SUSTAINABILITY AND PESTICIDE USE IN MAIZE: A SWOT-BASED COMPARISON BETWEEN ROMANIA AND INTERNATIONAL CASES

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RESEARCH ARTICLE

Abstract
The use of pesticides continues to play a central role in maintaining crop productivity, but it also generates ongoing debates regarding its impact on the environment and public health. This study examines the use of pesticides in maize (Zea mays) cultivation in Romania and the United States between 2018 and 2023, aiming to highlight differences in usage intensity, regulatory systems, and sustainability outcomes. The research is structured as an exploratory analysis based on secondary data, drawing on international databases (FAOSTAT, USDA, Eurostat, Worldometer), Romanian national statistics, and relevant scientific literature. Quantitative indicators such as total pesticide consumption, application rates per hectare, maize yields, and sales volumes by category were analyzed descriptively and then interpreted in relation to regulatory contexts and technological developments. To integrate these findings, a SWOT framework was employed in order to capture both internal strengths and weaknesses, as well as external opportunities and risks. The results show that Romania has one of the lowest pesticide application rates within the European Union, averaging around 0.8 kg per hectare and amounting to 5–7 thousand tonnes annually. By contrast, the United States records much higher intensities, with nearly 2.5 kg per hectare and over 400 thousand tonnes in total use. This difference is mirrored in productivity levels: average maize yields in the U.S. exceed 10 t per hectare, while in Romania they usually reach 4–5 t per hectare in favorable years. The findings also underline the divergence between regulatory models, with the European Union applying a more precautionary principle, whereas the United States relies on permissive risk–benefit evaluations. Overall, the study suggests that neither heavy dependence on chemical inputs nor drastic reductions without viable alternatives represent sustainable solutions. Instead, a balanced strategy that integrates rational pesticide application with innovative and environmentally sound practices is required to maintain maize productivity while protecting the long-term resilience of agroecosystems.

Keywords: Pesticides, Maize cultivation, Romania, United States, Sustainability
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INTRODUCTION

Over the past few decades, the global use of pesticides in agriculture has increased sharply, establishing itself as both a pillar of food security and a major source of environmental concern. Some of the world's most powerful agricultural regions, including the United States, the European Union, China, and Brazil, stand out not only for their role as leading food producers but also as the largest pesticide consumers worldwide (Donley, 2019). In 2016, for example, U.S. agriculture alone applied around 1.2 billion pounds of pesticides, the equivalent of approximately 544 million kilograms, representing nearly 23 percent of total global use. In the same year, the European Union (EU-28) reported an estimated 827 million pounds. Such figures clearly illustrate the heavy dependence of contemporary farming systems on chemical crop protection, used to control weeds, insect pests, and plant diseases (Atwood et Paisley-Jones, 2017).

While pesticides bring farmers undeniable advantages by protecting harvests and increasing yields, their intensive application also generates significant environmental and health-related challenges. Research consistently shows their negative effects on pollinator populations, biodiversity, and the overall quality of soil and water ecosystems. More recent studies have emphasized that many commonly used substances can cause toxic effects on non-target organisms and contribute to persistent environmental contamination, thereby raising public health concerns (Costea et al., 2024).

A striking example comes from the European Union, where strict restrictions on neonicotinoid insecticides have been enforced following strong evidence of their harmful impact on bees and other beneficial insects. Nevertheless, the complete abandonment of pesticides without effective alternatives would expose crops to severe losses. This situation resembles a fragile balancing act, where agricultural systems must reconcile the necessity of crop protection with the equally pressing need to safeguard ecological stability and human well-being.

Maize (Zea mays) is among the most widely cultivated and economically important crops worldwide, and it holds a central role in Romania. It supports human nutrition, animal feed, and numerous industrial applications. In Romania, maize exceeds all other cereals in cultivated area and total production, surpassing wheat in national output (Romania Country Commercial Guide, 2024). The United States is the largest global producer, accounting for about 32 percent of world output, close to 390 million tonnes in the 2023 to 2024 agricultural year (Filipenco, 2024).

Given this global relevance, maize is an excellent case for comparing plant protection strategies. Romania reflects a European context with moderate pesticide inputs, while the United States exemplifies high input, technology driven, intensive agriculture. This contrast was chosen to show two distinct systems: the United States, known for large scale pesticide use, including some active substances banned in the European Union, which supports record yields, and Romania, aligned with the European model of stricter regulations and comparatively lower pesticide consumption (Popescu et al., 2021).

A substantial body of research has addressed pesticide use. At the international level, a comparative analysis examined policies governing the prohibition of hazardous pesticides across the United States, the European Union, Brazil, and China, highlighting marked regulatory differences. In 2016, more than 70 active substances banned in the European Union were still approved for use in the United States (Donley, 2019).

In Romania, recent studies have evaluated pesticide consumption and long term trends. One analysis for 2007 to 2020 reported a 25.8 percent decrease in overall insecticide use and a 23 percent reduction in herbicide use, while fungicide applications increased by about 8 percent (Popescu et al., 2021). These shifts point to a changing phytosanitary profile, with fewer severe pest outbreaks and a higher incidence of fungal diseases. Another study ranked Romania tenth in the European Union for total pesticide consumption, at 6.9 thousand tonnes in 2018, and last in pesticide use per hectare, at approximately 0.8 kg per hectare, compared with more than 3.6 kg per hectare in top consuming countries such as Spain, France, and Italy (Popescu et al., 2021).

Domestic research highlights several specific challenges for maize cultivation in Romania, most notably the persistent threat posed by Diabrotica virgifera (Western corn rootworm) and Tanymecus dilaticollis (leaf weevil). Both species are capable of generating severe yield losses when effective control strategies are absent. Local studies emphasize that chemical treatments applied to seeds, soil, and crops remain “necessary for control” of these invasive pests in situations where viable alternatives are limited (Costea et al., 2024).

At the same time, an increasing number of studies are directed toward integrated pest management and environmentally sustainable approaches. Between 2021 and 2023, field trials carried out in western Romania compared the effectiveness of pheromone traps, natural enemies, and bioinsecticides in both organic and conventional maize plots. The results showed that promoting natural predators and biopesticides can significantly reduce pest pressure and lower dependence on synthetic chemicals (Amarghioalei et al., 2025).

These findings provide the basis for the central hypothesis of the present study, namely that substantial differences exist between Romania and other countries in how pesticides are used in maize cultivation. Such differences are shaped by the intensity of agricultural practices, the regulatory frameworks in place, and the degree of technological advancement. The working assumption is that Romania applies lower quantities of pesticides, under stricter regulatory oversight, but also records lower yields per hectare. In contrast, the United States achieves some of the world’s highest production levels by relying on intensive chemical inputs, while accepting a greater degree of environmental risk.

The overarching aim of this research is to compare pesticide use in maize production in Romania and the United States over the past five years, drawing attention to the major trends, the advantages and limitations of each system, and the directions currently being pursued for improvement. The specific objectives are as follows:

1. to compare quantitative indicators such as total pesticide consumption, per-hectare

application rates, production levels, and yields between the two countries;
2. to analyze the influence of agricultural policies and practices on these indicators, focusing for example on the impact of EU pesticide bans versus the use of genetically modified organisms in the United States;
3. to conduct a SWOT analysis of pesticide use in maize, integrating internal strengths and weaknesses with external opportunities and risks;
4. to develop conclusions and recommendations for optimizing pesticide use, ensuring an appropriate balance between the need to protect crops and the equally important requirement of safeguarding environmental sustainability.

MATERIAL AND METHOD

This study follows an exploratory and comparative design, combining statistical data analysis with a review of recent scholarly literature published between 2018 and 2023. For the quantitative component, information on agricultural pesticide use was collected from official international and national databases, including FAOSTAT and Our World in Data (indicator: Pesticide use, updated in 2024), as well as the Romanian National Institute of Statistics (INS). In particular, Eurostat and INS reports were consulted to obtain figures on the sales volume of plant protection products, expressed in tonnes of active substance, together with data on average consumption per unit of agricultural area (Worldometer, 2021).

Global rankings of pesticide consumption were also analyzed in order to position Romania and the United States within the broader international context. According to FAO-based data compiled by Worldometer, the United States applies approximately 407,779 tonnes of pesticides each year, equivalent to about 2.5 kg per hectare of arable land. Romania, by comparison, records much lower figures, with an estimated 6,859 tonnes annually and an intensity of only 0.8 kg per hectare. These numbers point to a striking contrast in pesticide application between the two countries.

Agricultural production indicators were examined alongside these data, with a particular focus on average maize yield expressed in tonnes of grain per hectare. For the United States, the National Agricultural Statistics Service (NASS) reported a national average yield of approximately 177 bushels per acre in 2023, which corresponds to about 11 t/ha, representing an all-time record (USDA Report, 2024). In Romania, statistics from the Ministry of Agriculture and estimates by the USDA show yields fluctuating between 2.5 and 7 t/ha depending on weather conditions, with average levels of around 4 to 5 t/ha during favorable agricultural years (FAS, 2017).

The analytical approach combined direct quantitative comparison with qualitative interpretation of the main indicators for Romania and the United States. The first step involved examining agricultural data side by side, with particular attention to pesticide use and maize productivity. Whenever possible, the analysis was refined by breaking down pesticide consumption into categories such as herbicides, insecticides, and fungicides, in order to highlight differences in the phytosanitary profiles of the two production systems.

Alongside the quantitative analysis, a qualitative assessment was conducted on the regulatory frameworks and agricultural practices shaping pesticide use. For Romania, this review included European Union legislation, such as the 2013/2018 ban on neonicotinoids, the Directive on the Sustainable Use of Pesticides, and the National Action Plan. For the United States, the focus was on the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) and the Environmental Protection Agency's procedures for approving or restricting chemical substances.

This regulatory comparison was supported by evidence from the scientific literature. For instance, the analysis drew on comparative studies documenting the number of active substances banned in the European Union but still permitted in the United States (Rasche, 2021). It also incorporated reports on Romania's recurring use of derogations for certain prohibited pesticides, such as neonicotinoids (Harrison, 2021). To complement these perspectives, Romanian case studies were reviewed, covering both the chemical control of the Western corn rootworm in eastern regions and trials of alternative methods tested in organic versus conventional systems (Amarghioalei, 2025).

A key instrument for interpreting the results was the SWOT analysis (Strengths, Weaknesses, Opportunities, Threats). This framework was applied to synthesize the main insights on pesticide use in maize cultivation, considering both the Romanian case and the U.S. model, as well as intensive agriculture more generally. Strengths and weaknesses were treated as internal factors, including elements such as efficiency, costs, and the direct effects of current practices, while opportunities and threats were defined as external forces, encompassing technological innovations, regulatory shifts, climate change, and global market dynamics.

This assessment was built on a synthesis of the existing literature, incorporating agricultural policies, pesticide reduction strategies, and technological innovations such as precision agriculture. The objective was to present an integrated perspective on the long-term sustainability of phytosanitary protection methods in maize cultivation.

The quantitative data were analyzed descriptively, with relevant percentage comparisons and absolute differences calculated where appropriate. Since much of the information originated from secondary sources, including published reports and prior research, the reproducibility of the analysis depends on continued access to these references. All major findings and statements are supported by bibliographic citations. No original field experiments or inferential statistical tests were performed, as the study was designed as a synthesis combined with a comparative case analysis.

The decision to use the United States as a benchmark for Romania rests on the striking contrasts between the two agricultural systems. The United States represents, in practice, the global model of large-scale farming, with nearly 90 million acres of maize cultivated annually and the highest overall pesticide consumption worldwide (Filipenco, 2024; Worldometer, 2025). Romania, by comparison, is defined by small average farm sizes of 4 to 5 hectares (Romania Country Commercial Guide, 2024), lower chemical input levels, and a more cautious regulatory framework. These sharp differences make it possible to more clearly identify the strengths and weaknesses of each model, offering a solid foundation for broader reflections on how pesticide use relates to agricultural productivity and sustainability.

RESULTS AND DISCUSSIONS

Pesticide consumption and maize productivity in Romania vs. the United States

The comparative analysis confirms the expected differences between Romania and the United States. Romania records very low pesticide use per unit of cultivated area, while the United States applies significantly larger volumes of plant protection products in maize production. To illustrate this contrast, Figure 1 presents side by side the average maize yield, expressed in tonnes of grain per hectare, together with the intensity of pesticide application, measured in kilograms of active ingredient per hectare.

The data indicate that average maize yields in the United States consistently exceed 10 t/ha, which is almost double the yields recorded in Romania, where in normal years production typically ranges between 4 and 5 t/ha (World Agriculture Production, 2017). This wide gap reflects the extent of production intensification in the United States. American farmers generally cultivate high-yielding hybrids, often genetically modified for herbicide and pest resistance, while also applying high levels of fertilization and implementing aggressive weed and pest management strategies. Together, these factors result in exceptionally high harvests. In contrast, although Romania remains one of the leading maize producers in Europe, a significant proportion of its farms continue to rely on more traditional cultivation methods and remain highly exposed to weather fluctuations. Periodic droughts, in particular, can severely reduce national average yields.

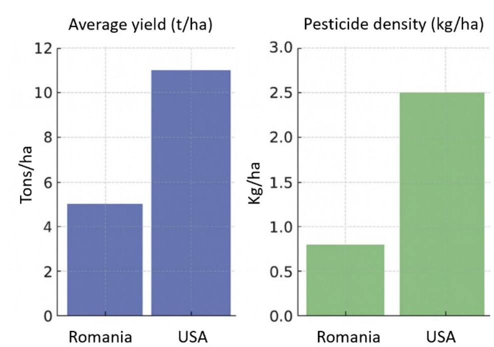

Figure 1 Average maize yield (t/ha) and pesticide use intensity (kg/ha) in Romania vs. United States, 2018–2022 (FAO, USDA)

The results underline the much higher productivity achieved under the intensive agricultural system of the United States, where the chemical load per unit area is nearly three times greater than in Romania. This situation reflects a clear trade-off between yields and pesticide use. The United States secures record harvests in part through the extensive application of plant protection products, while

Romania relies on a lower-input model that produces more modest yields. Other factors also play a role, including variations in soil fertility, climatic conditions, the hybrids used, the degree of mechanization, and access to irrigation, yet the level of pest and weed control continues to stand out as a key determinant of performance.

The overall volume of pesticides applied annually in Romania is minimal compared with the United States, amounting to only a few thousand tonnes against several hundred thousand. This stark difference can be explained both by Romania's much smaller agricultural area and by its distinct approach to crop protection. According to Eurostat, Romania is among the EU member states where pesticide sales declined between 2011 and 2020, a trend also observed in Denmark, Portugal, and Italy. In contrast, France, Germany, and Austria reported rising sales over the same period (Worldometer, 2021).

In 2020, with pesticide prices increasing and the wider economy in recession, EU-wide sales dropped sharply to about 292 thousand tonnes, the lowest figure recorded in the past decade. Romania's annual consumption of around 5 to 7 thousand tonnes represents only a small share of this total, placing the country among the lowest pesticide users in the Union (Robu et al., 2023). Although Romania does not yet have explicit national reduction targets—the EU goal is a 50 percent cut by 2030—the available evidence already indicates a downward trajectory, both in overall volume and in application rates per hectare (Eurostat, 2023).

Table 1 Trends in pesticide use and genetically modified corn adoption in the United States

Indicator	Analyzed context	Empirical evidence
Percentage of corn acreage treated with herbicides in the USA	"Over 90% of corn acreage has been treated with herbicides each season since the 1980s"	USDA ERS reports that in 2024, approximately 95.1% of planted acreage was treated with herbicides
Share of corn treated for weed control vs. mechanical/manual weeding	"Relies almost exclusively on chemical herbicides"	Reflects the current industrial model – data shows very extensive herbicide use (>95%)
Roundup Ready corn (glyphosate-resistant) and "carpet bombing"	Introduction of "Roundup Ready" seeds reinforced uniform herbicide spraying	Herbicide-tolerant varieties were gradually adopted; in 2024, about 90% of corn acreage is planted with these crops
Long-term effects: resistant weeds ("superweeds")	"...superweeds such as Amaranthus palmeri appear..."	Estimates show an increasing number of glyphosate-resistant weeds; no precise figures found for Amaranthus palmeri, but the phenomenon is confirmed
Ecological effects (beneficial insects, water, etc.)	"...possible impacts on ecosystem health..."	Critical literature highlights the impact of pesticides on beneficial insects and water pollution, but no recent quantitative data specific to corn/USA found in the latest sources reviewed

Source: authors elaboration based on data from www.ers.usda.gov

The evidence confirms that corn production in the United States continues to rely heavily on chemical herbicides and genetically modified (GM) traits. Since the 1980s, herbicide applications have covered more than 90 percent of the national corn acreage, and today the figure exceeds 95 percent. The widespread introduction of glyphosate-resistant "Roundup Ready" corn, along with stacked GM traits that combine herbicide tolerance with insect resistance, has consolidated a production model built primarily on chemical control rather than on mechanical or integrated alternatives. This approach ensures high yields and effective weed suppression, yet it has also accelerated the spread of glyphosate-resistant "superweeds" such as Amaranthus palmeri. In addition, it has raised ecological concerns, particularly regarding risks to beneficial insect populations and potential impacts on water quality. Taken together, the findings highlight both the immediate productivity gains of the U.S. corn monoculture system and the long-term sustainability challenges it faces.

Structure of pesticides use

In both Romania and the United States, herbicides constitute the largest share of pesticide use, underscoring the central role of weed control in maize cultivation. Across the European Union, herbicides together with fungicides account for roughly 75 percent of total pesticide sales (Eurostat, 2023). A similar trend is visible in the United States, where herbicides represent nearly 90 percent of all pesticides applied in agriculture (Clancy et al., 2016). This pattern is particularly evident in maize production, where most treatments consist of pre- or post-emergence herbicides aimed at controlling weeds. In Romania, these include products such as atrazine, acetochlor, and sulfonylureas, while in the U.S. common substances are glyphosate, atrazine, dicamba, and 2,4-D.

By contrast, insecticide use is far more limited and tends to be applied selectively. In Romania, insecticides have traditionally been used as seed treatments—especially neonicotinoids prior to their ban in 2013—or during the growing season based on pest monitoring, targeting species like the European corn borer (Ostrinia nubilalis) and the western corn rootworm (Diabrotica virgifera). In recent years, however, European restrictions have led to a sharp decline in insecticide use. Between 2007 and 2020, national consumption fell by nearly half. Even before the neonicotinoid ban, insecticide applications in maize were largely limited to substances such as tefluthrin for soil treatments against Diabrotica, or pyrethroids and organophosphates used occasionally when pest pressure was high. These volumes were minor compared with herbicides. For instance, in 2020 Romania used only about 641 tonnes of insecticides (active ingredient), compared with 2,901 tonnes of herbicides. This confirms that weeds remain the most significant phytosanitary challenge in national maize production, far outweighing the threat posed by insect pests (Popescu et al., 2021).

In the United States, even with its vast cultivated area, insecticide use on maize has declined significantly over the past few decades. This reduction is largely attributed to the widespread adoption of Bt hybrids, genetically modified maize that expresses insecticidal proteins derived from Bacillus thuringiensis (Abbas, 2018). The share of insecticides in total U.S. agricultural pesticide use fell from 58 percent in 1960 to only about 6 percent by 2008. In maize production, major insect pests such as wireworms, rootworms, and the European corn borer are now controlled primarily through Bt toxins expressed within the plants themselves. Nonetheless, new challenges have surfaced. Diabrotica virgifera has developed resistance to certain Bt toxins in parts of the United States, forcing farmers in those regions to return to conventional insecticide applications. In addition, outbreaks of Spodoptera frugiperda (fall armyworm) occasionally require supplementary treatments (Meinke et al., 2021).

The overall structure of pesticide use in maize underscores the dominant role of weed management strategies in both Romania, as a representative EU case, and the United States (Dragomir et al., 2022). Herbicides remain the primary category of pesticides in both systems, while insecticide use has decreased markedly. In the European Union, this decline stems mainly from regulatory restrictions, whereas in the United States it reflects the adoption of genetically modified Bt hybrids. The following table provides a synthesis of the main pesticide categories, their proportions, the most frequently used substances, and the key trends that define pesticide application in the two agricultural systems.

Table 2 Comparative structure of pesticide use in maize cultivation in Romania (EU) and the United States

Category / Aspect	Romania (EU context)	United States
Dominant pesticide category	Herbicides + fungicides ≈ 75% of pesticide sales (EU average)	Herbicides ≈ 90% of all agricultural pesticide use
Herbicides commonly used in maize	Atrazine, acetochlor, sulfonylureas	Glyphosate, atrazine, dicamba, 2,4-D
Herbicide volume (2020)	2,901 tonnes (active ingredient)	Very high, though exact tonnage varies annually; >95% of maize acres treated with herbicides
Insecticide use: level & trend	Limited, mainly seed treatments or on-demand spraying; fell by ~50% between 2007–2020 due to EU restrictions	Declined sharply with Bt maize adoption; share of insecticides in total pesticide use fell from 58% (1960) → ~6% (2008)
Insecticides used in maize	Before 2013 ban: neonicotinoids; also tefluthrin, pyrethroids, organophosphates	Residual use against resistant pests: rootworms, wireworms, European corn borer; occasionally fall armyworm
Volume (2020)	641 tonnes insecticides vs. 2,901 tonnes herbicides	Not expressed in tonnes; but acreage treated is minimal due to Bt traits
Key drivers	EU restrictions on	Adoption of Bt

of reduction in insecticides	neonicotinoids (2013) + integrated pest management monitoring	hybrids expressing *Bacillus thuringiensis* toxins
Emerging challenges	Dependence on herbicides; weed resistance risk (e.g., atrazine-resistant biotypes)	Resistance of *Diabrotica virgifera* to Bt toxins; fall armyworm outbreaks requiring insecticide sprays

Source: author elaboration based on Eurostat, 2023; Clancy et al., 2016; Popescu et al.,2021; Meinke et al., 2021; Dragomir et al. 2022

The comparative analysis shows that weed control continues to be the primary phytosanitary challenge in both Romania and the United States, which explains the heavy reliance on herbicides. In Romania, even with European Union restrictions, herbicides are applied in far greater volumes than insecticides, reflecting the persistent structural problem that weeds pose for maize cultivation. Insecticide use has declined sharply and is now confined to targeted interventions, with regulatory bans accelerating this reduction. In the United States, the same pattern is visible, although the drivers are different. Here, technological innovation—especially the adoption of Bt hybrids—has significantly lowered the need for insecticide applications. At the same time, both production systems face emerging biological threats: herbicide-resistant weed populations in Romania and Bt-resistant insects in the United States. These developments indicate that the long-term sustainability of current pesticide strategies is becoming increasingly uncertain.

The data further illustrate this trend. Herbicides dominate pesticide use in maize production in both Romania and the United States, accounting for 82 percent and 90 percent of total applications, respectively. Insecticides, though far less significant, make up about 18 percent of pesticide use in Romania compared with only 8 percent in the United States. These differences reflect the impact of EU regulatory measures on one side and the adoption of genetically modified Bt maize on the other. Taken together, the findings confirm that weed control remains the central issue in maize cultivation, while insect management plays a more limited and context-dependent role, shaped primarily by agricultural policy and the use of biotechnology.

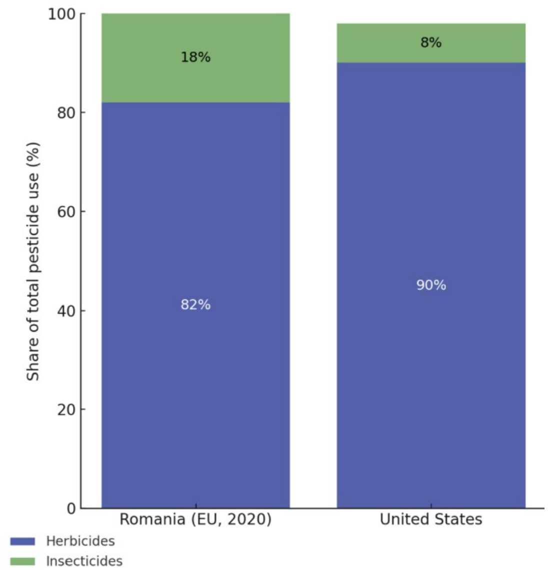

Figure 2 Herbicide vs insecticide use in maize cultivation Romania (2020) vs United Stated
Source: author elaboration based on Eurostat 2023 data

Regulations and crop protection practices: EU vs. U.S.

An essential factor influencing pesticide use is the regulatory and policy framework under which farmers operate. The European Union enforces some of the strictest rules worldwide for the approval and application of plant protection products. According to Regulation (EC) No. 1107/2009, an active substance can only be authorized in the EU if it is proven not to pose unacceptable risks to human or animal health or to the environment (Donley, 2019). The precautionary principle is central to this approach, meaning that substances classified as mutagenic, carcinogenic, toxic to reproduction, or endocrine disruptors are generally excluded from use. Over the past two decades, this policy has resulted in the progressive withdrawal of numerous pesticides from the European market.

One of the most widely discussed cases involves neonicotinoids. Three active substances—imidacloprid, clothianidin, and thiamethoxam—were partially restricted in 2013 for use on bee-attractive crops. In 2018, their application in any outdoor setting was banned across the EU due to the documented risks they pose to pollinators. A fourth molecule, thiacloprid, was withdrawn in January 2020 (Harrison-Dunn, 2021).

The situation in the United States stands in sharp contrast. Neonicotinoids have remained widely available, particularly as seed treatments. Nearly all U.S. maize is planted with seeds treated with compounds such as clothianidin or thiamethoxam, which are intended to protect against soil-dwelling and early-season pests. Only in recent years, between 2021 and 2022, has the Environmental Protection Agency begun to impose restrictions, while some states, such as California, have enacted their own bans. At the federal level, however, no comprehensive prohibition has been introduced.

This divergence in regulation has allowed American farmers to maintain access to a broader range of pesticides, including products that European farmers can no longer use (U.S. Geological Survey, 2020). A landmark study highlighted the scale of this gap: in 2016, U.S. agriculture applied about 322 million pounds (146 million kilograms) of pesticides that had already been banned in the EU, accounting for more than one quarter of all pesticides used in the United States that year (Pelaez, 2023). In other words, many substances considered too hazardous by European regulators continued to be applied on American fields. Notable examples include organophosphate insecticides such as chlorpyrifos, banned in the EU in 2020 but permitted in the United States until 2021, the herbicide paraquat, prohibited in the EU since 2007 but still used in the United States, and fungicides like chlorothalonil, withdrawn from the EU market in 2019 yet retained in U.S. agriculture (European Commission, 2021).

Table 3 Regulations and crop protection practices in the EU vs. the U.S.

Criteria	European Union (EU)	United States (U.S.)
Regulatory framework	Regulation (EC) No. 1107/2009: approval only if no unacceptable risks to health or environment; strong reliance on the precautionary principle.	Regulatory system more permissive; EPA evaluates risk–benefit but rarely enforces precautionary bans; many substances remain available longer.
Criteria for banning substances	Substances classified as mutagenic, carcinogenic, toxic to reproduction, or endocrine disruptors are generally prohibited.	No systematic prohibition at federal level; bans or restrictions often delayed, partial, or enacted only at the state level (e.g., California).
Neonicotinoids	Imidacloprid, clothianidin, thiamethoxam restricted in 2013, fully banned outdoors in 2018; thiacloprid withdrawn in 2020.	Widely used, especially as seed treatments for maize; clothianidin and thiamethoxam common. Only recently (2021–2022) did EPA start limiting some uses; no nationwide ban.
Examples of pesticides banned in EU but used in U.S.	Chlorpyrifos (2020), paraquat (2007), chlorothalonil (2019), and others.	Still permitted for years after EU ban: chlorpyrifos (until 2021), paraquat (still used), chlorothalonil (still used).
Extent of divergence	Over two decades, many active substances progressively removed.	In 2016, U.S. applied ~322 million pounds (146 million kg) of pesticides already banned in the EU (~25% of total U.S. use).

Source: authors elaboration based on Donley, 2019; Harrison-Dunn, 2021; Pelaez, 2023; European Comission, 2021; U.S. Geological Survey, 2020

The comparison brings into focus a fundamental regulatory divide between the European Union and the United States. The European Union has consistently followed a precautionary model, gradually banning substances identified as harmful to human health, pollinators, or ecosystems. By contrast, the United States has favored a system that emphasizes flexibility in crop protection, allowing farmers to use a broader range of pesticides, including many that are no longer permitted in Europe. These contrasting approaches have shaped not only pest management strategies but also the associated environmental and health risk profiles. In essence, while the European Union prioritizes long-term safety and precaution, the U.S. framework favors short-term agronomic efficiency and producer flexibility. This divergence illustrates the ongoing tension between regulatory caution and production pragmatism in global agriculture.

The regulatory system in the United States is anchored in the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA), which is widely considered more permissive. Under this framework, a pesticide can be authorized provided it does not cause “unreasonable adverse effects” when balanced against its economic benefits (Roberts et al., 2012). In practice, this means that approval is based on a risk–benefit compromise: if a substance ensures significant advantages, such as higher yields or reduced production costs, and the associated risks are not judged excessive, it remains available on the market.

This approach has contributed to delays in withdrawing older, hazardous substances. Analysts have pointed out that in recent years the Environmental Protection Agency has moved away from suspending pesticide registrations on its own initiative, often requiring agreement from industry stakeholders before taking such steps (Guha et al., 2024).

In the short term, this system provides U.S. farmers with a competitive advantage by granting them access to chemical tools that European producers can no longer use. Over the longer term, however, these benefits may be offset by hidden costs, including risks to public health through consumer and farmworker exposure, as well as environmental degradation caused by persistent chemical residues.

In Romania, as a member of the European Union, all EU regulations are fully applicable. Nevertheless, national authorities have occasionally relied on derogatory clauses to authorize the temporary use of banned pesticides in situations defined as phytosanitary emergencies (Popescu et al., 2024). Article 53 of Regulation 1107/2009 allows member states to issue emergency authorizations, valid for up to 120 days, for prohibited products if pest outbreaks cannot be controlled through other means. Romania has made extensive use of this mechanism, most notably for neonicotinoid seed treatments in maize and sunflower. The justification has consistently been the severe damage caused by soil pests such as the maize leaf weevil (Tanymecus) and the western corn rootworm (Diabrotica virgifera) (Toader et al., 2024).

Between 2016 and 2021, Romanian authorities approved a total of 28 derogations for imidacloprid, clothianidin, and thiamethoxam. This effectively kept these substances in annual use for spring seed treatments despite their EU-wide ban (Chiurciu et al., 2024). The practice sparked criticism from environmental organizations and was reviewed by the European Food Safety Authority. In 2020, the European Commission moved to sharply restrict derogations for neonicotinoids, turning down Romania's repeated requests. More recently, in March 2025, the Court of Appeal in Cluj suspended the last authorizations granted, effectively ending a long-standing reliance on annual exemptions (pan-europe.info).

This situation reflects the difficult position of Romanian policymakers. On one hand, they are required to comply with EU environmental legislation, while on the other they face pressure from farmers confronted with pests that are extremely difficult to control without neonicotinoids. Once these products were no longer available, growers were left with only limited alternatives such as crop rotation and localized treatments with other insecticides, which are often less effective. This creates uncertainty about production security and explains why demand for derogations persisted for so many years.

By contrast, farmers in the United States continued to use neonicotinoids without major restrictions until very recently. This illustrates the more flexible nature of U.S. regulation, although it comes at the potential cost of pollinator health. The country has also reported extensive losses of bee colonies, partly linked to neonicotinoid exposure. A 2019 study pointed out that many pesticides most commonly used in the United States—amounting to tens of millions of kilograms each year—had already been banned or phased out in the European Union, China, and Brazil. This suggests that the American system responds more slowly to toxicological evidence (Donley, 2019).

SWOT analysis of pesticide use in maize cultivation

To provide a structured evaluation of pesticide use in maize production, this study applies the SWOT framework, a tool that synthesizes internal strengths and weaknesses together with external opportunities and threats. This method goes beyond presenting numerical data, as it makes it possible to capture the wider implications of current practices, regulatory choices, and technological developments. By comparing Romania, which represents a lower-input and regulation-driven agricultural model, with the United States, characterized by intensive and technology-oriented farming, the SWOT analysis sheds light not only on the advantages of pesticide use but also on its limitations, risks, and future directions. Such a perspective is especially valuable for designing strategies that can strike a balance between crop protection and sustainability, ensuring that immediate gains in productivity do not compromise long-term environmental integrity or public health.

Strengths

Modern pesticides give farmers a reliable means of controlling harmful organisms, helping to prevent major crop losses and directly supporting higher yields. In intensive farming systems such as those found in the United States, the combined use of herbicides and herbicide-tolerant seed varieties allows weeds to be managed efficiently with relatively low labor costs, which in turn contributes to greater farm profitability. Another advantage is that chemical crop protection brings stability to maize production from one year to the next, reducing the risk of severe fluctuations that might otherwise result from pest outbreaks or widespread plant diseases (Katri et al., 2024).

In Romania, one of the notable strengths is the more cautious approach traditionally taken in pesticide application. Farmers tend to use moderate doses and intervene only when necessary. This practice has helped preserve a relatively diverse and functional ecosystem, with strong populations of natural predators and pollinators that contribute to biological control. At the same time, toxicological risks for consumers remain low, as residue levels in food products are generally found to be below the maximum permissible thresholds according to recent monitoring (Popescu et al., 2025). Taken together, these examples show that rational pesticide use continues to be one of the most effective strategies for safeguarding global food security, provided that yield benefits clearly outweigh the outcomes of non-treatment.

Weaknesses

Heavy dependence on synthetic pesticides comes with considerable drawbacks. One of the most critical problems is the development of resistance in pests and weeds, caused by the repeated and large-scale use of the same chemical compounds. This issue has been well documented in the U.S. Midwest, where numerous weed populations have evolved resistance to glyphosate, forcing farmers to resort to more toxic herbicide combinations (Benbrook, 2021). Another major weakness is the fact that pesticides do not distinguish between harmful and beneficial organisms. As a result, natural predators, parasitoids, and pollinators often decline in chemically intensive farming systems. This loss of biodiversity can create a vicious cycle, since the reduction of natural enemies tends to aggravate pest problems and further increase dependence on pesticides.

Beyond these biological effects, pesticide use generates a series of environmental and health-related externalities. Contamination of groundwater, soil, and even air has been recorded in regions of intensive agriculture. Substances such as atrazine, chlorpyrifos, and neonicotinoids have been found in water samples or wildlife tissues at concentrations that raised scientific concern. In Romania, another weakness is that the reduction in pesticide use has not been fully offset by the adoption of effective alternatives. The technological gap left by banned substances, particularly neonicotinoids, has not been completely filled, leaving many farmers—especially smallholders—with few options to manage pests effectively. This explains both the repeated requests for derogations and the frequent complaints from farmers about crop losses in seasons when adequate treatments were not available. Structurally, the fragmentation of farms in Romania, with many small holdings, also restricts the capacity to apply coordinated pest management strategies or to invest in advanced technologies such as precision agriculture (Ghiuleanu, 2023).

Opportunities

Although current challenges are significant, there are many opportunities to improve pesticide management in maize production systems. Advances in science and technology are creating promising alternatives to conventional chemicals. Biopesticides based on viruses, bacteria, or entomopathogenic fungi are emerging as viable solutions, while plant-derived compounds such as essential oils and botanical extracts with insect-repellent or antifungal properties are also gaining ground. At the frontier of research, innovative tools like RNA interference and gene editing hold the potential to enhance crop resistance to pests and diseases. Precision agriculture represents another important opportunity. By using sensors, satellite imagery, and artificial intelligence, farmers can identify and treat only the affected portions of their fields, which can greatly reduce pesticide use. In Romania, the availability of European Union funding and the increasing openness of younger farmers to adopt new technologies may accelerate the spread of such practices (Pergner et al., 2023).

Opportunities also exist at the level of agronomic knowledge and training. Wider adoption of integrated pest management (IPM) techniques—including crop rotation, soil cultivation to break pest life cycles, delayed sowing, or the use of resistant hybrids—can significantly lower reliance on chemical inputs (Aslam, 2025). At the same time, changing consumer preferences and stricter regulations are reshaping agricultural markets. Demand for organic maize and products free of chemical residues is steadily increasing, which provides strong incentives for farmers to adopt more sustainable practices. Countries that adapt early to these requirements stand to gain privileged access to premium markets. Policy frameworks are also evolving in support of this transition. The EU's Common Agricultural Policy for 2023–2027, for example, includes eco-schemes that reward farmers who reduce pesticide use, while in the United States, it is likely that future subsidies and insurance schemes will increasingly be tied to environmentally friendly practices (Runge et al., 2023). Together, these technological, agronomic, and market-driven changes offer clear opportunities to move towards greener and more sustainable production models without necessarily sacrificing productivity.

Threats

Several external threats influence pesticide use in maize cultivation, with climate change standing out as one of the most significant. Rising global temperatures and greater climatic variability are likely to intensify pest pressures. Milder winters may increase pest survival rates, while hotter summers could enable multiple pest generations within a single season. This situation may lead to higher pesticide consumption or, alternatively, render existing products less effective if current compounds fail under new environmental conditions. Prolonged droughts represent another challenge, as they weaken plants and make them more vulnerable to pest and disease attacks, often requiring additional treatments.

Another serious threat is the growing problem of resistance. Without the discovery and introduction of new active substances, an increasing number of pest populations may become resistant to the products currently available. This could trigger phytosanitary crises in which no registered pesticide remains effective. In addition, there is the regulatory and legal risk that key compounds—such as glyphosate in the United States—could be withdrawn as a result of litigation or shifts in policy, leaving farmers with fewer reliable options and potentially reducing yields in the short term (Rauf, 2024).

Economic risks also play a critical role. Volatility in global input markets can drive sudden increases in pesticide prices, as seen in 2022 during the energy crisis and the war in Ukraine, forcing farmers to reduce doses or skip treatments altogether, which heightens the risk of crop losses. Sudden regulatory changes carry similar dangers: when widely used products such as chlorpyrifos or certain triazoles are abruptly banned, farmers are compelled to adopt costlier or less effective substitutes, often with little time to adjust.

Public perception and activism represent another source of pressure. Negative attitudes toward pesticides—illustrated by campaigns to ban glyphosate in Europe—can prompt restrictive regulations that, if introduced too quickly, may undermine production stability. Trade-related risks are also significant. Divergences in maximum residue limits (MRLs) between countries can act as barriers to international commerce. For example, the European Union has considered banning imports of cereals containing neonicotinoid residues (Khandelwal et al., 2022). Such measures could jeopardize exports from countries with more permissive standards, forcing them to align with stricter regulations in order to maintain market access.

Table 4 SWOT matrix of pesticide use in maize cultivation

Strengths	***Weaknesses***
Effective control of pests and weeds, preventing major crop losses	Resistance in pests and weeds due to repeated use
Stable yields and reduced harvest fluctuations	Negative impact on beneficial organisms (pollinators, predators)
Efficient weed management with herbicide-tolerant seeds (U.S.)	Environmental contamination of soil, water, and air
Prudent pesticide use and preserved biodiversity (Romania)	Limited alternatives and farm fragmentation (Romania)
Opportunities	***Threats***
Biopesticides, natural extracts, and new genetic tools.	Climate change increasing pest pressures
Precision agriculture for targeted applications.	Growing resistance with fewer effective molecules
Rising demand for organic and residue-free maize.	Bans of key pesticides disrupting production
Policy support for eco-schemes and sustainable	Price volatility and sudden regulation changes

farming	
	Negative public perception and trade restrictions

Source: own elaboration

Overall, the SWOT analysis shows that pesticide use in maize cultivation combines important benefits, such as higher productivity and efficiency, with significant vulnerabilities and risks. The general direction, both in Romania and worldwide, is to build upon existing strengths, including accumulated knowledge and the demonstrated effectiveness of crop protection products, while addressing weaknesses through precautionary approaches and innovative solutions. At the same time, it is essential to take advantage of emerging scientific opportunities in order to reduce the impact of the growing threats that challenge the long-term sustainability of agricultural systems.

CONCLUSIONS

This study has emphasized the sharp differences between pesticide use in maize cultivation in Romania and the United States, while also offering a perspective on current trends in sustainable crop protection. The findings confirm that Romania operates with very low chemical inputs, averaging only about 0.8 kg of pesticides per hectare in recent years, one of the lowest levels in the European Union. This modest consumption is linked not only to strict regulatory requirements but also to the more traditional structure of many farms. Even so, Romania remains a significant agricultural producer, though its performance is vulnerable to unfavorable weather conditions and to the gradual reduction in the range of chemical tools available. In contrast, the U.S. model illustrates how extensive pesticide use—around three times more active substances per hectare than in Romania—can sustain exceptionally high yields, but at the cost of serious challenges, including resistance development, environmental stress, and systemic dependency on chemical inputs.

The comparison between these two systems highlights both their strengths and their weaknesses. The American intensive approach, driven by biotechnology and chemistry, secures very high short- and medium-term productivity but raises questions about long-term ecological sustainability. The European, and specifically Romanian, model follows a more precautionary path that reduces toxic risks and helps preserve biodiversity, yet it struggles to maintain productivity and competitiveness without access to certain key pesticides. The main contribution of this research lies in bringing these contrasting experiences into a common framework, through the combined use of SWOT analysis and policy review. The results suggest that the most promising future path may be a hybrid model: one that applies pesticides rationally and selectively, only when benefits clearly outweigh risks and alternatives are lacking, while simultaneously expanding the use of precision technologies and biological farming innovations to progressively reduce dependence on synthetic chemicals.

Over the past five years, both Romania and other countries have made visible progress in tackling the challenges associated with pesticide use. Within the European Union, initiatives such as the Green Deal have set ambitious reduction targets, stimulating research into alternatives and encouraging closer dialogue with farmers. In the United States, where regulatory changes have been slower, the consequences of intensive pesticide reliance are becoming harder to ignore. High-profile lawsuits, most notably those concerning glyphosate, have brought renewed scrutiny and spurred investment in safer products. What emerges from these developments is a clear message: reducing pesticide use is not only possible but also necessary, provided it is done carefully, in ways that do not undermine food security. Agronomic research in Romania and abroad points toward practical solutions—such as crop rotation, biological traps, biocontrol agents, and resistant hybrids—that could replace some conventional treatments. Yet these alternatives can only succeed if they are backed by coherent policies and supported by strong knowledge-transfer systems that help farmers put them into practice.

The findings of this study confirm the initial hypothesis. There are substantial differences between Romania and the United States in how pesticides are used in maize production, and these differences shape both yields and environmental outcomes. Romania's cautious, regulation-driven model helps protect biodiversity and reduce toxic risks but often struggles with productivity and competitiveness. The U.S. model, by contrast, sustains very high yields through intensive chemical use, though it carries growing risks linked to resistance, environmental damage, and dependency on synthetic inputs. The broader lesson is that neither extreme—complete dependence on pesticides nor their outright abandonment—can serve as a sustainable path forward.

The future of maize cultivation lies in integration. Rational and selective use of pesticides, only when benefits are clear and alternatives are lacking, must be combined with precision technologies, biological methods, and continuous innovation in farming practices. Equally important is the need for policy frameworks that evolve alongside scientific evidence, ensuring farmers are encouraged and supported in adopting safer and more efficient approaches. Following such a balanced path offers the best chance for maize production to remain productive, competitive, and sustainable not only in Romania but also worldwide.

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