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CURRENT KNOWLEDGE REGARDING THE SOIL PESTS AND THEIR CONTROL OPTIONS IN MAIZE CROPS FROM SOUTHERN ROMANIA

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Abstract: With an annual cultivated surface of 2.2 to 2.7 million hectares, maize is the most important cereal crop in Romania, followed by wheat and barley. Yields of maize crops have considerably fluctuation between years, mainly due to abiotic factors like drought and biotic factors represented by pest insects. Maize is attacked by a large number of arthropods, the southern area of Romania being particularly affected by the attack of some harmful species such as *Tanymecus dilaticollis*, *Opatrum sabulosum* and different complexes of wireworms that can compromise crops, on large areas, from the first stages of crop vegetation. The paper reviews the recent literature on general distribution and economic importance of main soil-dwelling pests in relation to maize production. Also, control methods that can be used for their integrated management are discussed.

Key words: *soil pests, maize crops, IPM, biological control*

INTRODUCTION

Maize (*Zea mays* L.), a crop originating from the Andean region of Central America, ranks among the most significant cultivated plants worldwide due to its diverse applications in human nutrition, animal feed, and industry. Globally, it is grown on roughly 208 million hectares, producing over 1241 million tonnes of grain (FAOSTAT, 2023). Together with wheat and rice, maize constitutes one of the three principal sources of dietary calories for the global population (Shiferaw et al., 2011).

In recent years, maize has become the cereal crop with the greatest share in Romania's agri-food balance, covering between 2.2 and 2.7 million hectares annually (MADR data, 2024). However, crop productivity is frequently constrained by climatic (Ray et al., 2015), soil condition (Furlan et al., 2017; Nanu et al., 2024) and biological factors, particularly soil-dwelling pests that can severely damage or even destroy young seedlings during emergence (Iamandei & Rujescu, 2023; Georgescu et al., 2018).

Among soil-dwelling pests, the maize leaf weevil (*Tanymecus dilaticollis* Gyll.) stands out as the most destructive species affecting maize crops across the Romanian Plain and South-Eastern regions. This broadly polyphagous insect feeds not only on maize and sunflower but also on sugar beet, various cereals, and leguminous crops, occasionally causing yield losses approaching 100% during drought years (Georgescu et al., 2018; Candan et al., 2020). The species produces a single generation annually and survives the winter as an adult in the soil. With the onset of warmer spring temperatures, adults emerge, initially feeding on weeds and winter cereals before moving to young maize plants, where their characteristic

feeding along leaf margins can induce wilting and complete seedling mortality. Infestation severity is closely associated with warm, dry conditions that favor adult activity. Following the European Union's ban on neonicotinoid seed treatments (Official Journal of the European Union, Commission Implementing Regulation (EU) No 485/2013 of 24 May 2013), effective control strategies have become limited, while warming climatic trends have further enhanced overwintering survival and contributed to increased pest pressure (Badiu et al., 2019; Chiriloaie-Palade et al., 2024).

In addition to *T. dilaticollis*, two other groups of pests contribute significantly to economic losses in the south of the country: the grey sand beetle (*Opatrum sabulosum* L.) and the complex of wireworms *Agriotes* spp. larvae.

O. sabulosum has become an increasingly problematic soil pest in southern and central regions of Romania, where dry and light-textured soils favor its development (Trotuș et al., 2015). Adults are most active in early spring, reaching densities of several dozen to hundreds of individuals per square meter. They feed on a wide range of crops, including maize, sunflower, cereals, and root crops, as well as young conifer seedlings. Both adults and larvae cause significant damage, adults gnawing at the roots and basal stem tissues and forming narrow feeding galleries, while larvae attack underground plant parts (Nazimov, 2024). In cultivated fields, *O. sabulosum* feeding often results in poor germination, uneven emergence, and plant losses reaching 20-30%. According to recent studies, the absence of seed treatments and the restrictions on neonicotinoids have led to increased pest populations, emphasizing the importance of integrated soil pest management strategies in maize- and sunflower-based agroecosystems (Trotuș et al., 2015; Tălmaciu et al., 2022).

The larval complex of *Agriotes* spp. represents a particularly damaging and hard-to-manage group of soil pests. Larvae remain active in the soil for extended periods, typically three to five years, during which they consume seeds, roots and the growing points of seedlings, undermining plant establishment (Furlan, 2014). In Central and Eastern Europe the dominant species are *A. brevis*, *A. sordidus* and *A. ustulatus* (Furlan, 2017) while *A. sputator*, *A. obscurus* and *A. lineatus* are frequently recorded across Romania's lowland regions (Bucurean & Bunta, 2011; Iamandei & Rujescu, 2023). In situations without preventive measures, high larval densities can translate into severe stand reductions, reports indicate losses of up to about 40% in susceptible crops, notably maize (Furlan, 2014). Under current agricultural and environmental conditions, soil pests can no longer be effectively managed through chemical control alone. An integrated pest management (IPM) approach has become essential, combining crop rotation, population monitoring, the use of traps and warning thresholds, and the implementation of viable biological alternatives (Georgescu et al., 2022; Furlan, 2014).

Accordingly, the present review aims to outline the distribution, economic impact, and environmental drivers of the main soil pests in southern Romania, while also addressing modern control strategies aligned with the European Union's objectives for reducing pesticide-related risks to both the environment and public health.

2. Distribution and Economic Importance of Soil Pests in Maize in Southern Romania

2.1. The grey maize weevil - *Tanymecus dilaticollis*

The grey maize weevil *T. dilaticollis* (Coleoptera:Curculionidae) is a polyphagous species belonging to the Curculionidae family. It is univoltine and overwinters as an adult in the soil at depths of 40-100 cm depending on soil type and temperature (Paulian, 1972; Pintilie et al., 2024). Adults emerge in early spring once soil temperatures exceed 9-10°C,

initially feeding on weeds and later on emerging maize plants. The critically phase of attack on maize generally lasts from the moment when coleoptile penetrates soil surface (BBCH 10) until the development of four to five leaves (BBCH 14-15). During this interval, adult insects feed on the tender foliage and frequently damage the apical meristem, which can result in the death of entire seedlings.

Females deposit their eggs in the soil, where larvae feed on maize roots during summer before pupating underground. The biological cycle concludes when new adults emerge in late summer and subsequently remain in the soil to overwinter (Paulian, 1972). The species exhibits a high reproductive potential that aligns with the phenology of maize and sunflower crops. This synchronisation, together with its trophic plasticity, allows *T. dilaticollis* to persist across diverse agroecosystems in Eastern and Southeastern Europe (Pintilie et al., 2024; Takov et al., 2023). Recent reports indicate that this adaptability, combined with favourable climatic conditions, contributes to recurrent population outbreaks in maize-growing regions.

T. dilaticollis is a thermo-xerophilous species well adapted to the warm, dry climates of southern and southeastern Romania, Bulgaria, and parts of Moldova region. Its seasonal dynamics are strongly influenced by spring temperature and rainfall. Warm, dry springs promote rapid post-hibernation emergence and prolonged feeding activity, while cool, wet conditions delay appearance and reduce crop injury (Pintilie et al., 2024). Reported densities vary substantially, ranging from 15-80 adults/m² under average conditions to peaks of up to 160 adults/m², during severe infestations (Takov et al., 2023; Georgescu et al., 2022). Such fluctuations reflect the combined influence of climatic variability and the inconsistent effectiveness of current pest management strategies. Climate change has contributed to pest expansion northward, where warmer winters and lower spring rainfall shorten hibernation and increase survival rates (Badiu et al., 2019).

Ecologically, *T. dilaticollis* plays a dominant role in early-season maize pest complexes, along with species of *Agriotes*. Studies from Central Moldova (Pintilie et al., 2024) confirm that adult attack intensity depends less on sowing time or hybrid genotype and more on climatic conditions, particularly April - May temperature fluctuations. The pest prefers monocultures of maize and sunflower, where its populations remain stable due to the continuous presence of food sources. Crop rotation and soil tillage can reduce local populations but rarely prevent migration from adjacent infested areas (Georgescu et al., 2018).

The economic impact of *T. dilaticollis* is severe and regionally significant. In Romania alone, between 0.8 and 1.0 million hectares of maize and about 0.5 million hectares of sunflower are affected annually (Georgescu et al., 2024). At densities exceeding 25-30 adults/m², maize yield losses reach 30-35%, and complete crop destruction may occur at higher densities (Paulian, 1972; Bărbulescu et al., 2001).

Before 2019, neonicotinoid seed treatments were the most effective protection method, preventing annual losses estimated at tens of millions of euros. Their EU-wide neonicotinoids ban (Regulation 485/2013) forced farmers to rely on pyrethroid soil and foliar applications, which have lower efficacy and higher costs (Toshova et al., 2021; Georgescu et al., 2022). In 2024, field trials in southeastern Romania confirmed that neither pyrethroids nor neem oil treatments fully prevent seedling damage in maize or sunflower (Georgescu et al., 2024).

In the absence of reliable chemical solutions, attention has shifted toward biological and IPM strategies. Entomopathogenic fungi, mainly *Beauveria bassiana* (Bals.) Vuill. and *Metarhizium anisopliae* (Metsch) Sorok have been isolated from adult beetles, suggesting a

naturally occurring biological control mechanism (Draganova et al., 2012; Takov et al., 2023; Fătu et al., 2023).

Bioinsecticides based on *B. bassiana* (Naturalis®) and azadirachtin (NeemAzal T/S®) assessed under laboratory conditions achieved promising results against *T. dilaticollis*, 100% corrected mortality, ten days after treatment, was reported at spore concentrations of *B. bassiana* over 2.3×10^5 conidia/mL for females and 2.3×10^6 conidia/mL for males; and moderate efficacy (48.5%) for neem oil at 4% concentration was reported 16 days after treatment (Toshova et al., 2021). The performance of these fungi, however, appears to be affected by environmental factors, particularly humidity, which may constrain their efficacy under field conditions (Fatu et al., 2023).

Furthermore, *Steinernema carpocapsae* Weiser nematodes demonstrated over 94% mortality in adult weevils under laboratory and semi-field conditions (Toshova et al., 2024). A three-year study performed in field conditions by Toader et al. (2020) reported that a commercial insecticide based on *Bacillus thuringiensis* (Bactospeine DF, at a dose of 0.01%) showed moderate efficacy in term of saved plants when applied on maize seeds (74.98%) or in vegetation (77.73%) and a good efficacy of Neem oil at a dose of 2.5 mL/250 g of seed (81.3%).

Despite these advances, large-scale adoption of biological methods remains limited by cost, application logistics and climatic dependency. Nevertheless, integrating biological control agents with targeted seed protection and adjusted sowing dates can substantially reduce yield losses. According to recent economic projections, unchecked *T. dilaticollis* infestations could reduce maize yields in southeastern Europe by up to 0.8 tons/ha annually, posing a significant threat to regional food security and export competitiveness (Pintilie et al., 2024; Georgescu et al., 2024).

2.2. The darkling beetle - *Opatrum sabulosum*

O. sabulosum (Coleoptera:Tenebrionidae) is a polyphagous pest frequently associated with maize and other spring crops in Eastern Europe. Adults are 7-10 mm long, compact, and covered with soil particles that protect against desiccation. They exhibit high adaptability and longevity, living for one to two years (Brygadyrenko & Nazimov, 2015; Nabozhenko, 2022). Adults overwinter in soil or under crop residues at depths of 10-30 cm, emerging in March - April, when average soil temperatures exceed 8-10°C (Nazimov, 2024). After emergence, beetles feed on decaying vegetation until maize seedlings appear. Egg laying occurs from late April to June; one female may lay 70-100 eggs in the upper 5 cm of soil (Brygadyrenko & Nazimov, 2015). Larvae develop in the soil, feeding on decomposing plant matter, and pupate by late summer. Newly emerged adults appear in July - August, feeding for several weeks before entering diapause.

In maize, *O. sabulosum* adults feed on the cotyledons, leaf margins, and basal stem tissue of young plants. At early growth stages (BBCH 10-14), they can destroy entire seedlings, particularly under hot, dry conditions (Grozea et al., 2006). The beetles prefer weakened or wilted plants, but under heavy infestations, they also attack vigorous seedlings, cutting them at the soil surface. Feeding trials demonstrated the beetle's remarkable trophic flexibility, consuming 95% of cultivated plants and 48% of wild herbaceous species offered under laboratory conditions (Brygadyrenko & Nazimov, 2015). This broad feeding capacity enables rapid adaptation to various crops, including maize, sunflower, sugar beet, tomato, and tobacco.

O. sabulosum is a thermo-xerophilous and euryoecious species, thriving in steppe and semi-arid regions with low spring precipitation. It is abundant in southern and southeastern Romania, Bulgaria, Moldova, and Ukraine, extending across the Caucasus up to 3000 m altitude (Nabozhenko, 2022). The beetle's ecology closely aligns with maize phenology. Its emergence period coincides with maize sowing and seedling establishment, resulting in synchronized pest pressure. Adults are most active during April - June, the critical window for maize germination and early vegetative growth. Population density can reach 20-80 adults/m², and in extreme cases, over 100 beetles/m² have been recorded in untreated maize fields (Brygadyrenko & Nazimov, 2015). In the western Romanian Plain, long-term studies in Jimbolia (Timiș County) found *O. sabulosum* among the top maize pests, attacking 17.5-31% of plants annually in untreated plots (Grozea et al., 2006). Its populations increase in continuous maize monocultures, particularly on light, sandy soils where plowing depth is insufficient to disrupt overwintering adults. Reduced-tillage or no-till systems further favor survival by preserving soil moisture and residues. Because adults can migrate between fields, localized treatments often fail to prevent recolonization.

The species' resilience is enhanced by its ability to survive periods without green vegetation by feeding on dried leaves, stems, and even manure. In dry years, this facultative detritivory allows *O. sabulosum* to bridge between cropping cycles, maintaining stable populations even after harvest (Brygadyrenko & Nazimov, 2015).

Recent ecological experiments identified natural enemies such as ground beetles (*Broscus cephalotes*, *Harpalus rufipes*) and assassin bugs (*Rhynocoris iracundus*) which preyed on *O. sabulosum* adults under laboratory conditions (Nazimov, 2024). However, field predation remains limited, and biological control is not yet sufficient to suppress populations under economic thresholds.

Although traditionally considered a secondary pest, *O. sabulosum* has become a significant economic threat to maize in Eastern and Southeastern Europe, especially under dry spring conditions and reduced insecticide use. Field research from 2002 to 2005 in western Romania demonstrated that *O. sabulosum* damaged 17.5-31% of maize seedlings, ranking immediately after *T. dilaticollis* (47-69.5%) and *Diabrotica virgifera virgifera* Le Conte (34-40%) (Grozea et al., 2006). The beetle attacks seedlings soon after emergence, chewing on the mesocotyl and young leaves. Damaged seedlings often wilt or die, leading to gaps in plant stands and irregular emergence. Yield losses in infested fields range between 10 and 30%, depending on plant density and environmental stress. In severe infestations, re-sowing may be required, increasing production costs by 20-40% (Brygadyrenko & Nazimov, 2015). In addition to direct yield loss, feeding damage delays growth, reduces photosynthetic area, and exposes plants to secondary infections. As in the case of *Tanymecus*, the economic importance of *O. sabulosum* has increased since the EU's 2019 ban on neonicotinoid seed treatments. Farmers have turned to pyrethroid-based soil or foliar treatments, but these provide limited efficacy due to the beetle's nocturnal and soil-surface feeding behaviour (Georgescu et al., 2024). In this context, for *O. sabulosum*, the literature mainly shows attempts at alternatives to neonicotinoids in which insecticides from pyrethroid group or *Beauveria* was used in the field, but the reporting was done on the pest complex or in other crops such as sunflower (Trotus & Buburuz, 2015; Gheorghe et al., 2021).

Climate change is expected to exacerbate the pest's impact: earlier beetle emergence, extended feeding seasons, and reduced soil moisture will increase maize vulnerability. Without reliable control measures, *O. sabulosum* could cause recurrent economic losses, affecting both crop profitability and regional food security.

2.3. *Agriotes* spp. – Wireworms

Wireworms are the subterranean larvae of click beetles belonging to the genus *Agriotes* (Coleoptera:Elateridae). A list of 16 species assigned to 8 Elateridae subfamilies was identified in a recent study performed over 5 years in maize crops from southern Romania; the dominant species were found: *A. ustulatus, Drasterius bimaculatus, A. sputator, A. obscurus, A. lineatus* and *Selatosomus latus* (Iamandei & Rujescu, 2023*)*.

The wireworms' life cycle typically lasts 3-5 years, depending on climatic conditions and soil type (Parker & Howard, 2002). Adults emerge in spring (April - May), mate, and lay eggs in moist soil at depths of 2-10 cm, particularly in grassy margins or fields rich in organic matter. Each female lays between 100 and 150 eggs. Larvae emerge after an incubation period of approximately 3-4 weeks and continue to live underground for several years, passing through 10 to 12 developmental stages before pupating towards the end of summer. Adult beetles appear in late summer or early autumn, and then enter overwintering until the next growing season (Furlan et al., 2017). The larval stage is primarily responsible for economic losses. During early maize development, they feed on germinating seeds, mesocotyls, and young roots, producing small holes that cause wilting or the eventual death of seedlings. This feeding activity is most intense within the first 3-4 weeks after sowing, when maize plants are at their most susceptible stage. In severely infested fields, crop losses can be so high that replanting becomes necessary (Parker & Howard, 2002). Even in the absence of host crops, larvae can survive for several years by consuming decaying plant matter or organic residues. This adaptability accounts for their continuous presence in maize-producing regions of Romania.

The spread and abundance of *Agriotes* species across Romania depend largely on soil characteristics, climate, and cultivation practices. Each *Agriotes* species displays distinct ecological adaptations within Romanian agroecosystems. Field studies have shown that *A. ustulatus* and *A. obscurus* are the dominant species, with the former commonly infesting maize and sunflower, while the latter occurs mainly in clover and wheat crops (Trașcă et al., 2019). *A. brevis* prefers compact and moist soils, *A. ustulatus* thrives in dry, sandy terrains of the southern and western zones of Romania, and *A. sputator* is mainly associated with cooler, humus-rich soils of Transylvania and northern Moldavia regions (Manole et al., 1999, Iamandei & Rujescu, 2023,). Meanwhile, *A. lineatus* appears sporadically in grass, maize rotations and are regarded as secondary pests of limited economic relevance (Furlan, 2017; Furlan et al., 2017; Trașcă et al., 2019).

Wireworm populations are highest in fields recently converted from pasture or perennial forage crops, where soil moisture and organic matter remain elevated. Adult click beetles prefer such areas for oviposition (Stolpe Nordin, 2017). Landscape elements such as field margins, grassy ditches and hedgerows serve as reservoirs for adult populations and larval infestations.

Climate also plays a crucial role. Warm, dry springs accelerate larval development and increase feeding synchrony with maize germination. Conversely, prolonged cold or excessive moisture may reduce activity. In recent years, climate warming has extended the active period of larvae, heightening maize vulnerability during early growth stages (Furlan, 2017).

In Romania, *Agriotes* species are considered major soil pests of maize, with severe consequences for crop establishment and yield stability. Literature sources mention an Economic Damage Threshold (EDT) for *Agriotes* spp. larvae of 3 larvae/m² until the plants reach the 3-5 leaf stage, while plants beyond this stage die at a larval density of 15-20 individuals/m² (Trasca et al., 2019).

The two species responsible for the most serious damage, *A. brevis* and *A. ustulatus*, differ notably in the way they attack maize crops. *A. brevis* typically injures the collar and root zone, which causes plants to wilt and develop "dead heart" symptoms, while *A. ustulatus* tends to destroy the maize kernel and mesocotyl before the seedlings even appear, leaving visible gaps in the rows (Furlan, 2017; Parker & Howard, 2002).

The extent of yield loss caused by wireworms depends heavily on soil conditions, the timing of sowing, and the level of infestation (Staudacher et al., 2013). In high-risk fields, production can fall by 1-1.5 tons per hectare, resulting in an estimated financial loss of €70-150 per hectare (Furlan et al., 2017). In severe cases, re-sowing becomes unavoidable, which raises production costs and postpones harvest.

After the prohibition of neonicotinoid seed treatments, wireworm pressure increased sharply in Romania, farmers have had to rely on early-season monitoring and localized soil treatments using pyrethroid-based or biological alternatives. Monitoring is now a cornerstone in the framework of IPM. Pheromone traps for adults, combined with bait traps for larvae, are used to assess both species distribution and population density before sowing. When larval numbers exceed the critical thresholds, typically over 5 individuals per square meter for *A. brevis* and *A. ustulatus* intervention is recommended (Furlan, 2014).

Biological control options with entomopathogenic fungi like *M. anisopliae* and *B. bassiana* have recently shown encouraging results (Razinger et al., 2020). Also, nematodes such as *Heterorhabditis bacteriophora* Poinar and *S. carpocapsae* can reduce wireworm populations with efficacy dependent on the concentration of infectious juveniles and on the combination of nematode strain and wireworm species (Poggi et al., 2021). Although their consistency under field conditions remains variable, these agents offer a valuable pathway toward sustainable pest control.

3. Integrated Pest Management – comparative analysis

Applying the principles of IPM to soil-dwelling pests in maize remains one of the most complex challenges in modern agriculture. Transitioning toward truly integrated systems requires not only a strong understanding of pest biology but also local knowledge of risk factors and the implementation of efficient monitoring practices adapted to regional conditions.

In Romania, as in much of Southeastern Europe, *T. dilaticollis*, *O. sabulosum* and *Agriotes* species are the most important soil pests affecting maize (Grozea et al., 2006). Each species has distinct ecological characteristics that determine its management requirements. *T. dilaticollis* is a univoltine species whose adults emerge in spring and feed intensively on young maize plants, frequently causing severe stand losses. Trials involving botanical and biological insecticides have yielded partial but promising results and are currently undergoing refinement to improve field-level consistency. Effective IPM strategies for this pest generally combine adjusted sowing dates, crop rotation, and the use of biological agents such as *S. carpocapsae* nematodes or *B. bassiana* -based mycoinsecticides, that have demonstrated consistent efficacy under field conditions (Toshova et al., 2021; Toshova et al., 2024).

For *Agriotes* species, Furlan et al. (2016) emphasised that success in management depends primarily on accurate risk evaluation rather than indiscriminate insecticide use. Their multifactorial risk model identified soil organic matter, rotation history, and surrounding vegetation as major predictors of infestation probability. Such risk mapping allows control measures to be applied only where necessary, thereby reducing both production costs and environmental pressure. A later study showed that multi-baited pheromone traps (YATLORf)

can capture multiple wireworm species simultaneously including *A. brevis*, *A. sordidus*, *A. ustulatus* and *A. litigiosus* offering a cost-effective and scalable monitoring tool for large-scale maize systems (Furlan et al., 2024). In contrast, *O. sabulosum* is primarily managed through preventive agronomic practices. Techniques such as residue management, proper tillage, and balanced fertilisation remain the most reliable control measures given the pest's broad host range and high mobility.

Comparable research conducted in maize-producing regions, reinforces the principle that sustainable pest management depends on the coordinated use of biological, ecological and cultural practices within a unified IPM framework. Blanco et al. (2014) reported that in countries with heavy reliance on chemical insecticides, the adoption of IPM programs is typically driven by cost-effectiveness and supported by efficient extension and advisory services. Consequently, the expansion of IPM in maize systems depends on the integration of predictive modelling, field-based monitoring, and farmer education programmes.

Overall, comparative evaluations of IPM strategies across major soil pest species suggest that the combination of ecological understanding, targeted monitoring and biological control can substantially mitigate maize yield losses while meeting the requirements of the EU Directive 2009/128/EC on the sustainable use of pesticides (EUROPEAN UNION, 2009).

4. Climate change and future perspectives

Climate change is reshaping the dynamics of maize pests in Europe and globally. Rising temperatures, prolonged droughts, and erratic precipitation patterns directly affect the biology, distribution, and severity of insect pests (Skendžić et al., 2021). In Romania and Southeastern Europe, these shifts are already evident through the earlier emergence and higher survival rates of *T. dilaticollis* and *Agriotes* larvae. Warmer winters enable more adults to overwinter successfully, increasing pest pressure on spring crops.

According to Porter et al., (1991), higher average temperatures accelerate insect development, increase voltinism and expand geographical ranges. Similar patterns are predicted for soil pests such as wireworms and darkling beetles, whose larvae develop more rapidly under mild conditions. Malschi et al. (2013) observed that recent climatic trends in Transylvania, particularly warmer and drier springs have intensified pest outbreaks in cereals and maize, reinforcing the need for adaptive management. From a broader perspective, climate-driven pest expansion is expected to intensify in the coming decades, with new invasive species such as *Spodoptera frugiperda* Smith already detected in parts of Europe (Skendžić et al., 2021; Toader et al., 2024).

As Skendžić et al. (2021) emphasized, climate change acts synergistically with globalization, facilitating the spread and establishment of invasive insects by reducing ecological barriers. Future IPM programs must therefore integrate climate forecasting, digital monitoring systems, and biological control innovations. Predictive models that connect soil temperature and moisture with pest development (Furlan et al., 2016; Keszthelyi et al., 2025) can be enhanced by integrating remote sensing data and pheromone trap networks to anticipate potential outbreaks. The combination of these tools provides a more accurate and timely understanding of pest population dynamics, allowing preventive actions before serious damage occurs.

Long term sustainability, however, depends on encouraging agricultural practices that maintain biodiversity and support ecological balance. Conservation agriculture and the protection of natural habitats for beneficial insects all contribute to the resilience of farming systems reducing the vulnerability of crops to pest pressure and climatic stress.

Climate changes analysis shows that under 2°C warming increased pest damage for maize is forecast to exacerbate yield losses of 31% (Ma et al., 2025). Adapting IPM strategies to a changing climate will require flexible and data based decision making. The success of such systems relies on collaboration between scientists and farmers, on continuous education and knowledge transfer and on policy measures that support the adoption of biological control and environmentally friendly technologies.

In the Romanian maize sector, where growing climate variability increasingly affects pest cycles and yields, the most effective path toward sustainable pest control lies in combining ecological knowledge with modern technological innovation. This integrated approach can strengthen the stability and adaptability of agricultural ecosystems, ensuring productivity and environmental protection in the long run.

CONCLUSIONS

Recent research on main soil-dwelling pests affecting maize crops in southern Romania, including *Tanymecus dilaticollis*, *Opatrum sabulosum* and *Agriotes* species, confirms their continued significance as major biotic factors limiting crop establishment and yield stability. Their persistence and economic importance have become more pronounced since the restriction of neonicotinoid seed treatments, which previously ensured effective early-season crop protection.

Romanian maize production needs successful IPM systems that combine preventive agronomic measures, such as crop rotation, residue management, and optimized sowing schedules, with biological control agents. Pest monitoring has become an essential component, allowing early detection and risk-based interventions that reduce chemical input without compromising crop protection efficiency. Refining pest monitoring programs and improving scientific knowledge are critical steps to reduce yield losses, minimize chemical dependency, and secure food production in an increasingly unstable climate.

Maintaining sustainable maize production in southern Romania depends on a coherent IPM framework that aligns ecological understanding, technological advancement, and adaptive management in response to climate variability and impact by integrating predictive modelling, soil and microclimate surveillance, and climate-resilient agronomic practices.

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