Elżbieta LOREK • Agnieszka LOREK • Beata MICHALISZYN-GABRYŚ

THE IMPORTANCE OF ECO-INNOVATIVE WEED CONTROL USING LASER TECHNOLOGY IN CREATING SUSTAINABLE AGRICULTURE IN THE EUROPEAN UNION. SOCIO-ECONOMIC PERSPECTIVE

Elżbieta **Lorek** (ORCID: 0000-0002-1648-7322) – *HUMANITAS University in Sosnowiec*
Agnieszka **Lorek** (ORCID: 0000-0002-1812-9692) – *University of Economics in Katowice*
Beata **Michaliszyn-Gabryś** (ORCID: 0000-0002-6805-1678) – *Institute for Ecology of Industrial Areas, Poland*

Correspondence address:
1 Maja Street 50, 40-287 Katowice, Poland
e-mail: agnieszka.lorek@ue.katowice.pl

ABSTRACT: The article aims to evaluate – from the point of view of selected socio-economic aspects – the implementation of an innovative weed control technology into agricultural practice using laser energy targeted at reducing pesticide use. The achievement of the stated objective required an analysis of the research output concerning the problem of pesticide sustainability in European Union agriculture and an analysis of EU policies in this field. The paper also utilises data obtained through research by conducting in-depth interviews with representatives of three stakeholder groups: farmers, society and business. The subject of the interviews was to assess the impact of large-scale dissemination of an innovative weed control technology on selected socio-economic aspects. The article is one of the first studies to assess the social impact of innovative technologies using artificial intelligence and laser technology for weed control in agriculture. The implementation of this technology can have a significant impact on running farms in a more sustainable way, but a prerequisite for its successful use is the inclusion of social and economic considerations.

KEYWORDS: sustainable agriculture, European Union agricultural policy, pesticides, laser technology

Introduction

Sustainable agriculture primarily means protecting the soil and atmosphere from pollution and generating raw materials with the quality parameters desired by consumers and industry, as well as producing safe food. Indeed, sustainable agricultural systems assume a symbiosis of production and ecological objectives. Organic farming, through agrochemical-free cultivation and controlled production methods, contributes to the preservation of biodiversity and the protection of natural resources, as well as the production of high-quality food.

As a result of the industrial development of agriculture in highly developed countries, the natural character of rural areas has been lost. Extensive changes have taken place in the natural and landscape space of the countryside, mainly due to modern agrotechnology, including high levels of chemical use. The natural environment of rural areas has been burdened with all the negative effects resulting from the rapacious and pro-industrial path of development. There is a need to integrate efforts to find solutions aimed at preserving the values of the natural environment and, at the same time, allowing a range of economic and social objectives to be met. The implementation of sustainable development is particularly pertinent in rural areas. Environmental protection and rural development measures are convergent and similar in nature. In essence, without a clean environment, there can be no long-term rural development. The article aims to evaluate – from the point of view of selected socio-economic aspects – the implementation of an innovative weed control technology into agricultural practice using laser energy aimed at limiting pesticide use.

Since the large-scale use of the new technology will be associated with changes in the existing working conditions of farmers, the quality of life of society and the economic sphere, the article analyses interviews conducted among representatives of the agricultural sector. The objective of the qualitative study was to gain insight into the opinions of experts representing selected stakeholder groups regarding the impact of the new technology on selected socio-economic aspects.

The problem of pesticides in sustainable development in European Union agriculture – a review of solutions and literature

As civilisation develops, the demands placed on agriculture are increasing and there are growing concerns about the sustainability of agricultural practices. These concerns relate to the ability of systems to continue to provide food, but also to the role agriculture plays in terms of its impact on ecosystems. Practices that have helped increase and maintain high yields have often had negative impacts. With these challenges in mind, the concept of sustainability has emerged.

The concept of sustainable agriculture is not precise, and there is a lot of debate on the subject. In 1988, the Food and Agriculture Organisation FAO adopted a definition of sustainable agriculture that reads: "Sustainable development consists in such use and conservation of natural resources and in such orientation of technologies and institutions as to achieve and maintain the satisfaction of human needs of present and future generations. This type of development (in agriculture, forestry and fisheries), while conserving soil, water resources, plants and animal genetic resources, does not degrade the environment, uses appropriate technologies, is ecologically viable and socially acceptable" (FAO, 1988). Another definition characterises sustainable agriculture as a modern concept of such development programming, which associates production goals with environmental requirements (Adamowicz, 2005).

Woś (1998) defines the concept of sustainable agriculture with the following five features:

- natural resources should be used in such a way that their capacity for self-renewal is not stifled,
- food production can only be expanded through an increase in resource productivity, i.e. through the introduction of technologies that both preserve resources and maintain their high quality for future generations,
- such agriculture shows low susceptibility to fluctuations and shocks,
- sustainable agricultural systems presuppose the full symbiosis of production and ecological objectives,
- management of natural resources makes it possible to meet changing needs while maintaining a high environmental quality and conserving resources.

DOI: 10.34659/eis.2024.88.1.741

In general, therefore, it can be said that sustainable agriculture is a concept that extends well beyond the traditional treatment of this economic sector. This extension also goes beyond the framework of agriculture itself and refers to rural areas and, thus, to non-agricultural fields in the countryside. The concept of sustainability refers, in general, to human activities in any field. The concept of sustainable rural development distinguishes four directions of development (Woś & Zegar, 2002; Wilkin, 2004; Adamowicz, 2006):

- protection of water, soil and atmosphere against pollution from agriculture, long-term and sustainable development of agriculture itself,
- protection of rural areas, including biodiversity, protection of landscape values and prevention of soil erosion,
- exercise the necessary caution in the development of biotechnology and genetic engineering.

The concept of sustainable development dominated political and economic agendas and was adopted by national governments in the process of designing and implementing development strategies. In the European Union (EU), sustainable development is widely discussed in various contexts, including the Common Agricultural Policy (CAP). These policies include the greening of production, including the application of cross-compliance, with the aim of reducing the negative environmental impact of agriculture (Kalinowska et al., 2022).

Currently, the core of EU action is focused on the *European Green Deal*, a strategy whose main objective is to achieve sustainability and climate neutrality in Europe by 2050 as a means to attract investment and drive economic growth. The Green Deal highlights the key role of managing the transition towards achieving a more sustainable food system, in particular, the need for farmers to step up their efforts to combat climate change, ensure environmental protection and preserve biodiversity.

Part of implementing sustainability in agriculture is reducing the use of chemicals (including herbicides). EU chemicals policy underwent a radical change with the adoption of *Regulation 1907/2006/EC (REACH Regulation)* in 2006. The aim of REACH was to better protect people and the environment from possible chemical hazards and to promote sustainable development. Another important regulation in this area was also the *Directive on the Sustainable Use of Pesticides*, which in Art. 1 states that: "it establishes a framework for achieving a sustainable use of pesticides by reducing the risks and impacts of pesticide use on human health and the environment and by encouraging the use of integrated pest management and of alternative approaches and techniques such as non-chemical alternatives to pesticides" (Directive, 2009). However, the current provisions of the Directive have proven to be insufficiently stringent and have been unevenly implemented across the Member States. The result of this state of affairs is that the problem of excessive pesticide use is still present in the EU. Between 2011 and 2021, pesticide sales in the EU fluctuated within ± 6%, around the level of 350 000 tonnes per year (Eurostat, 2023). Total herbicide use in the EU27 since 1990 indicates that the target of a 50% reduction in chemical pesticides by 2030 remains a major challenge (Tataridas et al., 2022). According to the model presented by Rasche (2021), herbicide use in the EU is expected to remain constant until the end of the century.

Currently, the European Commission has set a concrete strategic plan to reduce the use of chemicals, increase biodiversity and support farmers in decision-making processes to increase the sustainability of farms within the Union's borders. These objectives are consistent and in line with the United Nations' Agenda 2030 on sustainable production. As part of the European Green Deal, and in particular, the *Farm-to-Fork Strategy* and the *Biodiversity Strategy for 2030*, the European Commission is to take action to reduce the use of chemical pesticides and the associated risks, including the use of more hazardous pesticides by 50% by 2030. To make this possible, the Commission envisages a number of measures, including the promotion of mechanical weed control.

The topic of the following article focuses on one group of pesticides – herbicides.

Herbicides are considered essential to maintain agricultural production, but a number of issues related to their use can be mentioned. These can include the following problems:

- Residues from the use of herbicides persist in the environment (van der Werf, 1996; Vassilev & Kambourova, 2006; Edwards, 2013; Mahmood et al., 2016; Carvalho, 2017; Bilal et al., 2019) and destroy non-target plants and beneficial insects (Serrão et al., 2022; Duke, 2021),
- They cause health effects in animals and humans. There is overwhelming evidence of an association between pesticide exposure and an increased incidence of chronic diseases such as various

DOI: 10.34659/eis.2024.88.1.741

types of cancer, diabetes, neurodegenerative diseases, birth defects, and reproductive disorders (Mostafalou & Abdollahi, 2013; Blair et al., 2015; Cocco, 2016; Özkara et al., 2016; Shah, 2020; Pathak et al., 2022; Singh et al., 2022). The World Health Organization (WHO) categorises them based on their harmful effects, emphasising the importance of public health. In March 2015, the International Agency for Research on Cancer (IARC) classified glyphosate as "probably carcinogenic to humans" (Group 2A),

- Existing herbicides become less effective due to the evolution and spread of weeds resistant to their effects (Owen & Zelaya, 2005; Duke, 2005; Dill, 2005; Burke & Bell, 2014; Vrbničanin et al., 2017; Adamczewski et al., 2019; Beckie et al., 2019; Moss et al., 2019; Gage et al., 2019; Beckie, 2020). According to the International Herbicide – Resistant Weed Database (2023), there are currently 523 reported cases of herbicide -resistant weeds worldwide.

In 2023 (at the time of writing the article below), the herbicide of most controversy is glyphosate, which is linked to the renewal of its authorisation in the Member States. Glyphosate is currently approved in the EU until 15 December 2023, so glyphosate can be used as an active substance in plant protection products. During the public consultation, a number of NGOs highlighted their concerns about the reliability of the studies on the potential effects of this chemical. On 6 July 2023, the European Food Safety Authority (EFSA) adopted a conclusion on the review of the pesticide risk assessment. An Assessment Group on Glyphosate (AGG) was set up for the risk evaluation, consisting of the competent authorities of France, the Netherlands, Sweden and Hungary. The conclusions were based on an assessment of representative uses of glyphosate as a herbicide. EFSA's assessment of the effects of glyphosate on human, animal and environmental health did not identify critical areas of concern, but the report did list gaps requiring data supplementation and further research. On 13 October 2023, the European Commission voted to extend the use of glyphosate for another 10 years. The Member States did not reach the majority required to accept or reject the application, but the Commission, based on EFSA's assessment of the effects of glyphosate on human, animal and environmental health, announced the renewal of glyphosate's approval, subject to certain conditions and restrictions.

One of the more compelling arguments cited in favour of glyphosate use extension is the lack of alternatives to glyphosate and the economic cost of discontinuing its use. In a publication by Wynn and Webb (2022) summarising research and estimates on the abandonment of glyphosate, there are figures reporting costs to the agricultural industry of over €16 billion (EU-28 figures) for wheat, potatoes and vines in terms of increased costs and lost production. These authors point out that if these costs were extrapolated to other crops grown in the EU that have not been assessed, the total impact on European agriculture could be much higher. There are also a number of other difficulties associated with the withdrawal of glyphosate (e.g. a reduction in the competitiveness of European agriculture in a global context, an increase in the areas that will have to be devoted to crops, the need for significant investment in the development and implementation of alternative production systems). It should be noted, however, that these estimates do not take into account the existing external costs of herbicide use related to biodiversity loss and health effects. In this context, it seems increasingly important to look for alternative solutions. Nevertheless, this alternative requires incentive measures on a European scale that would promote the development of agricultural machinery, the non-chemical tools industry and investments in agricultural consultancy. One such alternative is the use of laser technologies and artificial intelligence in the construction of robots designed to weed crops.

Research methods

The research method applied in this article is tailored to the research problem posed, and the study carried out was based equally on diagnostic and predictive approaches. The achievement of the stated objective required an analysis of the research output concerning the problem of pesticide sustainability in European Union agriculture and an analysis of EU policies in this field. The paper also utilises data obtained through research by conducting in-depth interviews with representatives of three stakeholder groups: farmers, society and business. Interviews were conducted with 15 experts (5 experts from each group) from Poland, Denmark, Spain, Greece, and Finland. The interviews were carried out in 2023 during individual online meetings with experts using the MS TEAMS tool.

DOI: 10.34659/eis.2024.88.1.741

The subject of the interviews was to assess the impact of large-scale dissemination of an innovative weed control technology on selected socio-economic aspects. The topics discussed in interviews with representatives of farmers were health and working conditions, economic consequences, and risks for farm operation. During the interviews with representatives of the society, the following aspects were discussed: quality of life and environment, demographic consequences and just agricultural transition. Interviews were conducted with business representatives who were concerned with issues such as profitability, business risk, environmental performance, and perspectives on business development. For each of the selected aspects, questions were formulated, as presented in Table 1 – questions for experts from the group of farmers, Table 2 – questions for the group of social experts, and Table 3 – questions for representatives of business experts.

The study was of a qualitative nature. During the interviews, experts had the opportunity to express their opinions freely, but they were asked to summarise their opinions on a scale of 1 to 5 points, where: 1 point – means very negative impact, 2 points – negative impact, 3 points – neutral impact, 4 points – positive impact, 5 points – very positive impact.

The research results presented in sub-chapter 4 are a fragment of broader analyses devoted to the Social Life Cycle Assessment (S-LCA)[1] of the widespread dissemination of innovative weed control technology implemented as part of the WeLASER project.

Innovative technologies in agriculture exemplified by the WeLASER project

The growing demand for food in terms of both quantity and quality, as well as increasing environmental requirements, has reinforced the need to develop and apply modern agricultural technologies. One project in line with this trend is Sustainable Weed Management in Agriculture with Laser-based Autonomous Tools (acronym: We-LASER). The project has resulted in the development of a prototype weed control device using laser energy. This technology fits into the principles of precision farming and consists of several systems. The AI-equipped vision system distinguishes crops from weeds and detects the location of weed meristems to direct a laser beam at them with a scanner. An agricultural robot moves through a farmland thanks to an autonomous vehicle. The operation of the device is coordinated by a control system using IoT and cloud computing technologies. Basic technical characteristics (Gonzalez-de-Santos, 2021):

- Total weight: ~1243 Kg,
- Treatment efficiency: ~65%,
- Treatment speed: ~2 Km/h,
- Treatment rate:
  - ~4.8 Ha/day – 1st phase,
  - ~9.6 Ha/day – 2nd phase.
- Position accuracy: ±3 mm,
- (2+2)-row wide,
- Clearance: > 25 cm,
- Treatment speed: ~ 2 Km/h.

A functional diagram of the WeLASER device is shown in Figure 1. More information about the project and the technologies used can be found on the WeLaser project website (WeLaser, 2023) and scientific publications (Rakhmatulin & Andreasen, 2020; Vitali et al., 2021; Rakhmatuiln et al., 2021; Andreasen et al., 2022; Vitali et al., 2023; Emmi et al., 2023).

The WeLASER project was carried out between 2021 and 2023 as part of the Horizon 2020 European Union framework programme. The research was coordinated by the Centre for Automation and Robotics (car), Madrid, Spain. The project partners were academic institutions and companies from the following countries: Belgium, Denmark, France, Germany, Italy, the Netherlands, Spain and Poland. The main goal of developing the new technology is to eliminate the use of herbicides during weeding and, as a consequence, achieve a minimum impact on crops, the environment, and health.

[1] The Social Life Cycle Assessment (S-LCA) is an assessment of actual and potential social and socio-economic impacts of technologies, including positive and negative effects in their entire life cycle: from extraction and processing of raw materials, through production, distribution, use and reuse, recycling, up to waste management.

DOI: 10.34659/eis.2024.88.1.741

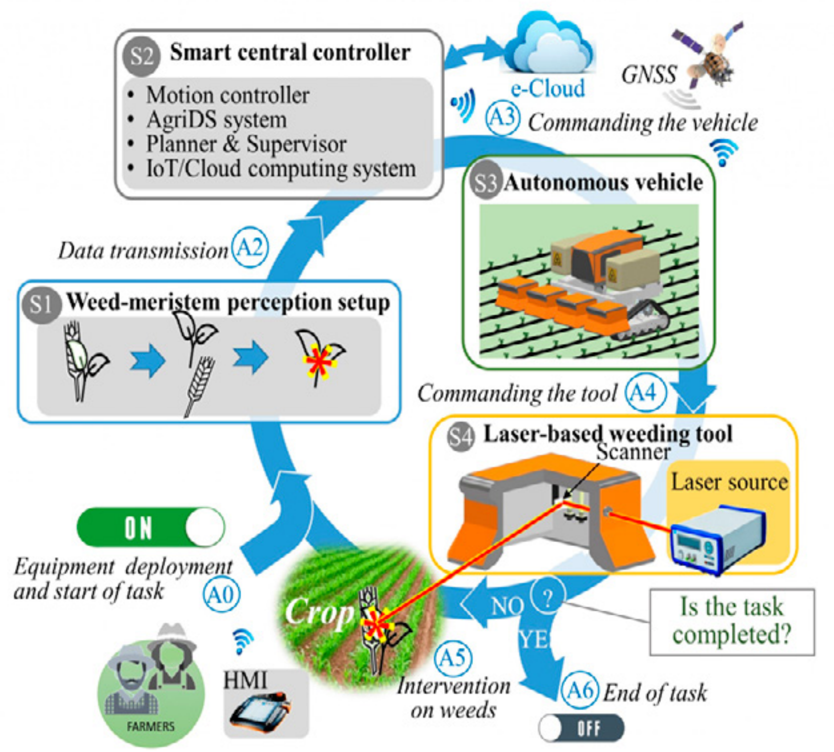

Figure 1. A functional diagram of the WeLASER device

Source: authors' work based on WeLaser (2023), https://welaser-project.eu/.

Socio-economic implications of implementing laser energy weed control technology in agricultural practice

Both the benefits, requirements and risks associated with the implementation of the innovative technology will have a significant impact on farmers' working practices and quality of life as well as cause changes for other stakeholders. The aim of carrying out interviews was to assess to what extent the wide implementation of technology developed in the WeLASER project in agricultural practice will affect society in European conditions.

In order to investigate the potential changes and impacts of the implementation of the innovative technology on selected stakeholders, in-depth interviews were conducted with experts representing farmers, society and businesses. The experts assessed the impact of the new device in relation to the influence exerted by current weed control methods, including the use of herbicides, mechanical methods and manual techniques.

The results from the three stakeholder groups- farmers, the public, and businesses- are presented below.

Those representing farmers during the interviews assessed the impact of the new technology on health and working conditions, farm economics and the risks that a farmer will have to bear when deciding to use an innovative technology on his/her farm. The questions answered by the group of farmers' experts and the map of answers are presented in Table 1.

Experts positively evaluated the device's impact on farmer comfort (average expert rating of 4.6 points) and time savings (average rating of 4.2 points). The technology will be more efficient and faster than mechanical weed removal, e.g. with a weeder. The risk of accidents will be much lower with the new technology compared to the use of other solutions (the average rating of experts in this area is 4.2 points), as there will be very little direct contact between the farmer and the machine. The positive impact on the farmer's health, particularly in relation to the use of chemicals, will be considerable (average expert rating of 4.4 points). Still, it should be stressed that the laser used in the technology may have a harmful effect on the eyes and therefore, protective measures will be required to maintain safety.

DOI: 10.34659/eis.2024.88.1.741

Table 1. Map of responses from experts representing farmers

Experts representing farmers	E1	E2	E3	E4	E5
Health and working conditions What impact will the use of devices such as an autonomous laser weeder have on:					
The farmer's working time?	Green	Green	Green	Green	Green
Comfort of work?	Green	Green	Green	Green	Green
Work safety and accidents?	Green	Brown	Brown	Green	Green
Health conditions (chemical hazards caused by the use of chemical plant protection products, back problems due to manual weeding)?	Green	Green	Green	Green	Green
Economic consequences What impact will the use of devices such as an autonomous laser weeder have on:					
Good quality agricultural products that meet customers' needs?	Brown	Green	Green	Green	Green
Farms' productivity per hectare?	Brown	Green	Green	Gray	Green
Demand on seasonal/temporary workers?	Green	Green	Green	Green	Green
Production costs	Brown	Gray	Green	Green	Brown
Risk for farms operation What impact will the implementation/purchase/rental of devices such as an autonomous laser weeder have on:					
Risks related to unexpected functional limitations of the device?	Green	Green	Green	Brown	Yellow
Farmers' liability for damage to third party property caused by the device?	Green	Green	Brown	Green	Brown
Risk of theft or damaging the device?	Yellow	Brown	Brown	Green	Yellow

Legend:
Green – positive or very positive impact (4-5 points).
Brown – neutral impact (3 points).
Yellow – very negative or negative impact (1-2 points).
Gray – No clear answer (these answers were not considered when calculating the averages).

Experts pointed out the beneficial impact of the implementation of the new technology on the quality of agricultural products due to the minimised use of chemicals (average rating 4.4 points). This is particularly true for conventional farms. There will be benefits for organic farming due to increased yields (answers regarding the impact on increasing productivity are not clear, with an average of 3.75 points). An important aspect is the replacement of human labour by machinery. In particular, this applies to the employment of seasonal workers, which is associated with high costs for the farmer and problems resulting from insufficient labour supply (the best possible ratings of all experts were recorded on this aspect). The purchase of innovative technology will involve a large financial outlay (the average assessment of the impact of WeLaser technology on production costs is 3.75 points). Experts indicated that in the first phase of introducing this device to the market, only a farmer managing a large-scale farm with strong economic potential will be able to buy it. Therefore, the purchase of a robot by a group of farmers and joint use may be a way to spread the application of the technology to a larger number of farmers.

During the use of the technology, problems may arise regarding the breakdown of the machine (average score for this aspect is 3.8 points), the machine causing damage to third-party property (average rating of 3.9 points) or the robot being stolen or damaged (average rating 2.9 points). According to experts, the risk of the aforementioned incidents will not be high, but nevertheless, experts pointed out that it will be necessary to insure the device and to monitor and control the operation as well as the environment of the device, which influences their assessment.

During the interviews, the representatives of society assessed the impact of the new technology on the quality of life of society and the state of the environment, the demographic consequences and the transformation of rural areas compared to other alternative methods of weed control. The questions were answered by a group of experts representing social organisations, and a map of the answers is presented in Table 2.

DOI: 10.34659/eis.2024.88.1.741

Table 2. Map of responses from experts representing social organisations

Experts representing society	E1	E2	E3	E4	E5
Quality of life and environment What impact will the use of devices such as an autonomous laser weeder have on values determining the quality of life due to limitation of methods used so far (including current weeding practices based on chemical plant protection products)?					
Quality and safety of agricultural products?	Brown	Green	Green	Green	Green
State of the environment	Green	Green	Green	Green	Green
Affordability of agricultural products for the society	Yellow	Green	Brown	Brown	Brown
Demographic consequences What will be the impact of the availability of devices such as an autonomous laser weeder on following demographic groups compared to the existing practice of weeding:					
Young people interest in running a farm?	Green	Green	Brown	Green	Green
Women's interest in working in agriculture?	Green	Green	Green	Green	Green
The demand for low-skilled labour?	Brown	Green	Brown	Brown	Brown
Just agriculture transformation What impact will the widespread use of devices such as an autonomous laser weeder have on following aspects of rural transformation in the long term perspective compared to the existing practice of weeding:					
The agrarian structure of agriculture?	Brown	Green	Yellow	Brown	Green
Development of ecological (organic) farms?	Green	Green	Green	Green	Brown
Economic diversification of rural areas?	Brown	Green	Brown	Brown	Brown

Legend:
Green – positive or very positive impact (4-5 points).
Brown – neutral impact (3 points).
Yellow – very negative or negative impact (1-2 points).
Gray – No clear answer (these answers were not considered when calculating the averages).

According to experts representing a social perspective, the implementation of the innovative weed control technology will be associated with an improvement in the quality and safety of agricultural products due to the elimination of chemical residues on crops, which occurs during the use of plant protection chemicals (average impact score of 4 points). The risk to honeybees, bumblebees and birds, among others, will be reduced. In the long term, there will be a significant improvement in the environment and biodiversity (average expert rating 4.8 points). At the beginning of the implementation of the new technology, the price of products made with the WeLASER device may be relatively higher compared to the price of alternative agricultural products, excluding organic production (average assessment of experts in the area of food availability for society at level 3).

Of particular concern to the European Commission is the creation of favourable conditions for the development of farms managed by young farmers, including female farm managers. According to experts, young farmers are keen to take advantage of technological innovations; nevertheless, it is difficult to assess whether the increasing possibilities of agricultural automation will encourage them to stay in the countryside. Experts pointed out that the most important factor influencing decisions regarding the young generation of farmers who have a high ability to take risks related to the implementation of innovation is the economic potential of the farm, including its size. The average assessment by experts for improving opportunities for young farmers is 3.8 points and for women working in agriculture – 4 points.

A major social impact of the replacement of people by machines is the reduced need for human labour. For low-skilled people, including immigrants, the impact of the introduction of the new technology may be detrimental. But, taking into account the insufficient supply of labour in relation to demand and the high probability of new opportunities where labourers can find employment, the negative impact should not be severe, hence the experts' assessment at a neutral level of 3.2 points.

DOI: 10.34659/eis.2024.88.1.741

A condition for the introduction of laser weed control technology on a wider scale will be the interest in the technology and the ability of farmers to bear the costs associated with its purchase. According to expert studies, only farmers managing large commodity farms will be able to invest in this innovation. Increasing the potential of a single farm is facilitated by the process of farm consolidation, which, moreover, offers a better chance of stabilising the income of the farming population and keeping agricultural activities profitable (the impact of the proposed innovation on the agrarian structure and economic diversification of rural areas was assessed at a neutral level of 3.2 points). On the other hand, the experts pointed out that there is a need to protect and support small farms and the local communities in which they operate because of their valuable cultural values. According to the experts, the WeLASER technology can significantly contribute to the development of organic farming (average rating 4 points), nevertheless, both supply and demand for organically grown products will be important in this regard.

During the interviews, the business representatives assessed the impact of the development of the new technology on the industrial sphere, including potential manufacturers of the device, the state of the environment and the prospects for business development, compared to the impacts of alternative weed control technologies. The questions answered by the group of experts representing business and the map of answers are presented in table 3.

Table 3. Map of responses from experts representing business

Experts representing business	E1	E2	E3	E4	E5
Profitability What impact will the widespread use of devices such as an autonomous laser weeder have on profits of following branches in value chain compared to the existing practice of weeding:					
Profits of companies producing the machines	Green	Green	Green	Green	Green
Business risks What impact will the production of devices such as an autonomous laser weeder have on following risks for the manufacturers with regard to the producers of alternative weeding machines:					
Manufacturer's responsibility for product's malfunctions (complaints, service)?	Yellow	Yellow	Yellow	Yellow	Yellow
Environmental performance of companies What impact will the wide scale production of devices such as autonomous laser weeder have on following environmental aspects with regards to alternative weeding machines?					
Demand on critical resources?	Yellow	Brown	Brown	Brown	Yellow
Manufacturer's responsibility for waste management of devices in its post-consumption phase?	Green	Brown	Yellow	Brown	Yellow
Production's pressure on the environment?	Brown	Brown	Yellow	Green	Yellow
Perspectives of business development What impact will the production and wide use of laser weeder have on perspectives of business development:					
Creation of new jobs?	Green	Green	Green	Brown	Green
New prospects for the companies development?	Green	Green	Green	Brown	Green
Strengthening competences of organisations, companies and workers?	Green	Green	Green	Green	Green

Legend:
Green – positive or very positive impact (4 – 5 points).
Brown – neutral impact (3 points).
Yellow – very negative or negative impact (1-2 points).
Gray – No clear answer (these answers were not considered when calculating the averages).

In the long term, the technology should be profitable for the manufacturer of the device and have a positive impact on the economic sphere (average expert rating 4.7 points). However, experts cautioned that the profitability of this investment will depend on the price of the device, the demand for it and the range of competing solutions on the market. Due to the advanced technological level of the machine, the manufacturer will be responsible for how the equipment will function in practice and will be obliged to provide maintenance and advice to the user (average score 1.8 points). Moreover, it should take into account how the used equipment will be managed, including the recycling of selected parts of the machine (average expert rating 2.8 points). The above obligations will incur high costs, which will reduce the potential profits of entrepreneurs.

The environmental impact of the production phase of the device – according to experts – may be higher compared to the production of current mechanical weedershence the relatively low average expert rating of 2.9 points. In the production of laser devices and electronic components, the use of chemicals will be important, and the production process will be prolonged, entailing higher energy consumption. In addition, the demand for rare earth elements will increase. This aspect is rated at 2.2 points.

According to experts, the transformation towards precision agriculture is a long-term process. The production of a device for laser weed control will require high-level specialists, including technicians and computer scientists, who will work on further refining the technology. New jobs are expected to emerge (average expert rating of 4.2 points), and entrepreneurial opportunities will increase as the device is launched on the market (average rating of 4.4 points). The competencies and skills of the technology service staff will increase (average expert rating of 4.4 points). The introduction of new technology to the market will involve a high degree of commitment from sales representatives and increasing competencies from consultants and users.

The assessment made from the point of view of three groups of stakeholders indicates the effects of the implementation of technology in agriculture (a summary of the results can be found in Table 4).

Table 4. The effects of the implementation of laser weed control technology in agriculture according to three stakeholder groups

Effects	Environmental	Economic	Social
Positive	• High potential for replacing herbicides and thus avoiding their use and minimising negative environmental impacts. • High potential for enhancing biodiversity.	• Beneficial impact on the quality of agricultural products. • Reduced expenditure on the purchase of chemicals. • Higher yields in organic farming. • Better opportunities for organic farming. • Solution to the problem of insufficient labour supply. • Lower labour costs. • Modern technology creates favourable conditions for the development of young farmers, including female farmers. • Increased competence of companies and users. • Emergence of new jobs for skilled workers. • New opportunities for business development.	• Improved product quality due to less chemicalisation of agricultural production. • Saving farmers' working time. • Improved farmer comfort. • Improved farmer safety. • Reduced need for human labour. • Beneficial impact on farmers' health.
Negative	• Increased demand for rare earth elements. • High environmental costs associated with the device manufacturing process itself. • Potentially high energy consumption of the device when using energy from conventional sources.	• Potentially higher price of agricultural output produced using the device in the first years of implementation. • High cost of manufacturing the device. • High cost to the producer of employing specialists to produce, sell and service the device. • High cost for the individual farmer to purchase the device. • Potentially high energy costs for the operation of the device when using energy perhaps from conventional sources. • Risk of theft or damage to the device. • Costs for the user to insure the device. • Costs for the user to monitor and ensure control of the device's operation.	• It takes away work from low-skilled people. • Risk of accidents. • Harmful effects of the laser on the eyes. • The need to apply precautionary measures.

The authors consider the availability of experts and a large number of refusals to carry out interviews to be a limitation in conducting the research. Furthermore, as work on the technology will continue to refine it, and as relevant data about the technology – in particular the market price, operating and servicing costs and the performance of the device – is currently unknown, the expert assessment is in some cases prudent and uncertain.

Conclusions

The future of agriculture and rural areas is very much linked to the development directions and priorities set out in the Common Agricultural Policy (CAP) for 2023-2027. One such direction is the reduction of pesticide use. This priority includes the WeLASER project, which assumes the use of modern laser technologies and artificial intelligence to eliminate burdensome weeds occurring in agricultural crops. Weed control technology based on laser energy reducing the overuse of chemical plant protection products is a solution with great potential in terms of providing more sustainable crops and improving yields while ensuring profitable production and on-farm competitiveness. The capabilities of the technology developed in the WeLASER project are a response to the reported need to find solutions to reduce the negative impact of agriculture on the environment, which is in line with the political priorities of the European Union, which promotes innovative, effective weed control technologies. There are challenges associated with the introduction of innovative weed control technology into agricultural practice, which will be the subject of further work and analysis following the completion of the WeLASER project. Among them, we should mention the safety of the technology, its reliability, the cost-effectiveness of its use by individual farms, and the selection of the energy source powering the autonomous vehicle with sustainable energy in mind. It should be noted that studies on assessing the social impact of the agricultural application of autonomous vehicles using artificial intelligence and laser technology are currently sparsely represented in the literature due to the innovative nature of the solutions studied (Tran et al., 2023). Hence, there is a need to address this topic in new research and to deepen and continue the studies presented in this article.

To conclude, the implementation of laser technology and artificial intelligence for the elimination of nuisance weeds found in agricultural crops can have a significant impact on running farms in a more sustainable manner. The investment cost of the device will be high. Therefore, its dissemination to farmers will require the provision of financial support and the consideration of new business models. The technology developed fulfils the concept of precision farming by providing a greater opportunity for higher productivity, safety, reliability and efficiency. It will have a positive impact on a number of socio-economic aspects of farmers, agribusinesses and society, including the local community. It is an example of an innovation that will have a positive impact on the conservation of natural resources and the shaping of sustainable local development, allowing for the rational and cost-effective application of this technology in agricultural practice.

Acknowledgements

This research has been supported by the WeLASER project (Sustainable Weed Management in Agriculture with Laser-based Autonomous Tools) funded by EU under the HORIZON 2020 programme according to the Grant agreement ID: 101000256.

The contribution of the authors

The article was written in collaboration with all authors.

References

Adamczewski, K., Kaczmarek, S., Kierzek, R., & Matysiak, K. (2019). Significant increase of weed resistance to herbicides in Poland. Journal of Plant Protection Research, 59(2), 139-150. https://doi.org/10.24425/jppr.2019.129293

Adamowicz, M. (2005). Zrównoważony i wielofunkcyjny rozwój rolnictwa a agronomia. Annales Universitatis Mariae Curie-Skłodowska. Sectio E. Agricultura, 60, 71-91. https://bibliotekanauki.pl/articles/11039722 (in Polish).

Adamowicz, M. (2006). Koncepcja trwałego i zrównoważonego rozwoju wobec wsi i rolnictwa. Prace Naukowe. Szkoła Główna Gospodarstwa Wiejskiego. Wydział Ekonomiczno-Rolniczy. Katedra Polityki Agrarnej i Marketingu, (38), 11-25. (in Polish).

Andreasen, Ch., Scholle, K., & Saberi, M. (2022). Laser Weeding with Small Autonomous Vehicles: Friends or Foes? Frontiers in Agronomy, 4, 841086. https://doi.org/10.3389/fagro.2022.841086

Beckie, H. J. (2020). Herbicide resistance in plants. Plants, 9(4), 435. https://doi.org/10.3390/plants9040435

Beckie, H. J., Ashworth, M. B., & Flower, K. C. (2019). Herbicide resistance management: Recent developments and trends. Plants, 8(6), 161. https://doi.org/10.3390/plants8060161

Bilal, M., Iqbal, H. M., & Barceló, D. (2019). Persistence of pesticides-based contaminants in the environment and their effective degradation using laccase-assisted biocatalytic systems. Science of The Total Environment, 695, 133896. https://doi.org/10.1016/j.scitotenv.2019.133896

Blair, A., Ritz, B., Wesseling, C., & Freeman, L. B. (2015). Pesticides and human health. Occupational and Environmental Medicine, 72(2), 81-82. https://doi.org/10.1136/oemed-2014-102454

Burke, I. C., & Bell, J. L. (2014). Plant health management: herbicides. In N.K. van Alfen (Ed.), *Encyclopedia of Agriculture and Food Systems* (pp. 425-440). Elsevier. http://dx.doi.org/10.1016/B978-0-444-52512-3.00181-9

Carvalho, F. P. (2017). Pesticides, environment, and food safety. Food and Energy Security, 6(2), 48-60. https://doi.org/10.1002/fes3.108

Cocco, P. (2016). Pesticides and human health. Oxford Research Encyclopedia of Environmental Science. https://doi.org/10.1093/acrefore/9780199389414.013.82

Dill, G. M. (2005). Glyphosate-resistant crops: history, status and future. Pest Management Science: formerly Pesticide Science, 61(3), 219-224. https://doi.org/10.1002/ps.1008

Directive 2009/128/EC of the European Parliament and of the Council of 21 October 2009 establishing a framework for Community action to achieve the sustainable use of pesticides, Pub. L. No. 02009L0128-20091125, 309 OJ L (2009). http://data.europa.eu/eli/dir/2009/128/2009-11-25

Duke, S. O. (2005). Taking stock of herbicide-resistant crops ten years after introduction. Pest Management Science: formerly Pesticide Science, 61(3), 211-218. https://doi.org/10.1002/ps.1024

Duke, S. O. (2021). Glyphosate: uses other than in glyphosate-resistant crops, mode of action, degradation in plants, and effects on non-target plants and agricultural microbes. Reviews of Environmental Contamination and Toxicology, 255, 1-65. https://doi.org/10.1007/398_2020_53

Edwards, C. (Ed.). (2013). *Environmental Pollution by Pesticides (Vol. 3).* London: Springer Science & Business Media.

Emmi, L., Fernández, R., Gonzalez-de-Santos, P., Francia, M., Golfarelli, M., Vitali, G., Sandmann, H., Hustedt, M., & Wollweber, M. (2023). Exploiting the Internet Resources for Autonomous Robots in Agriculture. Agriculture, 13(5), 1005. https://doi.org/10.3390/agriculture13051005

European Commission. (2019). Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions, The European Green Deal, Pub. L. No. 52019DC0640. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2019%3A640%3AFIN

European Commission. (2020). Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, A Farm to Fork Strategy for a fair, healthy and environmentally-friendly food system, Pub. L. No. 52020DC0381. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A52020DC0381

European Commission. (2020a). Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions EU, Biodiversity Strategy for 2030 Bringing nature back into our lives, Pub. L. No. 52020DC0380. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A52020DC0380

European Commission. (2023, November 21). *Renewal of the approval of glyphosate: Questions and Answers*.* https://ec.europa.eu/commission/presscorner/detail/en/qanda_23_5793

European Food Safet Authority. (2023, November 11). https://www.efsa.europa.eu/en

Eurostat. (2023, November 23). *Agri-environmental indicator – consumption of pesticides.* https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Agri-environmental_indicator_-_consumption_of_pesticides#Key_messages

FAO. (1988). *Rural households and sustainability.* https://www.fao.org/4/v5406e/v5406e04.htm

Gage, K. L., Krausz, R. F., & Walters, S. A. (2019). Emerging challenges for weed management in herbicide-resistant crops. Agriculture, 9(8), 180. https://doi.org/10.3390/agriculture9080180

Gonzalez-de-Santos, P. (2021). *Sustainable agriculture and natural resources: WeLASER.* https://welaser-project.eu/wp-content/uploads/2022/03/WeLASER-Sustainable-agriculture-and-natural-resources.pdf

IARC Working Group on the Evaluation of Carcinogenic Risks to Humans. (2017). *Some organophosphate insecticides and herbicides.* Lyon: International Agency for Research on Cancer. https://pubmed.ncbi.nlm.nih.gov/31829533/

International Herbicide – Resistant Weed Database. (2023, November 11). https://www.weedscience.org/Home.aspx

Kalinowska, B., Bórawski, P., Bełdycka-Bórawska, A., Klepacki, B., Perkowska, A., & Rokicki, T. (2022). Sustainable development of agriculture in member states of the European Union. Sustainability, 14(7), 4184. https://doi.org/10.3390/su14074184

Mahmood, I., Imadi, S. R., Shazadi, K., Gul, A., & Hakeem, K. R. (2016). Effects of pesticides on environment. In K. Hakeem, M. Akhtar & S. Abdullah (Eds.), *Plant, Soil and Microbes* (pp. 253-269). Cham: Springer. https://doi.org/10.1007/978-3-319-27455-3_13

Moss, S., Ulber, L., & den Hoed, I. (2019). A herbicide resistance risk matrix. Crop Protection, 115, 13-19. https://doi.org/10.1016/j.cropro.2018.09.005

Mostafalou, S., & Abdollahi, M. (2013). Pesticides and human chronic diseases: evidences, mechanisms, and perspectives. Toxicology and Applied Pharmacology, 268(2), 157-177. https://doi.org/10.1016/j.taap.2013.01.025

Owen, M. D., & Zelaya, I. A. (2005). Herbicide-resistant crops and weed resistance to herbicides. Pest Management Science: formerly Pesticide Science, 61(3), 301-311. https://doi.org/10.1002/ps.1015

Özkara, A., Akyıl, D., & Konuk, M. (2016). Pesticides, environmental pollution, and health. In M. Larramendy & S. Soloneski (Eds.), *Environmental health risk-hazardous factors to living species* (pp. 3-27). InTech. https://doi.org/10.5772/61472

Pathak, V. M., Verma, V. K., Rawat, B. S., Kaur, B., Babu, N., Sharma, A., Dewali, S., Yadav, M., Kumari, R., Singh, S., Mohapatra, A., Pandey, V., Rana, N., & Cunill, J. M. (2022). Current status of pesticide effects on environment, human health and it's eco-friendly management as bioremediation: A comprehensive review. Frontiers in Microbiology, 13, 962619. https://doi.org/10.3389/fmicb.2022.962619

Rakhmatuiln, I., Kamilaris, A., & Andreasen, Ch. (2021). Deep Neural Networks to Detect Weeds from Crops in Agricultural Environments in Real-Time: A Review. Remote Sensing, 13(21), 4486. https://doi.org/10.3390/rs13214486

Rakhmatulin, I., & Andreasen, Ch. (2020). A Concept of a Compact and Inexpensive Device for Controlling Weeds with Laser Beams. Agronomy, 10(10), 1616. https://doi.org/10.3390/agronomy10101616

Rasche, L. (2021). Estimating pesticide inputs and yield outputs of conventional and organic agricultural systems in Europe under climate change. Agronomy, 11(7), 1300. https://doi.org/10.3390/agronomy11071300

Regulation (EC) No 1907/2006 of the European Parliament and of the Council of 18 December 2006 concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH), establishing a European Chemicals Agency, amending Directive 1999/45/EC and repealing Council Regulation (EEC) No 793/93 and Commission Regulation (EC) No 1488/94 as well as Council Directive 76/769/EEC and Commission Directives 91/155/EEC, 93/67/EEC, 93/105/EC and 2000/21/EC, Pub. L. No. 02006R1907-20140410, 396 OJ L (2006). http://data.europa.eu/eli/reg/2006/1907/2014-04-10

Serrão, J. E., Plata-Rueda, A., Martínez, L. C., & Zanuncio, J. C. (2022). Side-effects of pesticides on non-target insects in agriculture: A mini-review. Die Naturwissenschaften, 109(2), 17. https://doi.org/10.1007/s00114-022-01788-8

Shah, R. (2020). Pesticides and human health. In A. Nuro (Ed.), *Emerging contaminants* (pp. 57-78). London: IntechOpen. https://doi.org/10.5772/intechopen.93806

Singh, P., Singh, G., Singh, A., & Mishra, V. K. (2022). Persistence of pesticides and their impacts on human health and environment. In P. Singh, S. Singh & M. Sillanpää (Eds.), *Pesticides in the Natural Environment* (pp. 139-162). Elsevier. https://doi.org/10.1016/B978-0-323-90489-6.00006-9

Tataridas, A., Kanatas, P., Chatzigeorgiou, A., Zannopoulos, S., & Travlos, I. (2022). Sustainable crop and weed management in the era of the EU Green Deal: A survival guide. Agronomy, 12(3), 589. https://doi.org/10.3390/agronomy12030589

Tran, D., Schouteten, J. J., Degieter, M., Krupanek, J., Jarosz, W., Areta, A., Emmi, L., de Steur, H., & Gellynck, X. (2023). European stakeholders' perspectives on implementation potential of precision weed control: the case of autonomous vehicles with laser treatment. Precision Agriculture, 24, 2200-2222. https://doi.org/10.1007/s11119-023-10037-5

United Nations. (2015). *Transforming our world: the 2030 Agenda for Sustainable Development.* https://sdgs.un.org/sites/default/files/publications/21252030%20Agenda%20for%20Sustainable%20Development%20web.pdf

van der Werf, H. M. (1996). Assessing the impact of pesticides on the environment. Agriculture, Ecosystems & Environment, 60(2-3), 81-96. https://doi.org/10.1016/S0167-8809(96)01096-1

Vassilev, K., & Kambourova, V. (2006). Pesticides as Global Environmental Pollutants. In L. Simeonov & E. Chirila (Eds.), *Chemicals as Intentional and Accidental Global Environmental Threats. NATO Security through Science Series* (pp. 173-191). Dordrecht: Springer. https://doi.org/10.1007/978-1-4020-5098-5_13

Vitali, G., Arru, M., & Magnanini, E. (2023). A Scalable Device for Undisturbed Measurement of Water and CO2 Fluxes through Natural Surfaces. Sensors, 23(5), 2647. https://doi.org/10.3390/s23052647

Vitali, G., Francia, M., Golfarelli, M., & Canavari, M. (2021). Crop Management with the IoT: An Interdisciplinary Survey. Agronomy, 11(1), 181. https://doi.org/10.3390/agronomy11010181

Vrbničanin, S., Pavlović, D., & Božić, D. (2017). Weed Resistance to Herbicides. In Z. Pacanoski (Ed.), *Herbicide Resistance in Weeds and Crops* (pp. 7-35). IntechOpen. https://doi.org/10.5772/67979

WeLaser. (2023, November 21). https://welaser-project.eu/

Wilkin, J. (2004). Dlaczego potrzebujemy długookresowej strategii zintegrowanego rozwoju wsi i rolnictwa w Polsce? Wieś i Rolnictwo, (2), 154-170. (in Polish).

Woś, A. (1998). Rolnictwo zrównoważone. In A. Woś (Ed.), *Encyklopedia agrobiznesu* (pp. 735). Warszawa: Fundacja Innowacja. (in Polish).

Woś, A., & Zegar, J. S. (2002). *Rolnictwo społecznie zrównoważone.* Warszawa: Instytut Ekonomiki Rolnictwa i Gospodarki Żywnościowej. (in Polish).

Wynn, S., & Webb, E. (2022). Impact assessment of the loss of glyphosate within the EU: A literature review. Environmental Sciences Europe, 34(1), 91. https://doi.org/10.1186/s12302-022-00667-3

Elżbieta LOREK • Agnieszka LOREK • Beata MICHALISZYN-GABRYŚ

ZNACZENIE EKOINNOWACYJNEGO ZWALCZANIA CHWASTÓW Z WYKORZYSTANIEM TECHNOLOGII LASEROWEJ W TWORZENIU ZRÓWNOWAŻONEGO ROLNICTWA W UNII EUROPEJSKIEJ. PERSPEKTYWA SPOŁECZNO-EKONOMICZNA

STRESZCZENIE: Celem artykułu jest ocena wprowadzenia do praktyki rolniczej innowacyjnej technologii zwalczania chwastów z wykorzystaniem energii lasera ukierunkowanej na ograniczenie stosowania pestycydów z punktu widzenia wybranych aspektów społeczno-ekonomicznych. Zrealizowanie postawionego celu wymagało analizy dorobku badawczego dotyczącego problemu pestycydów w zrównoważonym rozwoju w rolnictwa Unii Europejskiej oraz analizy polityk UE w tym zakresie. W artykule wykorzystano również dane uzyskane w drodze badań polegających na przeprowadzeniu wywiadów pogłębionych z przedstawicielami trzech grup interesariuszy: rolników, społeczeństwa i biznesu. Przedmiotem wywiadów była ocena wpływu upowszechnienia na szeroką skalę innowacyjnej technologii zwalczania chwastów na wybrane aspekty społeczno-ekonomiczne. Artykuł jest jednym z pierwszych opracowań dotyczących oceny wpływu społecznego zastosowania w rolnictwie nowoczesnych technologii wykorzystujących sztuczną inteligencję i technologię laserową usuwania chwastów. Wdrożenie tej technologii może mieć znaczący wpływ na prowadzenie gospodarstw w sposób bardziej zrównoważony lecz warunkiem koniecznym jej skutecznego wykorzystania jest uwzględnienie uwarunkowań społecznych i ekonomicznych.

SŁOWA KLUCZOWE: zrównoważony rozwój rolnictwa, polityka rolna Unii Europejskiej, pestycydy, technologia laserowa

DOI: 10.34659/eis.2024.88.1.741