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DEVELOPMENT OF HIGHLY PRODUCTIVE TECHNOLOGICAL SCHEMES FOR THE USE OF AGRODRONES FOR PLANT PROTECTION

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Abstract. *In agricultural production, to obtain high yields, reliable protection of cultivated plants is necessary, the crops of which are affected by various harmful organisms. The most effective in combating pests of agricultural plants is the chemical method, which, when successfully applied, provides high cost-effectiveness. To reduce the toxic impact on cultivated plants and the environment, the use of agricultural drone is promising due to their advantages over mobile ground sprayers. Agricultural drone do not compact the soil, do not damage agricultural crops, are extremely maneuverable, can work on fields of various configurations, are able to spray immediately after precipitation, can carry out local or point spraying, and provide accurate dosing of chemicals. They are characterized by high productivity and lower energy consumption. The implementation of the technological process by an agricultural drone was analyzed without taking into account the size of the field, the sown crop, the relief of the field, the type of agricultural drone, etc. As a result, the active, i.e. useful work performed by the drone, namely the technological process of spraying the drug, has been clearly delimited. The auxiliary actions necessary for the implementation of the technological process of spraying have been established: replacement (charging) of batteries, filling the tank with chemical liquid, take-off and landing, approach to the field boundary, U-turns when switching to another processing lane. A universal method for calculating the effective productivity of agricultural drones during the cultivation of agricultural crops has been proposed, which involves the analysis of each component of the technological process of applying pesticides by agricultural drones. Technological schemes have been proposed that provide a partial reduction in unproductive operations, increasing the productivity of agricultural drones, provided that the material support for the implementation of the technological process increases for each subsequent technological scheme. The use of agricultural drones-sprayers provides high productivity, which makes it possible to process crops in a short time, protecting them from diseases, pests and weeds.*

Key words: *agricultural drone, mobile charging station, spraying, productivity, technological scheme of drone operation, agricultural plants, pesticides, drone speed, shift time, spraying width.*

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1. INTRODUCTION

The rapid development of global mechanical engineering, including agricultural engineering, the creation of new designs of various machines, tools, aircraft, computer technologies, chemical synthesis, etc., has given impetus to the creation of new technologies in the agricultural sector. This paper considers one of them – the use of agricultural drones in agriculture [1–3].

The use of drones in agricultural production, in particular for field cultivation, is a reality that has its advantages. The combination of small-sized unmanned aerial vehicles and advanced computer technologies (using GPS technologies) with the use of modern preparative forms of pesticides provides reliable protection of agricultural crops from pests [4–7].

In modern agro-industrial production, it is possible to obtain high yields of cultivated plants only by applying appropriate methods of reliable plant protection. Crops of cultivated plants are affected by various harmful organisms, they are shaded by weeds, woody and shrub vegetation, which contribute to the reproduction of pests and pathogens. The most effective in combating weeds that litter crops of agricultural plants, diseases and pests is the chemical method, which, when successfully used, provides high cost-effectiveness [8–10].

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The basis of the chemical method of combating crop yields is the use of pesticides to destroy weeds and pests during their mass reproduction and the spread of pathogens of cultivated plants. Today, pesticides are a necessary component of agro-industrial production. Thanks to their use to protect cultivated plants, an increase in the yield of cultivated crops and the preservation of grown products is achieved [11–13]. Ill-considered or careless use of pesticides can negatively affect the soil, which is the basis for the growth and development of cultivated plants, which provide fodder for livestock and food for people [14, 15].

In each specific case, determining the appropriateness of using pesticides, their availability and effectiveness (biological, economic, and economic) are taken into account. The variety and popularization of the use of pesticides have caused an increase in the chemical (toxic) load on the fields, which leads to a disruption of the balance in agrobiocenoses, a possible increase in the resistance of harmful organisms, an increase in the risk of pollution of the environment and grown products [16, 17]. This can be prevented by reducing the rates of consumption of drugs and the frequency of their application.

Modern agriculture is unimaginable without the use of chemical plant protection products. Until the 1980s, crops were treated with ground-based self-propelled units, using medium-volume and high-volume spraying with flows of 50…400 l/ha and more than 400 l/ha, respectively [18].

In recent decades, ground sprayers have been partially replaced by agricultural drones. An agricultural drone is a small-sized aircraft for processing crops. The main design and technological parameters of an agricultural drone: distance above the surface 4...5 m; operating speed 6...8 m/s; liquid droplet size 50...150 microns; spray width 6...9 m; working fluid consumption 5...10 l/ha. For the active action of chemical crop protection products, the number of drops of the products per square centimeter of plants is required: 200 fungicides, 20...40 herbicides, 30...60 insecticides.

Modern plant protection science has achieved the ability to synthesize highly effective concentrated preparations for use in small doses over large areas, providing reliable protection of cultivated plants.

Agrodrones use sprayers designed for ultra-low-volume spraying, which form droplets of working fluid with a diameter of 50...150 microns, ensuring the required density of plant coverage with the drug at a flow rate of 5...10 l/ha. The calculation of the parameters of the agrodrone nozzles is performed taking into account the needs of modern agriculture and the requirements for the accuracy and efficiency of field processing.

The use of a lightweight yet durable drone design ensures an optimal load-to-weight ratio, and a high-quality power system will ensure reliable operation of the drones for a long time.

Agrodrones have advantages over mobile ground sprayers, namely: they do not compact the soil at all and do not damage crops; they are extremely maneuverable; they can work on fields of various configurations; they are able to spray immediately after precipitation; they can perform local or spot spraying; they provide precise dosing of chemicals, reducing the negative impact on the environment; they are characterized by high productivity and lower energy consumption [19, 20].

The objective of the work is to develop a methodology for calculating the productivity of using agricultural drones for processing crops and plantings of cultivated plants and to develop technological schemes for cultivating fields with agricultural drones with recommendations for their rational use based on a comparison of their productivity [21–26].

2. ANALYTICAL METHODS

To perform the technological process of spraying using agricultural drones, a mobile technological device for ground service is necessary [27–30].

Such ground-based mobile technological devices [29, 30] (Figure 1, position 1) are placed on one or both sides of the field, they are equipped with agricultural drones 5, charging devices (batteries) 3 with an antenna 4 for transmitting and receiving signals and a container 2, which is filled with a working solution of the pesticide. All these device components are necessary for the productive operation of the drone.

To model the technological process of spraying fields with agricultural drones, we will perform its schematization for the general case (Figure 2).

Let us assume: the field width l_p is less than one kilometer, the supply of chemical liquid in the agricultural drone tank and the battery charge are sufficient to cover a distance of several kilometers.

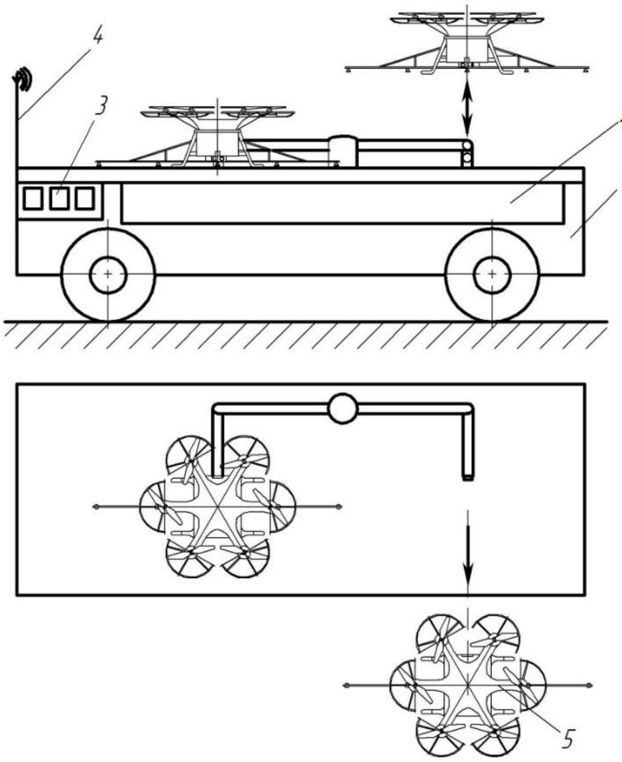


Figure 1. Mobile technological device for the ground service of agricultural drones

The time during which the entire volume of liquid in the tank of the agricultural drone is used will be called a stage and denoted by t_E. In one stage (i.e. in t_E) the drone will make several passes over the field, denoted by n_{PR}, spraying the chemical during the time t_0. To process the field, the drone needs to spend time on takeoff and landing and approach to the field boundary t_M, as well as time on idle runs during turns t_X.

The number of drone passes over the field in one stage is determined:

$$n_{PR} = l_0 / l_P , \quad (1)$$

if l_0 – length of the drone's path (flight) over the field or the length of the processed strip during the execution of the technological process in one stage, m.
l_p – f ield width, m.

Number of work passes of the agricultural drone per shift

$$N_0 = n_{PR} \cdot n_E , \quad (2)$$

if n_E – number of drone operation stages per shift is determined:

$$n_E = T_A / t_E \,. \tag{3}$$

if T_A – agrodrone flight time, hours;
t_E – time during which the entire volume of liquid in the agrodrone tank will be used.

The drone is assumed to work a full shift, so the working shift time of the agricultural drone will be

$$T_{CH} = T_A + T_C \,, \tag{4}$$

if T_C – time for replacing (charging) batteries and filling the tank with a chemical preparation, depending on the processing process $T_C \approx 0{,}1 \ldots 1{,}5$ hours.

The execution time of the technological process of applying pesticides by an agricultural drone T_0 over the entire field per shift depends on the number of active (working) passes of the agricultural drone N_0 and the time of one pass t_{01}.

$$T_0 = N_0 \cdot t_{01}. \tag{5}$$

if t_{01} – time during which the drone makes one pass of length l_P, h,
$t_{01} = l_P / V_P$; V_P – operating speed of the drone, km/h.

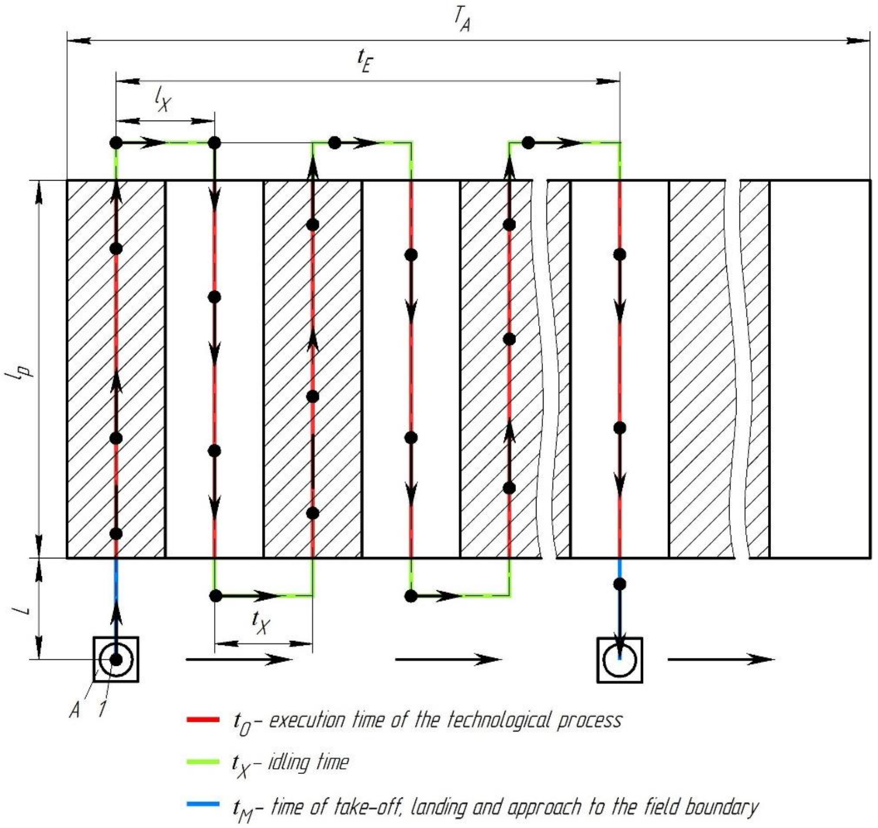


Figure 2. Schematization of the technological process of processing by agricultural drones

3. RESEARCH RESULTS

Some technological schemes for using agricultural drones to process fields of various configurations should be analyzed.

For processing small fields (Figure 3), it is advisable to use one mobile station and one drone. Mobile station *A* is placed at some distance L from the field boundary, provided that it is inconvenient to approach directly to the edge of the field. Drone 1 is installed on a mobile station, which charges the battery and fills the tank with the working pesticide solution during the time T_C. After charging and filling the tank with the pesticide solution, drone 1 performs the technological process of processing part of the field in one stage (in the time t_E) using the entire volume of one tank. During this time, mobile device A approaches point «*a*» to point «*b*», where the drone completes one stage. The drone is fixed on mobile station *A*, charges the battery, fills the tank with the chemical solution and begins the next stage of the technological process of processing the field.

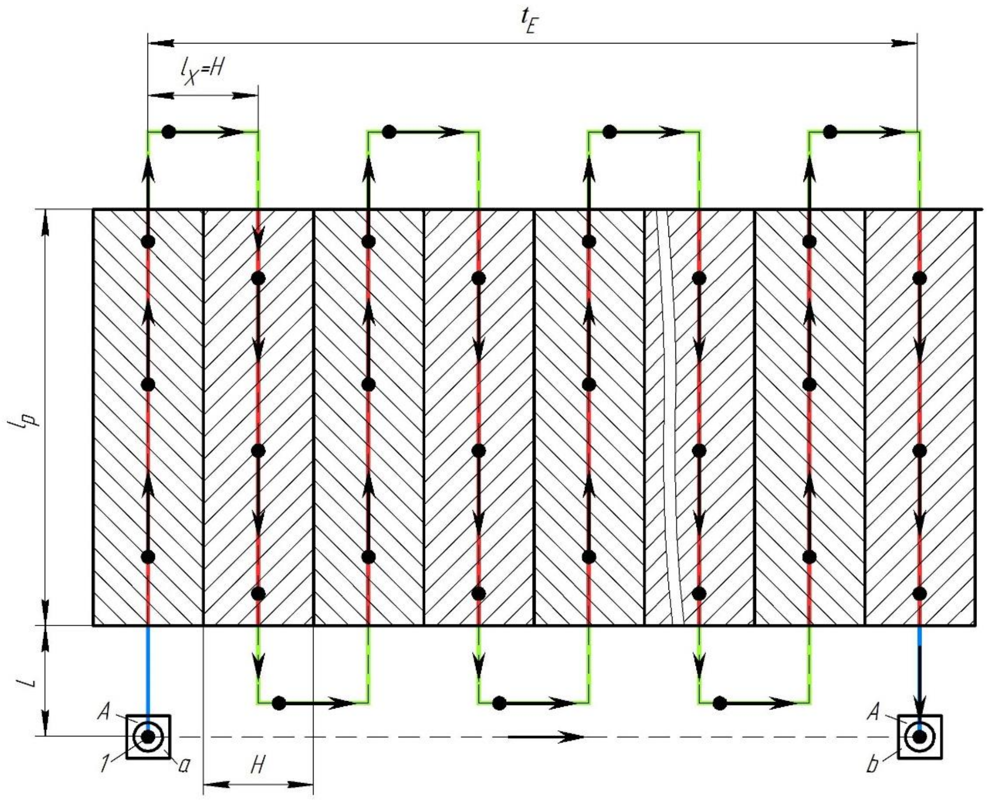


Figure 3. Schematization of the operation of one drone: *A* – mobile station (platform); 1 – drone; H – coverage width of the spray zone; L – the distance from the station to the field boundary; l_X – idling path of the drone (without spraying liquid); t_E – time of one stage (time of using the full volume of the tank filled with liquid; l_p – field width

For medium and large fields, in which the length of the treated strip is $l_0 > 1$ km, it is advisable to use a ground mobile service station *A* located on one side of the field (Figure 4). It contains two base points for recharging and refueling sprayer drones 1 and 2. The technological process is as follows: the first sprayer drone, filled with a working solution, rises above the field surface and performs chemical treatment of plants, the second drone remains at the station, recharges and fills the tank with working fluid.

At this time, the service ground mobile station *A* moves from position «*a*» to position «*b*». The first drone carries out spraying, capturing a strip with a width *H*. Having reached the edge of the field, it turns to the next strip, thus ensuring the processing of the sowing area with a width of *2H* and using the entire volume of the tank. Then, having reached the edge of the field, it makes a fixed landing on the station platform to recharge (replace) the battery and fills the tank with the working solution. At this time, drone 2 starts and performs similar work as the first drone.

The proposed technological scheme of field cultivation is recommended for cases when the chemical substance and battery charging are enough for only two passes through the field, i.e. for fields of large width. The length of the path (flight) of the drone during the technological process is $l_0 = 2\, l_p$, respectively $T_C \approx 0$; idle time is $T_X \approx 0$.

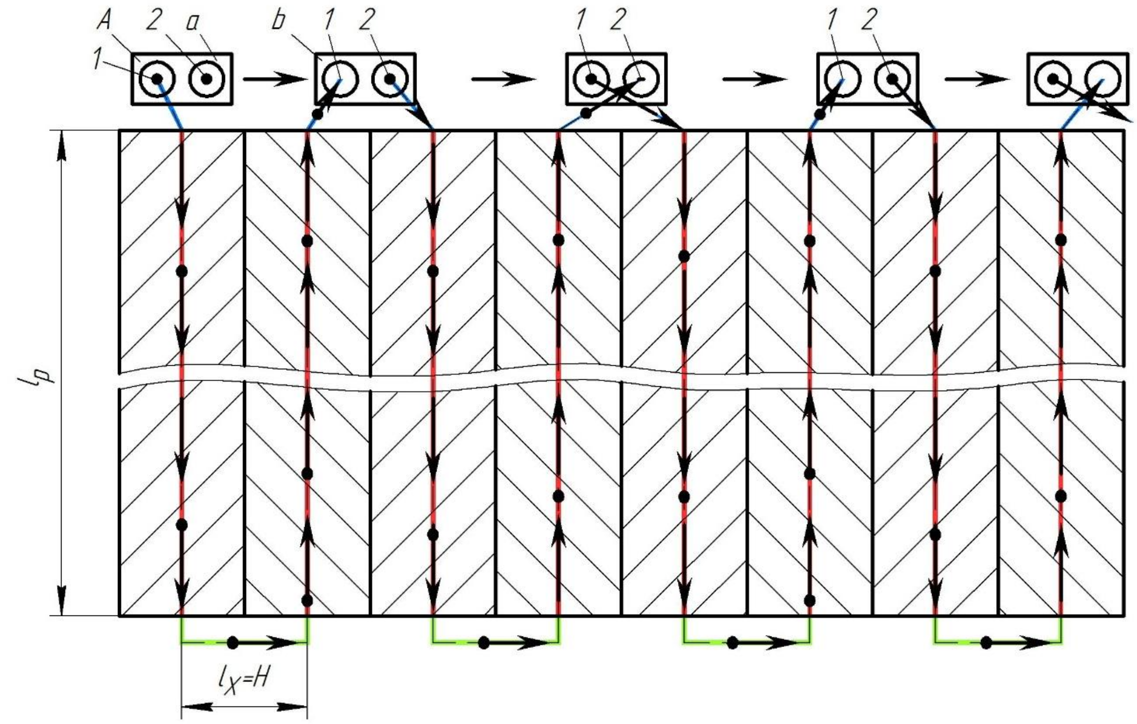


Figure 4. Scheme of movement of two drones using one mobile station: *A* – mobile station; 1, 2 – drones; *a*, *b* – mobile station positions

For large and medium-sized fields, provided that the length of the treated strip is equal to the width of the field $l_0 = l_p$., it is advisable to use a different technological scheme (Figure 5). Service ground mobile stations *A*, *B* for refueling and recharging (replacing) the batteries of sprayer drones are located on both sides of the field. The volume of the tank of chemical liquid filled into the agrodrone and charging the battery is enough for one pass through the field. Sprayer drone 1 takes off from station *A*, sprays the working fluid to the processing width *H*, while mobile station *A* moves from point «*a*» to point «*d*». Simultaneously with drone 1, sprayer drone 2 takes off from station *B* and performs the technological process moving in the opposite direction (from point «*b*» to point «*d*»). Both drones work simultaneously, performing cultivation on both sides of the field, moving towards each other, each capturing a separate strip of the field with width *H*. The first drone, having flown to the edge of the field, fixes at station *B* to replace the batteries and fill the tank. At the same time, mobile station *B* moves from point «*b*» to point «*e*». At the same time, the second drone also flies to the edge of the field and fixes at station *A* at point *d* to replace the batteries and fill the working fluid.

The time for replacing batteries and filling working fluid T_C per shift is calculated according to the standards, idling time $T_X \approx 0$.

The proposed technological scheme with two mobile stations (see Fig. 5) can, if necessary, be used with one agrodrone. In this case, drone 1 performs the technological process, moving from mobile station *A* to mobile station *B*. After fixing the drone on platform *B*, the batteries are replaced (charged) and the working fluid is filled, the platform moves to another cultivation strip, the drone takes off and continues the spraying process. For such a technological scheme, the operational productivity will be half as much.

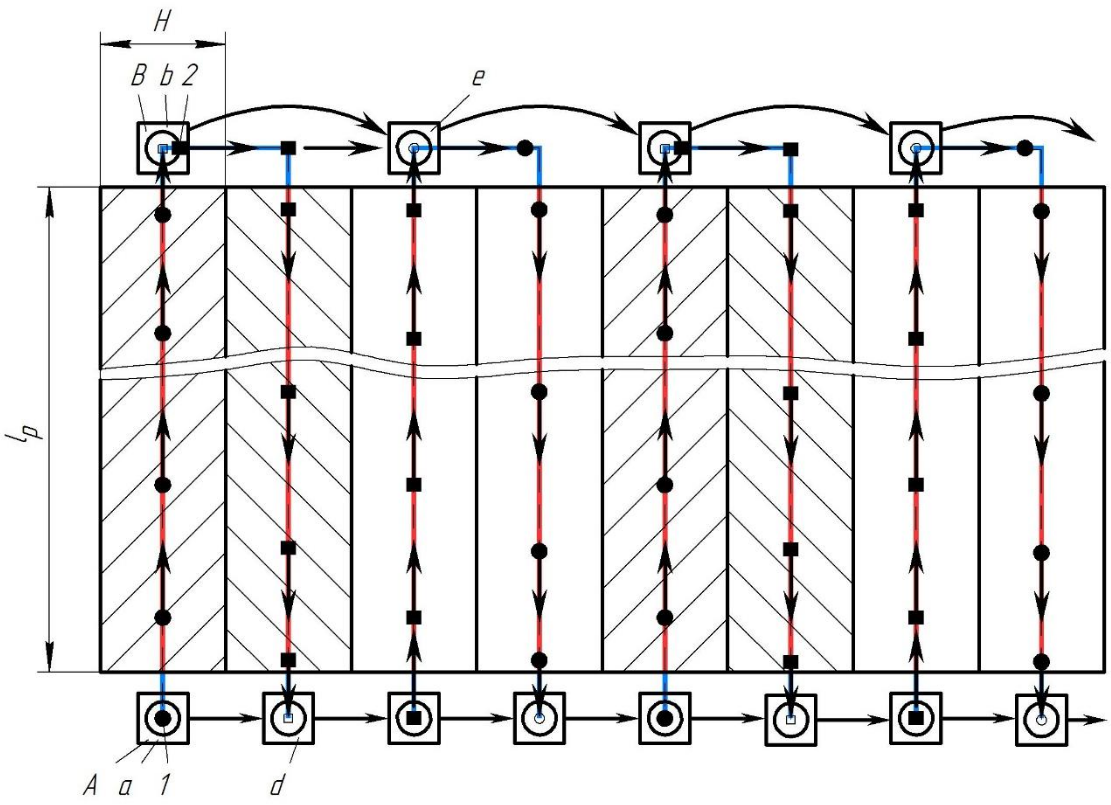


Figure 5. Technological scheme of operation of two drones with two mobile stations on two sides of the field: *A*, *B* – mobile stations; 1, 2 – drones

The technological scheme of field processing by drones is shown in Figure 6, requiring the use of two platforms *A* and *B*, on which four drones (1, 2, 3, 4) are placed. During the technological process, there is a free space on each of the mobile stations, where the active drone lands for recharging (replacement) and refueling. During field processing, two active drones are simultaneously involved.

The process occurs in the following sequence: drones 1 and 3 simultaneously start from mobile stations *A* and *B*. After the start of drone 1, platform *A* moves from point «*a*» to point «*b*», waiting for the fixation of drone 3 after the completion of the technological process. Platform *B*, fixing drone 1, moves from point «*d*» to point «*e*». Accordingly, drone 2 starts from point «*b*» of platform *A*, and drone 4 starts from point «*e*» of platform *B*.

The proposed technological scheme of cultivation (see Fig. 6) is appropriate for large areas occupied by agricultural crops, for cases when $l_0 = l_p$. For such a scheme, the time for replacing batteries and refueling drone tanks with working fluid is zero $T_C = 0$, there is no idling $T_X \approx 0$.

When using agricultural drones, the following recommendations should be followed: do not use drones in adverse weather conditions, when the wind exceeds 28 km/h, during rain, fog, snow, hurricanes, etc. Avoid spraying plant protection products on adjacent areas when processing field edges. This can be achieved by using software that sets field boundaries.

Each of the proposed technological schemes for processing fields with agricultural drones has its own advantages and disadvantages. The choice depends on the analysis of the drone movement pattern and the establishment of their operational performance.

The operation of each unit is characterized by several main indicators, one of which is productivity.

Operational productivity of an agricultural drone per hour of working time

$$W_H = 0{,}1\, H \cdot V_P \cdot \tau, \tag{6}$$

if H – width of the spraying zone captured by the agrodrone, m;
V_P – drone operating speed, km/h;
τ – shift time utilization factor.

$$\tau = \frac{T_0}{T_{CH}}, \tag{7}$$

T_0 – time of execution of the technological process by the drone per shift, hours, is determined according to dependence (5);
T_{CH} – shift time, hours.

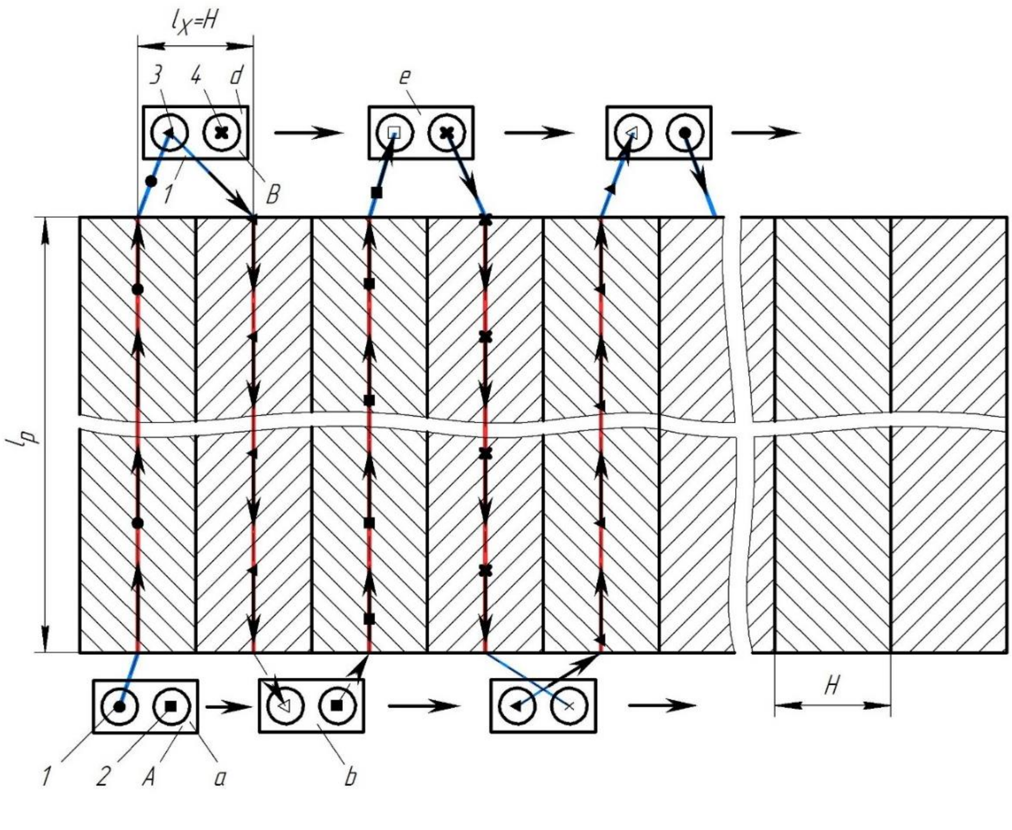


Figure 6. Technological scheme of operation of four drones with two mobile stations:
A, *B* – mobile stations; 1, 2, 3, 4 – drones.

During the shift, the agrodrone, processing the selected field, performs *n*-stages. In each of them, it uses a full tank of working fluid. The number of stages can be determined as follows

$$n_E = \frac{T_A}{t_E}, \qquad (8)$$

if T_A – drone flight time during a shift, hours

$$T_A = T_{CH} - T_C \qquad (9)$$

t_E – time of one stage, hours

For each of the proposed technological schemes, the time of one stage is the passage of the agricultural drone over the field in one or two directions until the chemical liquid tank is completely used up.

$$t_E = t_M + t_0 + t_X, \qquad (10)$$

if t_M – take-off and landing time and approach time to the field boundary, hours;
t_0 – execution time of the technological process per stage, hours;
t_X – Idling time, hours

Drone takeoff and landing time and time of its approach to the field boundary

$$t_M = 2 \cdot \left(t_R + \frac{L \cdot 10^{-3}}{V_0} \right), \qquad (11)$$

if t_R – drone takeoff and landing time, $t_R = 0{,}0083$ hours;
L – distance from the ground service station to the field boundary, m;
V_0 – average drone speed from the station to the field boundary, km/h, $V_0 = V_P/2$.

The time of execution of the technological process for one stage, i.e. the spraying time during which the volume of one tank is consumed

$$t_0 = \frac{l_0 \cdot 10^{-3}}{V_P}, \qquad (12)$$

if l_0 – length of the drone's path (flight) during the execution of the technological process in one stage, m.

The length of a drone flight in one stage is determined:

$$l_0 = \frac{v_B \cdot 10^4}{H \cdot q}, \qquad (13)$$

if v_B – volume of the liquid tank, l;
q – rate of use of technological fluid per 1 ha of field, l/ha.

Drone idle time per stage

$$t_X = \frac{l_X \cdot n_{PR} \cdot 10^{-3}}{V_X}, \tag{14}$$

if l_X – idling range when turning the drone, m, $l_X \approx H$;

n_{PR} – the number of passes (turns) of the drone per stage is determined according to (1);

V_X – drone speed on turns, km/h.

The total number of work passes of the agricultural drone per shift is determined using the dependence (3).

Based on the analysis of the above technological schemes, a methodology for calculating the productivity of agricultural drones in processing agricultural crops has been developed.

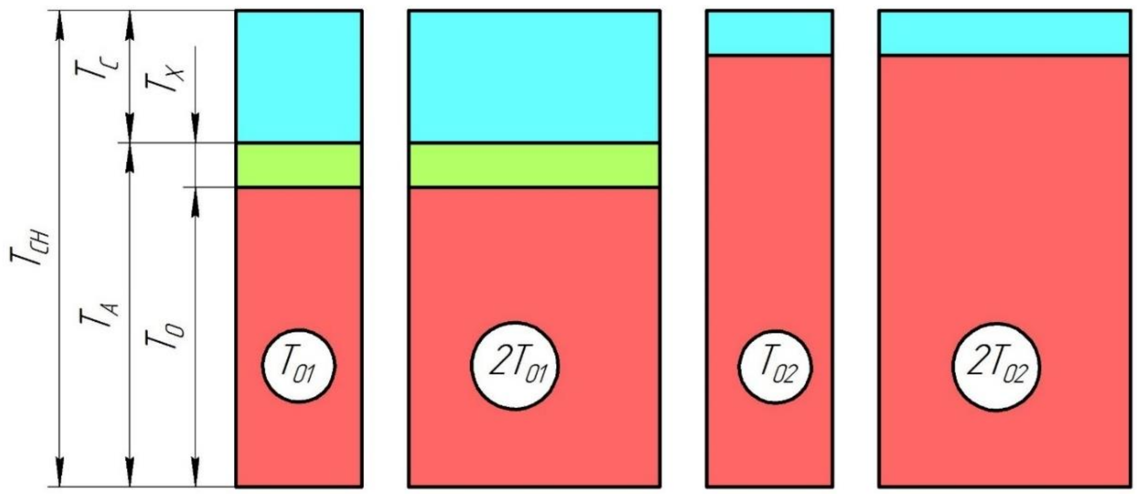
With the same technological characteristics of agricultural drones (working speed, spraying width, working fluid usage rate), operating productivity will increase due to an increase in the shift time utilization factor.

A relationship has been established between the productivity of agricultural drones for the proposed technological schemes (Figure 7)

$$W_b = 2\,W_a; \quad W_d = 2\,W_c;$$

because the time usage rate changes

$$\frac{\tau_b}{\tau_a} \approx \frac{\tau_d}{\tau_c} \approx 2.$$



a *b* *c* *D*

Figure 7. Diagrams of the time consumption of agricultural drones of sprayers per shift.
a – corresponds to the technological scheme, see fig.3;
b – corresponds to the technological scheme, see fig. 5;
c – corresponds to the technological scheme, see fig.4;
d – corresponds to the technological scheme, see fig. 6

T_{CH} – shift work time; T_0 – execution time of the technological process; T_C – time of charging batteries and refueling with chemical liquid; T_A – agrodrone time in the air; T_X – idling time.

4. CONCLUSION

The implementation of the technological process of applying pesticides by agricultural drones was analyzed without taking into account the size of the field, the sown crop, the relief of the field, the type of agricultural drone, etc. As a result, the active, i.e. useful work performed by the drone, namely the technological process of spraying the drug, was clearly delimited. Auxiliary actions necessary for performing the spraying technological process have been established: replacing (charging) batteries, filling the tank with chemical liquid, takeoff and landing, approaching the field boundary, and turning when moving to another treatment strip. A universal method for calculating the effective productivity of agricultural drones during crop cultivation is proposed, which involves the analysis of each component of the technological process of applying pesticides by agricultural drones. Technological schemes are proposed that provide a partial reduction in unproductive operations while increasing the productivity of agricultural drones, provided that the material support for the implementation of the technological process increases for each subsequent technological scheme. The use of agricultural drones-sprayers for field processing provides high productivity, which makes it possible to process crops in a short time, especially during adverse climatic periods, protecting them from diseases, pests, and weeds. The work has developed several technological schemes for cultivating agricultural crops with agricultural drones, which ensure the reduction of unproductive operations and directly affect the productivity of the spraying process.

References

1. Hafeez A., Husain M. A., Singh S. P., Chauhan A., Khan M. T., Kumar N., Chauhan A., Soni S. K. (2023) Implementation of drone technology for farm monitoring & pesticide spraying: A review. Information Processing in Agriculture, vol. 10, iss. 2, pp. 192–203. https://doi.org/10.1016/j.inpa.2022.02.002
2. Canicattì M., Vallone M. (2024) Drones in vegetable crops: A systematic literature review. Smart Agricultural Technology, vol. 7, 100396. https://doi.org/10.1016/j.atech.2024.100396
3. Rejeb A., Abdollahi A., Rejeb K., Treiblmaier H. (2022) Drones in agriculture: A review and bibliometric analysis. Computers and Electronics in Agriculture, vol. 198, 107017. https://doi.org/10.1016/j.compag.2022.107017
4. Ayamga M., Akaba S., Nyaaba A. (2021) Multifaceted applicability of drones: A review. Technological Forecasting and Social Change, vol. 167, 120677. https://doi.org/10.1016/j.techfore.2021.120677
5. Guebsi R., Mami S. & Chokmani K. (2024) Drones in Precision Agriculture: A Comprehensive Review of Applications, Technologies, and Challenges. Drones, 8 (11), 686. https://doi.org/10.3390/drones8110686
6. García-Munguía A., Guerra-Ávila P. L., Islas-Ojeda E., Flores-Sánchez J. L., Vázquez-Martínez O., García-Munguía A. M. & García-Munguía O. (2024) A Review of Drone Technology and Operation Processes in Agricultural Crop Spraying. Drones, 8 (11). https://doi.org/10.3390/drones8110674
7. Ahirwar S., Swarnkar R., Srinivas B., Namwade G. (2019) Application of Drone in Agriculture. International Journal of Current Microbiology and Applied Sciences. 8. 2500–2505. https://doi.org/10.20546/ijcmas.2019.801.264
8. Souvanhnakhoomman S. (2021) Review on Application of Drone in Spraying Pesticides and Fertilizers. International Journal of Engineering Research and Technology, 10 (11). Available at: https://doi.org/10.17577/IJERTV10IS110034.
9. Raj M., Harshini N. B., Gupta S., Atiquzzaman M., Rawlley O., Goel L. (2024) Leveraging precision agriculture techniques using UAVs and emerging disruptive technologies. Energy Nexus, vol. 14, 100300. https://doi.org/10.1016/j.nexus.2024.100300
10. Gaadhe S., Dipesh C., Mehta T., Chavda S., Gojiya K., Bandhiya R. (2025) A comparative study of drone spraying and conventional spraying for precision agriculture. Plant Archives. 25. 771–778. Available at: 10.51470/ PLANTARCHIVES.2025.SP.ICTPAIRS-111. https://doi.org/10.51470/PLANTARCHIVES.2025.SP.ICTPAIRS-111

11. Shanmugam P. S., Srinivasan T., Baskaran V., Suganthi A., Vinothkumar B., Arulkumar G., Backiyaraj S., Chinnadurai S., Somasundaram A., Sathiah N., Muthukrishnan N., Krishnamoorthy S. V., Prabakar K., Douresamy S., Johnson Edward Thangaraj Y. S., Pazhanivelan S., Ragunath K. P., Kumaraperumal R., Jeyarani S., Kavitha R., Mohankumar A. P. (2024) Comparative analysis of unmanned aerial vehicle and conventional spray systems for the maize fall armyworm Spodoptera frugiperda (J.E. Smith) (Lepidoptera; Noctuidae) management. Plant Protect. Sci., 60 (2): 181–192. https://doi.org/10.17221/96/2023-PPS
12. Jeevan N., Surla K., Yerradoddi S., Nunavath S. (2024) Advancements in drone technology for weed management: A comprehensive review. International Journal of Advanced Biochemistry Research. 8. 22–27. https://doi.org/10.33545/26174693.2024.v8.i9a.2058
13. Meesaragandla, Srija & Jagtap, Megha & Khatri, Narendra & Madan, Hakka & Vadduri, Aditya. (2024) Herbicide spraying and weed identification using drone technology in modern farms: A comprehensive review. Results in Engineering. 21. 101870. https://doi.org/10.1016/j.rineng.2024.101870
14. Gulak M. A. (2024). Implementation of Drone for Spraying Herbicide and Pesticide. Available at: 10.5281/zenodo.13337525.
15. Martyniuk V., Khoma V., Matskiv T., Yunko K., Gnatyshyna L., Stoliar O. & Faggio C. (2023) Combined effect of microplastic, salinomycin and heating on Unio tumidus. Environmental toxicology and pharmacology, 98, 104068. https://doi.org/10.1016/j.etap.2023.104068
16. Martyniuk V. V. (2022) Accumulation of microplastics in the bivalve mollusc Unio tumidus under experimental and field exposures. Studia Biologica, 16 (4): 33–44. https://doi.org/10.30970/sbi.1604.694
17. Musthaq Z., Baran M. F., Demir C., Saeed S., Islam M. & Siddiqui A. (2024). Role of sprayers drone in sustainable agriculture. Available at: 10.5281/zenodo.10841204.
18. Shahrooz M., Talaeizadeh A. and Alasty A. (2020) Agricultural Spraying Drones: Advantages and Disadvantages, 2020 Virtual Symposium in Plant Omics Sciences (OMICAS), Bogotá, Colombia, pp. 1–5. https://doi.org/10.1109/OMICAS52284.2020.9535527
19. Castaldo, João. (2023). Revolutionizing agriculture from the skies: exploring the potential of spraying drones in precision farming. Cadernos de Ciência & Tecnologia, 40, 2023. https://doi.org/10.35977/0104-1096.cct2023.v40.27284
20. Pidgurskyi M., Stashkiv M., Pidgurskyi I., Oleksyuk V., Pidluzhnyi O., Bykiv D., Borys I., Bulaienko R., Stashkiv V., Mushak A. (2024) Methodology of experimental and analytical research of technical systems. Scientific Journal of TNTU (Tern.), vol. 116, no. 4, pp. 50–58. https://doi.org/10.33108/visnyk_tntu2024.04.050
21. Menon B. K., Deshpande T., Pal A., Kothandaraman S. (2025) Critical regions identification and coverage using optimal drone flight path planning for precision agriculture. Results in Engineering, vol. 25, 104081. https://doi.org/10.1016/j.rineng.2025.104081
22. Andrii Babii, Taras Dovbush, Nadiia Khomuk, Anatolii Dovbush, Anna Tson, Vasyl Oleksyuk (2022) Mathematical model of a loaded supporting frame of a solid fertilizers distributor. Procedia Structural Integrity, no. 36, pp. 203–210. Science Direct. https://doi.org/10.1016/j.prostr.2022.01.025
23. Babii A., Levytskyi B., Dovbush T., Babii M., Khomuk N., Dovbush A., Valiashek V. (2024) Mathematical model of sprayer tank loading. Procedia Structural Integrity, no. 59, pp. 609–616. https://doi.org/10.1016/j.prostr.2024.04.086
24. Hevko R., Stashkiv M., Lyashuk O., Vovk Y., Oleksyuk V., Tson O., Bortnyk I. (2021) Investigation of internal efforts in the components of the crop sprayer boom section. Journal of Achievements in Materials and Manufacturing Engineering, vol. 105, iss. 1, 33–41. https://doi.org/10.5604/01.3001.0014.8743
25. Andreykiv O., Babii A., Dolinska I., Yadzhak N., Babii M. Residual lifetime prediction of field sprayer booms under the action of manoeuvre loading and corrosive environment. Procedia Structural Integrity, vol. 36, pp. 36–42. https://doi.org/10.1016/j.prostr.2021.12.080
26. Trappey Amy J. C., Lin Ging-Bin, Chen Hong-Kai, Chen Ming-Chi (2023) A comprehensive analysis of global patent landscape for recent R&D in agricultural drone technologies. World Patent Information, vol. 74, 102216. https://doi.org/10.1016/j.wpi.2023.102216
27. Loukatos D., Templalexis C., Lentzou D., Xanthopoulos G., Arvanitis K. G. (2021) Enhancing a flexible robotic spraying platform for distant plant inspection via high-quality thermal imagery data. Computers and Electronics in Agriculture, vol. 190, 106462. https://doi.org/10.1016/j.compag.2021.106462
28. Utility model patent No.: 141056. Technological complex for aerial chemical treatment of plants using sprayer drones. Application No.: u201907592. Application filing date: 08.07.2019 Date from which rights are valid: 25.03.2020. IPC (2006): A01M 7/00, A01M 11/00. Inventor: Hevko Roman Bogdanovich; Dovbush Taras Anatoliyovych; Lyashuk Oleh Leontiyovych; Tkachenko Igor Grigorovich; Khomyk Nadiya Igorovna; Dovbush Anatoliy Dmytrovych; Bortnyk Igor Myronovych. Owner: Ivan Pulyuy Ternopil National Technical University, Ruska St., 56, Ternopil. [in Ukrainian].
29. Dovbush T. A., Gevko R. B., Khomyk N. I. Method of aerial chemical treatment of plants using drones-sprayers. Modern technologies of the industrial complex-2020: materials of the V int. scient.-practical conf., vol. 5, Kherson, September 10–15, 2019. Kherson: KhNTU, 2019. pp. 40–41. [in Ukrainian].

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РОЗРОБЛЕННЯ ВИСОКОПРОДУКТИВНИХ ТЕХНОЛОГІЧНИХ СХЕМ ЗАСТОСУВАННЯ АГРОДРОНІВ ДЛЯ ЗАХИСТУ РОСЛИН

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Резюме. *В аграрному виробництві для отримання високих урожаїв необхідним є надійний захист культурних рослин, посіви яких вражають різні шкідливі організми. Найефективнішим ув боротьбі зі шкідниками сільськогосподарських рослин є хімічний метод, що при вдалому застосуванні забезпечує високу економічність. Для зменшення токсичного впливу на оброблювані рослини та довкілля перспективним є використання агродронів завдяки перевагам над мобільними наземними обприскувачами. Агродрони не ущільнюють грунт, не пошкоджують сільськогосподарські культури, надзвичайно маневрені, можуть працювати на полях різної конфігурації, здатні виконувати обприскування одразу після опадів, можуть здійснювати локальне або точкове розпилення, забезпечують точне дозування хімічних речовин. Для них характерні висока продуктивність та менші енергозатрати. Проаналізовано виконання технологічного процесу агродроном без урахування розміру поля, висіяної культури, рельєфу поля, типу агродрона і т.ін. У результаті чітко розмежовано активну, тобто корисну роботу, яку виконує дрон, а саме, технологічний процес розпилення препарату. Встановлено допоміжні дії, необхідні для виконання технологічного процесу розпилення: заміна (зарядка) акумуляторів, заливання в бачок хімічної рідини, злет-посадка, підліт до межі поля, розвороти при переході на іншу смугу обробки. Запропоновано універсальну методику розрахунку ефективної продуктивності агродронів під час обробітку сільськогосподарських культур, що передбачає аналіз кожної складової технологічного процесу внесення пестицидів агродронами. Запропоновані технологічні схеми, які забезпечують часткове зменшення непродуктивних операцій збільшуючи продуктивність роботи агродронів, за умови, що матеріальне забезпечення для виконання технологічного процесу зростає для кожної наступної технологічної схеми. Використання агродронів-розпилювачів забезпечує високу продуктивність, що дає можливість у короткі терміни обробляти посіви сільськогосподарських культур, захищаючи їх від хвороб, шкідників і бур’янів.*

Ключові слова: *агродрон, мобільна зарядна станція, обприскування, продуктивність, технологічна схема роботи дрона, сільськогосподарські рослини, пестициди, швидкість дрона, час зміни, ширина розпилення.*

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