

Sustainable Weed Control in the Agro-Ecosystems [†]

Emanuele Radicetti ¹  and Roberto Mancinelli ^{2,*} 

¹ Department of Chemical, Pharmaceutical and Agricultural Sciences (DOCPAS), University of Ferrara, 44121 Ferrara, Italy; emanuele.radicetti@unife.it

² Department of Agricultural and Forestry Sciences (DAFNE), University of Tuscia, 01100 Viterbo, Italy

* Correspondence: mancinel@unitus.it

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1. Introduction

Worldwide weeds are the cause of the highest potential crop losses (representing on average –34%), even if they are frequently underestimated since more attention is generally paid to dangerous insects (representing on average 18% of yield loss) or pathogens (representing on average 16% of yield loss). Therefore, there is a need to focus on finding agricultural practices that are able to perform effective and responsible management of these undesirable plants that naturally occur in agro-ecosystems. A wide range of scientific issues should be researched to this aim, as the study area varies from ecological to agronomical investigations. The methods currently adopted for managing weeds and their efficacy are related to environmental conditions, the available research information, the available tools, the economics, and the farmers' experience; for this reason, it is not possible to develop a standard method that can be efficiently applied under all conditions [1]. The introduction of synthetic chemical compounds throughout the application of herbicides has allowed the substitution of human, animal, and mechanical energy by chemical energy [2]. On the one side, the use of herbicides ensures high efficacy and reduced the need for labor better than any other methods; whilst on the other side, it evolved into the standard approach as the primary technology, reducing the importance of other means [1]. Indeed, the heavy reliance on chemical weed control is commonly considered objectionable because it hinders the progress of Weed Science and may continue to do so due to its low cost and extremely efficient results [1]. Nevertheless, the growing demand for environmentally friendly crop management has recently allowed the development of a variety of physical, cultural, and biological technologies.

Nowadays, the main goal of weed management is to provide the most appropriate methods to ensure a sustainable agro-ecosystem and the minimum influence of nuisance plants in various situations; therefore, the primary objective should be to improve our understanding of the relationship between weeds and crops [3]. The main issue concerns the concept of weeds that should be considered as a steady component of the agro-ecosystems and thus cannot be eliminated. In this way, each weed management practice adopted should supply a systematic approach aimed to minimize the undesired effects of the weeds and optimizing land use by combining prevention and control practices. These challenges call for the development of new weed management strategies. Therefore, it is necessary to modify our "agro-industry" approaches to weed control into a more sustainable management of agro-ecosystems. This change has been stimulated by a mixture of environmental, social, and economic pressures caused by the increased cost of production, soil erosion, degradation of water quality, and concern over the quality of rural life. Researchers can help growers meet such stakeholder needs. Only in this way it is possible to provide practical solutions for sustainable weed management.



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2. Weeds Grow Everywhere, Evolve, and Hinder Human Needs

The European Weed Science Society (E.W.R.S.) defines weeds as “any plant of vegetation, excluding fungi, interfering with the objectives or requirements of people”. Weeds are certainly as old as agriculture, and from the beginning, farmers recognized that the presence of those unsown species interfered with the growth of the crop they were intending to produce. Traditionally, weeds are any plants, regardless of their biology, that interfere with the utilization of land and water resources and thus, adversely affect human welfare. Therefore, all weeds’ interactions with human goals represent a permanent constraint to human activities and this justifies the employment of control tactics aimed at killing or managing as many weeds as possible. However, the complete eradication of actual (emerged plants) and potential (seed-bank) weeds is unachievable. Despite their potential to negatively affect farming objectives, it seems paradoxical that weeds may also be considered valuable [4]. Indeed, weeds interact not only with cultivated plants, but also show numerous interactions with other organisms, some of which can have direct effects on the functioning of agro-ecosystems. Based on the ecological approach, weeds are considered as valuable indicators of biodiversity, because of their role in providing food or shelter for animal species, much of the decline in farmland birds has been linked to the reduction in weed occurrence in arable crops. Weeds also serve as an indirect resource for predatory species, as in fact, they could provide alternative food sources for organisms that play a role in pest control. In addition, weeds could also cover the soil during the uncultivated period, generally during the rainy season, and thus help to reduce the negative impact of raindrops and wind on soil erosion [5]. With the adoption of sustainable approaches to weed management, it is possible to stimulate the evolution of populations of beneficial organisms to develop, i.e., some insects, which pollinate cultivated plants, need a source of nectar and pollen when the crop is not in flower, and weeds can provide this ecological service. All these issues highlight the fact that weeds are strongly related to other groups of organisms within agro-ecosystems. Considering that these interactions are often species-specific, the services provided by a weed community will strictly depend on the set of individual species and on their abundance within the community. For these reasons, weeds play an important role within agro-ecosystems, and therefore, they should be reconsidered as plants that are somewhat desirable or could become desirable. Understanding these interactions will lead to more effective weed prevention, management, and control [4]. However, from an agronomical point of view, weeds represent a permanent constraint to crop productivity, and this justifies the employment of control tactics aimed at killing as many weeds as possible. Weeds are highly competitive and are adaptable under adverse conditions and compete with crops at every stage of growth for nutrients, moisture, light, and space, thus reducing the quality and quantity of the final product. In addition, the reproductive mechanism in weeds is far superior to crop plants, particularly under unfavorable conditions; therefore, weeds constantly invade the fields and try to overcome the crops. Weed seeds germinate earlier, growing and flowering faster, and mature before cultivated plants can. Furthermore, weed seeds possess the characteristic of dormancy, which is an intrinsic physiological power of the seed to resist germination even under favorable conditions. The weed–crop interactions can be explained by giving a value to the weeds based on crop yield reduction and by comparing that cost with the cost of weed management to decide whether to apply a certain type of management. However, in order to assess the effects (including the economic aspects) of any weed management practice, it is necessary to understand the impact of weeds on a given crop. Generally, herbicide use underestimates the importance and the need to understand weed–crop relationships. The optimization of weed control programs depends on an early and a reliable prediction of the impact of weeds on crop yield [6].

Considering that most weed management practices are motivated by short-term goals, the effects on long-term changes in weed species and communities has not been well documented. Indeed, weed populations are dynamic in time, both within and between seasons, and in space, both within and between fields. The occurrence of a single weed

plant is not important to current crop performance, but if the single weed plant grows undisturbed for its entire life cycle, this can give rise to a large weed population which can greatly reduce future yields. A sound knowledge of weed population dynamics and how it is affected by different weed management strategies is fundamental for developing an optimum crop management strategy. The role of biodiversity in the functioning of agro-ecosystems has been discussed for many years, but it is only recently that the concept of the functional group has boosted research on the relationship between biodiversity and its role in ecosystems. In agricultural systems, characterized by continuous operations carried out to modify and control the environment, management success is based on crop yield, but each modification is a driving force for a new succession. The main factors which generally influence the establishment of weed communities include abiotic factors, such as climate or soil properties, biotic factors such as competition from the crop or other weed species, agricultural practices, and landscape heterogeneity. Usually, a few weeds dominate cropped fields, and their removal creates open niches that other species will colonize, and this explains why weed control is a never-ending process. Therefore, the best weed management systems may combine techniques to gain the desired level of control, but without encouraging the arrival of new weeds which cannot be controlled with present techniques and therefore may be more difficult to manage. Furthermore, the growing problem of weed resistance to herbicides indicates that weeds adapt to management practices. Although tools for managing weeds have greatly improved during the last century, weed communities have also changed rapidly, and floristic changes are likely to continue.

3. A Need for Ecological Approaches

Agriculture could be considered as a process for managing plant communities with the aim of obtaining useful biomass from a set of selected plant species. In this context, weeds are included in the other set of plant species that is possible to find in the agro-ecosystems. Although weeds are not intentionally sown, weed species are well adapted to environments dominated by humans and have been associated with crop production since the origins of agriculture. The increased reliance on herbicides has generally led to marked improvements in crop productivity and farm labor efficiency. However, herbicide-based control has failed to achieve long-term weed management, forcing producers to use more expensive management tactics, thereby increasing production costs. Therefore, these factors have led to the reappraisal of heavy emphasis on chemical weed control technology and to a growing interest in alternative management strategies that are less reliant on herbicides and more reliant on manipulations of ecological phenomena, such as competition, allelopathy, and response to soil disturbance [7]. The most successful weed management programs will be developed on a foundation of adequate ecological understanding. As weed management systems are being developed, ecological knowledge will become more and more important and the complexity of weed management must be considered. All levels of life are interdependent, and no level can exist independently of another, and this reason, weed management systems only focused on weeds are incorrectly devised and even if they may succeed temporarily, they are doomed to fail. Therefore, understanding weed-crop ecology will lead to more effective weed prevention, management, and control through a full range of factors regulating weed density, growth, and competitive ability [8]. The development of ecological weed management depends on the collective ability of farmers and scientists to convert local weed information into an improved understanding of weed ecology. Special attention must be paid when developing principles of weed ecology that are applicable in improved farm planning and decision-making. Ecological weed management involves the use of different types of information and various control tactics for developing strategies for subjecting weeds to multiple, temporarily variable stresses. Herbicides are not excluded from the toolkit but are viewed as options rather than absolute requirements for crop production. They are only used when and where the application of other control tactics fails to reduce and maintain weeds at acceptable

levels, and they are used in a manner that poses minimal risks to humans, other no-target organisms, and the environment. Ecological weed management differs from traditional weed management in that the primary focus is on creating an environment unfavorable for weed establishment, growth, and reproduction by integrating the options and tools that are available to minimize the impact of any weeds. Many of the components of an ecological management system are inextricably intertwined, thereby making it difficult to measure the individual contributions of specific elements of the systems. No single weed management tactic has proven to be the “magic bullet” for eliminating weed problems, given the nature of weed communities, but a better understanding of the underlying mechanisms that influence the success or failure of weeds in agro-ecosystems will further favor the development and adoption of ecological weed management systems for agricultural crops [9]. The integration of ecological principles into weed management decision making is a major challenge for weed science researchers and growers. Weed science must play a more important role in leading ecological research in agricultural systems and allow new and creative ways of meeting the challenge of managing weeds in ways that are environmentally and economically viable over the long term.

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