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# *Comparative Analysis of the Effectiveness of the Application of UAV and Conventional Ground Equipment for Plant Protection Measures in Sunflower Cultivation*

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***Abstract*— The use of various means of transport for plant protection measures in agriculture is not new. Its application increases productivity and reduces the cost of growing a variety of products. Conventional ground transport vehicles are self-propelled sprayers or those attached to agricultural tractors. The sprayed solution is stored in a container until it is applied or prepared on site. Inconveniences are created by the transfer of a large amount of detergent, its movement on uneven terrain, the processing of small and specific fields, the change of the working solution, etc. An alternative option is the use of unmanned vehicles – ground or in the air. They have their advantages and disadvantages. Their use is related to the implementation of a number of regulatory documents. However, they give autonomy to producers and enter more and more widely in agriculture. This article aims to compare the costs of using different means of transport as energy sources used for plant protection measures. As an example, when obtaining quantitative values, a sunflower crop typical for the country was used. In addition to standard costs, an attempt has been made to compare the carbon footprints of the use of different means of transport. The sensor part is made of standard soil moisture sensors, and the control part is entrusted to a single-board computer with the ability to control via a wireless network.**

***Keywords — agricultural machinery, means of transport, UAV, costs, carbon footprint.***

## I. INTRODUCTION

Sunflower is one of the most economically important field crops grown in Bulgaria [1]. The popularity of sunflower is growing due to its numerous positive qualities. In addition to the known nutritional qualities, it has the ability to react to various environmental factors, has a shortened development cycle, and is resistant to dry environments. All this makes it attractive for production by a number of farmers [2,3].

The implementation of plant protection measures aims to prevent the destructive losses of pests, weeds and diseases of agricultural crops [4]. Practices to combat them include distancing the host, destroying or reducing the pest or weed, improving resistance and direct protection of plants [4,5]. Known plant protection practices applied against diseases, cultural practices, physical, biological and chemical control are part of the applied pest and weed control methods [4,5].

Plant protection measures are part of the production costs of a farm [6]. The data from these events in many cases support product providers or administrations to improve policy development, administrative decisions or market efficiency. A number of farmers are also using the data to improve the economic performance of their farms. Apart from this, they are able to analyse and compare their activities with the leaders in the region and make informed decisions about future actions [5,6].

This article aims to compare the use of different machines for plant protection measures, thus separating the separate values of operating costs, additional costs and product costs. The obtained values for the machines used will be compared and recommendations for their use will be given depending on the size of the farm.

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## II. MATERIALS AND METHODS

The comparative study was carried out in the land of the village of Biser, Harmanli Municipality. The fields that were cultivated were sown with sunflower by ET "Rossi-Zlatka Koleva". The fields were selected with almost identical conditions and uniformly distant access from the plant. The specified time for moving the machine to the field and back from the base is 0.333 h.

Fig. 1. General appearance of the Pantera 4502 self-propelled sprayer.

There are three machines used for plant protection measures. One is a self-propelled sprayer AMAZONE Pantera 4502 (Fig. 1) [7]. The spraying range is 24 m. The sprayer is equipped with a tank of 4800 l, the spray speed is 3.06 m/s. Fuel consumption is determined when performing plant protection operations 6 l/ha. When moving from the base and back, a flow rate of 19.2 l/h is determined.

Fig. 2. General view of the greenhouse.

The second machine for plant protection measures is the AMAZONE UG2200 sprayer [8]. The working width of the sprayer is 24 m, and the capacity of the detergent tank is 2400 l. The sprayer is used in a machine-tractor unit together with a CLAAS Arion 520 tractor [9]. During the operation of the unit, a consumption of 10 l/h was reported, a spray speed of 2.2 m/s. When moving, the unit reported a consumption of 22 l/h.

Fig. 3. XAG P40 drone when spraying sunflower.

The third plant protection machine used in the current experiment is the UAV XAG P40 (Fig. 3) [10]. The capacity of the detergent tank is 22 l, and the flight time is 0.197 h. The speed of the operations performed is 5 m/s, and the transport to the loading site is fixed at 7 m/s. The working width of spraying from the drone is 4.5 m. In this way, minimal overlap and optimal operation of the drone are guaranteed.

The reported time for charging and returning to the breakpoint is 0.033 h. When the battery is connected to the charging unit, it starts automatically and stops when the battery is fully charged. A flow meter is installed on the fuel line, which reads 0.58 litres per battery charge. The movement of the drone to the field is carried out by pickup and is reported as additional costs, and movement from the base to each field and return.

The price of fuel is averaged and reported according to [11] as of 17.04.2024, diesel is €1.43, and gasoline is €1.38. The fuel consumed by the self-propelled sprayer and the tractor are recorded with flow meters to fuel, after reworking their fuel system according to [12].

The reported cleaning time of the machines after each operation is 0.333 h. For UAV, this time is 0.167 h, because the detergent capacity is 22 l.

According to the adopted methodology, the hourly rate of the workers operating and maintaining the machines (tractor driver) is 6 €/h, of the UAV pilot and the agronomist is 10 /h. This operation is performed by the agronomist for 0.083 h or 0.83 €.

The machines are set to the specified working speed and the time for each operation is recorded by a XINJIE XJ-011 stopwatch, with an accuracy of 1/100 s.

The labour for each operation LO is calculated by the dependence (1):

$$LO = TO.HW \quad (1)$$

In (1) TO is time to operation, measured in hours and HW is the hourly rate of the worker, evaluated in €/h.

Two plant protection measures were carried out with products authorized for use in the EU. According to EU regulations, these products are a second professional category – it requires a specialist who has a certificate for working with plant protection products. The products are

used once. Two treatments are required on each field – one for each product.

One event was held for perennial and annual cereal weeds with the product Tornado 5EK, at the beginning of April at a rate of 2.0 l/ha. More than 14 economically important weeds have been controlled. The product has been applied in the 3-5 leaf phase of the weed. The price of the product is 9.72 €/l.

The other plant protection product with which the event was carried out was MAZA 4SL [13,15]. The product was applied in the third ten days of April at a rate of 1.25 l/ha and a price of 29.67 €/l. The product was applied in phase 4-6 leaf of the weed and controlled over 24 economically important weeds.

The cost of products or fuels is defined as the product of the amount of product or fuel consumed (in litres) and the corresponding cost per litre.

On average, the value of each indicator is defined as the sum of the individual values for the different fields.

The total values of the area costs are determined as a quotient of the total costs and the sum of the area of cultivation.

## III. Results and discussion

The results of the experiments are shown in Table 1-5 and figure 4. The indications in the tables are as follows: F is number of fields, A is the area of the fields, FC – fuel consumption, P 1 and P 2 – plant protection products, T – time to operation, L – labor for operation.

In Table 1 contains the data from the experiment using the XAG P40 plant protection drone.

TABLE 1 Experimental data from plant protection measures with XAG P40 drone

| F | A, ha | FC, l | P 1, l | P 2, l | T, h | L, € |
|---|---|---|---|---|---|---|
| 1 | 4.38 | 2.32 | 8.76 | 5.48 | 0.691 | 6.91 |
| 2 | 2.43 | 1.16 | 4.86 | 3.04 | 0.35 | 3.5 |
| 3 | 1.61 | 0.58 | 3.22 | 2.01 | 0.197 | 1.97 |

Extremely low fuel consumption (FC) is noticeable. This is due to the fact that the generator turns on automatically when the battery is plugged into it and turns off when the battery is charged. It is noticeable that four charges of the drone's battery are required. The fuel consumed to charge the batteries is 2.32 l when processing field 1 and 0.58 l when processing field 3 (F). The consumed plant protection products (P 1 and P 2) are according to the manufacturer's norm. It was found that the time for spraying with a drone in larger areas increases with the times for loading and flying to the place of interruption of the operation. Accordingly, the areas treated with the drone per hour decrease. This reduction for the current experiment is 1.84 ha. The operation of the drone in the air depends on various factors, with the strongest influence being the amount of product consumed, the shape of the field and weather conditions. The operational time (T) of the drone in field 1 is 0.691 h, and in field 3 it is 0.197 h per treatment. In all machines for plant protection measures, the times are repeated for each field when processing with different products and therefore in the primary data it is given only for the performance of one operation.

In each working machine, the operating speed of movement and the amount of sprayed solution per ha can be set. A work computer in each machine monitors the correct implementation of the set process parameters.

The cost of labour to carry out the individual operations is impressive because of the high hourly rate of labour. This is due to the need for qualified personnel for ground and air operations. At the same time, these personnel have the necessary qualifications to work with category 2 products. The labour costs (L) of processing the individual fields in operations carried out with a field 1 drone are €6.91, and for field 3 are €1.97.

The experimental data from the plant protection measures carried out with the self-propelled sprayer AMAZONE Pantera 4502 are shown in Table 2. The increased fuel consumption (FC) and the minimum time for operations are impressive. The highest consumption was found in the largest field 1 – 31.2 l. Due to the large volume of the product tank, the fields are processed without additional loading. There are no differences in the time for performing individual operations. The cost of labour (L) to perform operations here is much lower, due to the specific category of labour of operators. In field 1, the cost of labour is 1.18 €, and in field 3 it is 0.22 €.

TABLE 2 Experimental data from plant protection measures with AMAZONE Pantera 4502

| F | A, ha | FC, l | P 1, l | P 2, l | T, h | L, € |
|---|---|---|---|---|---|---|
| 1 | 5.2 | 31.2 | 10.2 | 6.5 | 0.197 | 1.18 |
| 2 | 3.68 | 22.08 | 7.36 | 4.6 | 0.139 | 0.83 |
| 3 | 0.96 | 5.76 | 1.92 | 1.2 | 0.036 | 0.22 |

The analysis of the data from the implementation of plant protection measures with the UG 2200 sprayer shows the highest fuel consumption again at field 1 - 61 l (Table 3). The lowest consumption was found at field 3 - 12.1 l. An increase in the fuel consumption of the machine-tractor unit by almost twice compared to the self-propelled sprayer and the huge difference compared to the drone is impressive. This difference is due to the specifics of the individual machines. to charge the batteries, while the UG 2200 sprayer is dependent on the power machine. It has its own specifics and is universally applicable, while other machines for plant protection measures are strictly specific and cannot be used for any other purpose. As for the cost of labour to perform individual operations, there is a slight increase compared to the self-propelled sprayer. This finding can be explained by the lower productivity of this machine compared to the self-propelled sprayer. The labour cost of using the UG 2200 sprayer is lower than that of using a don, due to the shorter processing time and lower hourly cost of the operator's labour. The highest cost of

labour is in field 1 of €1.92 and the lowest in field 3 of €0.36.

TABLE 3 EXPERIMENTAL DATA FROM PLANT PROTECTION MEASURES WITH AMAZONE UG 2200

| F | A, ha | FC, l | P 1, l | P 2, l | T, h | L, € |
|---|---|---|---|---|---|---|
| 1 | 6.1 | 61 | 12.2 | 7.63 | 0.32 | 1.92 |
| 2 | 2.97 | 29.7 | 5.94 | 3.71 | 0.16 | 0.96 |
| 3 | 1.21 | 12.1 | 2.42 | 1.51 | 0.06 | 0.36 |

The average values from the experiments of plant protection measures in sunflower cultivation are shown in Table 4.1 and Table 4.2. Table 4.1 presents the data on fuel consumption (FC) in euros for the operation (O) and the additional costs (A) of moving the machines. It also gives the price in euros of plant protection products (PC). There is a lower operating cost when using a drone compared to conventional sprayers. This is due to the lower costs of carrying out operations and the lower value of additional costs, such as transporting the machines to the fields and cleaning the tanks for plant protection products. Conventional machines use the independent movement of machines to the field, while drones rely on small vehicles with low fuel consumption. Reducing fuel costs will reduce the carbon footprint generated by sunflower production. The cost of plant protection products depends solely on the consumption rate of the product per ha. The differences in costs found in this column are due to the different area of the fields.

TABLE 4.1 AVERAGE VALUES OF THE CONDUCTED EXPERIMENTS

| Machine | A, ha | F C, € | | P C, € | |
|---|---|---|---|---|---|
| | | O | A | P 1 | P 2 |
| XAG P40 | 8.42 | 11.21 | 4.99 | 163.68 | 312.43 |
| Pantera 4502 | 9.84 | 168.85 | 54.86 | 189.35 | 364.94 |
| UG 2200 | 10.28 | 294.00 | 62.86 | 199.84 | 381.26 |

TABLE 4.2 AVERAGE VALUES OF THE LABOR COST

| Machine | A, ha | Labor cost, € | |
|---|---|---|---|
| | | O | A |
| XAG P40 | 8.42 | 24.76 | 24.99 |
| Pantera 4502 | 9.84 | 4.46 | 17.98 |
| UG 2200 | 10.28 | 6.48 | 17.98 |

Table 4.2 shows the data on labour costs when performing the operations. In terms of labour costs, higher costs, both operational (O) and additional (A), are noticeable when using a drone.

The higher costs are due to the higher qualification of drone operators and the longer duration of drone operations. The drone operator is also a vehicle driver and moves the drone to the fields, while his hourly labour rate is higher.

TABLE 5 COMPARATIVE ANALYSIS OF THE RESULTS OF THE EXPERIMENT

| Machine | Total cost, € | Total cost per area, €/ha |
|---|---|---|
| XAG P40 | 542.06 | 64.38 |
| Pantera 4502 | 800.44 | 81.35 |
| UG 2200 | 962.42 | 93.62 |

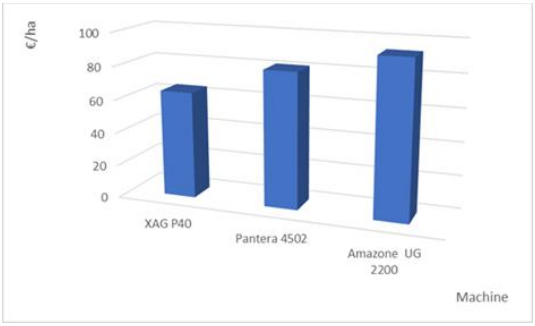


Fig. 4. Consumption per ha when growing sunflower crops.

The analysis of Table 5 and Fig. 4 shows that the cost per ha of growing sunflower crops is the lowest when using a drone and the highest when using a sprayer in a machine-tractor unit. These costs are respectively €64.38 and €93.62.

Using a self-propelled sprayer would reduce these costs by €12.27. With the total cost of growing sunflowers, the use of a drone will cost €540.06 for the current study. According to it, the total cost of using a self-propelled sprayer is €800.44, and for a sprayer in a machine-tractor unit, it is €962.42.

## IV. CONCLUSIONS

The lowest costs in growing sunflower crops are obtained when using a plant protection UAV. With it, the fuel costs are to charge the batteries and move it to the fields. However, the use of the drone is limited to small fields and irregularly shaped fields, due to the limited volume of its tank for plant protection products and due to the need to constantly charge the batteries. On this basis, the operating time and the cost of skilled labour increases.

The use of self-propelled plant protection machines significantly shortens the time for carrying out events. Labour costs are minimal, but there are increased fuel costs. It is used in very large fields with large areas close to each other. With self-propelled plant protection machines, the constant additional filling of the plant protection tank is not necessary.

Sprayers, which are part of a machine-tractor unit, are a suitable option for carrying out plant protection measures for medium and small farms, where the high costs of growing sunflower crops are compensated by the lack of an additional expensive self-propelled plant protection machine or UAV.

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