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IMPACTS OF AUTOMATIC AND PARALLEL DRIVING SYSTEMS ON THE PRODUCTIVITY OF MACHINE-TRACTOR UNITS IN THE NORTHERN REGION OF THE REPUBLIC OF KAZACHSTAN

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Precision farming systems are being intensively introduced into the agricultural production of the Republic of Kazakhstan. According to developers and dealers, precision farming can reduce the cost of fertilizers, seeds, PPA, fuel and lubricants by 20% on average. At the same time, the efficiency possibilities resulting from the utilization of precision farming systems under certain conditions have not been fully studied. The aim of this work was to assess the influence of parallel and automatic driving systems on the technical, operational and economic indicators of units for sowing, chemical processing, harvesting, and autumn deep tillage using comparative tests in the northern region of the Republic of Kazakhstan. For these purposes, comparative tests were conducted for a seeder for sowing wheat; self-propelled sprayer for chemical weeding of wheat and flax; combine harvester for harvesting wheat; and unit for deep, subsurface tillage in Northern Kazakhstan. The comparative tests determined the impacts of GPS navigation systems, automatic and parallel control systems, and seeding control systems on agricultural, energy, operational, technological and economic performance of units.

Keywords: comparative tests; precision farming; unit; navigation system; efficiency

In the early 1990s, a new concept appeared in the world agricultural science – precision farming, which originated due to the emergence possibility of global positioning system utilization (GPS, Glonass). The use of precision farming technology will lead to the transformation of agriculture, which is indicated by obtained economic effects in terms of profitability, productivity, crop quality and environmental protection (Yakushev, 2016; Celms et al., 2014).

Precision farming allows reduction of costs of fertilizers, seeds, plant protection agents (PPA), fuel and lubricant materials by an average of 20% (From precision farming to “smart farms”, 2019). In addition to reduction in energy costs, resources and increasing productivity, precision farming allows alignment of the physical and agrochemical properties of soil, resulting in a field state with better conditions and right shape that are convenient for agricultural operations (Kelc et al., 2019). Application of precision farming systems with maximum profit provided that agricultural production, economic and natural resources are optimized, opening thus real opportunities for producing high-quality products and preserving the environment (Yakushev and Yakushev, 2007; Keskin et al., 1999; Finger et al., 2019). Precision farming systems are well

established and successfully applied in the United States, Canada, Brazil, and Europe (Tsirulev et al., 2008; Shannon et al., 2018). Currently, the market of Kazakhstan offers various precision farming systems, such as parallel and automatic driving systems, seeding control, crop mapping, etc. Many of these systems are already used in agricultural production (Ji and Zhou, 2014; Lowenberg-Deboer and Erickson, 2019; Salimi et al., 2020) and can be purchased and installed on existing farm equipment. Furthermore, it is possible to obtain new technology, to which these devices were already installed by the manufacturer. Concurrently, the potential efficiency resulting from the utilization of precision farming systems under certain conditions of their use have not been fully studied (Sharda et al., 2015; Vecchio et al., 2020)

Material and methods

In 2019, the experiments were conducted at the Kostanay branch of Scientific and Production Center of Agricultural Engineering LLP in order to determine the influence of GPS systems – GPS navigation of automatic control GreenStar 3-2630 and seeding control (wheat sowing); GPS navigation and automatic control system GreenStar 2-2600 (chemical

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processing of crops); GPS navigation and parallel driving system with a course indicator of the Raven company (wheat harvesting); GPS navigation and parallel driving system Trimble EZ-Pilot with CFX-750 display (subsurface deep tillage) – on agrotechnical, energy, operational, technological, and economic indicators of the unit.

Comparative tests were conducted to determine the influence of automatic and parallel driving systems on the unit's performance. There were obtained evaluations regarding the agrotechnical, energy and operational and technological indicators of units consisting of:

- seeding complex John Deere 1890 with John Deere 1910 seed hopper combined with tractor John Deere 9410R for wheat sowing equipped with GPS navigation systems, automatic control GreenStar 3 and seeding control;
- self-propelled sprayer John Deere 4730 for chemical weeding equipped with GPS navigation and automatic control systems GreenStar 2;
- combine harvester ACROS-530 and Power Stream 9 header with GPS navigation and parallel driving systems (course indicator) by the Raven company;
- deep-ripper SPT-7 and tractor K-744R3 equipped with GPS navigation and parallel driving Trimble EZ-Pilot with CFX-750 display and without seed control systems, automatic and parallel driving (systems were disabled).

The tests were conducted in the North Kazakhstan region, the Republic of Kazakhstan. The method of conducting comparative tests was based on the requirements of regulatory documentation. Test conditions were determined in accordance with the requirements of the standard GOST 20915-2011 (2013). Assessment of agrotechnical indicators was performed according to the standard GOST 31345-2007 (2009) for seeding; standard GOST R 53053-2008 (2009) for chemical weeding; standard GOST 33736-2016 (2017) for tillage; and standard GOST R 28301-2007 (2007) for harvesting. Assessment of energy indicators was carried out according to the standard

GOST 52777-2007 (2007). Operational and technological evaluations were conducted in compliance with the standard GOST 24055-2016 (2018). The data obtained were processed using mathematical statistics using MS Excel. The economic efficiency of units was determined according to the standard ST RK GOST R 53056-2010 (2010).

The total expenditures I_t per unit of operating time (tenge-unit of operating time⁻¹) was calculated as follows:

$$I_t = (I_1 + I_2 + I_3 + I_4) \quad (1)$$

where:

I_1 – direct operating expenditures, tenge-unit of operating time⁻¹; I_2 – expenditures taking into account changes in the quantity and quality of products, tenge-unit of operating time⁻¹; I_3 – expenditures taking into account the level of working conditions of service personnel, tenge-unit of operating time⁻¹; I_4 – expenditures taking into account the negative impacts on environment, tenge-unit of operating time⁻¹

The experiments were carried out in triplicate. The costs for obtaining the navigation systems and their operation were taken into account.

Results and discussion

The State University of Ponta Grossa, Uvaranas Campus, Brazil has been conducting research on navigation manoeuvres for seeding. The results showed that the manoeuvres

performed using the navigation system were faster by 49% on average than those with the conventional system. Cost reductions of \$ 4.15 per hectare have been observed on plots with length of 800 metres. Moreover, on plots with shorter lines (50 metres), these savings reached \$ 19.90 per hectare, proving that the utilization of a satellite communication navigation system in combination with an autopilot device can significantly save time and reduce operating costs when growing soybeans (Garcia et al., 2016). The research results for the Republic of Kazakhstan obtained so far are not sufficient and this paper thus observes a wide range of technologies.

Comparative tests of the seeding complex John Deere 1890 combined with tractor John Deere 9410R equipped with the GPS navigation and automatic driving system GreenStar 3, AutoTrac (automatic control) and seeding control by the John Deere company and the unit without these were conducted from 16 to 22 May 2019. The GPS navigation and automatic driving system GreenStar 3 provided an accuracy of ± 20 cm from passageway to passageway. Preparation of seeding unit for operation (Fig. 1) was carried out by farm specialists.

In terms of wheat crops, the comparative test conditions were typical for the zone. Average values of indicators at a soil depth of up to 15 cm: soil moisture – 22.3%; soil volume mass – 1.08 g·cm⁻³; soil hardness – 1.1 MPa; humidity – 42%; air temperature – 20.5 °C; seed purity –

Fig. 1 Sower unit John Deere 1890 + trailed pneumatic hopper John Deere 1910 combined with tractor John Deere 9410R (front side view)

Fig. 2 Utilization impacts of GPS navigation system, automatic driving GreenStar 3 and seeding control on technical and economic indicators of the unit for wheat sowing

98.2%; seed moisture – 14.2%; bulk density of wheat seeds – $773 \text{ kg}\cdot\text{m}^{-3}$. Prior to tillage, the soil was treated by dust mulching (weeder harrow), fertilizers were applied to a depth of 15–16 cm (seeder SGS-2,1).

The structural complex width was 12.4 meters. The performance evaluation was carried out while sowing the steam pre-treated wheat. During the operational and technological assessment, the operating time was 35.0 hours of main time and sown area was 1500 hectares for the seeding unit (John Deere 9410R tractor; John Deere 1890 seeding complex; John Deere 1910 seed hopper). The comparative test results of the unit without GPS navigation system, automatic driving and seeding controls while wheat sowing showed that, at speed of $11.3 \text{ km}\cdot\text{h}^{-1}$ and operating width of 12.4 m, the productivity was 14.1 ha per hour of main time; shift and operating times were 10.4 ha. Coefficients of

use of shift and operating times were 0.74. Failures were not recording during the assessment, making the utilization rates of shift and operating times equal. The power consumption necessary for moving the unit across the field was 202.4 kW and its specific fuel consumption was $5.3 \text{ kg}\cdot\text{ha}^{-1}$. The specific energy consumption was $50.2 \text{ MJ}\cdot\text{ha}^{-1}$ per hour of main time. The actual seed consumption was $71.5 \text{ kg}\cdot\text{ha}^{-1}$.

Employment of GPS navigation and automatic driving system for sowing provided an increase in the seeder working width of 12.8 m. At $11.3 \text{ km}\cdot\text{h}^{-1}$ speed, the unit showed productivity of 14.5 hectares per hour of main time; shift and operating times were 11.0 ha. Seeding control system utilization contributed to an increase in the utilization rate of shift and operating times. Coefficients of use of shift and operating times were 0.75. This unit showed specific fuel

consumption of $5.1 \text{ kg}\cdot\text{ha}^{-1}$; specific energy consumption of $49.2 \text{ MJ}\cdot\text{ha}^{-1}$ per hour of main time; and actual seed consumption of $70.0 \text{ kg}\cdot\text{ha}^{-1}$.

It was found that, in terms of wheat sowing, the utilization of GPS navigation systems, automatic driving and control of seeding provided an increase in operating width by 0.4 m (3.2%). Simultaneously, the unit productivity increased by 0.6 ha per hour of shift and operating time (5.7%). Furthermore, its employment to wheat crops panting resulted in a reduction in specific energy consumption by 2%. Specific fuel consumption was reduced by $0.2 \text{ kg}\cdot\text{ha}^{-1}$ (4.0%), seed consumption by $1.5 \text{ kg}\cdot\text{ha}^{-1}$ (2.0%) (Fig. 2).

It was established that the unit consistently and efficiently could perform the technological process regardless of the availability of GPS navigation, automatic driving and seeding control systems.

The economic efficiency calculation showed that the use of GPS navigation systems, automatic driving and seeding control led to a reduction of costs by 8.2%, while the annual expenditure reduction was 1465 thousand tenge (3.6 thousand US dollars) compared to the unit without systems.

In the period from 19 to 26 June 2019, there were conducted the comparative tests of the self-propelled sprayer John Deere 4730 equipped with GPS navigation and automatic driving systems (AutoTrac) with GreenStar 2 display and the unit without automatic driving system. This type of sprayer in operation is shown in Fig. 3.

Comparative tests of a self-propelled sprayer were carried during the chemical processing of cereals (wheat) and oilseeds (flax). The operation was carried out from 8 p.m. until 10 a.m. the next day due to the high wind speed ($8 \text{ m}\cdot\text{s}^{-1}$) and temperature ($25\text{--}30^\circ\text{C}$) throughout the day. The sprayer preparation for operation was carried out by farm specialists.

Comparative tests conditions were typical for the zone when carrying out chemical processing of cereals and oilseeds. Average values of indicators at soil depth of 10 cm: soil moisture – 26.4%; soil volume mass – $1.1 \text{ g}\cdot\text{cm}^{-3}$; soil hardness – 1.5 MPa. Other indicators taken into account included: humidity – 38%; air

Fig. 3 Sprayer John Deere 4730 in operation (rear side view)

Fig. 4 Influence of the automatic driving system on technical and economic indicators of the self-propelled sprayer John Deere 4730 during chemical weeding of cereals

temperature – 16.2 °C; wind speed – 0.8 m·s⁻¹; plant height – 11.2 cm; working fluid temperature – 15 °C; row spacing – 25.2 cm for flax and – 15.3 cm for wheat; weed amount – 229 pcs·m⁻².

The comparative test results in terms of chemical weeding of cereals and oilseeds indicated that, at 26.2 km·h⁻¹ speed and 27.8 m working width, the self-propelled sprayer John Deere 4730 (without GPS navigation system and automatic control) showed productivity of 72.8 ha per hour of main time; shift and operating time were 38.6 ha. Coefficients of use of shift and operating times were 0.53. The power consumption for moving the sprayer across the field was 94.9 kW, specific fuel consumption was 0.78 kg·ha⁻¹, specific energy consumption was 5.4 MJ·ha⁻¹ per hour of main time. The pre-set working fluid

flow rate was 55.0 l·ha⁻¹, the actual one was 59.6 l·ha⁻¹.

The total operating time of the unit for chemical treatment was 3000 hectares. It was found that the utilization of GPS navigation and automatic driving system led to an increase in the working width to 30.4 m. At a speed of 26.2 km·h⁻¹, the unit demonstrated the productivity of 79.6 ha per hour of main time; shift and operating times were 45.2 ha. Coefficients of use of shift and operating times were 0.57. Specific energy consumption was 5.0 MJ·ha⁻¹ per hour of main time, specific fuel consumption was 0.66 kg·ha⁻¹. The pre-set working fluid flow rate was 55.0 l·ha⁻¹, the actual one was 52.0 l·ha⁻¹.

The use of GPS navigation system, automatic driving for chemical weeding of cereals and oilseeds provided an increase in the working width by 2.6 m (8.4%). Sprayer

productivity increased by 6.6 ha per hour of shift and operating time (14.6%). Specific fuel consumption was reduced by 0.12 kg·ha⁻¹ (17%), specific fluid consumption by 7.6 l·ha⁻¹ (14.5%). It was found that the unit stably and efficiently performs the process regardless of the availability of GPS navigation, automatic control. Based on the data obtained, the economic efficiency of the self-propelled sprayer John Deere 4730 equipped with GPS navigation and automatic control system and the unit without it was calculated. Figure 4 shows a diagram depicting the influence of automatic driving system on the technical and economic indicators of the self-propelled sprayer John Deere 4730 during chemical weeding of cereals.

Comparative test results showed that employment of the self-propelled sprayer John Deere 4730 equipped with a GPS navigation and automatic control system provides an annual expenditure reduction of 6562.6 thousand tenge (16.4 thousand \$ US) in terms of chemical weeding of grain and oilseeds. Total costs were reduced by 9%, specific fuel and herbicide consumption by 17% and 14.5%, respectively.

In the period from 12 to 15 September 2019, there were conducted comparative tests of the combine harvester ACROS-530 with Power Stream 9 header (Fig. 5) equipped with a parallel driving system (GPS navigation with direction indicator) by the Raven company (USA) and the unit without parallel driving system.

During testing, the average values of indicators at a soil depth of 10 cm: soil moisture – 19.7%; soil hardness – 1.2 MPa. Characteristics of harvested crop were as follows: wheat grain yield – 20.2 centner·ha⁻¹; 1000 grain weight – 43 g; grain moisture – 18%; straw moisture – 16.2%; plant height – 0.6 m; plant density – 379 pcs·m⁻²; weediness – none. The comparative test conditions were typical for the zone when conducting the agrotechnical, energy and operational-technological assessments of combine harvester ACROS-530 with Power Stream 9 header.

The unit's constructive working width was 9 metres, and total operating time was 1700 hectares.

Fig. 5 Combine harvester ACROS-530 with Power Stream 9 header

Fig. 6 Influence of parallel driving system on technical and economic indicators of the combine harvester ACROS-530 with Power Stream 9 header for wheat harvesting

In terms of cereals harvesting, the comparative test results of combine harvester ACROS-530 (without GPS navigation system and parallel driving) showed that, at $7.8 \text{ km}\cdot\text{h}^{-1}$ speed and 8.6 m working width, the productivity was 6.7 ha per hour of main time; shift and operating times were 4.7 ha . Coefficients of use of shift and operating times were 0.7 . The unit showed specific fuel consumption of $7.1 \text{ kg}\cdot\text{ha}^{-1}$; specific energy consumption of $76.9 \text{ MJ}\cdot\text{ha}^{-1}$ per hour of main time.

The header working width increased to 8.7 m thanks to the GPS navigation system and parallel driving. At $7.8 \text{ km}\cdot\text{h}^{-1}$ speed, the productivity reached 6.8 ha per hour of main time; shift and operating times were 4.8 ha . Coefficients of use of shift and operating times were 0.7 . The unit

showed specific fuel consumption of $7.0 \text{ kg}\cdot\text{ha}^{-1}$; specific energy consumption of $75.8 \text{ MJ}\cdot\text{ha}^{-1}$ per hour of main time.

When harvesting cereals, the utilization of GPS navigation and parallel driving system resulted in an increase in the working width by 0.1 m (1.2%). Concurrently, the productivity increased by 0.1 ha per hour of shift and operating time (2.1%). Employment of system allowed the reduction in specific energy consumption by $1.1 \text{ MJ}\cdot\text{ha}^{-1}$ (1.4%), and specific fuel consumption by $0.1 \text{ kg}\cdot\text{ha}^{-1}$ (1.4%) compared to the unit without these.

It was established that the combine harvester ACROS-530 with Power Stream 9 header steadily and efficiently performs the process regardless of the availability of GPS navigation and parallel control.

Based on the economic assessment, it was established that the use of combine harvester ACROS-530 with parallel driving system (GPS navigation with direction indicator) allowed reduction of costs by 3% , labour costs and specific fuel consumption by 1% in contrast to the unit without it. The utilization of combine harvester ACROS-530 with Power Stream 9 header equipped with a parallel driving system for wheat harvesting provided annual expenditure reduction of 233.4 thousand tenge ($\$ 585 \text{ US}$). Diagram of the parallel driving system impacts on technical and economic indicators is given in Fig. 6.

Based on the comparative tests results, it was found that the system utilization required higher attention capacity, which led to rapid fatigue of machine operator.

In the period from 16 to 19 September 2019, there were conducted comparative tests of the deep-ripper SPT-7 combined with a tractor K-744 P3 (Fig. 7) equipped with a parallel driving system Trimble EZ-Pilot (auto-steering) and a CFX-750 display manufactured by Trimble (USA) and the unit without these.

The tests were carried while performing deep tillage in field in the North Kazakhstan region. The Trimble EZ-Pilot parallel driving system with CFX-750 display was operated using a free satellite signal (GPS) with an accuracy of up to 100 cm . Equipment preparation for operation was performed by farm specialists and Navistar Asia Kazakhstan LLP.

Test conditions for deep tillage were typical for the area. Average values of indicators at a soil depth of up to 30 cm : soil moisture – 24.9% ; soil volume mass – $1.2 \text{ g}\cdot\text{cm}^{-3}$; soil hardness – 2.7 MPa . Other indicators taken into account included: humidity – 28% ; air temperature – $21.4 \text{ }^{\circ}\text{C}$; wind speed – $4.5 \text{ m}\cdot\text{s}^{-1}$. Cultivation to a depth of 12 cm was performed prior to tillage.

The unit constructive working width was 7.6 meters . The total operating time of this unit was 1200 hectares .

There were conducted comparative tests of the deep-ripper SPT-7 combined with tractor K-744 P3 equipped with the parallel driving system EZ-Pilot and a unit without it. The tests were carried out at $7.8 \text{ km}\cdot\text{h}^{-1}$ speed, the path depth

Fig. 7 Deep-ripper SPT-7 combined with tractor K-744 P3

Fig. 8 Impacts of parallel driving system EZ-pilot and CFX-750 display on technical and economic indicators during deep tillage

of plough working bodies was 22.0 cm, and the standard deviation was within 2.4 cm. The working width of units with and without the system was 7.3 m.

It was established that the use of parallel driving system EZ-Pilot with a free signal (GPS) from a satellite with an accuracy of 100 cm does not provide technical and technological advantages for the unit in question in terms of primary tillage.

Based on the data obtained, the economic efficiencies were calculated for the unit equipped with the parallel driving system EZ-Pilot with and without the CFX-750 display.

Diagram depicting the impacts of parallel driving system on technical and economic indicators of the deep-ripper SPT-7 combined with tractor K-744 P3 equipped with the parallel driving system EZ-Pilot and CFX-750 display is given in Fig. 8.

The economic assessment showed that the operation of unit consisting of the tractor K-744 P3 and deep-ripper SPT-7 equipped with the parallel driving system EZ-pilot and CFX-750 display resulted in an increase in total expenditures of \$ 174 tenge·ha⁻¹ (\$ 0.4 US) in contrast to unit without these, leading to cost overruns of 160.6 thousand tenge (\$ 402, 3%) per year.

Conclusion

1. Considering the wheat sowing, the use of GPS navigation system, automatic driving system GreenStar 3 provided an increase in the unit's productivity per hour of shift time by 5.7%, and decrease in labour costs
2. In regard to the chemical weeding of cereals and oilseeds, the employment of GPS navigation and automatic control system GreenStar 2 contributed to an increase in shift productivity by 14.6%, and a reduction in specific energy consumption by 8%, fuel consumption by 17.0%, and working fluid consumption by 14.5%. Simultaneously, total expenditures decreased by 9%, the total annual saving were 6562.6 thousand tenge (\$ 16.4 thousand US).
3. In relation to wheat harvesting, utilization of the parallel driving system (GPS navigation with a direction indicator) led to an increase in productivity by 2.1%, and a decrease in total costs by 3%, labour costs and specific fuel consumption by 1.4%. The total annual savings reached the amount of 233.4 thousand tenge (\$ 585 US). However, the use of parallel driving system for harvesting cereals required increased attention, which resulted in increased stress and fatigue of the machine operator. If the efficiency of combine harvester is to be increased, it must be equipped with an automatic driving system.
4. The use of parallel driving system EZ-Pilot and CFX-750 display using

a free GPS signal from satellite in the North Kazakhstan region was not economically feasible for the tillage purposes, since their employment led to an increase in total expenditures of 174 tenge·ha⁻¹ (\$ 0.4 US) and cost overruns by 160.6 thousand tenge (\$ 402 US) per year. To ensure the efficiency of units equipped with the parallel driving system Trimble EZ-Pilot and CFX-750 display for the purposes of deep tillage in the northern region of the Republic of Kazakhstan, it is necessary to use a paid GPS signal from the satellite with better accuracy of 15–20 cm.

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