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GOOD PRACTICES IN REFORMING THE COMMON AGRICULTURAL POLICY TO SUPPORT THE EUROPEAN GREEN DEAL – A PERSPECTIVE ON THE CONSUMPTION OF PESTICIDES AND FERTILIZERS

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Abstract
Against the background of the goals of the European Green Deal to reduce the use of pesticides by 50% and fertilizers by 20% by 2030, the current analysis aims to: (1) identify key economic, institutional, and legislative levers that can play an important role in the agricultural specialization of the EU according to the European Green Deal and the reform of the Common Agricultural Policy; (2) analyze representative variables of the European agricultural environment during the 2000-2019 period concerning the alignment of Member States with the objectives of the Green Deal and the overall performance of the agricultural sector; (3) present a set of good practices to reduce the use of fertilizers and pesticides in agricultural systems based on the documentation of the impact of these substances on human health and the environment. The results show that available agricultural solutions, in line with the objectives of the Green Deal and the Common Agricultural Policy, are effective in practice. Our findings can help define national sustainable production policies and develop practical measures for farmers and companies in the agricultural industry.

Keywords: best practices**,** European Green Deal, pesticides, inorganic fertilizers, sustainable crop production.

JEL Classification: Q01, Q56.

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Introduction

Global food systems are at a crossroads and face unprecedented challenges, the most pressing one being how to provide food security to the fast-growing global population, sustain the incomes and livelihoods of the large number of people employed in agriculture or involved in the food supply chain, and respond sustainably to climatic changes by reducing waste and reliance on non-renewable resources. Agricultural operations worldwide rely on the widespread application of fertilizers and pesticides to improve crop quality and meet global food demand (European Parliament, 2021). While their use is considered vital for food security, their adverse effects for human health and the environment is becoming unquestionable.

According to the European Environment Agency, there is a causal link between the EU's agri-food systems and the deterioration of Europe's environment and climate, which results in "pollution of air, water, and soil, contributing to biodiversity loss, climate change, and resource depletion" (European Environmental Agency, 2019, p. 14). The Green Deal (European Commission, 2019) aims to promote resource efficiency, protect natural capital, and human health while acknowledging the magnitude of the necessary economic and social changes. Similarly, the Farm to Fork strategy (European Commission, 2020) emphasizes the critical role of farmers throughout the value chain in achieving agri-food system security and sustainability. Several agricultural practices are also included in the EU Biodiversity Strategy for 2030, such as halving pesticide consumption by 2030, reducing with at least 20% fertilizer consumption, allocating at least 25% of agricultural land to organic farming, and supporting the general extension of organic farming practices, actions that overlap with those already included in the Farm to Fork Strategy. Simultaneously, the reform of the Common Agricultural Policy (CAP) aims to improve coordination with the Green Deal and develop more concrete measures to implement the goals outlined with agricultural applicability. Agriculture and rural areas play a central role in the Green Deal, and the Common Agricultural Policy is meant to be a key element in accomplishing the transition from sustainability to compliance.

The article is structured as follows: The first section summarizes the scientific literature on economic, institutional, and legislative levers that may influence agricultural specialization under the European Ecological Pact and CAP reform; the second section discusses the impact of the use of pesticides and fertilizers on human health and the environment; and the third section is dedicated to a detailed presentation of identified best practices at the European level.

1. Literature review

The review of the scientific literature will be structured starting from the types of production methods, technical solutions, and production management that allowed meeting the objectives of reducing pesticides and fertilizer consumption under the European Green Deal and CAP. In parallel, economic, institutional, and legal determinants of the adoption of these methods by farmers will be identified. The new CAP legislative framework proposes a new model that gives Member States greater flexibility and a new green architecture with mandatory standards, aimed at promoting green practices by farmers. Amendments have been introduced to help achieve the objectives of the European Green Deal and F2F, such as (European Commission, 2022a):

- Increasing funding for rural development, growing ecosystems, and resource efficiency.

- Introduce eco-schemes: A minimum of 20% of the first pillar (usually dedicated to payments per hectare) will go to farmers who carry out additional activities related to climate, environment, animal welfare, and antimicrobial resistance and contribute to achieving the objectives of the Green Deal.

- Improving conditionality under the first pillar: To benefit from income support, farmers must comply with the basic requirements called Good Agricultural and Ecological Conditions (GAEC) linked to green agricultural practices and standards. For example, at least 3% of the arable land on each farm will be dedicated to biodiversity, with the possibility of receiving support through eco-schemes to reach 7%. In the fruit and vegetable sector, operational programs will allocate at least 15% of expenditure to environmental actions (European Commission, 2022b).

- CAP Strategic Plans: The member states will have to present the CAP strategic plans detailing how they intend to implement the CAP rules. The Commission makes recommendations to ensure compliance with the ambitions of the European Green Deal and six of the Farm to Fork Strategy and the EU.

To stimulate the reduction in the use of inorganic pesticides and fertilizers, the determinants of their use must be used as levers (summarized in Table 1). In addition to economic factors, institutional and regulatory factors can play an important role in farmers' decision to specialize in ecological agriculture, for example: institutional barriers, institutional communication, and legislative instability (Łuczka and Kalinowski, 2020). Environmental policies, infrastructure, investments, and agricultural research and development tend to support ecological agriculture activities (Lohr and Salomonsson, 2000). The general level of education of the population positively influences the demand for healthy foods and, therefore, the demand for fertilizers and pesticides in a negative way (Lohr and Salomonsson, 2000).

Table 1. Levers needed to implement agricultural production methods that reduce the consumption of pesticides and inorganic fertilizers

Production methods/ technical solutions	**Economic levers**	**Institutional levers**	**Legislative levers**
Precision agriculture and broadband connections (a, b, c)	- Eliminating excessive inorganic inputs* - Higher sales prices for finished products - Eco-schemes for financing the initial investments - Taxing inorganic inputs - Dedicated subsidies	- Expanding broadband Internet infrastructure - Establishing platforms and cooperation networks - Institutional and administrative changes for the CAP implementation	- Protecting data shared by farmers - Egulating farmers' associations - Transposing the CAP into national law
Integrated pest management (IPM) (a)	- Eliminating excessive inorganic inputs* - Superior productivity * - Higher prices for finished products - Eco-schemes financing - Taxing pesticides	- Information campaigns, training courses for farmers - Dedicated distribution channels - Consumer information campaigns	- Transposing the CAP into national law - IMP products' certification

Production methods/ technical solutions	Economic levers	Institutional levers	Legislative levers
Organic agriculture (d)	- Higher sales prices for finished products - Eco-schemes financing - Dedicated subsidies	- Monitoring the organic products' certification - Consumer information campaigns	- Regulations on subsidy schemes - Transposing the CAP into national law - Regulating organic products' certification

European Green Deal objectives: a. Pesticides' consumption decrease; b. Fertilizers' consumption decrease, c. Nutrient loss decrease, d. Ecological crop surface increase

* Benefits appear automatically after implementing the specified production methods

Source: authors' processing based on the production methods' classification made by Guyomard et al. (2020, p. 63)

The Farm to Fork Strategy introduces the following modern and sustainable methods of agricultural production and management that will be funded through the eco-schemes under the reformed Common Agricultural Policy: precision agriculture, agro-ecology (integrated pest management, organic farming), low carbon footprint agriculture, and agroforestry (European Commission, 2020). Of these, we note the first two as having an impact on reducing the consumption of pesticides and fertilizers.

Precision farming reduces costs for farmers by making precise calculations of the needed quantity of seeds, pesticides, fertilizers, herbicides, and irrigation, while maintaining productivity and simultaneously avoiding waste, which leads to sustainability and environmental protection. Excessive nutrient loss or accumulation in certain areas of the culture is also monitored to rebalance the concentration (Hedley, 2015). Implementation is done through a series of technologies, such as: satellite monitoring, ground sensors, remote sensing, and artificial intelligence (European Commission, 2020; Blasch et al., 2022). To this end, the Farm to Fork Strategy aims to ensure 100% access to broadband internet in rural areas by 2025 (European Commission, 2020). At the same time, precision agriculture involves investments made by farmers in equipment purchase and Internet connection (Guyomard et al., 2020), the associated costs being a major impediment (Blasch et al., 2022; Zarco-Tejada et al., 2014). In the case of small agricultural areas, the acquisition of technologies for precision agriculture is not profitable, some authors (Zarco-Tejada et al., 2014) proposing the solution of farmers' associations to make investments in collaboration or to cooperate with specialized contractors. It is necessary to revise the regulations concerning farmers' legal forms of association, these showing significant differences between EU Member States (Rebega, 2019). On the other hand, Despotović et al. (2019) conclude that for integrated pest management (MID), the larger the farm, the more difficult and unlikely it becomes to implement such production methods, recommending the application of this strategy for small farms.

IPM is a long-studied practice in the literature (Bottrell, 1979; Kogan, M., 1998) and included in Directive 2009/128/EC on the sustainable use of pesticides (European Parliament and the Council, 2009). The Directive defines MID as the analysis and integrated use of plant protection methods so that the economic and, at the same time, ecological effects are

minimal, including: crop rotation, use of pest-resistant seeds, natural pest protection materials and methods, balanced irrigation, hygiene measures (disinfection of equipment), etc. Although mitigation of pesticide consumption leads to lower production costs, this advantage is diminished by other additional costs: crop rotation involves the introduction of less profitable crops (e.g. sunflower), a greater contribution of labor and capital (monitoring and more frequent crop work), the cost of organic substitutes (Lefebvre et al., 2015).

The costs of implementing methods for early identification of diseases and of precise spraying of plants are recovered over time by reducing pesticide consumption (Vasileiadis et al., 2011). Many of these methods increase efficiency and productivity (Lefebvre et al., 2015). For less chemically intensive products, the selling price may be high, facilitating cost recovery (Lefebvre et al., 2015), although it does not necessarily lead to a higher profit margin (Uematsu, Mishra, 2012). Certification of products as organic or low in harmful substances currently works only in the case of organic products (Lefebvre et al., 2015). A certification of IPM products would provide the necessary motivation for farmers to adopt these methods (Kvakkestad et al., 2021).

There can be identified methods to persuade distributors to dedicate special distribution channels to IPM products (Lefebvre et al., 2015). Various public policies are used to change the structure of production costs: additional taxation of inorganic pesticides and fertilizers and subsidies to farmers to offset the additional costs of switching to precision agriculture (Finger et al., 2019). Reducing fertilizer consumption leads to decreased agricultural productivity, and reduced pesticide consumption leads to increased crop losses caused by pest (Thilagavathi et al., 2017; Tudi et al., 2021), and these economic losses must be offset. Kvakkestad et al. (2021) identifies a positive impact of the additional taxation of pesticides on IPM in Norway, as well as of the legal obligations to implement Directive 2009/128/EC. Subsidies for switching to organic farming have also shown positive results (Serebrennikov et al., 2020).

Organic production is regulated at EU level by *Regulation (EU) 2018/848 of the European Parliament and of the Council of 30 May 2018 on organic production and labelling of organic products* and is defined as an agricultural management and food production system covering the whole production chain and bans genetically modified organisms, while the use of artificial fertilizers, pesticides, and herbicides is only limited. Practices needed to adopt organic farming while maintaining plant health and soil fertility include: crop rotation, the use of natural fertilizers such as compost, a ban on mineral fertilizers with nitrogen, the cultivation of resistant and naturally nitrogen-fixing varieties, etc. (European Commission, 2022a). For organic farming, the goal of the European Green Deal is to extend this practice to 25% of the agricultural area, which puts pressure on profit because productivity decreases (Offermann and Nieberg, 2000; Guyomard et al., 2020). This goal seems difficult to achieve because organic products are considered niche products (Alroe and Noah, 2008). There is a consumer preference for organic products from local suppliers and the desire to support small farmers and traditional farms (Bojnec et al., 2019). At the same time, certification facilitates international trade in organic products due to consumers' preference for a particular origin, making it necessary to harmonize regulations at the international level (Vogl et al., 2005). The market for organic products requires a broad monitoring and inspection framework, and the popularization of these products among consumers must be followed by broader information and education campaigns, which require institutional efforts.

There are several new technologies that can be applied in agriculture to improve crop yields, with less impact on the environment and human health. For example, nano-fertilizers and nano-pesticides are released in a targeted and efficient manner compared to conventional ones (Chhipa, 2017). However, these technologies are not available to ordinary farmers due to high costs. Some authors suggest that subsidies or public funding schemes could at least partially cover the increased costs of organic farming, regardless of whether or not innovative production methods are used (Sane et al., 2021; Skevas et al., 2012). However, in many cases, subsidies have been used to purchase pesticides and fertilizers to improve crop yields (Rahman and Zhang, 2017). In the European Union, subsidies for this specific purpose were withdrawn in 2000 (Kelch and Osborne, 2009). Bowman and Zilberman (2013) suggest eliminating subsidies for unsustainable production methods or redirecting them to sustainable agriculture, while finding that this policy change would have a lesser effect on stimulating the shift to organic farming compared to market access (Lohr and Salomonsson, 2000), less restrictive requirements of the financing scheme, or flexible contractual terms (Christensen et al., 2011).

The lack of farmers' technical knowledge and the reluctance to adopt new technologies (Schimmelpfennig and Ebel, 2011) can be addressed by creating a mechanism for collaboration, mutual information, and knowledge transfer in the case of precision agriculture (Busse et al, 2014). Platforms can be set up for learning and sharing knowledge with other farmers or for research purposes (Finger et al. 2019). Farmers can also be informed about new technologies by specialized institutions (Vecchio et al., 2020). An appropriate institutional framework, focused on such objectives, stimulates the adoption of precision agriculture and even innovation in the field based on data collected from farms (Busse et al., 2014). Therefore, it is necessary to regulate the protection of personal data shared by farmers (Finger et al., 2019). In the case of IPM, it is not the lack of knowledge about these methods that is the problem, but the perception that the methods are not effective, which can be solved through information campaigns and courses dedicated to farmers (Despotović et al., 2019). Reganold and Wachter (2016) state the need for legal, financial, and knowledge-sharing tools on organic farming practices and sustainable production methods in agriculture in general.

2. The impact of pesticide and fertilizer use in the EU

In this section, we have aimed to capture the pan-European agricultural trends in order to determine if the EU has achieved progress towards the set-up Green Deal objectives. Additionally, the section highlights the importance of reducing chemical fertilizer and pesticide consumption while taking into account the effect on human health and the environment.

2.1 Trends in the European agricultural landscape

In the last 10 years, the EU agricultural sector has taken significant steps toward a more sustainable future without affecting its ability to provide quality food: in 2019, sales of pesticides fell by almost 30,000 tons (-7% compared to 2011), the area devoted to organic production reached 13.8 million ha in 2019, the EU market for organic food and beverages has doubled in size (reaching a level of around € 41 billion in 2019), the gross value added of EU agricultural production reached 224 billion euros, and the food trade balance grew at an average annual rate of around 10% between 2010 and 2020, reaching 62 billion euros in net trade in 2020 (European Commission, 2022a).

Table 2 illustrates the evolution of some representative variables for the European agricultural landscape between 2000-2019. The analysis was performed at EU level (EU-27) using data provided by Eurostat and FAO. The analysis aims to investigate the level of Member States' alignment with Green Deal objectives (reflected in fertilizer consumption, pesticide use and organic farming) and the performance of the agricultural sector (highlighted by the index of real income factors, subsidies on agricultural products, and the financial support granted by the public actors to research and development in this sector).

Table no. 2. Trends in the European agricultural environment (EU-27) between 2000-2019

Variable	Mean 2000-2019	Value in 2019	Δ (2000-2019)	Source
Consumption of inorganic fertilizers (nitrogen and phosphorus) (tons)	11,501,043	10,746,130	-3.2%	Eurostat
Fertilizer consumption (kilograms per hectare of arable land)	150.93	154.84	-1%	FAO
Pesticide use (tons)	339,559	348,406	1.4%	FAO
Subsidies on agricultural products (million euro)	15,817.01	4,487.99	-88%	Eurostat
Hectare of organic crop area	8,471,192	13,793,665	246%	Eurostat
Index of the real income of factors in agriculture per annual work unit	104.13	134.91	56%	Eurostat
Government support to agricultural research and development (million euro)	2,651.50	2,962.66	39%	Eurostat

Source: Authors' computation

As indicated above in Table no 2, the average consumption of inorganic fertilizers was 11.5 million tons (average consumption of 151 kilograms/hectare) between 2000 and 2019, with a decrease in aggregate level of 3% during the analysed period (FAO). On average, the quantity of pesticides was of 340 tons (3.2 kilograms per hectare), with a clear upward trend in 2019 compared to 2000 (FAO), despite the EU's ambitious targets to shift toward organic farming and reduce chemical consumption. However, there are notable differences between Member States: while Netherlands and Belgium have had a pesticide consumption of over 11 kilograms per hectare, the Baltic States and Bulgaria have recorded values below half a kilogram per hectare (FAO). Moreover, the EU's agricultural landscape includes 13.8 million hectares of organic crops, the average area being 365 thousand hectares per Member State (Eurostat). This area has increased significantly between 2000-2019, reflecting on the one hand the sustained interest of consumers towards healthier products and on the other hand the redefinition of cultivation patterns in the European agricultural sector. Some countries, such as France and Spain, deviate from the Community average by achieving superior performance, in line with the objectives of the post-2020 CAP and the Green Deal. On average, in 2019, subsidies for agricultural crops amounted to EUR 15.8 billion (Eurostat,

2019), with a downward trend over the last 20 years. Regarding the index of the real income in agriculture, representative for the sectoral competitiveness, except for periods of crisis, it has registered a constant increase to the value of 134.9 in 2019 (Eurostat). Last but not least, the evolution of government support to research and development in the agricultural sector also indicates an increased interest in this field, the average value recorded at Eu-27 level being 2.7 billion euros (Eurostat).

The analysis conducted in this section suggests an orientation towards organic farming and an increase in the financial support granted by governmental actors to agricultural research and development. However, data on fertilizer and pesticide consumption do not indicate significant progress in recent years in line with the objectives of the CAP and the European Green Deal. Moreover, gaps between Member States still persist so that for those countries with an agriculture sector highly based on the use of inorganic fertilizers and beneficiaries of agricultural subsidies, the reconfiguration of the business models and the orientation towards organic farming can prove to be a difficult to reach objective at least in the short term.

2.2 Impact on human health and the environment

A wide range of pesticides and artificial fertilizers, as well as other chemicals, are frequently employed in agricultural production to ensure a high enough level of productivity to meet the worldwide demand for agricultural products. However, the detrimental effects of these compounds on human health and the environment have been extensively studied in the literature and the growing public concern has necessitated the identification of solutions to mitigate their side effects.

Food security also encompasses the concept of health security (Dinu, 2018) and refers not only to the right to have access to sufficient food, but also to healthy products. EC Regulation 178/2002, which also addresses pesticides' health impacts, refers to the importance of protecting food safety across the production chain. Due to the free movement of goods within the European Union, it is natural to adopt common standards for marketed foods and to have an institutional framework to monitor their implementation.

There are numerous banned or counterfeit pesticides on the market, the sale of which is illegal due to their extremely dangerous effect on human health and the environment (UNEP, 2021). It is estimated that there have been 168,000 deaths worldwide each year and between one and two million cases of pesticide poisoning (UNEP, 2021). Among the adverse effects of pesticides and fertilizers on human health are heart disease, gastrointestinal cancer, immuno-deficiencies, headache, skin irritation, vision problems, fatigue, shortness of breath, nervousness, and depression (Zhang et al., 2019; Alavanja et al., 2001), fetal malformations (Liu et al., 2021). Their magnitude depends on the types of substances, their concentration, and duration of exposure (Nicolopoulou-Stamati et al., 2016). Pesticide and fertilizer poisoning occurs through ingestion, inhalation, or skin contact (Nicolopoulou-Stamati et al., 2016), affecting not only consumers of agri-food products treated with such substances, but also farmers during or after the substances' application. Consumers may become intoxicated by direct consumption of treated agri-food products or polluted water resulting from unsustainable agricultural practices (Kruhm-Pimpl, 1993; Ovez et al., 2005; Agarwal et al., 2015).

Pesticides and fertilizers are frequently misused: when they are used in excess of what is necessary, endangering consumer health, or when farmers do not wear suitable safety

equipment. This conduct is the result of a lack of information or financial resources (UNEP, 2021). According to Alavanja et al. (2001), storing these compounds at or near the home results in an increased prevalence of diseases reported by farmers. Zhang et al. (2019) report that farmers consume more pesticides and are exposed to more pesticides when pesticides are applied manually rather than mechanically. Lichtenberg and Zimmerman (1999) have shown that farmers who have experienced health problems as a result of pesticide exposure are more ready to utilize more sustainable pest management strategies.

In terms of environmental impact, the use of these chemicals is contentious mainly due to their detrimental impacts on the sustainability of ecosystems (Liu et al., 2012; Pingali, 2012, Popp et al., 2013). Crops typically retain about half of the used fertilizers, with the remainder being absorbed by the environment (Liu et al., 2010). Eutrophication of surface waters, degradation of downstream water quality, loss of biodiversity, tropospheric smog, and soil acidification are all significant environmental consequences of fertilizer use (Carpenter et al., 1998; Russell et al., 2009; Vitousek et al., 2009).

As for pesticides, they leave a residue on the dead plant material that is deposited in the soil and can be dumped into the waterways or groundwater after being sprayed on crops. A 2014 study, conducted in 38 states, detected glyphosate in most rivers, streams, ditches, and wastewater treatment plants, as well as in 70% of rainfall samples (Battaglin, 2014). Even at levels considered safe, pesticides have been shown to cause biodiversity loss (Oosthoek, 2019). In this respect, there is a set of worldwide used indicators such as: Pesticide Potential Environmental Risk Indicator (EPRIP), Pesticide Environmental Analysis (EYP), National Pesticide Risk Indicator Survey (SYNOPS), Pesticide Prediction System Environmental Impact of Pesticides (SyPEP), Environmental Pesticide Risk Indicator (PERI), Environmental Impact Coefficient (EIQ), Chemical Hazard Assessment for Management Strategies (CHEMS1) and Multiple Attribute Toxicity Factor (MATF) (Sande et al., 2011).

3. Synergies between the CAP and the European Green Deal - best practice on reducing fertilizer and pesticide consumption

In the current section, we will review examples of best practice for reducing the pesticide and fertilizer consumption, projects that contribute to the objectives of the European Green Deal and the CAP, reducing the impact of negative effects on human health and the environment.

In order to strengthen the efforts to protect and restore ecosystems, promote sustainable use of resources and improve human health, the CAP framework has been redesigned at Community level, being created synergies with the European Green Deal (European Commission, 2020). The Community institutions have proposed the reconfiguration of post-2020 agricultural practices, given the difficulty of putting into practice the objectives established in the European Green Deal. Experts from the Policy Department for Structural and Cohesion Policies (Guyomard et al., 2020) noted that the European group had made no sustained progress in reducing greenhouse gas emissions, which required rethinking the agricultural practices and systems to reduce pesticide and chemical fertilizers consumption. The agricultural landscape of the Community is also characterized by the erosion of biodiversity, which occurs under the conditions of the perpetuation of simplified agricultural systems and the widespread use of chemical fertilizers. In this context, the CAP is becoming a key pillar to strengthen the European farmers' efforts to align with the European Union's climate and environmental goals, and eco-schemes will support this transition (European

Commission, 2021). Based on the list compiled by the European Commission (2021) and Guyomard et al. (2020) and in order to facilitate the adaptation of agricultural practices to the environmental objectives, Table 3 comprises examples of agricultural practices, which would respond to the strategic plans set out in the CAP and also to the objectives of the European Green Deal.

With the purpose of meeting the targets of the European Green Deal, farmers can take a wide range of measures, ranging in complexity from mechanical pest control and irrigation management to land conversion to meet the requirements of organic farming. Precision agriculture also provides the framework for the adoption of technical means for soil control and monitoring of the quantity of fertilizers and pesticides used. However, Guyomard et al. (2020) noted that many rural areas in the EU still do not benefit from broadband internet access, a trend that makes it difficult to adapt technology widely in agriculture.

Another proposed method for achieving the environmental targets aims at the integrated pest management (IPM), which has the advantage of significantly reducing pesticide consumption without loss of yield. However, there is currently a reluctant attitude of farmers, mainly due to the risks induced in the activity, the need for investment, and the acquisition of new skills (Guyomard et al., 2020). Awareness of the importance of environmental goals among farmers could also lead to the establishment of individual targets for reducing the consumption of pesticides and chemical fertilizers. Consequently, in addition to aligning internal strategies with the environmental targets set at the Community level, European farmers could reposition themselves on the global market as major players in the field of organic products.

Last but not least, by integrating nanotechnology into agriculture and developing new categories of pesticides and fertilizers that are safe for human health, European farmers can become more competitive by increasing productivity and efficiency, reducing pollution, and diminishing labor force costs. Nanotechnology is based on nanoparticles that have benefits in seed treatment and germination, plant growth and development, and the diagnosis of pathogens (Zhao et al., 2020). In this case, innovative farmers who will focus in the upcoming period on the development, testing, and implementation of new categories of pesticides and fertilizers, which meet both human health and environmental requirements, will benefit from the first-mover advantage and the learning effects that derive from it.

Table 3. Best practice in reducing the consumption of pesticides and fertilizers. Interconnections between the CAP and the European Green Deal

Practice	Activities	CAP specific objective	Green Deal objective
Implementing organic farming practices	• Conversion of land to organic farming. • Balanced fertilization and sustainable fertilizer management; • Adoption of ecological practices; • Use of crops / varieties of plants resistant to climate change; • Cultivation of mixed species, in parallel with permanent grassland, to encourage biodiversity.	Objectives 4, 5,6	Increasing the share of agricultural land under organic farming; Reducing fertilizer consumption.

Practice	Activities	CAP specific objective	Green Deal objective
Adoption of integrated pest management practices	• Mechanical control of parasitic plants; • Use of pest-resistant crop varieties and species; • Outlining an input management strategy, including the reduction of chemical fertilizers use; • Development of networks and fast Internet access in rural areas, including the use of technical means for soil and fertilizer control; • Improving the irrigation system.	Objectives 4,5	Reducing pesticide use; Reducing nutrient losses.
Focusing on precision farming	• Establishing an input management strategy, also including the reduction of chemical fertilizers use; • Development of networks and fast Internet access in rural areas, including the use of technical means for soil and fertilizer control; • Improving the irrigation system.	Objectives 5,6	Reducing pesticide use; Reducing fertilizer consumption; Reducing nutrient losses.
Proper nutrient management	• Implement measures to reduce and prevent environmental pollution, for example by taking samples from soil; • Adopt internal targets to reduce the consumption of chemical fertilizers, which exceed the conditionality obligations.	Objectives 4,5	Reducing fertilizer consumption; Reducing nutrient losses.
Promoting sustainable agriculture through nanotechnology	• Establishing partnerships between the private and academic environment and/or establishing start-up companies, in order to develop bio-pesticides and nanofertilizers based on nanomaterials; • Testing of nanotechnology-based products in order to identify both the benefits of efficiency and the potential risks on human health.	Objective 5	Reducing nutrient losses.

** Note: Objective 4: Climate change mitigation and adaptation; Objective 5: Promote sustainable development and efficient management of natural resources; Objective 6: Protection of biodiversity, conservation of habitats and landscapes.*

Source: Elaborated by the authors based on European Commission (2021) and Guyomard et al. (2020, pp. 63-65)

The EU's ambitious goals of mitigating climate change and protecting the environment have also been reflected in Horizon 2020 funding priorities, the EU providing financial support to research projects proposing viable solutions to reduce pesticide use, proper management of fertilizers, the creation of know-how networks and best practices or the identification of organic fertilizers. The EU's strong interest in reducing the consumption of pesticides and inorganic fertilizers, as well as in identifying innovative agricultural soil management techniques, was reflected in the € 3.8 billion net contribution to the priority of food security and organic farming under Horizon 2020 programme (European Commission a). According to the Institute for European Environmental Policy (2020), the research proposals that received funding aimed to identify crop protection and land management techniques under low pesticide application scenarios. A selection of projects that can stimulate productivity in a sustainable manner is presented below:

- **DESSA** project (Decision Support System for Smart Agriculture), carried out between March and June 2019, aimed to create synergies between the agricultural environment and technology through a system based on the Internet of Things (IoT) and the placement of sensors on the farm in order to measure environmental conditions. It is the first system to integrate sensors placed on the farm with cloud-based analytics software that uses advanced models for a wide range of fruits and vegetables. The data obtained from the environment are transmitted in real time on smart devices, thus informing the farmer about the conditions of the soil and the measures which are necessary in order to maintain optimal conditions for agricultural production. The project was developed by a consortium between two Italian companies that combine crop research with the development of ICT and IT infrastructure and will target farmers and agricultural cooperatives across Europe. This solution can increase crop yield by up to 20% and quality (60% reduction in waste production) while reducing resource consumption (10%-30% reduction in chemical applications and 10%-20% emission of CO2). In addition, it is fully aligned with the *Directive 2009/128/EC* establishing a framework for Community action to achieve the sustainable use of pesticides by involving farmers in practices with a limited risk to human health and the environment, giving priority to low pesticide intake (European Commission b).

Research projects have also aimed to improve IPM techniques, which are one of the main tools for reducing the use of chemical pesticides under the Farm to Fork Strategy (Institute for European Environmental Policy, 2020):

- The EU-funded **IPM Decisions** project (Stepping-up IPM decision support for crop protection) offers a decision support system for farmers, with the general aim of improving pest control and increasing the profitability of the agricultural sector. The program will run from 2019 to 2024, involving research institutions, universities, and public bodies from 12 Member States (European Commission c).

Other projects under the auspices of the Horizon program focused on soil management, while reducing fertilizer consumption:

- **ISQAPER** (Interactive Soil Quality Assessment in Europe and China for Agricultural Productivity and Environmental Resilience) created an application that provides information to farmers on soil quality, including best practice, adapted to local pedoclimatic conditions and agricultural system (European Commission d).

- **LANDMARK** (LAND Management: Assessment, Research, Knowledge Base) established a framework for soil management to support European food production, developing a "Soil Navigator" tool. The project was conducted between May 2015 and October 2019, benefiting from an EU co-financing of € 5 million and involving research institutes, universities and public bodies, including Romania (European Commission e).

- **CIRCASA** (Coordination of International Research Cooperation on Soil Carbon Sequestration in Agriculture), focused on research and exchange of know-how in the field of soil carbon preservation. CIRCASA has created a Strategic Research Agenda on soil organic carbon sequestration (European Commission f).

- **EJP SOIL** (Towards climate-smart sustainable management of agricultural soils) is currently in progress and is focused on adapting agricultural soils to the key societal challenges, such as climate change mitigation. The project, which has received € 40 billion in European Union funding, will run from 2020 to 2025 and aims to establish an integrated European agricultural research community. The EJP Soil consortium brings together a group of 26 European research institutes and universities from 24 countries, with the purpose of creating a roadmap for sustainable management of agricultural soils, in line with the climate change (European Commission g).

- **BEST4SOIL** (Boosting 4 BEST practices for SOIL health in Europe) focused on soil health and networking for the exchange of knowledge and best practice, took place between 1 October 2018 and 31 March 2022. The BEST4SOIL project was based on both the creation of a web platform and the organization of local activities, which facilitated the exchange of best practices between farmers, involving public and private institutions from 8 Member States (European Commission h).

Complementary to soil management, there were developed and implemented projects that aimed to identify alternatives of organic fertilizers, in order to improve production and increase the incomes from agriculture.

- **Biota Nutri BV**, a Dutch organic fertilizer producer founded in 2017, received EU funding from December 2019 to March 2020 to create an organic fertilizer suitable for all types of crops (European Commission i).

- **LEX4BIO** (Optimizing Bio-based Fertilizers in Agriculture - Knowledgebase for New Policies) focused on optimizing the use of organic fertilizers, which benefited from EU co-financing of 6 million euro. LEX4BIO involves 20 participants from 14 Member States and runs from 1 June 2019 to 31 May 2024. The project aims to reduce the dependence on mineral/fossil fertilizers and to create a set of tools to optimize the use of organic fertilizers in agriculture ((European Commission j).

- **SUSFERT** (Sustainable multifunctional fertilizer – combining bio-coatings, probiotics and struvite for phosphorus and iron supply), aimed at identifying sustainable fertilizers, received Community funding of € 6.5 million. The project runs from May 2018 to October 2023 and focuses on the development of multifunctional fertilizers for the supply of phosphorus and iron, in order to be integrated into existing production processes and common EU agricultural practice (European Commission k).

Table 4 presents a number of start-up initiatives in EU countries that focus on innovative ways to reduce the consumption of fertilizers and pesticides and meet the specific objectives

of the CAP. These initiatives can be a source of documentation for public and entrepreneurial initiatives in the agricultural industry.

Table 4. Private best practices for reducing the consumption of pesticides and fertilizers

Company name	Country of origin	Solution	CAP objective
GeoPard Agriculture	Germany	Precision independent platform that uses data from a variety of sources, including satellite open-source or user-provided data on environmental conditions.	Objective 5 Objective 9
Novihum Technologies	Netherlands	Fertilizer based on humus concentrate that increases nutrient absorption	Objective 5
AgroGNOME	Estonia	Measuring soil parameters using wireless sensor networks and providing personalized access to farmers to yield prediction systems.	Objective 5 Objective 9
Glen Biotech	Spain	Biotechnology that offers sustainable pest management solutions.	Objective 5
Strigiformes	Poland	Biostimulant that combines garlic extract and horseradish together with a nanomolar concentration of nano-copper that stimulates the growth and development of plants by increasing the absorption of water and nutrients.	Objective 5
Nanomnia	Italy	Encapsulation of herbicides, molluscicides, biocides, biostimulants, fungicides, agrochemicals and insecticides for the effectiveness of active ingredients beneficial to crops.	Objective 5 Objective 6
Augmenta	Greece	IoT-based artificial intelligence solution and software platform that connects a farmer to his land, anywhere in the world. The "Field Analyzer" can be attached to any tractor and can determine the amount of fertilizer, fungicide and pesticide the farm needs to reach its full potential, all in real time.	Objective 9

Note: Objective 5: Promote sustainable development and efficient management of natural resources; Objective 6: Protection of biodiversity, conservation of habitats and landscapes. Objective 9: Promote knowledge, innovation and digitalization in agriculture.
Source: Authors processing using data from company websites and of Valuer (2019)

Conclusions

The use of pesticides and inorganic fertilizers in agriculture is a difficult habit to break. All the years farmers have used them as the first and only line of action have led to the loss of traditional knowledge and skills in pest control and increased productivity, leaving few options for farmers today. Purchasing equipment and committing time and resources to alternative pest management methods can be too costly for many farmers, particularly those who have previously made significant investments in genetically modified seeds and

insecticides. Agriculture that is not based on chemical pesticides requires the farmer to employ expertise, additional time, and more skilled labor, resulting in an increase in the price of agricultural products. To meet the growing demand for healthier food, as well as the challenges posed by soil degradation, food waste, pollution, and climate change, investment in modernizing physical assets, increasing the use of digital technologies in production processes, and improving resource efficiency are key to upgrading the EU agricultural sector. However, factors such as increasing the number of organic farms, raising awareness of the importance of sustainability in modern agriculture, and increasing the number of government-sponsored initiatives are propelling the organic fertilizer market forward and encouraging more and more farmers to specialize in organic farming.

Our findings indicate that EU-funded start-up projects and businesses have proposed viable consulting and soil management solutions based on technology and environmental data, while reducing the consumption of pesticides and chemical fertilizers, including by providing environmentally friendly alternatives. Consequently, agricultural economic actors need to be incentivized to develop innovative production methods, while also finding appropriate complementarity between labor and machineries. At the same time, in the context of the ambitious targets of the European Environment Pact, further steps are needed to raise awareness among farmers about the importance of aligning agricultural practices with environmental objectives. Thus, the development of digitized practices and tools should be complemented by an increase in farmer training by meeting EU requirements. All these solutions are meant to help increase productivity, income, and the added value of the agricultural sector. Agricultural producers' strategies must be rethought in order to sustain their competitive advantages in the coming years. To overcome the reluctance of the agriculture sector to adopt digital solutions, they must be developed in conjunction with farmers and agricultural cooperatives.

The examples provided in the study can facilitate the exchange of good practices by serving as examples of innovative solutions that can help achieve the objectives of the Green Deal and the Common Agricultural Policy (CAP) through soil management, promoting agriculture innovation and digitalization, and the development of alternatives to organic fertilizers that shall enhance production in a sustainable manner.

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