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Editorial: Innovative technology and techniques for effective weed control

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Editorial on the Research Topic
Innovative technology and techniques for effective weed control

Weeds continue to be one of the greatest challenges faced by agricultural producers globally due to a variety of concerns including, but not limited to, increasing herbicide resistance, high labor requirements, and increased input costs (Fennimore, 2014; Fennimore et al., 2014; Soltani et al., 2016, 2017; Heap, 2025). In addition to these concerns, the regulatory environment is ever-changing, with added constraints on weed management strategies in the U.S (US EPA, 2025). This has been a direct response to rising concerns over herbicide off-target movement, thereby negatively impacting our environmental stewardship (Butts et al., 2022). In Europe, increasing societal and political pressure has led the European Commission to implement stricter legislation on pesticide use to address concerns over food safety, ecosystems, and human health (European Commission, 2020). Meanwhile, agricultural regions in Latin America, Australia, and Southeast Asia face their own challenges, including widespread herbicide resistance and the need to reduce operational costs (Casimero et al., 2022; Merotto et al., 2022; Thompson and Chauhan, 2022). Adding to these pressures, evolving pesticide regulations not only affect local management practices but also directly impact global trade because of pesticide residue limits in agricultural commodities (Gerhards et al., 2022).

As a result of the aforementioned challenges, farmers and the agricultural industry worldwide are compelled to explore and adopt innovative weed management solutions to enhance agricultural productivity, environmental stewardship, and economic profitability (Gerhards et al., 2022; Spaeth et al., 2024). One possible solution that can aid in these efforts is to implement innovative technological tools and techniques to precisely target areas of concern (Fennimore et al., 2016; Avent et al., 2024, 2025; Sosnoskie et al., 2025). Furthermore, "Cultural and Preventive Weed Management" along with "Precision Weed Management and Robotics" were recently listed as top research priorities among weed scientists, exemplifying the need for these innovative and integrated approaches for effective weed control (Brainard et al., 2023).

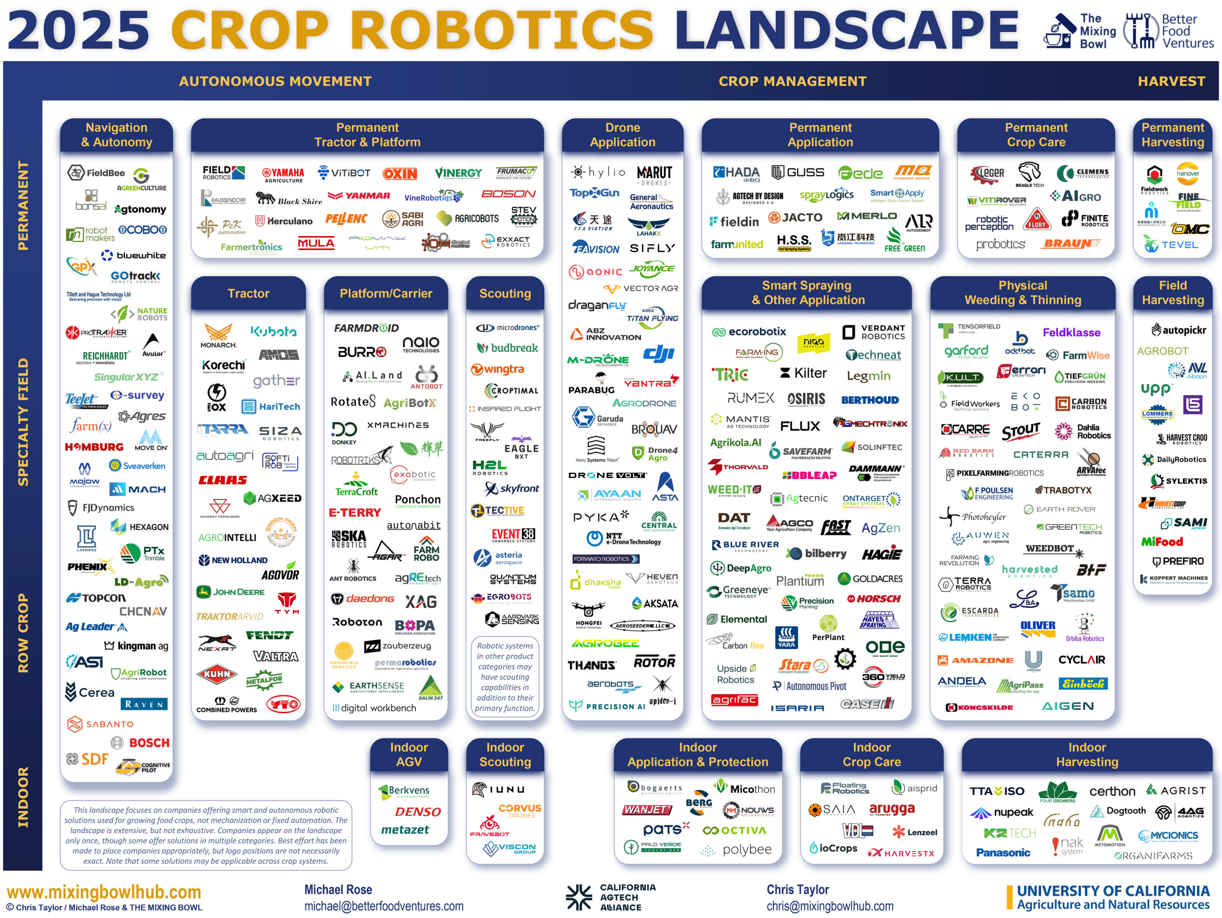

FIGURE 1
Image depicting the 2025 agricultural technology market landscape aiming to provide innovative technology and techniques for crop production, including weed management, moving forward. Reproduced with permission from "The 2025 Crop Robotics Landscape, Mapping Progress and Possibility" by Michael Rose, Chris Taylor, Better Food Ventures (https://betterfoodventures.com/) and The Mixing Bowl (www.mixingbowlhub.com).

Significant business capital has been invested recently in various agricultural technology enterprises (Figure 1). As these innovations continue to expand in the marketplace, it is imperative to thoroughly understand these technological tools and techniques, and their potential for implementation into weed management programs, and economic and social viability of adoption. As such, this Research Topic was created to highlight innovative research delving into these futuristic options and to establish a resource for foundational technological weed management literature components.

Innovative technologies comprised five separate manuscripts within this Research Topic. Baccin and Moretti explored the use of electrical weeding equipment in highbush blueberry. They identified reducing equipment speed and using sequential applications improved season-long weed control, and concluded electrical weeding served as an effective, non-chemical management option. Mwitta et al. designed a specialized, autonomous robotic platform and incorporated a deep learning, machine vision algorithm for the detection and laser diode elimination of weeds in cotton. They reported that their proprietary system could achieve nearly 73% weed mortality with an optimal operational setup, and would be a low-cost, reduced labor alternative for innovative weed management.

With the rapid increase in drone adoption, the global agricultural drone market is forecasted to grow to \$11.9 billion USD by 2028 from an approximate worth of \$1.4 billion USD in 2021 (Research and Markets, 2023). Butts et al. explored the combined effects of various hydraulic nozzle types and spray volumes on coverage and deposits from remotely piloted aerial application systems (spray drones). They observed increased spray recovery in the center of the spray swath compared to ground spray equipment, and identified specific nozzles to improve deposits while mitigating off-target movement potential. Paul et al. observed similar weed control in rice from a spray drone application compared to a knapsack manual sprayer despite significant reductions in spray volume, coverage, and droplet deposits. Their findings highlighted the potential of spray drones to reduce both labor and pesticide exposure in direct-seeded rice production.

Proper weed identification is a critical first step towards effective weed management efforts. Venkataraju et al. explored multiple algorithms, including machine learning, deep learning, and object detection, to correctly identify troublesome weeds such as Palmer amaranth (*Amaranthus palmeri* S. Wats.) and waterhemp [*Amaranthus tuberculatus* (Moq.) J. D. Sauer]. Their deep learning model was most successful, achieving 93% accuracy in identifying the two species.

Innovative techniques also involve viable strategies for improving future weed management efforts. Somala et al. explored the capabilities of a fungal extract (*Diaporthe* spp.) to reduce growth characteristics of barnyardgrass (*Echinochloa crus-galli* P. Beauv.). Their laboratory research demonstrated greater than 80% reduction in barnyardgrass seed germination, root length, and shoot length. In other laboratory allelochemical research, Trespidi et al. identified that root exudates from *Baccharis halimifolia* L. reduced germination by 50-75% and reduced root length by more than 85% across all tested species. However, they noted the challenges of consistently translating laboratory allelochemical results to field applications, and thus further research is needed to refine the use of allelochemicals for effective weed management. Nikolić et al. investigated biological characteristics, including germination thresholds and seed properties, of common ragweed (*Ambrosia artemisiifolia* L.) across different European climatic conditions. Their research demonstrated high adaptability of common ragweed to varying weather patterns, further exemplifying the need for site-specific weed management strategies.

Finally, understanding practitioners' perceived needs, current practices, and thoughts about novel technologies is vital for establishing stakeholder-driven research and providing meaningful outreach. Ugljic et al. surveyed 128 stakeholders across the U.S. Midwest to assess these values. Results revealed more than 75% of respondents were unsure of adopting innovative targeted spray technologies. Survey results also showed that nearly 50% of respondents indicated they needed additional information on targeted spray equipment, underscoring the importance of further innovative technology research in conjunction with effective outreach efforts.

This Research Topic collection of works serves as a critical example of the innovative weed management research being conducted globally, and the need for continued exploration. Long-term career forecasts have predicted that there will be a need for professionals who understand weed biology, ecology, and management principles, while simultaneously comprehending sensors, automation, and engineering technologies (Westwood et al., 2018). Additional funding resources and support are also required in this critical agricultural research crossroad. Collaborations with industry partners are a necessity, but there is also a pressing requirement for state, federal, and international funding resources to evaluate innovative weed management technologies and techniques. These novel tools will be released commercially regardless of the research background; therefore, funding not tied to a specific company will be crucial to validate marketing claims, supply non-biased data, and disseminate recommendations through engagement and Extension outreach for the successful implementation of these tools.

Author contributions

TB: Writing – original draft, Writing – review & editing. SV: Writing – review & editing. TW: Writing – review & editing. BV: Writing – original draft, Writing – review & editing.

Conflict of interest

Author Tom Wolf was employed by company Agrimetrix. Author Bruno Canella Vieira was employed by company Syngenta Crop Protection AG.

The remaining author(s) declared that this work was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Generative AI statement

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