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Editorial

Current Trends for a Modern, Integrated, and Sustainable Approach to Weed Management

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The need to reduce the use of agrochemicals in order to work towards sustainable farming systems has influenced scientific research on weeds in recent years. From 2018 to 2023, *Agronomy* published 323 papers in the areas of weed science and weed management. We divided the total number of published papers (PPs) in different sub-sections and topics as follows: Weed Science (WS): "Effects of herbicide on weeds" (HE), "Weed Resistance to herbicide" (WR), "Weed morphological, genetic and botanical characteristics, physiology and competition ability" (WC), and "Alien, invasive and new weeds" (NW). Weed Management (WM): "Chemical management with herbicides application" (CHM), "VRA application of Herbicides" (VRM), "Use of Bio-Herbicides" (BHM), "Agronomical (crop rotation, fertilization, irrigation, density and spacing of plants, use of cover crops and allelopathy) and direct physical (mechanical and thermal) weed management" (APM), and "Integrated management" (INM). The distribution of the PPs is shown in Figure 1. The main topics are APM (30%) and WR (20%). Other topics, like VRM (3%), BHM (6%), and INM (7%), confirm the current interest within weed science research towards alternative methods within an integrated and sustainable management approach. The aim of this Editorial is to briefly describe the current trends for a modern integrated and sustainable approach to weed management.

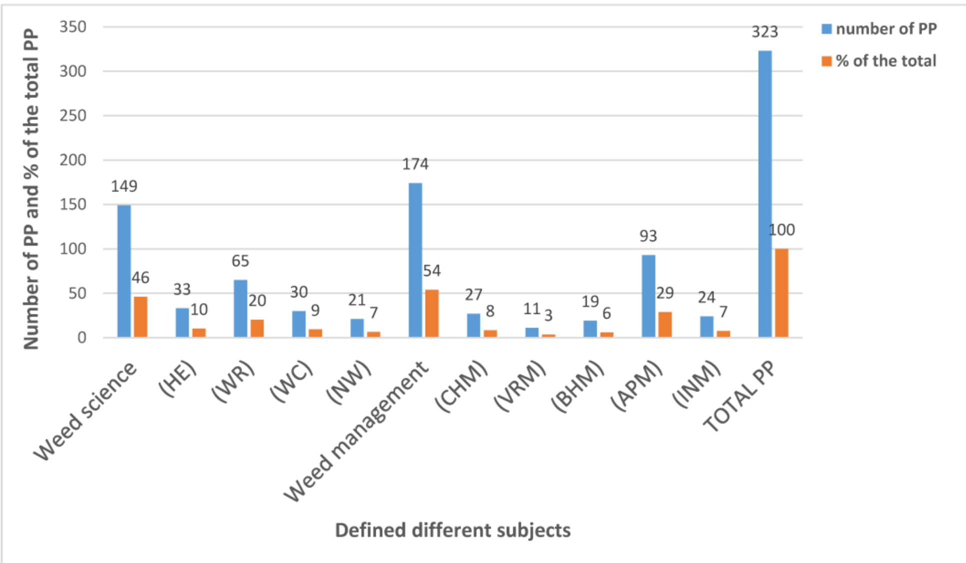

Figure 1. Number and percentual incidence of the total of published papers (PPs) in the "Weed Science and Weed Management" section of *Agronomy*, divided into different sub-sections and topics. Weed Science: "Effects of herbicide on weeds" (HE), "Weed Resistance to herbicide" (WR), "Weed morphological, genetic and botanical characteristics, physiology and competition ability" (WC), and

"Alien, invasive and new weeds" (NW). Weed Management: "Chemical management with herbicides application" (CHM), "VRA application of Herbicides" (VRM), "Use of Bio-Herbicides" (BHM), "Agronomical (crop rotation, fertilization, irrigation, density and spacing, use of cover crops and allelopathy) and direct physical (mechanical and thermal) weed management" (APM), and "Integrated management" (INM).

Weeds represent one of the main challenges for agricultural practices and constitute the highest potential for yield loss among several key food crops [1–3]. However, adopting an ecological approach, weeds should be considered as an important source of biodiversity, providing several important services to the agroecosystem [4]. In addition, in orchards, weeds can provide soil cover during the rainy season, contributing to the reduction in soil erosion [5].

For these reasons, a modern integrated weed management concept should comprise not only the integration of different techniques for weed control, but also a completely new design of the cropping system aiming at managing weed communities at a level that does not significantly affect crop yields [6]. MacLaren and colleagues [7] argued that, in current weed management, there is an excess of "techno-fixes", i.e., techniques and technical solutions that can effectively control the unwanted plants in the short term. However, in the long term, their continuous use in simplified agroecosystem management could be counterproductive, as there is a tendency to postpone, rearrange, and transfer problems, as well as creating new ones. A classic and didactic example of a techno-fix is the simplified use of chemical herbicides, which stimulated the onset of the weeds that had acquired resistance to their active ingredients [7]. The use of biotechnologies related to genetic engineering in weed control, creating crops resistant to glyphosate, led to a simplified management of agroecosystems [8]. Recently, several bioherbicides and natural herbicides have been studied as environmentally friendly tools that should be included in sustainable and integrated weed control strategies [9–11].

Research into an innovative weed management approach should focus on a long-term ecological approach, taking into account the interaction between weed communities, crops, management actions, and environmental and socio-economic aspects for each specific agroecosystem [7,12]. Research into sustainable weed management should provide solutions by integrating different information, technologies, and tools related to ecology, biology, chemistry, agronomy, and aeroengineering, as well as electronic and informatic ICT (information and communication technologies) [13,14], and more recently, the applications of AI [15]. In modern agriculture, physical weed control methods should be synergically integrated into weed control strategies, adopting the approach of "many little hammers" and the use of technological advancement in order to form a mixture of connected weed control tactics that has a cumulative effect on weed abundance and weed competitiveness, with the final goal of a balanced and profitable coexistence in the agroecosystem between crops and spontaneous flora [13]. Non-chemical weed management is mandatory in organic farming, and can be performed focusing on preventive, cultural, and direct physical weed control methods [16]. The adoption in agriculture of direct physical weed control methods should be consistent to the punctual verification of their effectiveness and their economic and energetic sustainability. In this regard, Coleman and colleagues compared energy requirements and effectiveness for chemical, mechanical, and thermal weed control [1]. The thermal weed control methods taken into account for the energy consumption estimation included some innovative technologies such as ultraviolet light, infrared weeders, flame weeding, hot water, hot foam, electrical weeding, laser weeding, and microwave weeding [11,17].

The energy consumption estimation of these technologies was conducted when applied in both broadcast (whole field) and site-specific treatments [1]. The results of the estimations highlighted that a broadcast approach to mechanical weed control (such as flex-tine harrow) consumed the least amount of energy per unit surface [1]. Regarding the site-specific approach, the performed estimation indicated that a conspicuous reduction in energy consumption (ranging from 97% to 99%) can be obtained for all the exanimated weed control techniques [1,14]. These last results confirmed the importance of the adoption of new electrotonic, computer, and communication technologies in agricultural research in order to obtain a sustainable and integrated weed control management approach [14].

In conclusion, research into weed management mainly addresses the definition of alternative agronomical strategies to herbicide application through the use of reduced doses of chemicals combined with the adoption of mechanical and thermal means (VRM and INM). Moreover, this research focuses on the definition of strategies for weed management based on the use of agronomical and direct physical means (APM and BHM) and the application of bioherbicides (BHM) according to the increasing demand for efficient and sustainable strategies.

Conflicts of Interest: The authors declare no conflict of interest.

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