Chapter 1

Introductory Chapter: Actual Issues (Moments) in Herbicide Resistance Weeds and Crops

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Weeds are the most important pest complexes that globally reduce the ability of mankind to produce food, fiber, and fuel [1]. They have always been a component of agriculture and have successfully thwarted all attempts by humans to eliminate them from interfering with crop production [2]. Weeds result in a 34% loss of crop yield, on an average, worldwide.

In most parts of the world, herbicides are the dominant technology and the most effective weed control tools ever developed for the control of weeds that infest crops, killing 90 to >99% of the weeds targeted [3]. Consequently, the arable surface treated and the range of weed species targeted by herbicides increased rapidly worldwide after their development [1]. Weed communities have evolved over time in response to this control practice imposed on them. For the past half century, a principal method of weed management in commercial crops has been using herbicides in the most developed countries. But, this golden age of herbicides was quickly cut short, by the detection of the first herbicide-resistant weeds in the early 1970s [4], although it was described as a potential problem as early as 1957 [5, 6].

Resistance of weeds to herbicides is an unwanted response formed after the remade use of a same herbicide, where a weed population is once controlled with the similar efficacy by an herbicide which, in regular circumstances in an appropriate crop, had been efficient against the weed population [7]. Over the last several decades, in situations of intense herbicide usage, there have been many examples of the evolution of weed populations that are resistant to herbicides [8, 9]. However, "resistance evolution" does not mean that an herbicide directly changes a plant genetically (i.e., by causing mutations). Instead, the herbicide selects plants with some level of natural genetic resistance to the mechanism of action.

Weed adaptations to management tactics, including the biochemical mimicry in the form of an evolved resistance to the herbicides that are used for weed control, have increased rapidly throughout agriculture and now threaten global food security [10, 11]. From an evolutionary perspective, many factors influence the dynamics of herbicide-resistant evolution under herbicide selection [12, 13]. One crucial factor in herbicide-resistant evolution is the selection pressure caused by the repeated use of herbicides with the same mechanism of action in conventional crop cultivars [14], of which a major determinant is the herbicide use rate [15]. The use of an herbicide (or herbicides from the same herbicide group) continuously for many years can drastically decrease the number of susceptible biotypes within the natural weed population and dramatically increase the number of resistant biotypes.

Resistance has increased rapidly since 1975, and today, there are currently 477 unique cases (species × site of action) of herbicide-resistant weeds globally, with 251 species (146 dicots and 105 monocots) in more than one million fields. Herbicide-resistant weeds have been reported in 90 crops in 66 countries [8]. The total area affected, although not estimated, may cover several thousand hectares of crops regularly treated with herbicides in countries such as Australia, Canada and the United States of America, as well as countries in the European Union and South America. Weeds have developed resistance to 23 of the 26 known herbicide sites of action and to 161 different herbicides [8], and no new mode of action has been marketed since 1991 [16].

Herbicide resistance in weeds is a global problem. Resistance to herbicides in arable weeds is increasing rapidly worldwide and threatening global food security. Resistance has now been reported to all major herbicide modes of action despite the development of resistance management strategies in the 1990s. Despite it being a known issue, farmers in many states reveal the problem of herbicide weakness when the resistance is present in the field; alike bad, occasionally, they are using other herbicide ingredients that have the same mechanism of action as the one already used, which deteriorates the problem.

Proactive, evolutionary-based weed management options that integrate both herbicides and non-chemical tools are of utmost importance in agriculture today [14]. As resistance is generally the consequence of using a single herbicide repeatedly, any proactive or reactive approach should take an opposite view: the use of a diverse method to avoid repetition as much as possible. Because of that, herbicide-resistant weed management practices most often recommended by weed scientists include (1) identification of resistant populations through diligent field monitoring; (2) biosanitary practices, such as cleaning equipment and removing and destroying resistant plants to prevent re-infestation of the field with resistant seeds or plant parts; (3) crop rotations and/or the use of competitive covers that allow the use of alternative mechanism of actions or that change the balance of weeds in a field or both; (4) cultivation and hoeing that provide weed control, which reduces reliance on herbicides; (5) using herbicide rotations and mixtures, which include compounds from classes of herbicides with different modes of action that control similar spectra of weeds; (6) using only labeled herbicide rates at labeled application timings; (7) introduction of new herbicides and herbicide modes of action to replace those herbicides failing due to resistance; and (8) controlling weed escapes [17].

Since 1996, herbicide-resistant crops (HRCs) have had a major effect on agriculture, particularly in the United States of America, Brazil, Argentina, and Canada [18]. The introduction of HRCs in the United States of America, for example, helped solve a major weed-management problem that was developing at that time—the evolution of weeds resistant to the acetolactate synthase (ALS)-inhibiting and protoporphyrinogen oxidase (PPO)-inhibiting herbicides [19]. The adoption of HRCs has resulted in significant changes to agronomic practices as well. HRCs have allowed for the acceptance of practical, uncomplicated, and below hazard crop production systems with minor dependencies on soil cultivation and diminished energy demands [20]. Long-term differences have had an affirmative environmental issue by diminishing soil erosion [21], fueling the needs for soil cultivation [22], and numbering herbicides with groundwater advisories [23], leading to a slight reduction in the overall environmental impact quotient of herbicide use [24, 25]. Because of the adoption of herbicide-resistant crops, conservation tillage used in crop production has increased [18, 26, 27], and the volume of herbicides used in HRCs has decreased [28]. Finally, the effect on soil and plant microbial populations has not been shown to be a potential environmental risk [29, 30]. Because of these reasons by 2015, more than 179 million hectares worldwide were planted to HR varieties of soybean, maize, canola, cotton, alfalfa, and sugar beets [31].

Controversies surrounding HRCs commonly focus on human and environmental safety, labeling and consumer choice, intellectual property rights, ethics, food security, poverty reduction, and environmental conservation [32]. Of potential concern with HRCs, it is a possibility for the development of weed-resistant mechanisms to non-selective herbicides [21] and shifts in the composition of weed flora, which provoke a change of biodiversity [33, 34]. Other risks for this system are “volunteer HR crops”. Volunteer plants of the previous HR crop in the next HR crop can be a problem if the next HR crop is resistant to the same herbicide like the previous HR crop [35]. Possible direct influences of HRCs acceptance on biodiversity, especially in South America, encompassed a shift in the genetic diversity of crops, expended volunteer crop issues, and induced aggression by resistant varieties of natural ranges above the farm line [36]. Also, there is a risk correlated with the probability for the exchange of genetic material between related HRCs, from the one side wild progenitors and conventional crops and weeds from the other side [37, 14].

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