

Article

Role of Crop-Protection Technologies in Sustainable Agricultural Productivity and Management

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Abstract: After the Second World War, technological advancements helped to develop agriculture and meet urgent food needs. The green revolution was based on the cultivation of new high-yielding varieties, the adoption of plant protection measures, and synthetic fertilizer use. Today, agriculture is called upon to recover its productivity in environmentally friendly terms and to face challenges such as climate change and international political–military events that threaten global sufficiency in agricultural products. The objective of the study is to evaluate the function that crop-protection technologies play in ensuring the continuity of agricultural output. The research was conducted by the use of a questionnaire in a sample of 250 farmers in Northern Greece. Specifically, through descriptive and regression analysis, the roles of biological crop protection, chemical crop-protection techniques, and mechanical crop-protection techniques were explored, and it was found that they either have a positive effect or a significant relationship with sustainable agricultural productivity. In order to meet the current environmental, economic, and political challenges, the agriculture sector at the global and local level should improve and further adopt existing technologies, consolidate the use of integrated pest-management strategies, and fully introduce innovations, combined with digital transformation, into agricultural management and production.

Keywords: crop protection; biological control; chemical control; mechanical control; plant pests; plant diseases



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1. Introduction

A variety of tools, goods, and tactics are used in crop protection to safeguard crops from weeds, pests, viruses, plant diseases, and other undesirable elements [1]. They may have disastrous effects, greatly decreasing or even eliminating subsequent harvests. Pesticides, also known as crop-protection products (CPPs), are either naturally occurring or synthetic compounds manufactured by humans, that aid farmers by reducing crop losses to pests and diseases and increasing yield per hectare [2].

Humans have battled to increase food production and minimize insect damage for thousands of years. Throughout the years, there have been several early efforts to increase agricultural production and quality, with varying degrees of success. Fewer people are cultivating bigger acreages and producing higher yields, as agriculture has developed. In the United States and Canada, 98 percent of the population depends on the remaining 2 percent of the population to produce the food because of this change in production outputs. Although this idea is not always accurate, today's food producers make up a far smaller percentage of the population than they did even 100 years ago. This strategy has been successful in large part because of previously unheard-of advancements in agricultural techniques, such as artificial chemical fertilizers and pesticides. Unfortunately, our

continued reliance on a single approach to tackle pest issues has undermined our capacity to maintain the security of our food supply and resulted in the loss of both chemical and cultural control skills [3,4].

Similar to the late 1950s and early 1960s, when synthetic chemical pesticides were widely used [5,6], plant protection is experiencing a revolution. This revolution is being driven by the fact that target pests are becoming resistant to pesticides; that market forces are making the development, registration, and use of new pesticides prohibitively expensive; and that pesticides have real or imagined side effects on nontarget organisms like humans. However, synthetic chemical pesticides have made it possible for agricultural production to reach previously unheard-of heights, and they are still crucial for sustaining consistently high yields despite rising pressure from weeds, insects, and diseases, including invading species from other countries.

By 2050, the population of the globe will approach nine billion, and the need for food will increase by up to 98% [7–10]. It seems sensible to enhance plant output in order to meet this demand [11]. According to Kubiak et al. (2022), 40% of agricultural loss is caused by various weed species, illnesses, insects, and animals. Losses in commercial crops might be either qualitative or quantitative. Lower yields per unit area as a consequence of subpar output result in quantitative losses. A decrease in the market value of crops and a reduction in the quantity of vital nutrients they contain create qualitative losses [8].

According to Majrashi [9], both abiotic and biotic factors might contribute to decreased agricultural production. Temperature, nitrate pollution, the accessibility of water, light, and nutrients are examples of abiotic factors [9,12,13]. Other examples include soil erosion [14], growing soil salinity [15–17], considerable aquifer horizon decline [18], and the removal of trees as a result of increased environmental pollution [19–21]. The three main groups into which biological agents may be divided are pathogenic organisms (viruses, fungi, and bacteria), animal parasites (insects, mites, nematodes, snails, rodents, birds, and mammals), and weeds (monocotyledons or dicots) [9]. The challenges brought on by climate change have now joined those that everyone has previously experienced year after year [22–26]. As climate change and environmental degradation in general are now high on the global agenda, the impact of agriculture and agricultural management on the environment is constantly being examined and studied [27–29], while the objective of reducing the environmental and climate footprint of the European Union (EU) food system has become part of the Green Deal (GD) [28,30].

Blakeney [31] indicates that over the last ten years, there has been a significant increase in public support for the development of more sustainable agricultural production systems in Europe. The agricultural community has taken steps to build new and better farming and production techniques. These measures were a result of both official policy and, to a greater or lesser degree, private market activities. Farmers are being encouraged by private food market efforts from merchants, the food business, and farmer organizations to change their traditional agricultural practices and embrace more advanced production techniques. Such market efforts often mix marketing tactics with resource management that is sustainable. In order to implement agricultural techniques that safeguard the environment, new methods for employing plant-protection agents must be used. Global agrifood systems might be made more economically, socially, and environmentally sustainable with the use of digital technology [1,5,32]. Although affluent countries have been at the forefront of digital agricultural innovation and uptake, poor nations stand to benefit greatly. Additionally, there are growing social and environmental pressures, including the call for more moral and sustainable farming practices that can help enhance agricultural productivity. This study focuses on the role played by crop-protection technologies in regard to sustainable agricultural productivity.

The protection technologies in sustainable agricultural productivity and management are categorized into three large groups, which in fact have no clear boundaries between them: (1) chemical crop-protection techniques, (2) biological crop-protection techniques and (3) mechanical crop-protection techniques (Figure 1).

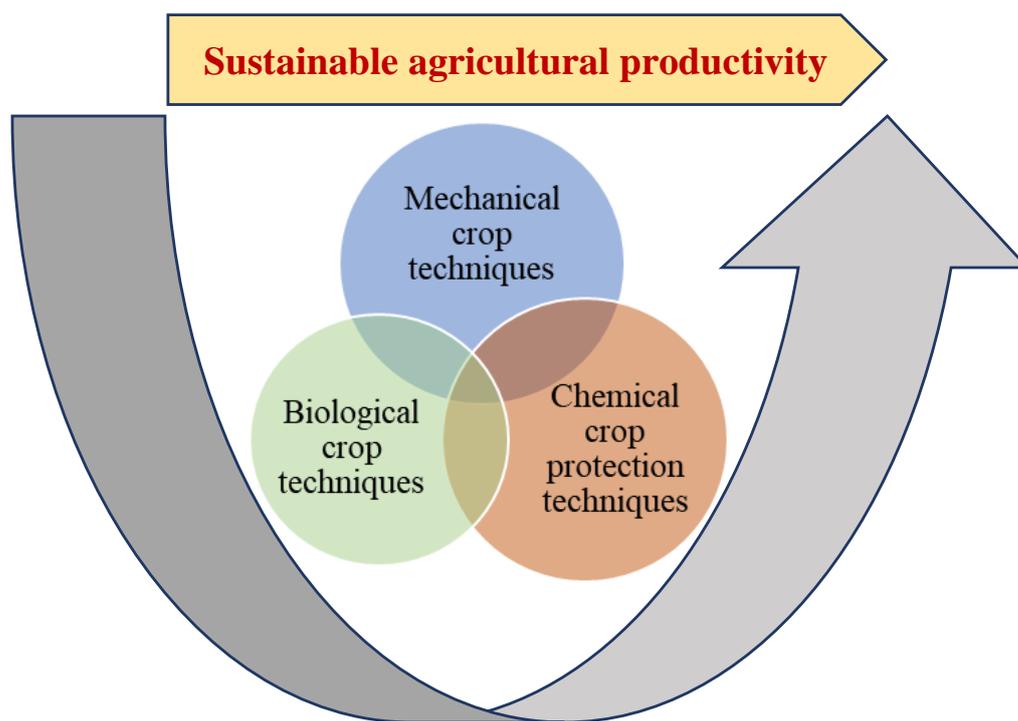


Figure 1. Sustainable agricultural productivity.

Among the areas of research that have received the most attention is the increasingly intensive use of chemical pesticides to control pests, which unfortunately can remain in the soil for decades after application and pose serious health risks [33–36]. Integrated pest management (IPM) and the use of biocontrol solutions are experiencing wider acceptance by citizens and research investments, as new alternative ways to achieve sustainable control solutions [28,37–40].

Chemical control is an integral part of ICM, an integrated agricultural system based on a healthy combination of all available pest control methods [41]. Crop protection, which is currently mostly accomplished by using chemical agents, is also undergoing change. However, as pests often attack crops, farmers must continue to control them below the level at which the drug’s active component begins to harm the crop [42–44].

Additionally, the need for ongoing production growth drives up the prevalence of certain illnesses, necessitating the use of additional pesticides. Chemicals accumulate in the ecosystem, and environmental damage is increased by pesticide use. From a practical standpoint, other options, such as the adoption of genetically modified kinds, provide fascinating control strategies, but not without running the danger of the pathogen’s resistance genes emerging. Another strategy for reducing the pollution and annoyance brought on by the use of synthetic chemicals is the use of biological controls employing microorganisms. With the goal of creating sustainable agriculture with fewer ecological costs, the notion of biocontrol has sparked significant scientific, economic, and political discussion [44–48].

To address the current challenges of modern agriculture in recent times, advanced materials have been used for the construction of environmentally friendly nanoplateforms with excellent properties for sustainable agricultural development. Thus, the field of nanotechnology is within the studied field and has gained particular interest in the agricultural sector compared to conventional agricultural practices [19,49,50]. To the current challenges of modern agriculture can be added the development of ribonucleic acid (RNA) interference technology [(RNAi technology or post-transcriptional gene silencing (PTGS) technology], which is an environmentally friendly, flexible, safe, and potentially effective alternative solution for crop protection [51,52].

At this point, the boundaries between chemical, biological, and mechanical crop-protection techniques to achieve sustainable crop protection and safe product use are blurred. Consider weed management as an example. Interest in organic and low-input agricultural systems has caused the emphasis to move from chemically effective control to other alternative ways. Weed management includes chemical, mechanical, and biological control. If chemical control is used in accordance with established formulas and always within limitations, it might be regarded as biological. Manual weeding is time-consuming, costly, and labor-intensive, but it is undoubtedly biological [53–56]. Thus, farmers are forced to resort to other reliable methods, such as mechanical control using weed cultivators, which is also biological [56–58].

A wide range of technologies have been used to make modern agriculture more efficient. The rapid development of precision agriculture has been made possible using the Global Positioning System (GPS) with geographical information systems (GIS) techniques and remote sensing data. Applications of GIS in agriculture have grown since the early days of GIS [59–62]. Therefore, the assessment of spatial differences in soil properties and characteristics is very important for crops with the help of technology [Internet of Things (IoT), unmanned aerial vehicles (UAVs), and wireless sensor networks (WSNs)] [63,64].

The primary objective of the research is to evaluate the function that crop-protection technologies play in ensuring the continuity of agricultural output.

The specific objectives of the study include the following;

1. To establish the effect of biological crop protection on sustainable agricultural productivity.
2. To explore the relationship between chemical crop-protection techniques and sustainable agricultural productivity.
3. To determine the effect of mechanical crop-protection techniques on sustainable agricultural productivity.

H1: *Biological crop protection has a positive effect on sustainable agricultural productivity.*

H2: *There is a significant relationship between chemical crop-protection techniques and sustainable agricultural productivity.*

H3: *Mechanical crop-protection techniques have a positive effect on sustainable agricultural productivity.*

This study provides new knowledge on how important plant technologies are to preserving and improving the dynamics of agricultural output and the food chain in Europe. The study provides a summary of the successes of more environmentally friendly production techniques in European agriculture as well as the responses of the agricultural community to market- and government-driven initiatives. Such acts create novel agricultural practices. The study provides assessments to put trends in perspective together with factual facts.

Section 1. Introduction presents the background, the objectives, the significance of the study, and, of course, the research hypothesis. The rest of this paper is organized as follows: Section 2 presents the theoretical framework and the trends in crop protection regarding the current connectivity and productivity in agriculture. Materials and methods are then described in Section 3. Moreover, Section 4 gives a statistical analysis of farmers' preference regarding crop protection. Subsequently, Section 5 presents a discussion about the results and presents policy proposals. Finally, the conclusions, recommendations, and, of course, limitations and future research are given in Section 6.

2. Literature Review

2.1. Theoretical Framework

According to the “adoption and diffusion of innovations” theory, ideas are created by scientists, passed on to extension agents, and then used by farmers [2]. This transfer-

of-technology paradigm (ToT) has a long history of breakthroughs and increased food production efficiency in agricultural research and extension. This “linear” model has limitations when issues are complex, such as the more intricate modern agricultural systems or the shift to sustainable development, which necessitates trade-offs between environmental, social, and economic sustainability [2,65]. Such a “traditional linear” approach fails to handle challenging issues and rapidly changing settings for a number of reasons. To begin with, extension disregards the knowledge and experience of farmers. Second, given the socioeconomic realities of specific farms and farmers, regional suggestions are sometimes insufficient. This research-based, linear, and technocratic approach is being challenged by a new understanding of innovation as primarily a socially and territorially embedded process that cannot be understood apart from its institutional and cultural surroundings. This viewpoint on innovation makes the assumption that innovation is considered a non-linear process that involves participatory learning as well as a social and technical process [66,67]. Nowadays, learning itself is given more and more importance in innovation studies, with a special focus on facilitation and the social interactions that promote learning. Demirozer et al. (2012) contend that it is critical to include farmers’ perspectives when assessing whether new technological solutions are consistent with the current management standards in place as well as more general social–organizational conditions. In general, the switch from conventional farming to more environmentally friendly forms of agriculture entails a systemic change and thus necessitates “double loop” learning, i.e., a profound change in the assumptions and strategies underpinning subsequent actions or a switch from traditional to modern crop-protection techniques [68].

2.2. Trends in Crop Protection

Pirzada et al. (2020) indicate that, with the present focus on sustainability for agricultural output, the biological management of plant diseases is becoming increasingly significant [66]. A variety of nematode species are afflicted by the obligatory parasites known as *Pasteuria* spp. The only *Pasteuria* species known to parasitize soybean cyst nematode (SCN) is *Pasteuria nishizawae* (Pn). Long-term practical research is required to create effective biological agents, as well as fundamental research on these topics. In the present era of big data, researchers are adopting new technologies, such as metagenomics, to acquire a better understanding of microbiomes. Many researchers are interested in the root–soil link, which is influenced by both the soil and plant roots in the rhizosphere community. Additionally, funding is required for long-term farming system research [3,5].

Researchers conducted tests on continuous cropping systems for 14 years, and during that time they were able to show how biologically driven suppressive soils form [69,70]. When soil becomes capable of being inhibiting, the exact organisms that are causing it can be found, and farming methods can be changed to help the change happen faster. Other studies that have already been done look at specific species or do large-scale screening to find a specific antagonist or some other activity that stops an infection. A more recent analysis of 465 biological treatments for synergistic interactions found that antagonism among biocontrol agents was more likely than synergism, suggesting that research should concentrate on single species [71].

Ratcliffe et al. (2017) indicate that the use of invertebrate agents and biopesticides for the biological control of arthropod pests is growing gradually. As more products become available, the use of commercial invertebrate agents will become more widespread. Worldwide production of 219 species is already taking place, with quality control methods being made accessible for the most significant ones [72].

According to Shrestha et al. (2021), the sector has been expanding at a pace of 15 to 20 percent annually, which means that it has likely surpassed \$200 million in annual revenue. In addition to 70 species of helpful nematodes, mites, insect parasitoids, and insect predators, they are included in a current inventory for North America [67]. A new synthetic pesticide generally takes nine years and \$250 million to develop and obtain regulatory clearance, as opposed to four years and \$10 million for a microbial pesticide [73].

According to Kao-Kniffin et al. (2013), people will utilize commercial biological weed control solutions if they deliver identical or better weed control at a similar or lower cost. Biological goods may be embraced if buyers believe they represent fewer health and environmental dangers [74]. Demirozer et al. (2012) came to the conclusion that effective biocontrol solutions will fill economic gaps in organic systems as well as those where chemicals fail or are not politically acceptable [68]. The reality is that just a few bioherbicides have been commercialized; manufacturing and formulation improvements remain the key impediments to marketing. The commercialization potential, on the other hand, is commonly recognized to be limited by the essentially tiny weed-control window and environment-dependent effectiveness [75]. Streamlining the discovery and screening process, for example, by swiftly identifying natural products and making genetic alterations to improve the performance of biocontrol bacteria, might aid in the successful commercialization of biologicals or natural goods [67].

2.3. Crop-Protection Technology Solutions in Pest and Disease Control

A study by Weller et al. [4] revealed that, whether dealing with invasive, fungicide-resistant, or non-herbicide-resistant (non-HR) weed populations, invasive or resistant pathogens, or insect species, pest monitoring is a crucial component and precondition for IPM practices. Small, unmanned aircraft systems, also known as drones, may be used for pest control in general, as well as for weed research. Drones have a lot of promise for monitoring insect populations over much larger regions or applying site-specific pesticide applications on commercial-scale farms [76,77].

According to Bremmer et al. [78], when new technologies for managing larger amounts of data are created, the automation of pest-management data processing will improve. More systematic, regular HR or invasive weed monitoring and reporting on a state, provincial, and national level, whether carried out by producers, land managers, or crop consultants on the ground or by drones or other remote-sensing technologies, would assist with awareness and prompt control. Such methods are significantly more frequent for insect pests such as the diamondback moth, as well as plant ailments in strawberries, soybeans, and a few other crops. The most significant impediment to attaining this aim is the time necessary for verification in the field of herbicide resistance in weeds or the identification of the range extension of alien invasive species. Site-specific management is one use for remote sensing map data [31,71].

According to Polyzos [79], sensing approaches in the future will use more than one or two detecting sensors. To manage weeds in agricultural rows, cultivators like the rotary hoe have been designed. Growers of organic and vegetable crops value this equipment particularly. Farmers of organic and specialty crops must rely on crop rotation, cultural approaches, and mechanical weed-control techniques since there are not many chemical options accessible to them. To prevent harming the crop stand, rotary hoes and other in-row equipment must be used at the appropriate stage of crop development. Avoiding pests and illnesses is one of the core principles of IPM, and this does not necessitate continuously maintaining a chemical barrier around a crop. Prophylactic pesticide usage alone is a costly technique that might lead to additional pest outbreaks and pest revival in addition to increasing environmental consequences [5,66]. It results in a fragile crop that can only be momentarily protected by applying pesticides more efficiently, often, or in larger volumes. In the end, new pesticides with different modes of actions (MOAs) will be required as replacements or for rotation, and the cost of pesticides is rising (Figure 2).

Establishing a pest-resistant crop by employing cultivars that are less vulnerable to pests and cultural measures that reduce pest survival and reproduction, such as crop rotation and sanitation, while conserving competitors and natural enemies, is a sustainable method of controlling pests. With general pest population thresholds and reconnaissance, reduced-risk insecticides are used sparingly [66,68].

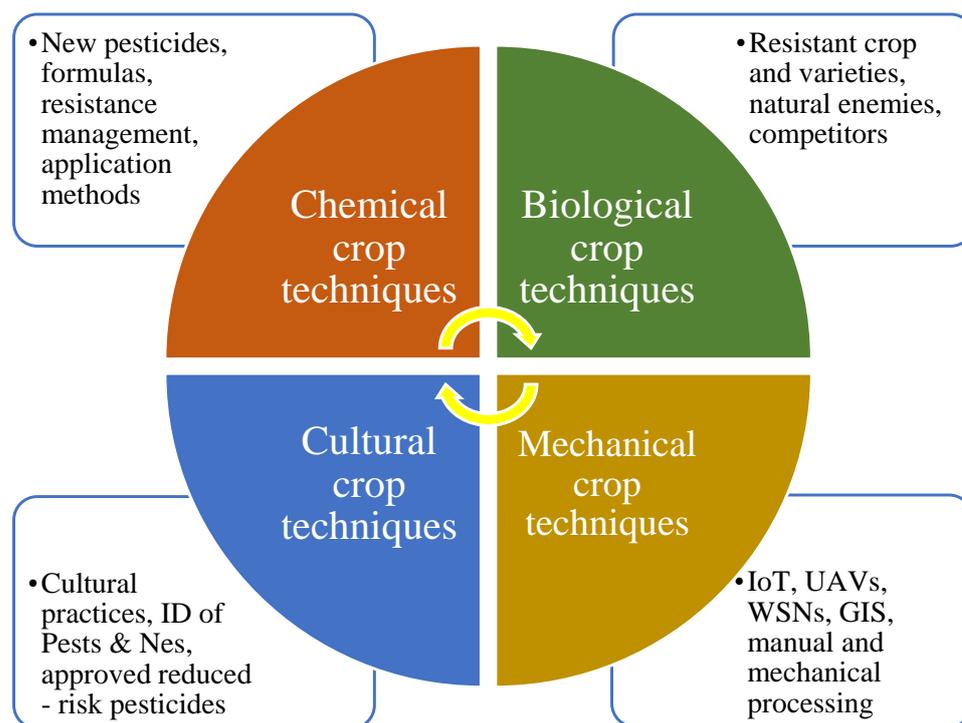


Figure 2. Preventative practices for crop protection. Source: Authors' own work (2022).

2.4. Current Connectivity in Agriculture

In recent years, many farmers have started using data on important aspects such as soils, crops, animals, and weather. But few, if any, have access to the cutting-edge digital technology that can help transform that data into meaningful and actionable insights Table 1. In less developed areas, almost all agricultural work is done by hand, requiring little or no modern equipment [80]. Even in the United States, a pioneer in connectivity, only about 25% of farms are accessing data using connected tools and devices, and the technology is running on 2G or 3G networks, limiting communication, or a very low-bandwidth IoT network [6], which is difficult and expensive to set up. In any case, such networks can only support a limited number of devices and are unable to support the real-time data transmission necessary to fully meet the promise of increasingly complex and demanding use cases [3,6]. Nonetheless, existing IoT technologies operating over 3G and 4G cellular networks enable a variety of simple use cases such as: improving agriculture and animal management. However, in the past, the high cost of hardware has rendered the economic justification for using IoT in agriculture untenable. Hardware and device prices are already falling rapidly, and some companies are offering solutions that they think will pay for themselves in the first year [1]. But even the most basic tools fall short of fully exploiting the potential benefits that compounds can bring to agriculture. To do this, the industry will need to make full use of digital applications and analytics. This requires low latency, high bandwidth, high resilience, and high-density device support provided by cutting-edge breakthrough connectivity technologies. As connectivity increases, many devices will open up new agricultural opportunities [67].

Large farms may profit initially because they have higher buying power and stronger incentives to digitize. Because of connection, big areas of land may be more readily scanned, and large production facilities are better equipped to bear the fixed costs of building IoT solutions than small family farms. Most of the value we have found comes from agricultural commodities such as grains, fruits, and vegetables for the same reason. Connectivity enables more use cases in these industries than in the meat and dairy industries. This is due to the larger average size of farms, the higher concentration of players, and the better application of linked technology. The Internet of Things networks are particularly well-suited for static

monitoring of many variables. It is also worth noting that, since Asia produces the most crops overall, it should get around 60% of the entire value [66].

Table 1. Crop-Protection advancements in agriculture.

Smart Crop Monitoring	Connected irrigation and using connected sensors to facilitate nutrient-distribution equipment. Utilizing image analysis to optimize the utilization of resources towards crop protection and growth
Drone Farming	Utilizing drone surveillance, as well as remote interventions, to boost farm yields and lower losses caused by crop pests
Smart Livestock Monitoring	Individualized feeding and care plans to help enhance crop protection and maximize crop growth
Autonomous Farm-Based Machinery	Self-operated machinery and robots to boost yields
Smart Equipment Management	Prescriptive maintenance to reduce the risks of mold, fire, and other threats

Source: Authors' own work (2022).

2.5. Agricultural Productivity

In the last three decades, the amount of food produced on a worldwide scale has more than doubled, outpacing the rise in the population. Increased yields were made possible by the intensification of agricultural output in the world's major agricultural areas, which also enabled them to keep up with the growing competition for land from forestry, physical infrastructure, and urban growth. The production regions closest to metropolitan centers are where this trend of intensification is most prevalent. Because of competition from other users for agriculturally utilized land, land prices have grown and production has been encouraged to intensify even more [5,67].

In the EU, agricultural output increased at a pace of around 2.5% annually in the 1960s and 1970s, which again dropped to less than 1% in the 1980s and 2000s [75]. The Common Agricultural Policy's (CAP) development had a major role in this turning point. The CAP's goal has been to eliminate output surpluses and bring the market back into balance since the late 1990s. Over the last several decades, Western Europe's population grew by around 0.5% annually [31]. The EU's whole agricultural output is valued at over 220 billion euros. The production techniques used in European agriculture are quite heterogeneous and reflect a variety of regional factors. In the European Union, agriculture is no longer a significant economic sector [78]. It only makes up a small portion of the gross domestic product (GDP) of the majority of member states, with percentages ranging from less than 2% in the UK to 12% in Greece. However, food and agricultural goods make up a significant portion of exports in the majority of member states. A quarter or so of Denmark's and the Netherlands' total exports are made up of food and agricultural goods. In comparison, Denmark's GDP barely includes more than 2% from agriculture [68,80].

Even though it only makes up a small portion of the national GDP, agriculture dominates the use of land in the majority of European nations. In the EU, agricultural production takes up around 40% of the total land area. In other developed agricultural regions of the globe, similar patterns in the marginal share of primary output in the national economy are seen. In the USA, for instance, agriculture makes up around 2.6% of GDP, and in 1997, 25% of agricultural output was exported. About half of all revenue inflows from farming and ranching, or USD 109 billion, comes from agricultural output. Here, increased agricultural output was also significantly aided by the intensification of agricultural production. The expense of using plant protection agents is around USD 8 billion, with herbicides accounting for almost two-thirds of that amount and insecticides for roughly 20% [66,78].

Table 2. Labor farmer force in annual working unit (AWUs).

Administrative Region (NUTS 3)	Total
Study area	
Anatoliki Makedonia, Thraki	42,490
Kentriki Makedonia	76,010
Dytiki Makedonia	16,190
Ipeiros	21,660
Thessalia	43,850
Total farmers in study area	
200,200	
Rest of the regions of Greece	
Attiki	9930
Voreio Aigaio	16,050
Notio Aigaio	12,110
Kriti	55,290
Ionia Nisia	12,070
Dytiki Ellada	54,410
Stereia Ellada	38,680
Peloponnisos	58,410
Total Greece	
457,150	

Source: Eurostat (2022), <https://ec.europa.eu/eurostat/web/main/home> (accessed on 14 August 2022) [83].

Sample size was determined after assessing survey reliability (P = 99.7%) and precision—accuracy (ha 11.83). The variance $S^2 = 3175.43$ and the standard deviation $s = 56.35$ were estimated for each farmer using a preliminary (or pilot) sample of 50 people to assess changes in farmland area in 2022. The value of z is determined by the desired degree of confidence (P). A value of $z = 3$ is often used when calculating the samples; this corresponds to a confidence of P = 99.7%. We use the values $N = 200,200$, $s = 56.35$, $z = 3$, and $d = 10.70$ (the desired precision d was chosen arbitrarily to represent half of the confidence interval, giving the confidence interval 10% “air”) [84–86]. Equation (1) calculates that the minimum sample size should be 249.23 or 250 people.

$$n = \frac{N(zs)^2}{Nd^2 + (zs)^2} \tag{1}$$

where by

n is the minimum sample of respondents

d is the needed precision

N is the total population

s is the standard deviation of the preliminary sample

z is the critical value which equates to a level of dependability P = 99.7%

Calculation of the minimum sample of respondents:

$$n = \frac{200,200 (3 * 56.35)^2}{200,200 * 10.70^2 + (3 * 56.35)^2} \Leftrightarrow n = 249.23$$

3.2. Data Analysis

The data was collected via making an online survey form available to the research participants. The data acquired was analyzed using the Statistical Package for Social Sciences (SPSS) software. Regression analysis was also performed to examine the extent to which various crop-protection techniques aid in predicting the degree of sustainable agricultural yield. In this scenario, a multiple regression model is used to determine the various predicted values.

$$Y = \beta_0 + \beta_1X_1 + \beta_2X_2 + \beta_3X_3 + \varepsilon \dots\dots\dots 1$$

where;

Y = sustainable agricultural productivity

β_0 = constant (coefficient of intercept);

X_1 = biological crop protection

X_2 = chemical crop protection techniques

X_3 = mechanical crop protection techniques

ε = represents the error term in the multiple regression model

The hypothesis of the study was tested at a 5% (0.05) level of significance.

For compliance with privacy regulations, data confidentiality, etc., the results are presented in an aggregate manner, and the respondents are risk-free.

4. Results

4.1. Descriptive Results

This section focuses on the presentation and general interpretation of the results.

The results in Table 3 show that most of the individuals in the research (64.8%) were males and that only 35% were females. A majority of the study participants (47.2%) had spent 12 years and above in agriculture, and the lowest number of participants (7.2%) had spent 5 to 8 years. Concerning the crop-protection technique used, most of the study participants (47%) use chemical techniques for crop protection, 29.6% use biological techniques and only 10.8% use mechanical techniques for crop protection.

Table 3. Showing background characteristics of the study.

Background Characteristics	Frequencies	Percentages (%)
Sex		
Male	162	64.8
Female	88	35.2
Years spent in agriculture		
Below 5 years	21	8.4
5 to 8 years	18	7.2
9–12 years	93	37.2
12 years and above	118	47.2
Common crop-protection technique used		
Biological techniques	74	29.6
Chemical techniques	149	59.6
Mechanical Techniques	27	10.8
Total	250	100

Source: Authors' own work (2022).

The study sought to establish the effect of the biological crop protection of sustainable agricultural productivity, and the results are presented in Table 4.

The results in Table 4 show that the bulk of the individuals in the research (66.2%) agreed that biological control supports parasites, predators, diseases, and protozoa, as well as nematodes that attack insect pests, and 78.4% agreed that biological plant protection basically utilizes natural defense mechanisms to control different plant pests; 91.9% disagreed with the notion that a possible strategy is to use gamma radiation to sterilize male insects and then release them into a population of wild insects, and 86.5% disagreed that, because nature makes provisions for both useful and deadly insects to survive, biological controls cannot completely replace pesticides. However, 66.2% agreed that generic crop protection is possible with new innovations in agriculture.

Table 4. Showing opinions on biological techniques with regard to crop protection.

Opinions	Agree	Disagree
Biological control uses parasites, predators, diseases, and protozoa, as well as nematodes that attack insect pests.	66.2%	33.8%
Biological plant protection basically utilizes natural defense mechanisms to control the different plant pests.	78.4%	21.6%
A possible strategy is to use gamma radiation to sterilize male insects and then release them into a population of wild insects.	8.1%	91.9%
Because nature makes provisions for both useful and deadly insects to survive, biological controls cannot completely replace pesticides.	13.5%	86.5%
Generic crop protection is possible with new innovations in agriculture.	66.2%	33.8%

Source: Authors' own work (2022).

The study sought to establish the relationship between chemical crop-protection techniques and sustainable agricultural productivity, and the results are presented in Table 5.

Table 5. Opinions on the relationship between chemical techniques with regard to crop protection.

Opinions	Agree	Disagree
Spraying is the most common method, permitting extremely small amounts to be applied uniformly because of dilution.	56.2%	43.8%
With spray machines rather than granular applicators, sprays may be more precisely directed below developing plants, and calibration and rate control are simpler.	38.8%	61.2%
Many farmers decide to employ pesticides to prevent weeds and pests from ruining their crops and to enrich the soil with additional nutrients.	91.9%	8.1%
Modern fertilizers are effective in controlling plant diseases.	54.4%	45.6%
Advanced synthetic chemical pesticides are effective in protecting crops.	75.3%	24.7%

Source: Authors' own work (2022).

According to Table 5's findings, the vast number of research participants (56.2%) agreed that spraying is the most popular method because it allows very small amounts to be applied uniformly due to dilution; however, 61.2% disagreed that spray machines rather than granular applicators allow for more precise targeting of sprays below developing plants as well as easier calibration and rate control. A total of 54.4% of study participants agreed that modern fertilizers are effective in controlling plant diseases, and 75.3% agreed that advanced synthetic chemical pesticides are effective in protecting crops, while 91.9% agreed that many farmers use pesticides to prevent weeds and pests from ruining their crops and to enrich the soil with additional nutrients.

The study sought to determine the effect of mechanical crop-protection techniques and sustainable agricultural productivity, and the results are presented in Table 6.

Results in Table 6 show that majority of the study participants (74.7%) showed that machines are effective in weeding to control pests. Furthermore, 63.5% agreed that it is possible to remotely detect and monitor a variety of pests through electronic monitoring, and 72.7% agreed that physical means such as electric wire fences help to enhance crop protection. However, 58.4% disagreed with the fact that the changing of temperature across the garden area helps to control pests

The study sought to establish the different aspects of sustainable agricultural productivity as a result of crop protection, and the results based are presented Table 7.

Table 6. Showing the opinions on mechanical techniques with regard to crop protection.

Opinions	Agree	Disagree
Machines are effective in weeding to control pests.	25.3%	74.7%
It is possible to remotely detect and monitor a variety of pests through electronic monitoring.	63.5%	36.5%
Mechanical ways of pest control do not harm the ecosystem.	72.7%	27.3%
Physical means such as electric wire fences help to enhance crop protection.	41.6%	58.4%

Source: Authors' own work (2022).

Table 7. Showing opinions concerning aspects of sustainable agricultural productivity.

Opinions	Agree	Disagree
New crop technologies increase the general productivity and value within food systems.	63.7%	36.3%
The spraying of crops with a non-disastrous chemical improves agricultural yields.	57.1%	42.9%
Weed control is vital to agriculture, because weeds decrease yields, increase production costs, interfere with harvest, and lower product quality.	51.6%	48.4%
Improved technologies in agriculture are important for the protection of ecosystems.	14.8%	85.2%
The careful use of herbicides in farm production lowers cost, resulting in a more economical product for the consumer.	71.1%	28.9%

Source: Authors' own work (2022).

According to the findings in Table 7, 63.7% of research participants believed that new crop technologies boost overall production and value in food systems. Agricultural yields are improved by spraying crops with non-disastrous chemicals, according to 57.1% of respondents. Furthermore, 51.6% of respondents believe that weed control is essential for the agricultural sector as weeds reduce yields, increase production costs, interfere with harvests, and affect product quality. However, a sizable portion of responders (85.2%) disagreed that better agricultural technology are crucial for ecosystem conservation. Moreover, as 71.1% of research participants agreed, the cautious use of herbicides in agricultural production decreases costs and produces a more affordable product for consumers.

4.2. Regression Analysis

Regression analysis helped to establish the level to which the different independent variables predict sustainable agricultural productivity.

The results presented in Table 8 clearly demonstrate that the various study variables can predict 68.3% of the change in employee performance (adjusted R-square: 0.683). The results clearly show that, while crop protection is a determinant of agricultural productivity, there are other factors that can influence the level of sustainable agricultural productivity. Regression analysis is a group of statistical procedures used in statistical modeling to determine the associations between a dependent variable and one or more independent variables. In order to ascertain the nature and strength of the connection between one dependent variable and a number of other variables, regression is a technique used in finance, investing, and other areas.

Table 8. Regression analysis.

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.
	B	Std. Error	Beta		
Constant	2.441	0.354		5.186	0.000
Biological crop-protection protection	0.263	0.041	0.354	4.431	0.000
Chemical crop-protection techniques	0.092	0.036	0.451	2.596	0.000
Mechanical crop-protection techniques	0.073	0.083	0.158	1.1284	0.317
Dependent variable: Sustainable agricultural productivity					
R	0.531				
R square	0.604				
Adjusted R square	0.683				
Std. error of the estimate	0.713				
Change statistics					
F statistic	14.128				
Sig.	0.000				

Source: Authors' own work (2022).

4.3. Diagnostic Tests

4.3.1. Test for Heteroscedasticity

The heteroscedasticity test was used to determine if the error components in the cross-sectional data are correlated across observations. Given that the p -value is higher than 5%, the null hypothesis is that heteroscedasticity is not a problem with the data. Due to the reported value of $0.4881 > 0.05$, the null hypothesis was not eliminated at the threshold p -value of 0.05. As a result, the data were not heteroscedastic. The results in Table 9 indicate that the null hypothesis of constant variance is not rejected as supported by a p -value of 0.4881.

Table 9. Model Summary.

Breusch–Pagan/Cook–Weisberg test for heteroscedasticity	
Ho: Constant variance	
Variable: fitted values of sustainable agricultural productivity	
chi2(1)=	0.480
Prob > chi2=	0.4881

Predictors: (Constant), biological crop-protection protection, chemical crop-protection techniques, mechanical crop-protection techniques.

4.3.2. Test for Autocorrelation

In Table 10, the dependent variable must be independent, and this was tested using the Durbin–Watson (d) test, which states that $d = 2$ indicates that there is no autocorrelation. The value of (d) always lies between 0 and 4, wherein 0 shows autocorrelation, while above 1 indicates the residuals are interdependent; the results from the study were 1.621, which indicates that the residuals are not autocorrelated.

Table 10. Durbin–Watson test.

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	0.793	0.693	0.681	0.261	1.621

Predictors: (Constant), biological crop-protection techniques, chemical crop-protection techniques, mechanical crop-protection techniques.

4.4. Regression Test

4.4.1. Fitness of the Model

A simple regression analysis was conducted between all of the independent variable (biological crop-protection techniques, chemical crop-protection techniques, and mechanical crop-protection techniques) and the dependent variable (sustainable agricultural productivity). The results presented in Table 11 present the fitness of regression model in explaining the study phenomena. Aspects of crop protection technologies (Biological crop-protection techniques, chemical crop-protection techniques, and mechanical crop-protection techniques) were satisfactory in explaining sustainable agricultural productivity. This is supported by a coefficient of determination, also known as the R square, of 0.559. This means that the three aspects of crop-protection technologies explain 55.9% of the variations in the dependent variable that is sustainable agricultural productivity.

Table 11. Model Fitness.

R	R Square	Adjusted R Square	Std. Error of the Estimate
0.538 a	0.568	0.559	0.261

Predictors: (Constant), biological crop-protection techniques, chemical crop-protection techniques, mechanical crop-protection techniques.

4.4.2. Regression of Coefficients

The results in Table 12 represents the coefficients of regression for the independent variables.

Table 12. Coefficients.

Model	Unstandardized Coefficients		Standardized Coefficients	T	Sig.
	B	Std. Error	Beta		
(Constant)	0.528	0.261		5.186	0.035
1 Biological crop-protection techniques	0.263	0.041	0.354	4.431	0.010
Chemical crop-protection techniques	0.192	0.137	0.451	2.596	0.007
Mechanical crop-protection techniques	0.073	0.083	0.158	1.1284	0.018

Dependent Variable: Sustainable agricultural productivity.

The regression coefficients in Table 12 show the level to which the different aspects of crop-protection technologies, namely, biological crop-protection techniques, chemical crop-protection techniques, mechanical crop-protection techniques, predict the sustainable agricultural productivity. Regression coefficients revealed that there was a positive and significant relationship between the different aspects of crop-protection technologies and sustainable agricultural productivity.

The hypotheses were tested and assessed as below;

H1: *Biological crop protection has a positive effect on sustainable agricultural productivity.*

The p value for biological crop protection was 0.010, and therefore, the hypothesis H1 was accepted since p value < 0.05 . The study therefore found that biological crop protection has a positive effect on sustainable agricultural productivity.

H2: *There is a significant relationship between chemical crop-protection techniques and sustainable agricultural productivity.*

The p value of chemical crop-protection techniques was 0.007, and, therefore, the hypothesis H2 was accepted, since the p -value < 0.05 . The study therefore confirmed

that there is a significant relationship between chemical crop-protection techniques and sustainable agricultural productivity.

H3: *Mechanical crop-protection techniques have a positive effect on sustainable agricultural productivity.*

The p -value of mechanical crop protection techniques was 0.018, while the p value < 0.05 . Therefore, this led to the acceptance of hypothesis H3, that mechanical crop protection techniques have a positive effect on sustainable agricultural productivity.

5. Discussion

The research found that various crop technologies have a considerable influence on long-term agricultural production. Plants are vulnerable to damage, competition, and aggression. Insects, nematodes, plant diseases, rodents, weeds, and air pollution are just a few of the many enemies that can undermine agricultural productivity and prevent people from eating food stored on farms. Insects, for example, have the ability to quickly devastate a crop. Farmers and scientists have been working on control strategies for many years, but no comprehensive victory has been reached, and the struggle continues. Control measures may affect honeybees, parasites, and predators that eat insect life, in addition to eradicating undesirable insects, complicating the situation. The study found that agriculture must embrace a connectivity-enabled digital revolution to meet production challenges. Agriculture, on the other hand, is less digitally advanced than many other sectors around the world. Previous developments were mechanical in nature, such as more powerful and efficient equipment, and genetic in nature, such as more productive crops and fertilizers. Strong digital technology is required. More complex ones have been developed, some of which are now available to help farmers use their resources more ethically and productively. Adopting these new technologies improves decision-making by improving risk and volatility management, maximizing yield, and optimizing profitability. When used in animal husbandry, it can improve the welfare of cattle and address growing animal welfare concerns. According to the study's findings, connected technologies may give an indirect advantage in crop protection, the value of which is not included in case-use estimations. Individual farm owners do the vast majority of the work in the agricultural economy, which is highly fragmented. The adoption of connection technology on such farms might provide farmers much more time to produce more land for money or to hunt for jobs outside the corporation [4,69,87].

Pest resistance to control techniques is a well-known topic, generating both governmental and private sector product stewardship activities. Significant study has been undertaken on how these crops should be used to reduce the possibility of pest resistance as a result of the creation of insect-resistant and HR agricultural plants using genetic biology technologies [73]. To reduce pest outbreaks or occurrences, existing and future plant protection strategies will become increasingly sophisticated, costly, and technology-driven. Crop rotation, crop-residue destruction, cover crops, the planting of dividers that attract natural enemies and pollinators, best soil- and climate-adapted crops, crop nutrient management and better watering, harrowing techniques to control soil pests, planting and harvesting dates, use of hedges, pruning, and field isolation are all being studied [66,88].

The push-pull system, which uses repellent plants in combination with others to prevent insects from entering a crop, is used for a variety of crops such as corn, sorghum, and vegetables. To fulfill these complicated goals, experts from all pest-management disciplines must increase communication and collaborate to create integrated-pest-control techniques that protect ecosystem services and farm productivity [5,32]. It is important to recognize that agriculture is at a technological crossroads. The agriculture business will need to overcome the hurdles of deploying improved crop-protection technologies in order to appropriately address rising demand and multiple disruptive tendencies. This calls for infrastructural upgrades, as well as a rearrangement of existing tasks. This

technological change could impact the success and sustainability of one of the world's oldest businesses, and those that adopt it early may be best-positioned to thrive in the agriculture-related future.

The study revealed that biological control supports parasites, predators, diseases, and protozoa, as well as nematodes that attack insect pests, and that generic crop protection is possible with new innovations in agriculture. This agrees with Bremmer et al. [78], who revealed that new innovations in pest management and plant growth have become common in the field of agriculture, which has helped to increase productivity. Plant protection is going through a revolution that justifies the increasing level of innovation in plant-protection techniques [5,6]. Target pests are growing more resistant to pesticides; market pressures are making the development, licensing, and usage of new pesticides prohibitively costly, and pesticides have actual or hypothetical negative effects on nontarget creatures, including people. However, despite increased pressure from weeds, insects, and illnesses, including invasive species from neighboring nations, synthetic chemical pesticides have enabled agricultural productivity to reach previously unheard-of heights. They are nevertheless essential for maintaining consistently high yields.

Relatively to the effect of crop-protection technologies on productivity, the findings showed that it is possible to remotely detect and monitor a variety of pests through electronic monitoring and that physical means such as electric wire fences have helped to enhance crop protection. This is in line with the findings of Polyzos [79], who stated that farmers of organic and specialty crops must rely on crop rotation, cultural approaches, and mechanical weed control techniques since there are not many chemical options to enhance productivity in the field. The results also confirm that different crop-protection practices are important for sustainable agricultural productivity. For example, new crop technologies increase the general productivity and value within food systems, and weed control is vital to agriculture, because weeds decrease yields, increase production costs, interfere with harvest, and lower product quality. This agrees with the findings of Majrashi [9], who confirmed that several factors, like weed control and the applicability of crop technologies, have a significant impact on agricultural productivity.

It is particularly important that policies related to the increase of productivity in the agricultural sector are based on the two main axes that could work effectively and promote sustainable agriculture to overcome modern challenges. These two axes are agricultural research and agricultural education. In the case of agricultural research, according to the findings of the relevant studies, the following should be further financially supported:

- Research related to plant protection, so as to substantially reduce its chemical footprint and create more effective techniques for sustainable and efficient agriculture;
- Research that develops and promotes precision agriculture, as well as intermediate IT technologies that help guide and inform farmers;
- Research that links knowledge with application in the field and is essentially linked to promotional information and advisory actions to farmers;
- In the axis of education and training, emphasis should be placed on young farmers, i.e., new entrants to the farming profession, through policy measures such as:
- The mandatory theoretical and practical training of young farmers in plant protection, sustainable agriculture, and precision agriculture;
- The attendance of seminars or optional training by all farmers, related to the new findings of agricultural research in the stages of agricultural production and plant protection;
- The organization of regional exhibitions of new agricultural technologies, wherein the farmer will have the opportunity not only to be informed, but also to get to know new products, new agricultural machinery, new techniques, and new practices.

6. Conclusions

This article emphasizes the value and contributions of crop-protection technologies to agricultural productivity. However, in order to ensure contemporary food security, it is necessary to improve existing technologies, maintain a multidisciplinary emphasis

on scientific discoveries, and make progress in the use of integrated pest management strategies. Contemporary trends that set current crop-protection-technology dynamics apart include pest resistance, the requirement for novel modes of action, the high costs of developing and registering new products, the usage of biological control products, and treated seed technologies. The agriculture sector's digitization will almost certainly provide new value-generating possibilities. Due to their close relationship with farmers, deep expertise in agronomy and history of innovation, input suppliers supply traditional seeds, fertilizers, herbicides, and equipment. The system has played an important role in the data ecosystem. To improve field equipment performance, a major equipment manufacturer is creating precise controls that take advantage of satellite imagery and vehicle-to-vehicle communications. No one organization will be able to do it alone, regardless of who leads the essential investment in agricultural connectivity. As a result of all these improvements, the major players in the field will have to communicate more often. Future winners of the agricultural connectivity offer must be able to provide solutions that quickly and efficiently interact with other nearby platforms and sectors. These skills must be broad and deep in several areas, including farming operations and complex data analysis. For example, the computer responsible for irrigation equipment could use data from weather stations to improve watering schedules based on data obtained by autonomous tractors.

Agriculture, which is one of the most time-honored industries in the world, is now at a technological crossroads. In order to effectively handle the increasing demand and the numerous trends that are disruptive to the agricultural industry, the sector will need to find a way to get over the challenges that come with introducing enhanced crop technology.

Even today, the COVID-19 pandemic brought many limitations on the conducting of this research; it was very difficult for the survey to be face-to-face with the selected sample. In research like this, where the researchers would gain more than the direct transfer of farmers' experience with crop-protection technologies, the interview's limitations due to the pandemic were significant. Another limitation was the impossibility of explaining the questionnaire face-to-face (due to distance reliability) to the farmers (cultivated land, quantities of plants, drugs, fertilizers, prices, costs of smart farming technologies, etc.) so that questions could be answered as quickly and easily as possible. This limitation was sought to be resolved by writing a simple and understandable questionnaire, which certainly cannot replace face-to-face communication. In future research, the research team intends to collect primary quantitative data from farms to conduct techno-economic analyses by the type of plant-protection technology. Furthermore, a goal for future research is to investigate, in the agricultural production of northern Greece, the effects of climate change, especially on water resources and on plant protection in key crops.

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