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CRITICAL ANALYSIS OF MINI UNMANNED AERIAL VEHICLES (UAV) DEVELOPMENT CAPABILITIES AND PERSPECTIVES OF EFFECTIVE INTEGRATION IN HORTICULTURAL AGROECOSYSTEMS IN ROMANIA

Pompilica IAGĂRU[1], Mircea BOȘCOIANU[2], Ionel-Lucian CIOCA[1], Ioana Mădălina PETRE[2], Sebastian POP[2], Flavius Aurelian SÂRBU[2], Romulus IAGĂRU[1]

[1]Lucian Blaga University of Sibiu, 10 Victoriei, Romania, Phone: +40269216062, Fax: +40269217887, Mobile:+40729950222, Emails: pompilica.iagaru@ulbsibiu.ro, Lucian.cioca@ulbsibiu.ro, romulus.iagaru@ulbsibiu.ro,
[2]Transilvania University of Brasov, Romania, 29, Eroilor Boulevard, Postal Code 500036, E-mails: mircea.boscoianu@unitbv.ro, ioana.petre@unitbv.ro, pop.sebastian@unitbv.ro, sflavius@unitbv.ro.

Corresponding author: romulus.iagaru@ulbsibiu.ro

Abstract

The present attests to the development of autonomous unmanned aircraft systems and their widespread use in various fields. The article presents the level of development of mini UAVs, the rapid growth of their use in various fields and challenges for various civil applications. At the same time, current research trends are highlighted and future perspectives for use in precision horticulture are identified. For this, the research methodology used included both quantitative and qualitative methods of the type of secondary analysis of statistical data and specialized literature, respectively the SWOT analysis model, supplemented with the observation method. The realization of the study allowed to obtain an overview of the level of development of mini UAV and the possibilities of increasing the degree of use in various fields.

Key words: *research, horticulture, precision, mini Unmanned Aerial Vehicles (UAV), perspectives*

INTRODUCTION

The development of unmanned aircraft systems is a certainty of the present in which society shows increased interest. If at the time of their appearance they were intended and used in various military applications, we have gradually witnessed their adoption by civil society where there is a rapid increase in interest regarding the use in various civilian applications. At the same time, the interest of researchers in the development and implementation of unmanned aircraft systems is also increasing, indicated by the numerous topics addressed in SCOPUS publications, for example, whose numerical evolution registers a spectacular increase between the years 2000 and 2015, from 539 to 23,502 topics [31].

Unmanned aircraft systems comprise different components (unmanned aerial vehicle, launch and recovery station, data network, technical support systems, control station, human interface, etc.) whose complexity configures different classes among which the mini UAS is considered the fastest growing class [43]. The growth is due to recognized features such as: low costs [40], implementability directly from the field, accessibility of technologies [43], flexibility etc., which give it advantages and ensure a dominant presence in applications civilians from all fields of activity [6, 7, 27, 12, 28, 55, 9, 42]. Missions and applications dedicated to precision horticulture are relatively new, emerging and fruiting capabilities to provide a unique recognizable image of agricultural/horticultural land and even precision detailing solutions starting from broad spectrum sensors (EO-optical, infrared IR , NIR quasi-infrared TR thermal sensors). These details were almost impossible a few years ago even for conventional UAV systems. Starting from the success of these applications, attention was also directed to the area of precision agriculture/ horticulture. The first type of missions for agriculture/

horticulture applications refers to the rapid integration of crop images, a comparison with the classic method performed with conventional tractors for areas of 5-10 x 5-10km is provided [23]. In this case it is suggested that multiple drone systems [11]. connected to ground robots may be used in the future (the problem of communication between these types of robotic vehicles will benefit from disruptive technological progress). The new missions specific to precision agriculture/horticulture [39]. are moving towards analyzing and comparing soils, evaluating the effects of specific procedures, evaluating specific performances [23,17].

The current state of research in the field

Yamaha Motor Company (Japan, 1987) [60] proposed the RMAX-R50 concept dedicated to spraying rice crops with pesticides. Cisneros (2013) [13] proposed the low-cost concept for use in emerging South American countries (especially Peru). Subsequently, Glen (2015) [22] anticipated the downsizing effect and showed a possible market entry of medium and small UAV robotic systems that take advantage of the downsizing of specific multispectral sensor systems [2].

Gogarty and Robinson (2012) [23] proposed a classification of modern drones based on endurance and flight altitude: HALE (high-altitude long endurance), such as Global Hawk and Predator, or MALE (medium-altitude long endurance). For applications for precision agriculture/horticulture, there is no question of special performances, the endurance not being over 30-60 minutes of flight [24, 20]. The correlation between types, missions and specific performances starts from the following reference elements [5]:

a) Maximum take-off mass
- -giant drones: Global Hawk
- -heavy drones: m=200-2,000kg (e.g. Fire Scout)
- -medium drones: m=50-200 kg
- -light drones: m=5-50 kg (RMAX, Yintong, Autocopter)
- -micro-drones: mass under 5 kg (Raven, Lancaster, eBee, Swinglet, CropCam)

b) Endurance and range
- -long endurance (24h) and range (over 1,500km): Global Hawk
- -medium endurance (3-24h) and 100 km range
- - drones for agricultural missions typically achieve an endurance of 30-60 minutes and a range of 20-25 km

c) Maximum flight altitude
- - high altitude
- - medium altitude (500-5,000m) - rarely used in agriculture (NIR, TS)
- -low altitude (100-500m)

d) Alar loading - for agriculture/horticulture applications, reduced loads are preferred to ensure transport capabilities

e) Propulsion system: classic (RMAX, Autocopter) or electric

f) Power source.

Regarding drones for precision agriculture/horticulture (plane or multicopter type), there are very few bibliographic references [32]. In this case, the elements of interest (performance, flight qualities, specific transport aspects) refer to the semi-autonomous flight capabilities, the initial acquisition cost, the level of complexity of the possible missions, maintenance costs (including periodic corrections specific to drones small).

In this context, the purpose of the study is to know the level of development of mini UAVs and to identify future prospects for their use in precision agriculture/horticulture. Achieving the goal was possible by fulfilling the following objectives: knowing the current state of research in the field; benchmarking analysis with the main achievements worldwide; identifying the main uses of mini UAVs in precision agriculture/horticulture; future prospects for the use of mini UAVs in precision agriculture/horticulture.

MATERIALS AND METHODS

Achieving what was proposed was possible by carrying out research from a double perspective: descriptive to ensure the understanding of the evolution of mini UAVs and the need for their adoption in precision horticulture, as well as explanatory to identify the variables and the relationships between them for their widespread adoption in precision horticulture.

From a methodological point of view, quantitative and qualitative methods belonging to strategic management were used because they allow obtaining an overview of the level of development of mini UAVs and the possibilities of increasing the degree of use in various fields.

The research was organized in two stages. In the first stage, the secondary analysis of statistical data and specialized literature was carried out, identifying critical factors and successful initiatives. The second stage included the application of the SWOT analysis model where, based on the combination of information from the four quadrants, the current research trends were highlighted and the future prospects for the use of mini UAVs in precision horticulture were identified (Fig. 1).

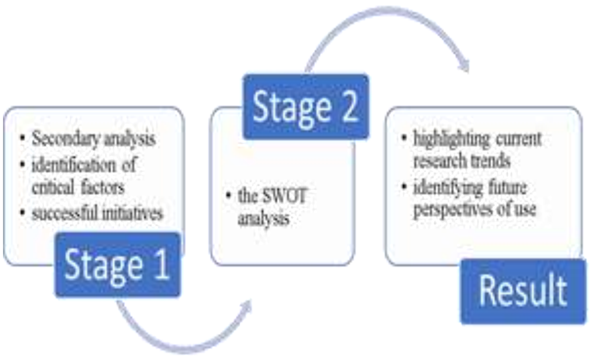

Fig. 1. Schematic structure of the research Source: Own conception.

RESULTS AND DISCUSSIONS

The present study was carried out according to the schematic structure of the research presented in Figure 1. The secondary analysis of the statistical data and the relevant specialized literature allowed both the highlighting of the achievements and the level of development of UAVs and the scenarios of their application in horticultural ecosystems from the perspective of the following directions: monitoring the state of vegetation and identifying possible vulnerabilities in horticultural ecosystems, applying the necessary treatments with precision and with a reduced volume of solution; soil texture mapping, irrigation scheduling, production maturity mapping.

The main achievements worldwide have been highlighted with the help of the benchmarking analysis and highlight the following types of UAVs (Table 1).

Table 1. Benchmarking analysis with the main achievements worldwide

Airplane type drones	Rotary wing/multicopter drone	Parachute/aerostat flexible surface drones
Precision Hawk Lancaster	RMAX	SUSI-62
Swinglet Cam	Yintong	-
eBee	Venture Outrider/ Nenture Surveyor	-
Wave Sight	EnsoMOSAIC	-
CropCam	-	-
Trimble UX5	-	-
Agribotix Horne	-	-

Source: prepared by the authors based on the secondary analysis of the specialized literature.

The rapid evolution of mini UAV technology leads us not to detail the types of drones further and to bring to attention those mentioned by Dalamagkids (2015) and Stark et al., (2013) [15, 46].

Mini UAVs have the ability to collect a large volume of high-resolution spatial images, their processing leads to obtaining useful information for the identification, quantification and classification of vulnerabilities within agro-ecosystems determining a quick reaction from the management to correct the vulnerabilities.

The collection of information takes place with the help of sensors mounted on the mini UAV. There are four types of sensors that cover almost all UAV remote sensing research applications in precision agriculture: RGB, multispectral, hyperspectral and thermal sensors. The first three categories compete in the creation of georeferenced reflectance maps, and the last category in the creation of temperature maps [35].

The SWOT analysis

SWOT analysis is used in numerous studies to evaluate the capabilities and shortcomings of the analyzed subject [33]. The results obtained proved relevant for increasing the level of development of mini UAVs and highlighting the types of missions applied in precision horticulture. The SWOT analysis model was applied to evaluate current research trends and identify future perspectives of use. It allowed the development of strategic options for boosting the use of mini UAVs in precision horticulture.

Strong points

Mini UAVs are emerging technology elements increasingly used in agriculture. Their adoption in specific technologies in horticulture is based on the ability to collect, store and analyze large volumes of digital data related to the crops of interest, with reference to the identification of possible disease and pest attacks and implicitly to the development of solutions regarding the optimization of resources. This results in a number of benefits:

- economic benefits based on cost reduction (especially those associated with labor, energy and water resources)
- speed/agility and precision in action
- ensuring the sustainability of the soil
- non-destructive analysis capabilities, solutions and strategies.

Weaknesses

Like all activities and the use of mini UAVs, they present a series of weaknesses: operating under strictly regulated conditions, which often do not keep up with the evolution of technology and slow down the expansion of these applications; short flight time and the need to purchase several batteries; the existence of restrictive environmental factors (wind) and restrictions for certain areas imposed by the aeronautical authority; the timidity of integrated educational initiatives regarding training in the operation of mini UAVs and monitoring of horticultural fields; few partnerships between horticultural and IT specialists to analyze, interpret and develop solutions to regulate agroecosystem vulnerabilities.

Oportunities

The analysis carried out led to the highlighting of the following opportunities regarding the adoption of mini UAVs in horticulture: the manifestation of a flexibility on the part of the authorities manifested with the change of regulations regarding UAV management in 2001 and implicitly of a continuous availability to adapt the regulations to the evolution of technologies and market requirements; imprinting agriculture with the character of high-tech industry with decisions based on the collection and real-time processing of data for the automation and optimization of the management of the agricultural enterprise; the opening of new directions of research and development; the attraction of young people to drone technology and the need for their entrepreneurial education for the development of service enterprises to operate in the rural area; the creation of new jobs; improving production and profitability of horticultural enterprises.

Threats

The following threats to the increase in the adoption of mini UAVs in horticultural fields have been identified: the shyness of actions to promote among farmers the need to adopt aerial monitoring of horticultural fields even at the level of access as a third-party service; the lack of partnerships at the level of small farmers for the joint purchase of aerial monitoring services for horticultural crops; lack of educational partnerships between farmers and public institutions (universities and central/local authority) regarding drone technology education.

Missions to monitor the state of vegetation and identify possible vulnerabilities in horticultural ecosystems

Aerial monitoring of horticultural ecosystems involves the development of work processes based on the use of space technologies with a very low impact on the environment, for monitoring resources to increase production and the state of vegetation of crops using UAV (unmanned aerial vehicle) type equipment to capture of aerial images and an information system for the processing of aerial photographs, the creation and georeferencing of orthophoto planes. The implementation of aerial monitoring takes place by carrying out flight missions at certain heights (heights for example 100 m), according to a flight plan made by selecting a terrain area on a Google Earth or Map support. It follows obtaining approvals from the Aeronautical Authority and the Ministry of National Defense for flying over a land surface at this height with the specification of the take-off and landing points; the realization of the flight plan aiming primarily at the coverage of the area of interest, then the generation of the flight trajectories that the drone must cover, so that the photos taken have an overlap of 70% and the flight times are supported by the power of the batteries (approx. 25 min for a battery); preparation for the takeoff of the drone (favorable weather conditions - clear sky and wind below 7m/s, coverage of the telephone network necessary for data transmissions, adequate GPS signal); carefully following the trajectories traveled [29]. The images obtained during the aerial monitoring of horticultural ecosystems are processed with the help of dedicated software leading to the early detection of diseases and pests in the crop; accurate weed mapping; accuracy in forecasting; the application of pesticides with precision and in a small volume of solution; optimizing nutrient administration; monitoring plant growth [4]. Thorp et Tian (2011) [48] identified spectral differentiation solutions and proposed spectral response testing solutions. Thus, remote detection is possible, fruiting the ability to provide the aerial image and location precision specific to drone-based technologies [50]. In this sense, the following phases are identified [49]: mission planning; flight for image acquisition (EO and NIR sensors); spectral image processing.

The SWOT analysis of aerial monitoring missions of horticultural ecosystems highlights the existence of some strong points for their adoption represented by the short time required for flying over the surfaces and the ability of the sensors mounted on the drone to capture images that contain information about the presence of stressors and the recording of GPS coordinates. Large-scale adoption of aerial monitoring is hampered by operating under strict regulatory conditions and a lack of action to train farmers in the operation of mini UAVs. Added to this is the shyness of actions to promote aerial monitoring services offered by different companies. However, the flexibility and willingness of the authorities to adapt operating regulations to the evolution of technologies and market requirements represent an opportunity that favors the orientation of farmers towards aerial monitoring of horticultural ecosystems in order to identify possible vulnerabilities early.

Missions of application with precision and in a small volume of solution of phytosanitary treatments

The use of mini UAVs in agriculture was not limited to the aerial monitoring of crops and the research of the state of vegetation through captured images, but continued with the application of imputations, respectively of pesticides [47]. Thus, mini UAVs for disease and pest control manage to maintain their control in identified areas, by applying variable doses of pesticides [30]. The positive impact of the activity on the environment and human health is evident [16] as a result of spraying small volumes of pesticides and only in identified areas compared to the classical administration of treatments uniformly and over the entire surface. However, the risk of spraying deviation from the target area as a result of the negative influence exerted by technical and environmental factors is not excluded, which attests to the development of research to improve the technique [3, 34] in the conditions of finding a real potential for the use of mini UAVs in the precision application of pesticides [18, 19, 10]. In Japan, the use of UAVs has a history and remarkable achievements since the 80s with the creation in 1987 of the first unmanned helicopter for pesticide application with a payload of 20 kg [58] and subsequently numerous improved variants. As a result of the success recorded in rice fields in Japan, UAVs for pesticide spraying have been extended to numerous agricultural crops: wheat, oats, soybeans [59] including horticultural ecosystems in California vineyards [21]. This attests to the utility of these practices and the development of spray platforms compatible with numerous commercial UAVs in numerous states [58, 45, 25, 37]. Moreover, there are studies that highlight the use of drones in the biological control of pests [54] and in the elimination of stress factors by ensuring conditions at the level of requirements and thus maintaining the state of health and implicitly resistance to diseases and pests [41, 57].

The SWOT analysis of the precision application missions in a small volume of phytosanitary treatment solutions highlights their favoring of the possibility of application in a variable rate and implicitly of the positive impact on the environment and human health, of the speed and low cost, respectively of the quick access in conditions where other machines cannot operate. Weaknesses are also indicated, such as the negative influence of some technical and environmental factors, but also opportunities offered especially by the real potential for the use of mini UAVs in the precise application of plant protection products.

Soil texture mapping missions

The importance of the soil for the manifestation of the productive characters of the plants is known, and obtaining fast and precise information about its characteristics is very useful. Because soil texture is a relatively stable natural property of soil that influences a number of physical and chemical properties (structure, porosity, hydraulic properties, and nutrient retention capacity), research is oriented toward rapidly obtaining information about it (Wang et al. . 2015) [56]. Numerous studies attest to different methods of soil mapping: quantitative methods based on the theory of the soil-landscape relationship [26], respectively on geo-statistical factors [38]; method based on artificial neural network operating on remote sensing data [61]; establishing regression models between the reflected spectrum and the percentage content of sand or clay [36]; using microwave remote sensing of soil moisture [44]; methods for evaluating soil texture by studying the relationships between the content and size of different soil particle fractions and its surface temperature (daytime, nighttime, diurnal temperature range) using predictive linear regression models [56].

The SWOT analysis of the soil texture mapping missions brings to the fore the ability to obtain information in a short time about the physical and chemical properties of the soil which, along with the development of different categories of sensors and remote sensing, favors their adoption. The lack of solid partnerships between horticultural, pedological, IT and public institutions to analyze, interpret and develop sustainable solutions to improve soil characteristics and ensure their maintenance is delaying the large-scale adoption of these missions. The high-tech industry character imprinted on horticulture by these technologies capable of real-time collection and processing, automation and optimization of business management, creation of new jobs for young people are opportunities for their adoption.

Irrigation monitoring missions in agricultural/horticultural lands

The objective refers to the selection of sensors for obtaining relevant images. The first test [53] refers to an airplane-type drone with a wingspan of 2.5m and an endurance of 40 minutes with capabilities to retrieve digital data and images (in real time) of soil quality variation, salinity and crop development. Research has focused on the ability to create temperature maps through thermal imaging [8, 14]. Turner (2011) [52] equipped a multicopter with electric motors for vineyard mapping missions; sensors used were EO and IR. Tsouvaltsidis et al. (2015) [51] proposed the use of a low-endurance multicopter (10-15 minutes) equipped with IR sensors (QE, Ocean Optics) in synergy with EO in a way that allows the identification of drought effects on crop productivity. Real-time data allows identifying the need for irrigation in a remarkable timing [62]. Drones have been used in 3D surveying missions and are excellent robots for farms, providing capabilities for monitoring irrigation equipment and its operation mode, highlighting the need for maintenance. Another related mission concerns the surveillance of water resources for irrigation [1].

The SWOT analysis of horticultural field irrigation monitoring missions highlights numerous assets for their widespread adoption: the ability to collect real-time information on soil quality variation, soil salinity and crop development; the ability to create temperature gradients; identifying the need for irrigation, monitoring water resources, etc.

The analysis of the four elements of the SWOT analysis leads to the elaboration of the following strategic options for increasing the degree of adoption of mini UAVs in horticultural fields:

Dynamic adaptation of UAV management regulations to technological evolution and market requirements;

• Promotion of educational partnerships regarding the utility of aerial monitoring of horticultural crops and the application of variable rate imputations;

• automation and optimization of agricultural enterprise management;

• promoting an entrepreneurial education for the development of aerial monitoring service companies of horticultural fields to operate in the rural area;

• encouraging partnerships between farmers and their joint access to aerial monitoring services;

• the attraction of young people to drone technology and the need for their entrepreneurial education for the development of service enterprises to operate in the rural area;

CONCLUSIONS

There is a particular interest in expanding the applications of UAV systems in the conditions of the fruition of the aspects of modularity, scalability and the reduction of operating costs through the downsizing conferred by the developments at the level of materials, sensors, and propulsion systems. Starting from the analysis of the current state of the miniUAV, new capabilities and possible developments in the field of precision agriculture and horticulture were demonstrated. The realization of this study leads to the development of recommendations with a positive impact in the process of dynamizing the effective implementation of mini UAV applications in the horticultural field.

This article promotes specific research and accelerates capabilities regarding the adaptation of mini UAV systems to specific horticultural technologies. By studying the numerous applications of mini UAV systems in the agricultural field, new research and development directions and new implementation perspectives result. Capitalizing on the high potential to develop mini UAV systems dedicated to precision agriculture and horticulture applications involves not only the development of materials to reduce the mass of the pods, the improvement of electric propulsion systems, with a focus on batteries, C2 capable systems, but also the development of sensors suitable for the applications and the missions analyzed, respectively ensuring efficiency and adequate implementation at the level of users. These mini UAV systems can thus contribute to increasing yields and productivity by automating and optimizing the management of agricultural enterprises in a scalable way. In this way, superior results can be obtained at the level of the capabilities to ensure the food needs, under the conditions of awareness of the fact that resources are limited and in a way that also integrates the active management of the negative impact of climate change on the agricultural/horticultural field.

Technological progress in mini UAV systems equipment cannot be fruitful without the support of entrepreneurial educational partnerships for understanding and training in the process of aerial monitoring of horticultural fields. In this way, new directions for the development of service enterprises are opened and new jobs are created in the field of precision horticulture. The field of mini UAV technologies is emerging and attracts young people, and its adoption can help keep them in rural areas where they can capitalize on the employment opportunities created through this entrepreneurial educational partnership.

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REFERENCES

[1]Achtilik, M., 2015, UAV Inspection and Survey of Germany's Highest Dam. Ascending Technologies. pp. 1–3.

[2]AIRX3, 2015. Visual Solutions. Sky is the Limit: Mining, p. 14.

[3]Al Heidary, M., Douzals, J. P., Sinfort, C., Vallet, A., 2014, Influence of spray characteristics on potential spray drift of field crop sprayers: A literature review. Crop protection, 63, 120-130.

[4]Anderson, K., Gaston, K. J., 2013, Lightweight unmanned aerial vehicles will revolutionize spatial ecology. Frontiers in Ecology and the Environment, Vol. 11(3), 138-146.

[5]Arjomani, M., 2013, Classification of Unmanned Aerial Vehicles. The University of Adelaide. Australia.

[6]Aswini, N., Krishna, E.K., Uma, S.V., 2018, UAV and obstacle sensing techniques – a perspective, International Journal of Intelligent Unmanned Systems, Vol. 1(3), 256-275, doi: 10.1108/IJIUS-01-2013-0001.

[7]Barbedo, J.G.A., 2019, A review on the use of unmanned aerial vehicles and imaging sensors for monitoring and assessing plant stresses. Drones, Vol. 3(2), 40.

[8]Berni, J. A. J., Zarco-Tejada, P. J., Sepulcre-Cantó, G., Fereres, E., Villalobos, F., 2009, Mapping canopy conductance and CWSI in olive orchards using high resolution thermal remote sensing imagery. Remote Sensing of Environment, Vol. 113(11), 2380-2388.

[9]Borra-Serrano, I., Van Laere, K., Lootens, P., Leus, L., 2022, Breeding and Selection of Nursery Plants Assisted by High-Throughput Field Phenotyping Using UAV Imagery: Case Studies with Sweet Box (Sarcococca) and Garden Rose (Rosa). Horticulturae, Vol. 8(12), 1186.

[10] Brown, C. R., Giles, D. K., 2018, Measurement of pesticide drift from unmanned aerial vehicle application to a vineyard. Transactions of the ASABE, Vol. 61(5), 1539-1546.

[11]Bürkle, A., Leuchter, S., 2009, Development of micro UAV swarms. In Autonome mobile systeme 2009 (pp. 217-224). Springer, Berlin, Heidelberg.

[12]Călina, J., Călina, A., Miluţ, M., Croitoru, A., Stan, I., Buzatu, C., 2020, Use of drones in cadastral works and precision works in silviculture and agriculture. Publisher NARDI Fundulea, România, 37, 273-284.

[13]Cisneros, L. J., 2013, In Peru, Drones Used for Agriculture, Archaeology. AFP News. 2013, pp 1–4. http://phys.org/news/2013-08-peru-drones-agriculture-archaeology.html, Accessed on December 14, 2022.

[14] Costa, J. M., Grant, O. M., Chaves, M. M., 2013, Thermography to explore plant–environment interactions. Journal of experimental botany, Vol. 64(13), 3937-3949.

[15]Dalamagkidis, K., 2015, Classification of UAVs, pp. 83 – 91. In K. P. Valavanis and G. J. Vachtsevanos (eds.), Handbook of unmanned aerial vehicles. Springer, Dordrecht, Netherlands.

[16]Damalas, C. A., 2015, Pesticide drift: seeking reliable environmental indicators of exposure assessment. In Environmental indicators (pp. 251-261). Springer, Dordrecht.

[17]Dobberstein, J., 2013, Technology: Drones Could Change Face of No-Tillage. Precision Farm Dealer. pp 1–7. https://www.precisionfarmingdealer.com/articles/393-technology-drones-could-change-face-of-no-tilling Accessed on 12.01.2023.

[18]Faiçal, B. S., Pessin, G., Filho, G. P., Carvalho, A. C., Gomes, P. H., Ueyama, J., 2016, Fine-tuning of UAV control rules for spraying pesticides on crop fields: An approach for dynamic environments. International Journal on Artificial Intelligence Tools, Vol. 25(01), 1660003.

[19]Faiçal, B. S., Freitas, H., Gomes, P. H., Mano, L. Y., Pessin, G., de Carvalho, A. C., ... Ueyama, J., 2017, An adaptive approach for UAV-based pesticide spraying in dynamic environments. Computers and Electronics in Agriculture, 138, 210-223.

[20] Falcal, B., Pessin, G., Filho, G. P., Furquin, G., Carvalho, A., Ueyama, J., 2015, Exploiting Evolution on UAV Control Rules for Spraying Pesticides on Crop Fields. Proceedings on Conference on Engineering Applications of Neural Networks. 2015 , pp. 1–3. DOI: 10.1007/978-3-319-11071-4_5

[21]Giles, D., Billing, R., 2015, Deployment and performance of a UAV for crop spraying. Chemical engineering transactions, 44, 307-312.

[22]Glen, B., 2015, Rise of the Field Drones. Precision Agriculture of the Future Employs Robots to Work Fields and it's Here Now. The Western Producer. 2015, pp. 1–12.

[23]Gogarty, B., Robinson, I., 2011, Unmanned vehicles: A (rebooted) history, background and current state of the art. Journal of Law, Information and Science, Vol. 21(2), 1-34.

[24] Grassi, M., 2014, Five Actual Uses for Drones in Precision Agriculture Today. Drone Life, pp. 1-3.

[25]Huang, Y., Hoffmann, W. C., Lan, Y., Wu, W., Fritz, B. K., 2009, Development of a spray system for an unmanned aerial vehicle platform. Applied Engineering in Agriculture, Vol. 25(6), 803-809.

[26]Hudson, B. D., 1992, The soil survey as paradigm-based science. Soil Science Society of America Journal, Vol. 56(3), 836-841.

[27]Iagăru, P., Pavel, P., Iagăru, R., 2019, Implementation of the concept Agriculture of Precision a way to improve the Management of Agricultural Enterprises. Scientific Papers Series-Management, Economic Engineering in Agriculture and Rural Development, Vol. 19(1), 229-233.

[28]Iagăru, P., Pavel, P., Iagăru, R., Şipoş, A., 2022, Aerial Monitorization—A Vector for Ensuring the Agroecosystems Sustainability. Sustainability, 14(10), 6011.

[29]Iagăru, P., Pavel, P., Iagăru, R., Şipoş, A., 2021, Using drone technology for preserving the economic sustainability of the agricultural holdings. International Journal of Advanced Statistics and IT&C for Economics and Life Sciences, Vol. 11(1), 85-90.

[30]Iost Filho, F. H., Heldens, W. B., Kong, Z., de Lange, E. S., 2020, Drones: innovative technology for

use in precision pest management. Journal of economic entomology, 113(1), 1-25.

[31]Kotsemir, M., 2019, Unmanned aerial vehicles research in Scopus: analysis and visualization of publication activity and research collaboration at the country level. Quality & Quantity, 53(4), 2143-2173.

[32]Krishna, K. R., 2016, Push Button Agriculture: Robotics Drones and Satellite Guided Soil and Crop Management; Apple Academic Press Inc.: Waretown, New Jersey, p. 405.

[33]Laksham, K. B., 2019, Unmanned aerial vehicle (drones) in public health: A SWOT analysis. Journal of family medicine and primary care, Vol. 8(2), 342.

[34]Lan, Y., Thomson, S. J., Huang, Y., Hoffmann, W. C., Zhang, H., 2010, Current status and future directions of precision aerial application for site-specific crop management in the USA. Computers and electronics in agriculture, Vol. 74(1), 34-38.

[35]Maes, W. H., Steppe, K., 2019, Perspectives for remote sensing with unmanned aerial vehicles in precision agriculture. Trends in plant science, 24(2), 152-164.

[36]Maselli, F., Gardin, L., Bottai, L., 2008, Automatic mapping of soil texture through the integration of ground, satellite and ancillary data. International Journal of Remote Sensing, Vol. 29(19), 5555-5569.

[37]Martinez-Guanter, J., Agüera, P., Agüera, J., Pérez-Ruiz, M., 2020, Spray and economics assessment of a UAV-based ultra-low-volume application in olive and citrus orchards. Precision Agriculture, Vol. 21(1), 226-243.

[38]McBratney, A. B., Odeh, I. O., Bishop, T. F., Dunbar, M. S., Shatar, T. M., 2000, An overview of pedometric techniques for use in soil survey. Geoderma,Vol. 97(3-4), 293-327.

[39]Moffet, C., 2015, Unmanned Aerial Vehicles Advance Agriculture. Samuel Roberts Noble Foundation Ardmore, Oklahoma, USA.

[40]Mordor Intelligence, 2019, Drones market- growth, trends, and forecasts (2020–2025), https://www.mordorintelligence.com/industry-reports/drones-market, Accessed on 12.01.2023.

[41] Nansen, C., Sidumo, A. J., Martini, X., Stefanova, K., Roberts, J. D., 2013, Reflectance-based assessment of spider mite "bio-response" to maize leaves and plant potassium content in different irrigation regimes. Computers and electronics in agriculture, 97, 21-26.

[42]Petre, I. M., Boșcoianu, M., Pop, S., Iagăru, P., Sârbu, F. A., Iagăru, R., 2022, An Analysis of the Possibilities to Develop and Implement a Modular and Scalable System Based on Mini-Aerial Robots for Precision Agriculture. RECENT J. (2022), 68:100-106 https://doi.org/10.31926/RECENT.2022.68.100.

[43]Ramesh, P. S., Jeyan, J. M. L., 2021, Terrain imperatives for Mini unmanned aircraft systems applications. International Journal of Intelligent Unmanned Systems.

[44]Santanello Jr, J. A., Peters-Lidard, C. D., Garcia, M. E., Mocko, D. M., Tischler, M. A., Moran, M. S., Thoma, D. P., 2007, Using remotely-sensed estimates of soil moisture to infer soil texture and hydraulic properties across a semi-arid watershed. Remote Sensing of Environment, Vol. 110(1), 79-97.

[45]Shim, D. H., Han, J. S., Yeo, H. T., 2009, A development of unmanned helicopters for industrial applications. Journal of Intelligent and Robotic Systems, Vol. 54(1), 407-421.

[46]Stark, B., Smith, B., Chen, Y., 2013, A guide for selecting small unmanned aerial systems for research-centric applications, pp. 38 – 45. In IFAC Proceedings. IFAC Workshop on Research, Education and Development of Unmanned Aerial Systems, 20–22 November 2013, Compiegne, France.

[47] Sylvester, G. (Ed.), 2018, E-agriculture in action: drones for agriculture. Food and Agriculture Organization of the United Nations and International Telecommunication Union, p. 45.

[48]Thorp, K.R., Tian, L.F., 2011, A Review on Remote Sensing of Weeds in Agriculture. Precis. Agric., 5, 477–508.

[49]TOAS Project, 2015, New Remote Sensing Technologies for Optimizing Herbicide Applications in Weed-Crop Systems; CSIC: Madrid, Spain. pp. 1–2.

[50]Torres-Sánchez, J., López-Granados, F., De Castro, A. I., Peña-Barragán, J. M., 2013, Configuration and specifications of an unmanned aerial vehicle (UAV) for early site specific weed management. PloS one, Vol. 8(3), e58210.

[51]Tsouvaltsidis, C., Zaid Al Islam, N., Benari, G., Vreckalic, D., Quine, B., 2015, Remote Spectral Imaging Using a Low Cost UAV System. Paper presented at international conference on Unmanned aerial vehicles in Geomatics. Toronto, Canada. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences. 2015, XL, pp. 25–31.

[52]Turner, D., Lucieer, A., Watson, C., 2011, Development of an Unmanned Aerial Vehicle (UAV) for hyper resolution vineyard mapping based on visible, multispectral, and thermal imagery. In Proceedings of 34th International symposium on remote sensing of environment (p. 4).

[53]Valencia, E., Acevo, R., Bosch-Lluis, X., Aguasca, A., Rodriiguez-Alvarez, N., RamosPerez, I. A., 2008, Initial Results of an Airborne Light-Weight L-Band Radiometer. Geoscience and Remote Sensing Symposium. IGARSS 2008. IEEE International 2008, 2, 1170–1176.

[54]Van Lenteren, J. C., Bolckmans, K., Köhl, J., Ravensberg, W. J., Urbaneja, A., 2018, Biological control using invertebrates and microorganisms: plenty of new opportunities. BioControl, Vol. 63(1), 39-59.

[55]Wang, S., Xu, T., Li, X., 2022, Development Status and Perspectives of Crop Protection Machinery and Techniques for Vegetables. Horticulturae, Vol. 8(2), 166.

[56]Wang, D.-C., Zhang, G.-L., Zhao, M.-S., Pan, X.-Z., Zhao, Y.-G., Li, D.-C., et al., 2015, Retrieval and Mapping of Soil Texture Based on Land Surface Diurnal Temperature Range Data from MODIS.PLoS ONE 10(6): e0129977. https://doi.org/10.1371/journal.pone.0129977

[57]West, K., Nansen, C., 2014, Smart-use of fertilizers to manage spider mites (Acari: Tetrachynidae) and other arthropod pests. Plant Science Today, Vol. 1(3), 161-164.
[58]Xiongkui, H., Bonds, J., Herbst, A., Langenakens, J., 2017, Recent development of unmanned aerial vehicle for plant protection in East Asia. International Journal of Agricultural and Biological Engineering, Vol. 10(3), 18-30.
[59]Yamaha. RMAX-History, 2014, pp. 1–4.
[60]Yamaha Motors, 2018, Yamaha's first industrial drone Yamaha Motor NewsLetter (December 20, 2018, No.68), https://www.mynewsdesk.com/yamaha-motor/news/yamahas-first-industrial-drone-yamaha-motor-newsletter-december-20-2018-no-68-341676, Accessed on 12.01.2023.
[61]Zhai, Y., Thomasson, J. A., Boggess III, J. E., Sui, R., 2006, Soil texture classification with artificial neural networks operating on remote sensing data. Computers and Electronics in Agriculture, Vol. 54(2), 53-68.
[62]Zhang, C., Walters, D., Kovacs, J. M., 2014, Applications of low altitude remote sensing in agriculture upon farmers' requests–a case study in northeastern Ontario, Canada. PloS one, Vol. 9(11), e112894.