. In the first measurement ("Load 1B"), the difference was 3.5 %, which is outside the range due to the limit values for the absorption of mass into objects, so that further measurements were carried out. Three further measurements followed, with a value of 0.2% being achieved in the last measurement ("Load 4B") and no further measurements being necessary. The values achieved can be influenced by soiling of the sensors during further work, so that both sensors must be cleaned for a certain period of time as a preventive measure. The technical-technological operation of the wheat harvest was carried out according to the same principle as for barley. In the first measurement ("Load 1W"), it can be seen from the results displayed (Table No. 4) that the difference is 14.3%, i.e. the combine harvester's yield sensor measured 812 kg less than the calibrated scales used as a reference device. Three further measurements were carried out in which the difference after the last measurement ("Load 4W") was between 1-2%, more precisely 70 kg, which is a small difference compared to the initial mass, so that no additional calibration of the sensor is required after this measurement. In the moisture measurement, the sensor showed a difference of 3.7% in the first measurement ("Load 1W"), so as in the previous case, three more measurements were taken, with no difference after the last one ("Load 4W"), i.e. the value of the reference hygrometer and the "Ag Leader" moisture sensor within the yield monitoring system matched. In addition to monitoring moisture content and yield, the most important parameters during harvest, this system offers the possibility of geo-positioning the readings. All data can be analyzed and applied in production in the form of variable standards for the use of seeds, fertilizers or chemicals, using appropriate software such as QGIS, Agro-Map, Trimble Ag software and specialized technical tools. [3, 10, 12].

Table 3. Comparative presentation of the measurements of mass, threshed mass and moisture content in the barley harvest

Name and number of measurements	Mass (kg) (harvester)	Mass (kg) (measuring device)	Moisture percentage (harvester)	Moisture percentage (measuring device)
Load 1B	2467	3210	9.9%	13.4%
Load 2B	2922	3287	12.1%	13.6%
Load 3B	3334	3440	12.7%	13.1%
Load 4B	3495	3557	13.2%	13.4%

Table 4. Comparative representation of mass measurement, threshed mass and moisture content in the wheat harvest

Name and number of measurements	Mass (kg) (harvester)	Mass (kg) (measuring device)	Moisture percentage (harvester)	Moisture percentage (measuring device)
Load 1W	4882	5694	11.0%	13.7%
Load 2W	5277	5508	12.8%	13.6%
Load 3W	5496	5583	13.1%	13.5%
Load 4W	5457	5527	13.7%	13.7%

5. CONCLUSION

In this research, the calibration process of the yield monitoring and mapping system was carried out during the technological operation of harvesting barley and wheat. The research has shown that the systems are available for retrofitting harvesting machines and can perform precise measurements and displays in real time for the purpose of measuring the yield level and its mapping when properly calibrated. The results obtained, i.e. measurement errors of 2-3% when measuring yield height and moisture measurement with an even lower error percentage after the calibration process, confirm the justification for using this system. To achieve realistic results, at least 3-4 measurements are required during the calibration process, which is the recommendation of the system manufacturer and was confirmed by this study. With the geolocation of the results obtained, it is possible to analyze the entire production process and opens up the possibility of applying VRA technology. The recordings of the yield sensors can be compared with satellite images, i.e. vegetation indices of the crops, and the overlaps of the results obtained can be used in prediction maps for the following crop years of these crops. Yield monitoring and mapping is just one of the steps towards sustainable agricultural production, where we need to make rational use of resources, which are not unlimited, as a contribution to a better relationship with the environment and the production of higher quality food.

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