Current Chemistry Letters 15 (2026) 161–168

Contents lists available at GrowingScience

Current Chemistry Letters

homepage: www.GrowingScience.com

Glyphosate and biodiversity: Implications for ecosystems

Mohamed R. Fouad[a*], Amine El Maraghi[b], Mohammed E. Gad[c], Mohammed Bouachrine[d], Marwa Alaqarbeh[e], Zakaria F. Fawzy[f], Nagwa M. A. Al-Nagar[g], and Ahmed Abdou O. Abeed[h]

[a]*Department of Pesticide Chemistry and Technology, Faculty of Agriculture, Alexandria University, Aflaton St., 21545, El-Shatby, Alexandria, Egypt*
[b]*Molecular Modeling and Spectroscopy Research Team, Faculty of Science, Chouaïb Doukkali University, PB 20, 24000 El Jadida, Morocco*
[c]*Department of Zoology and Entomology, Faculty of Science, Al-Azhar University, Nasr City, Cairo 11884, Egypt*
[d]*Molecular Chemistry and Natural Substances Laboratory, Faculty of Science, Moulay Ismail University of Meknes, B.P. 11201, Meknes, Morocco*
[e]*Applied Science Research Center, Applied Science Private University, Jordan*
[f]*Vegetable Crops Department., Agriculture and Biological Research Institute, National Research Centre, 33 El Buhouth St., Dokki, 12622 Giza, Egypt*
[g]*Plant Protection Research Institute, Agricultural Research Center, Sabahia, Alexandria, Egypt*
[h]*Department of Chemistry, Faculty of Science, Assiut University, 71516 Assiut, Egypt*

C H R O N I C L E

Article history:
Received April 10, 2025
Received in revised form
June 12, 2025
Accepted October 2, 2025
Available online
October 2, 2025

Keywords:
Agriculture
Glyphosate
Biodiversity
Ecosystems

A B S T R A C T

Glyphosate is indeed one of the most extensively used herbicides worldwide, valued for its effectiveness in controlling weeds and increasing crop yields. However, its widespread use has prompted ongoing debates and research regarding its environmental and ecological impacts. Concerns include potential effects on non-target plant species, soil health, aquatic ecosystems, and overall biodiversity. Some studies suggest that glyphosate may influence soil microbial communities and have unintended consequences on beneficial insects and wildlife. As a result, many countries and organizations are reevaluating regulations and promoting integrated weed management practices to balance agricultural productivity with ecosystem sustainability.

© 2026 by the authors; licensee Growing Science, Canada.

Graphical Abstract

* Corresponding author
E-mail address mohammed.riad@alexu.edu.eg (M. R. Fouad)
© 2026 by the authors; licensee Growing Science, Canada
doi: 10.5267/j.ccl.2025.10.002

1. Introduction

Glyphosate is a widely used broad-spectrum systemic herbicide, first introduced in the 1970s and commercially available under brand names such as Roundup. Its chemical name is N-(phosphonomethyl) glycine (**Fig. 1**). Its popularity stems from its effectiveness in controlling a variety of weeds and its relatively low cost.[1-2] However, the extensive application of glyphosate in agriculture, forestry, and urban settings has raised concerns regarding its environmental impacts, particularly on biodiversity and ecosystem health. Biodiversity (the variety of life forms within a given habitat or ecosystem) is fundamental to maintaining ecological balance, resilience, and productivity. The use of glyphosate can influence biodiversity directly by affecting plant communities, which serve as habitats and food sources for a multitude of organisms, and indirectly by altering soil health, water quality, and trophic interactions.[3-4] Understanding the implications of glyphosate application for ecosystems involves examining its effects on non-target plant species, soil microbiota, aquatic life, and overall habitat integrity.[5] While glyphosate's mode of action targets specific biochemical pathways in plants, its persistence in the environment and potential to disrupt ecological relationships may lead to reductions in plant diversity, shifts in community composition, and declines in dependent fauna.

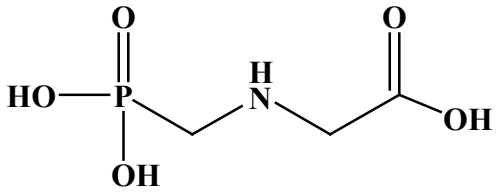

Fig. 1. Chemical structure of glyphosate.

2. Mechanism of action

EPSP synthase catalyzes the reaction which converts shikimate-3-phosphate + phosphoenolpyruvate to 5-enolpyruvylshikimate-3-phosphate (EPSP) by way of an acetal-like tetrahedral intermediate. Acidic and basic amino acids in the active site are involved in deprotonation of the hydroxyl group of phosphoenolpyruvate (PEP), and in the proton-exchange steps related to the tetrahedral intermediate itself (**Fig. 2**). The precise order and energetics of each step of the process have been established by studies of the enzyme kinetics for this reaction. A neutrally charged lysine (lys-22) acts as a general base, deprotonating the hydroxyl group of 3-phospho shikimate (S3P) such that the resulting oxyanion can attack the most electrophilic carbon atom of PEP. A glutamic acid (glu-341) acts as a general acid by donating a proton. The deprotonated glu-341 then acts as a base, taking back its proton, and the S3P group is kicked off and protonated by the protonated lysine. Glyphosate inhibits the enzyme EPSP synthase, which is crucial in the shikimate pathway. This pathway is responsible for the biosynthesis of aromatic amino acids (phenylalanine, tyrosine, and tryptophan) in plants, fungi, and some bacteria. Since the shikimate pathway is absent in animals, glyphosate is considered selectively toxic to plants.[6-7]

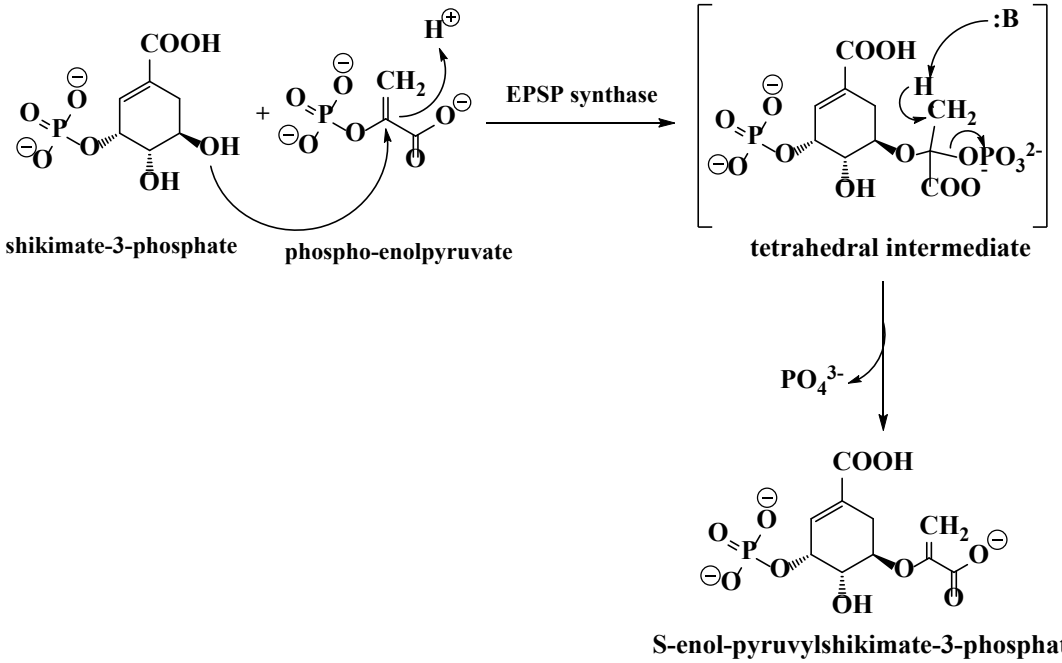

Fig. 2. Biochemical pathway of EPSP synthase-catalyzed conversion of shikimate-3-phosphate and phosphoenolpyruvate to 5-enolpyruvylshikimate-3-phosphate.

3. Uses

Uses of glyphosate; a) used extensively as a non-selective herbicide for controlling weeds in various crops, especially glyphosate-resistant genetically modified crops like soy, maize, and cotton, b) applied to clear invasive weeds and unwanted vegetation in non-crop areas, along fences, roadsides, and industrial sites, c) used in forest management to control competing vegetation and prepare sites for planting, and d) employed to kill crop residues before planting new crops or for harvesting purposes.[8-9] While glyphosate is widely used, its safety and environmental impact are subjects of ongoing debate, with discussions about potential health effects and ecological impact. **Table 1** summarizes estimated glyphosate use rates around the world, along with references for each data point. Keep in mind that actual figures can vary based on sources and time.

Table 1. Glyphosate use rates around the world

Region	Approximate Usage (kg/ha/year)	Notes	References
North America (USA, Canada)	1.5-2.0	High use, widespread adoption in genetically modified organism crops	10-11
Latin America (Brazil, Argentina)	1.0-1.8	Major agricultural producers with significant glyphosate use	12-13
Europe	0.1-0.5	More regulated, lower usage	14
Asia	0.2 – 1.0	Varies by country; growing use in some regions	15-16
Australia	0.3-0.8	Used mainly in agriculture and forestry	17
Africa	<0.2	Limited use, mostly in South Africa and North Africa	13

4. Impact on plant diversity

Glyphosate can significantly impact plant diversity, especially when used extensively or improperly. Since glyphosate is a non-selective herbicide, it can kill a wide range of plant species, including both weeds and non-target native plants, leading to decreased plant diversity in treated areas. The loss of native and diverse plant species can disrupt local ecosystems, affecting insects, birds, and other wildlife that depend on a variety of plants for food and habitat. Widespread glyphosate use can favor the growth of resistant species or invasive plants, leading to monocultures that diminish overall biodiversity. Persistent application may alter soil health and plant succession patterns, further impacting plant community composition and diversity over time. Overall, while glyphosate is effective for weed control, overuse or misuse can threaten plant diversity and ecosystem health. The study by Sullivan and Sullivan, [18] examines the effects of glyphosate herbicide on plant diversity within terrestrial ecosystems. They find that while glyphosate is effective for controlling invasive and unwanted plant species, its use can lead to reductions in plant diversity, particularly when applied extensively or improperly. The study by Puricelli and Tuesca, [19] examined how sequences of glyphosate-resistant crops affect weed populations. They found that using glyphosate in these systems effectively reduced overall weed density, but it also led to a decline in weed species diversity. The study by Scursoni and Satorre,[20] examined how different glyphosate management strategies influence weed diversity and soybean yields in Argentina. They found that integrating glyphosate with other weed control methods helps maintain higher weed diversity, which is beneficial for ecosystem health. Proper use of glyphosate, especially when combined with cultural practices, does not negatively impact soybean yields. The study by Rodriguez and Jacobo,[21] investigated the effects of glyphosate application on plant community composition and species diversity in the Flooding Pampa grassland in Argentina. The researchers found that glyphosate treatment led to a significant reduction in overall species richness and diversity. Specifically, the herbicide caused a decline in native plant species and favored the proliferation of resistant or tolerant species, resulting in altered floristic composition. Glyphosate application can diminish native seed banks and modify vegetation composition, potentially leading to reduced biodiversity and changes in grassland ecosystem functioning.[22] The study by Comeau and Fraser,[23] investigated how single versus repeated glyphosate applications affected plant community diversity and the growth of white spruce trees in a plantation. They found that repeated glyphosate treatments significantly reduced understorey plant diversity, whereas a single application had a less pronounced effect. The study by Koning et al.,[24] compared the effects of glyphosate application and tillage on weed vegetation in a field experiment. They found that glyphosate significantly reduced weed biomass and diversity shortly after treatment, but over time, resistant species tended to dominate.

5. Effects on insect populations

Glyphosate's effects on insect populations are complex and can vary depending on exposure levels, ecosystem context, and insect species. While glyphosate primarily targets plants, some studies suggest that certain insects may experience direct toxicity or sublethal effects when exposed to glyphosate residues, especially through contaminated plant tissues or soil.[5,25] Glyphosate can reduce plant diversity and abundance, which in turn affects herbivorous insects that rely on specific host plants, potentially leading to declines in those insect populations. By altering plant communities, glyphosate may disrupt pollination networks and other ecological interactions that are critical for insect survival and reproduction.[26] Some insect species may adapt or develop resistance over time, but overall, broad-spectrum herbicide use can negatively impact insect biodiversity, including beneficial insects such as pollinators and natural pest controllers.[27] In summary, glyphosate can indirectly and directly influence insect populations, often leading to declines in diversity and abundance, which can have cascading effects on ecosystem health. The study by Schneider et al.,[28] examined how glyphosate affects the predator insect

Chrysoperla externa. They found that exposure to glyphosate negatively impacts the insect's development, fertility, and overall population dynamics. Specifically, glyphosate can slow down development, reduce reproductive success, and potentially threaten the stability of *C. externa* populations. The study by Saska et al.,[29] examined how exposure to glyphosate-based herbicides influences the life history traits of the rose-grain aphid (*Metopolophium dirhodum*). They found that such herbicide treatment can alter key parameters like development time, reproduction, and survival rates of the aphids. Specifically, glyphosate exposure tended to negatively affect their survival and reproductive output, which could impact their population growth and dynamics. The study by Pereira et al.,[30] examined how glyphosate affects the non-target leaf beetle *Cerotoma arcuata* under both laboratory and field conditions. They found that glyphosate exposure increased mortality rates and negatively impacted the beetle's development and reproduction. In field experiments, glyphosate applications appeared to reduce beetle populations, likely through direct toxicity or indirect effects such as diminished host plant quality. The study by Zanuncio et al.,[31] examined how glyphosate-based herbicides affect the life history traits of *Podisus nigrispinus*, a beneficial predatory insect. They found that exposure to these herbicides can negatively influence survival, development, and reproduction of the insect. The study by Galin et al.,[32] examined how glyphosate affects *Drosophila melanogaster* (fruit flies). They found that exposure to glyphosate reduced the flies' fertility and shortened their lifespan. These results suggest that glyphosate may have detrimental effects on reproductive health and longevity in non-target organisms, highlighting potential ecological risks associated with its use. The study by Rainio et al.,[33] examined how a glyphosate-based herbicide affects the non-target herbivore, the Colorado potato beetle (*Leptinotarsa decemlineata*). They found that exposure to the herbicide reduced beetle survival and caused oxidative stress, indicated by changes in antioxidant enzyme activity and increased oxidative damage. The study by Pereira et al.,[34] investigates how glyphosate herbicide impacts arthropod populations associated with both Roundup Ready and conventional soybean crops. The researchers assessed changes in the abundance, diversity, and community structure of arthropods following glyphosate application. Their findings indicate that glyphosate can significantly affect arthropod communities, with variations observed between the two soybean systems. The study by Lacava et al.,[35] examined how glyphosate impacts the predatory behavior of a wolf spider. They found that glyphosate's effects were pest-specific, meaning that exposure altered the spider's ability to prey on different types of pests in varying ways. Overall, the research suggests that glyphosate can influence predator efficiency and prey interactions, which may have broader ecological implications beyond its herbicidal action. The study by Smith et al.,[36] examined how glyphosate affects insect immunity. They found that glyphosate inhibits melanization, a crucial immune process in insects that helps fight infections. As a result, insects exposed to glyphosate become more vulnerable to infections. The study by Feng et al.,[37] explores how glyphosate impacts the silkworm (*Bombyx mori*), focusing on growth, development, and physiological functions. The researchers found that exposure to glyphosate adversely affect silkworm growth rates, disrupts developmental processes, and alters physiological activities such as enzyme functions and nutrient metabolism. The study by Gao et al.,[38] investigates the effects of glyphosate, on the ladybird beetle *Harmonia axyridis*, a natural predator of pests. The researchers found that exposure to glyphosate decreased the beetle's survival rates but paradoxically increased its fecundity (reproductive output). Additionally, glyphosate altered the composition of the beetle's microbiome. The study by Du et al.,[39] examined how a glyphosate-based herbicide affects the beneficial insect *Chrysopa pallens*. They found that exposure decreased the insect's lifespan and reproductive capacity. Importantly, some negative effects persisted across generations. The study by Pasquier et al.,[40] examined the effects of a glyphosate-based herbicide on male *European earwigs* across six different populations. They found that, the herbicide had limited effects on both behavioural traits (such as activity and aggression) and immune responses, with some variation among populations.

6. Soil microbial and faunal communities

Glyphosate can have significant effects on soil microbial and faunal communities. Glyphosate application can reduce the diversity of soil microbes, including bacteria and fungi, by inhibiting or killing susceptible species. It may affect vital soil processes such as nutrient cycling, organic matter decomposition, and nitrogen fixation by disrupting key microbial populations. Repeated use can promote the proliferation of glyphosate-resistant microbial strains, potentially leading to shifts in community structure. Changes in microbial communities can impair soil resilience, fertility, and plant growth support. Glyphosate residues can affect soil fauna like nematodes, collembolans, and earthworms, either directly through toxicity or indirectly via changes in microbial prey availability. Disruption of microbial communities can cascade through the soil food web, impacting invertebrate populations and overall soil health. Although less studied, some soil fauna may accumulate glyphosate or its metabolites, leading to sub-lethal effects. The extent of glyphosate's effects depends on factors such as application rate, frequency, soil type, and existing microbial diversity. While some studies report minimal effects, others highlight significant shifts in community composition, emphasizing the need for cautious use and ongoing research. Liphadzi et al.,[41] found that glyphosate use had minimal impact on the diversity and abundance of soil microbes and nematodes. The study by Lane et al.,[42] examined how glyphosate application affects soil health, focusing on microbial activity, and community structure. They found that glyphosate did not significantly diminish overall microbial activity but did alter the composition of soil microbial communities. The study by Zaller et al.,[43] examined how glyphosate herbicide affects interactions below the soil surface, specifically between earthworms and symbiotic mycorrhizal fungi. Using a model ecosystem, they found that glyphosate influences these interactions, potentially disrupting soil organism relationships that are vital for soil health, nutrient cycling, and overall ecosystem functioning. The study by Hagner et al.,[44] examined how glyphosate-based herbicides affect soil animal communities and their functions. They found that glyphosate application influenced the abundance and composition of various soil trophic groups such as decomposers, predators, and herbivores. These changes in soil fauna also impacted ecosystem processes like decomposition and nutrient cycling. The study by

Kepler et al.,[45] examined how soil microbial communities across various agricultural systems respond to glyphosate herbicide exposure. They found that, glyphosate application caused minimal or inconsistent changes in microbial diversity, community composition, and functional potential. While some microbial taxa showed slight shifts, these were not uniform or indicative of widespread disturbance. The findings suggest that soil microbial communities in diverse agroecosystems are relatively resilient to glyphosate, and its typical use does not significantly compromise soil microbial health or ecosystem functions. Van Bruggen et al.,[46] explain that glyphosate impacts soil, water, and plant-associated microbes, which play crucial roles in processes like nutrient cycling, disease suppression, and overall ecosystem health. The study by Ramula et al.,[47] examined how glyphosate residues affect the microbiota associated with a perennial weed. They found that glyphosate residues significantly altered the composition and diversity of the weed's microbial community. The study by Zhang et al.,[48] investigates how glyphosate, affects soil *Enchytraeid* worms and their gut microbiota. The researchers found that exposure to glyphosate disrupt the microbial community within the worms' guts, leading to reduced diversity and altered composition.

7. Implications for ecosystem services

Glyphosate has significant implications for ecosystem services due to its effects on plant communities, soil health, and non-target organisms.[44,49] Glyphosate is primarily used to control weeds, but its non-selective nature can affect native plant species, leading to reduced plant diversity. Loss of native flora can alter habitat availability for insects, birds, and other wildlife, disrupting ecological interactions. Glyphosate can influence soil microbial diversity and function. Some studies suggest it may inhibit beneficial microbes involved in nutrient cycling, decomposition, and soil structure maintenance, potentially impairing soil fertility and resilience. By reducing flowering plant abundance, glyphosate can diminish food resources for pollinators such as bees and butterflies. Additionally, exposure to glyphosate residues can affect non-target fauna, including aquatic organisms and insects, with cascading effects on food webs. Declines in flowering plants can reduce pollination services vital for both wild plants and crops. Altered microbial communities may impair soil nutrient cycling, affecting plant growth and productivity. Runoff containing glyphosate can contaminate water bodies, impacting aquatic ecosystems and filtering services. Changes in vegetation cover due to glyphosate application can influence carbon sequestration and local climate regulation. Repeated glyphosate use may lead to invasive species dominance, monocultures, and reduced resilience to environmental stresses, compromising the sustainability of ecosystem functions.[18,50-52]

8. Controversies and research gaps

The International Agency for Research on Cancer (IARC) classified glyphosate as probably carcinogenic to humans (group 2A) in 2015, citing limited evidence of carcinogenicity in humans and sufficient evidence in animals.[53-54] Conversely, regulatory agencies like the EPA (USA), EFSA (European Union), and other national bodies have generally concluded that glyphosate is unlikely to pose a carcinogenic risk when used as directed. Studies investigating links between glyphosate exposure, and other health issues such as endocrine disruption, reproductive problems, and antibiotic resistance. Concerns about glyphosate's effects on non-target organisms, including bees, aquatic life, and soil microbiota. Potential for glyphosate to contaminate water sources and affect biodiversity. Overreliance on glyphosate has led to resistant weed species, prompting discussions about sustainable farming practices. While glyphosate remains widely used globally, ongoing controversies highlight the importance of filling research gaps through rigorous, transparent studies. Addressing these gaps can inform safer use practices and policy decisions. The processes that occur with pesticides in the environment, such as adsorption/desorption,[55-57] degradation,[55-57] leaching,[58] and ubtake by plant,[59] must be taken into account. In addition to industrially produced chemicals used for research purposes in developing new bioactive compounds.[60-61] Amino acids such as glycine and its derivatives (e.g., phosphate esters) are an extremely important synthon in the synthesis of azomethynoylides, which in turn are the basis for the stereoselective synthesis of azoles.[62-63]

9. Conclusion

While glyphosate plays a significant role in modern agriculture, its implications for biodiversity and ecosystems warrant careful assessment. Sustainable weed management strategies and diversified agricultural practices may help mitigate negative impacts and promote healthier ecosystems.

Declaration of Competing Interest

The authos hereby declare that the above details are true and accurate to the best of my knowledge and belief, and I undertake to inform you immediately of any changes thereto.

Data availability

The corresponding author can provide the datasets used or analyzed in this study upon reasonable request.

References

1. Khurpade, A., Rathor, J., Gaikwad, P., Dhurvey, V., Nagwanshi, A., & Sharma, A. (**2025**) Toxicological impacts of glyphosate on the liver, intestine and Kidney: A mini review. https://www.doi.org/10.22271/j.ento.2025.v13.i3b.9508

2. Panzacchi, S., Tibaldi, E., De Angelis, L., Falcioni, L., Giovannini, R., Gnudi, F., & Mandrioli, D. (**2025**) Carcinogenic effects of long-term exposure from prenatal life to glyphosate and glyphosate-based herbicides in Sprague–Dawley rats. *Environ. Health*, 24(1), 36. https://doi.org/10.1186/s12940-025-01187-2
3. Kanissery, R., Gairhe, B., Kadyampakeni, D., Batuman, O., & Alferez, F. (**2019**) Glyphosate: Its environmental persistence and impact on crop health and nutrition. *Plants*, 8(11), 499. https://doi.org/10.3390/plants8110499
4. Leoci, R., & Ruberti, M. (**2020**) Glyphosate in agriculture: Environmental persistence and effects on animals. A review. *J. Agric. Environ. Int. Dev.*, 114(1), 99-122. https://doi.org/10.12895/jaeid.20201.1167
5. Muñoz, J. P., Soto-Jiménez, D., Brito, A., & Quezada-Romegialli, C. (**2025**) Glyphosate-Based Herbicides and Their Potential Impact on the Microbiota of Social Bees. *Toxics.*, 13(7), 551. https://doi.org/10.3390/toxics13070551
6. Leino, L., Tall, T., Helander, M., Saloniemi, I., Saikkonen, K., Ruuskanen, S., & Puigbo, P. (**2021**) Classification of the glyphosate target enzyme (5-enolpyruvylshikimate-3-phosphate synthase) for assessing sensitivity of organisms to the herbicide. *J. Hazar. Mater.*, 408, 124556. https://doi.org/10.1016/j.jhazmat.2020.124556
7. Caygill, S., Köcher, T., & Dolan, L. (**2024**) MurA-catalyzed synthesis of 5-enolpyruvylshikimate-3-phosphate confers glyphosate tolerance in bryophytes. *Proc. Nati. Acad. Sci.*, 121(47), e2412997121. https://doi.org/10.1073/pnas.2412997121
8. Soares, D., Silva, L., Duarte, S., Pena, A., & Pereira, A. (**2021**) Glyphosate use, toxicity and occurrence in food. *Foods*, 10(11), 2785. https://doi.org/10.3390/foods10112785
9. de Araujo, L. G., Zordan, D. F., Celzard, A., & Fierro, V. (**2023**) Glyphosate uses, adverse effects and alternatives: focus on the current scenario in Brazil. *Environ. Geochem. Health*, 45(12), 9559-9582. https://link.springer.com/article/10.1007/s10653-023-01763-w
10. Bruce, R. C., Wang, R., Rawson, J., Therien, M. J., & You, W. (**2016**) Valence band dependent charge transport in bulk molecular electronic devices incorporating highly conjugated multi-[(porphinato) metal] oligomers. *J. Am. Chem. Soc.*, 138(7), 2078-2081. https://doi.org/10.1021/jacs.5b10772
11. USDA Economic Research Service (ERS). (**2018**) *Adoption of genetically engineered crops in the U.S.* Available at: https://www.ers.usda.gov/data-products/adoption-of-genetically-engineered-crops-in-the-u-s/data-on-herbicide-resistant-crops/
12. Séralini, G. E., Clair, E., Mesnage, R., Gress, S., Defarge, N., Malatesta, M., & De Vendômois, J. S. (**2012**) RETRACTED: Long term toxicity of a Roundup herbicide and a Roundup-tolerant genetically modified maize. *Food Chem. Toxicol.*, 50(11), 4221–4231. https://doi.org/10.1016/j.fct.2012.08.005
13. FAO. (**2018**) *FAOSTAT Statistical Database*. Food and Agriculture Organization of the United Nations. Available at: http://www.fao.org/faostat/en/
14. European Food Safety Authority (EFSA). (**2018**) *Scientific Opinion on the evaluation of the pesticide risk assessment for glyphosate*. *EFSA J.*, 16(5), 5264. Available at: https://efsa.onlinelibrary.wiley.com/doi/10.2903/j.efsa.2018.5314
15. World Health Organization. (**2016**) *Glyphosate: Evaluation of Carcinogenic Potential.* International Agency for Research on Cancer. Available at: https://monographs.iarc.fr/wp-content/uploads/2018/06/mono112-006.pdf
16. Pesticide Action Network (PAN). (**2019**) *The Global Pesticide Campaigner, Issue 138: Glyphosate and Beyond.* Available at: https://www.pesticideinfo.org/
17. Australian Pesticides and Veterinary Medicines Authority (APVMA). (**2017**) *Annual Report 2016–17*. Available at: https://apvma.gov.au/sites/default/files/documents/annual_report_16-17.pdf
18. Sullivan, T. P., & Sullivan, D. S. (**2003**) Vegetation management and ecosystem disturbance: impact of glyphosate herbicide on plant and animal diversity in terrestrial systems. *Environ. Rev.*, 11(1), 37-59. https://doi.org/10.1139/a03-005
19. Puricelli, E., & Tuesca, D. (**2005**) Weed density and diversity under glyphosate-resistant crop sequences. *Crop Prot.*, 24(6), 533-542. https://doi.org/10.1016/j.cropro.2004.10.005
20. Scursoni, J. A., & Satorre, E. H. (**2010**) Glyphosate management strategies, weed diversity and soybean yield in Argentina. *Crop Prot.*, 29(9), 957-962. https://doi.org/10.1016/j.cropro.2010.05.001
21. Rodriguez, A. M., & Jacobo, E. J. (**2010**) Glyphosate effects on floristic composition and species diversity in the Flooding Pampa grassland (Argentina). *Agr. Ecosyst. Environ.*, 138(3-4), 222-231. https://doi.org/10.1016/j.agee.2010.05.003
22. Rodriguez, A. M., & Jacobo, E. J. (**2013**) Glyphosate effects on seed bank and vegetation composition of temperate grasslands. *Appl. Veg. Sci.*, 16(1), 51-62. https://doi.org/10.1111/j.1654-109X.2012.01213.x
23. Comeau, P. G., & Fraser, E. C. (**2018**) Plant community diversity and tree growth following single and repeated glyphosate herbicide applications to a white spruce plantation. *Forests*, 9(3), 107. https://doi.org/10.3390/f9030107
24. Koning, L. A., de Mol, F., & Gerowitt, B. (**2019**) Effects of management by glyphosate or tillage on the weed vegetation in a field experiment. *Soil Till. Res.*, 186, 79-86. https://doi.org/10.1016/j.still.2018.10.012
25. McHenry, L. C., Schürch, R., Council-Troche, M., Gross, A. D., Johnson, L. E., Ohlinger, B. D., & Couvillon, M. J. (**2025**) Sublethal glyphosate exposure reduces honey bee foraging and alters the balance of biogenic amines in the brain. *J. Exp. Biol.*, 228(9), jeb250124. https://doi.org/10.1242/jeb.250124
26. Bertrand, C., Aviron, S., Pelosi, C., Faburé, J., Le Perchec, S., Mamy, L., & Rault, M. (**2025**) Effects of plant protection products on ecosystem functions provided by terrestrial invertebrates. *Environ. Sci. Pollut. Res.*, 32(6), 2956-2974. https://link.springer.com/article/10.1007/s11356-024-34534-w
27. Capinera, J. L. (**2018**) Direct and indirect effects of herbicides on insects. In *Weed control* (pp. 76-91). CRC Press.

28. Schneider, M. I., Sanchez, N., Pineda, S., Chi, H., & Ronco, A. (**2009**) Impact of glyphosate on the development, fertility and demography of *Chrysoperla externa* (Neuroptera: Chrysopidae): ecological approach. *Chemosphere*, 76(10), 1451-1455. https://doi.org/10.1016/j.chemosphere.2009.05.029
29. Saska, P., Skuhrovec, J., Lukáš, J., Chi, H., Tuan, S. J., & Honěk, A. (**2016**) Treatment by glyphosate-based herbicide alters life history parameters of the rose-grain aphid Metopolophium dirhodum. *Sci. Rep.*, 6(1), 27801. https://www.nature.com/articles/srep27801
30. Pereira, J. L., Galdino, T. V., Silva, G. A., Picanço, M. C., Silva, A. A., Corrêa, A. S., & Martins, J. C. (**2018**) Effects of glyphosate on the non-target leaf beetle *Cerotoma arcuata* (Coleoptera: Chrysomelidae) in field and laboratory conditions. *J. Environ. Sci. Health B*, 53(7), 447-453. https://doi.org/10.1080/03601234.2018.1455363
31. Zanuncio, J. C., Lacerda, M. C., Alcántara-de la Cruz, R., Brügger, B. P., Pereira, A. I., Wilcken, C. F., & Sediyama, C. S. (**2018**) Glyphosate-based herbicides toxicity on life history parameters of zoophytophagous *Podisus nigrispinus* (Heteroptera: Pentatomidae). *Ecotoxicol. Environ. Saf.*, 147, 245-250. https://doi.org/10.1016/j.ecoenv.2017.08.055
32. Galin, R. R., Akhtyamova, I. F., & Pastukhova, E. I. (**2019**) Effect of herbicide glyphosate on Drosophila melanogaster fertility and lifespan. *Bull. Exp. Biol. Med.*, 167(5), 663-666. https://link.springer.com/article/10.1007/s10517-019-04594-x
33. Rainio, M. J., Margus, A., Lehmann, P., Helander, M., & Lindström, L. (**2019**) Effects of a glyphosate-based herbicide on survival and oxidative status of a non-target herbivore, the Colorado potato beetle (*Leptinotarsa decemlineata*). *Com. Biochem. Physiol. C Toxicol. Pharmacol.*, 215, 47-55. https://doi.org/10.1016/j.cbpc.2018.09.005
34. Pereira, J. L., Pereira, R. R., Resende-Silva, G. A., Jakelaitis, A., Silva, A. A., & Picanço, M. C. (**2020**) Glyphosate impact on arthropods associated to roundup ready and conventional soybean (*Glycine max* L.). *Planta Daninha*, *38*, e020171361. https://doi.org/10.1590/S0100-83582020380100047
35. Lacava, M., García, L. F., Viera, C., & Michalko, R. (**2021**) The pest-specific effects of glyphosate on functional response of a wolf spider. *Chemosphere*, 262, 127785. https://doi.org/10.1016/j.chemosphere.2020.127785
36. Smith, D. F., Camacho, E., Thakur, R., Barron, A. J., Dong, Y., Dimopoulos, G., & Casadevall, A. (**2021**) Glyphosate inhibits melanization and increases susceptibility to infection in insects. *PLoS Biol.*, 19(5), e3001182. https://doi.org/10.1371/journal.pbio.3001182
37. Feng, P., Dai, M., Yang, J., Wang, Y., Mao, T., Su, W., & Li, B. (**2022**) Effects of glyphosate on the growth, development, and physiological functions of silkworm, *Bombyx mori*. *Arch. Insect Biochem. Physiol.*, 111(2), e21919. https://doi.org/10.1002/arch.21919
38. Gao, X., Hu, F., Cui, H., Zhu, X., Wang, L., Zhang, K., & Cui, J. (**2023**) Glyphosate decreases survival, increases fecundity, and alters the microbiome of the natural predator *Harmonia axyridis* (ladybird beetle). *Environ. Res.*, *238*, 117174. https://doi.org/10.1016/j.envres.2023.117174
39. Du, Q., Ren, X., Ma, X., Wang, D., Song, X., Hu, H., & Ma, Y. (**2024**) Impact of a glyphosate-based herbicide on the longevity, fertility, and transgenerational effects on *Chrysopa pallens* (Rambur)(Neuroptera: Chrysopidae). *Environ. Sci. Pollut. Res.*, 31(14), 21845-21856. https://link.springer.com/article/10.1007/s11356-024-32601-w
40. Pasquier, L., Lécureuil, C., & Meunier, J. (**2024**) Limited effects of a glyphosate-based herbicide on the behaviour and immunity of males from six populations of the *European earwig*. *Environ. Sci. Pollut. Res.*, 31(31), 44205-44217. https://link.springer.com/article/10.1007/s11356-024-34063-6
41. Liphadzi, K. B., Al-Khatib, K., Bensch, C. N., Stahlman, P. W., Dille, J. A., Todd, T., & Head, G. (**2005**) Soil microbial and nematode communities as affected by glyphosate and tillage practices in a glyphosate-resistant cropping system. *Weed Sci.*, 53(4), 536-545. https://doi.org/10.1614/WS-04-129R1
42. Lane, M., Lorenz, N., Saxena, J., Ramsier, C., & Dick, R. P. (**2012**) The effect of glyphosate on soil microbial activity, microbial community structure, and soil potassium. *Pedobiologia*, 55(6), 335-342. https://doi.org/10.1016/j.pedobi.2012.08.001
43. Zaller, J. G., Heigl, F., Ruess, L., & Grabmaier, A. (**2014**) Glyphosate herbicide affects belowground interactions between earthworms and symbiotic mycorrhizal fungi in a model ecosystem. *Sci. Rep.*, 4(1), 5634. https://www.nature.com/articles/srep05634
44. Hagner, M., Mikola, J., Saloniemi, I., Saikkonen, K., & Helander, M. (**2019**) Effects of a glyphosate-based herbicide on soil animal trophic groups and associated ecosystem functioning in a northern agricultural field. *Sci. Rep.*, 9(1), 8540. https://www.nature.com/articles/s41598-019-44988-5
45. Kepler, R. M., Epp Schmidt, D. J., Yarwood, S. A., Cavigelli, M. A., Reddy, K. N., Duke, S. O., & Maul, J. E. (**2020**) Soil microbial communities in diverse agroecosystems exposed to the herbicide glyphosate. *Appl. Environ. Microbiol.*, 86(5), e01744-19. https://doi.org/10.1128/AEM.01744-19
46. Van Bruggen, A. H., Finckh, M. R., He, M., Ritsema, C. J., Harkes, P., Knuth, D., & Geissen, V. (**2021**) Indirect effects of the herbicide glyphosate on plant, animal and human health through its effects on microbial communities. *Front. Environ. Sci.*, 9, 763917. https://doi.org/10.3389/fenvs.2021.763917
47. Ramula, S., Mathew, S. A., Kalske, A., Nissinen, R., Saikkonen, K., & Helander, M. (**2022**) Glyphosate residues alter the microbiota of a perennial weed with a minimal indirect impact on plant performance. *Plant Soil*, 472(1), 161-174. https://doi.org/10.1007/s11104-021-05196-1
48. Zhang, Q., Lei, C., Jin, M., Qin, G., Yu, Y., Qiu, D., & Qian, H. (**2024**) Glyphosate disorders soil *Enchytraeid* gut microbiota and increases its antibiotic resistance risk. *J. Agric. Food Chem.*, 72(4), 2089-2099. https://doi.org/10.1021/acs.jafc.3c05436

49. Damour, G., Tixier, P., & Coulis, M. (**2023**) Glyphosate reduces the biodiversity of soil macrofauna and benefits exotic over native species in a tropical agroecosystem. *Basic Appl. Ecol.*, 73, 18-26. https://doi.org/10.1016/j.baae.2023.10.001
50. Hamama, W. S., El-Bana, G. G., Mostafa, M. E. H., & Zoorob, H. H. (**2019**) Synthesis and Acaricidal Activity of Some New 1, 2, 4-Triazine Derivatives. *J. Heterocycl. Chem.*, 56(1), 239-250. https://doi.org/10.1002/jhet.3401
51. El-Bana, G. G., Abd El Ghani, G. E., Ramadan El-Rokh, A., & Hassanien, A. E. (**2024**) Synthesis and insecticidal assessment of some innovative heterocycles incorporating a pyrazole moiety. *Polycycl. Aromat. Comp.*, 44(9), 6314-6334. https://doi.org/10.1080/10406638.2023.2276248
52. Lozano, V. L., & Pizarro, H. N. (**2024**) Glyphosate lessons: is biodegradation of pesticides a harmless process for biodiversity?. *Environ. Sci. Eur.*, 36(1), 55. https://doi.org/10.1186/s12302-024-00884-y
53. Williams, G. M., Aardema, M., Acquavella, J., Berry, S. C., Brusick, D., Burns, M. M., & Weed, D. L. (**2016**) A review of the carcinogenic potential of glyphosate by four independent expert panels and comparison to the IARC assessment. *Crit. Rev. Toxicol.*, 46(sup1), 3-20. https://doi.org/10.1080/10408444.2016.1214677
54. Tarone, R. E. (**2018**) On the International Agency for Research on Cancer classification of glyphosate as a probable human carcinogen. *Eur. J. Cancer Prev.*, 27(1), 82-87.
55. Fouad, M. R., El-Aswad, A. F., & Aly, M. I. (**2024**) Mathematical models of the adsorption-desorption kinetics of fenitrothion in clay soil and sandy clay loam soil. *Curr. Chem. Lett.*, 13(4), 641-654. http://dx.doi.org/10.5267/j.ccl.2024.6.002
56. Mostafa, A. S., Nassar, D. M., Abdul-Malik, M. A., Abdel-Halim, K. Y., Mohamed, A. E., Alsehli, B. R., & Fouad, M. R. (**2025**) Competitive adsorption/desorption of dimethoate pesticide and phosphorus fertilizer in texturally different soils. *Soil Environ.*, 44(1), 1-7.
57. Fouad, M. R., & Abdel-Raheem, S. A. (**2024**) An overview on the fate and behavior of imidacloprid in agricultural environments. *Environ. Sci. Pollut. Res.*, 1-11. https://doi.org/10.1007/s11356-024-35178-6
58. Fouad, M. R., El-Aswad, A. F., Aly, M. I., & Badawy, M. E. I. (**2024**) Environmental impact of biochar and wheat straw on mobility of dinotefuran and metribuzin into soils. *Asian J. Agric.*, 8(1), 57-63. https://smujo.id/aja/article/view/17992/7789
59. Fouad, M. R., El-Aswad, A. F., & Aly, M. I. (**2024**) Uptake and Translocation of Fenitrothion and Thiobencarb in Rice Plant under Laboratory and Filed Conditions. *Korean J. Environ. Agric.*, 43, 188-199. https://doi.org/10.5338/KJEA.2024.43.18
60. Ibrahim S. M., Abdelkhalek A. S., Abdel-Raheem Sh. A. A., Freah N. E., El Hady N. H., Aidia N. K., Tawfeq N. A., Gomaa N. I., Fouad N. M., Salem H. A., Ibrahim H. M., & Sebaiy M. M. (**2024**) An overview on 2-indolinone derivatives as anticancer agents. *Curr. Chem. Lett.*, 13(1), 241-254. http://doi.org/10.5267/j.ccl.2023.6.005
61. Hussein B. R. M., Moustafa A. H., Abdou A., Drar A. M., & Abdel-Raheem Sh. A. A. (**2024**) Preparation, agricultural bioactivity evaluation, structure-activity relationships estimation, and molecular docking of some quinazoline compounds. *J. Agric. Food Chem.*, 72 (16), 8973–8982. https://doi.org/10.1021/acs.jafc.3c08840
62. Jasiński, R. (**2025**) Recent progress in the synthesis of nitropyrrolidines via noncatalyzed (3+2) cycloaddition reactions of azomethine ylides. *Chem. Heterocycl. Compd.*, 61(5/6). http://osi131.osi.lv/index.php/hgs/article/view/10347
63. Sadowski, M., & Kula, K. (**2024**) Unexpected course of reaction between (1E, 3E)-1, 4-Dinitro-1, 3-butadiene and n-methyl azomethine ylide—a comprehensive experimental and quantum-chemical study. *Molecul.*, 29(21), 5066. https://doi.org/10.3390/molecules29215066

© 2026 by the authors; licensee Growing Science, Canada. This is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC-BY) license (http://creativecommons.org/licenses/by/4.0/).