Chapter

Weed Management in Pulses: Overview and Prospects

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Abstract

Pulses, the world's second-most consumed food, are an important source of food. They face several major challenges, including weed infestations, as a wide variety of weeds compete with them. Because of their competition with weeds, pulses can suffer a significant yield reduction. So as to alleviate such a menace, growers rely on different management tools, such as tillage, intercropping systems, and herbicides. Each method has been effective, albeit to varying degrees, in resolving the issue. Chemical herbicides, however, have served as double-edged swords over the past few decades due to their indiscriminate use. The repetitive use of the same herbicide or herbicides with the same mode of action confers resistance, thereby, leading to a serious impact on only nontargets. Therefore, it requires well-thought-out planning for a weed management strategy to maximize yields without creating environmental issues concomitantly. At the present, the integrated weed management approach has been accepted as the most reasonable tool for many farmers, which includes using preventive strategies, mechanical tools, crop rotation, intercropping, and herbicides with different modes of action, but cautiously. Modeling and robotics are the cutting-edge technologies that growers will be using for weed management in the coming days, thanks to the advent of such new innovation.

Keywords: weed flora, herbicides, weed resistance, Site-Specific Weed Management (SSWM), AI-driven machines

1. Introduction

The Fabaceae or Leguminosae family, also referred to as the legume, pea, or bean family, is the third-largest group of flowering plants, with more than 20,000 species [1]. The term "pulse" is limited to the annual legume crops that are specifically grown for dried and edible seeds. Chickpea, cowpea, pigeon pea, faba beans, lentils, and dry beans are some of the types of pulses [2]. Pulses are the second-most consumed food crop in the world, right behind cereal grains. They are a crucial source of food for the poor, particularly in developing and underdeveloped countries. Moreover, pulse-based products are in high demand among consumers around the world due to the significant nutritional value for the human diet they offer in terms of protein and mineral quality and bioavailability [3]. Incorporated into cropping systems, pulses increase the efficiency of both water and nutrient use, as they can fix atmospheric nitrogen into soils and allow companion crops to use stratified soil water, thereby contributing to sustainability in crop production [4].

A total of 89.8 million metric tons of pulses were produced worldwide in 2020, with India being the largest pulse producer [5]. A wide range of pulse crops are cultivated around the world, including chickpea (Cicer arietinum), pigeonpea (Cajanus cajan), mungbean (Vigna radiata), urdbean (Vigna mungo), cowpea (*Vigna unguiculata*), lentil (Lens culinaris *Medikus ssp. culinaris*), horse gram (Macrotyloma uniflorum), French bean (Phaseolus vulgaris), and lathyrus (Lathyrus sativus). There have been major challenges in increasing total pulse production to meet its global demand due to both biotic and abiotic stresses. Since pulses take so long to reach maturity, weeds often get a head start on the crops and end up smothering them. Furthermore, most pulses are grown in conjunction with nonlegume crops, and 84% of that area is grown under rain-fed conditions. For this reason, pulses are vulnerable to a wide range of biotic and abiotic stresses [6]. Weed infestation in crops accounts for the highest yield loss, i.e., 34%, compared to the losses associated with any pests, such as insects and pathogens, depending upon crops and weed's emergence time, density and nature [7, 8]. Weeds not only reduce crop yields but also impede other agricultural operations and serve as an alternative host for a wide variety of pests and diseases. It is vital to bring the weed density below the threshold level and maximize the crop yield and quality. In this review article, a specific focus is given on pulse's weed control choices for growers at the present and in the days to come.

1.1 Major weed flora

Various types of weeds have been reported to be associated with pulse crops, varying with the agro-ecological conditions and practices of crop management. However, the most abundant ones are presented in **Table 1**. The type of weed flora and the level of infestation in the field determine the extent to which crop growth and yield are affected. Reference [9] reported that non-grass types and sedges had a greater impact on the case of pigeonpea and sorghum intercropping than grass types. *Cyperus rotundus* L., more commonly known as nut grass, is a rhizospheric competitor with its network of underground tubers and is most prevalent during the summer and wetter months. Lambs quarter (*Chenopodium album*) is the most common and destructive weed in pulse crops. It thrives quickly and easily disseminates through seeds carried by the breeze. It not only competes with them for moisture but also spreads viral diseases [10]. Furthermore, WSSA [11] is in agreement with the fact that the aforementioned weed is the most prevalent weed in gardens.

A better understanding of environmental practices is by either increasing germination to kill seedlings or suppressing germination [12]. As a strategy for depleting weed seed banks, Gallandt [13] suggests influencing seed germination. In a similar way, understanding weed phenology could lead to more specific control methods by accurately estimating when and how weed competition affects crop yield [14]. It is important to note that most studies on the biology and ecology of weeds are based on a small number of populations. One region's population, however, may differ from another due to differences in management practices, rainfall, climate, soil type, etc. Consequently, it is necessary to include multiple populations in future studies.

1.2 Crop loss

The reduction in yield due to weeds can be up to 97% (**Table 2**); however, it varies with crops, weed intensity, crop management practices, and agro-climatic conditions.

Weeds	Family	Types	Seasons		
			Kharif	**Winter**	**Spring/ Summer**
Ageratum conyzoides	Asteraceae	Broad-leaf weed		*	
Amaranthus viridis	Amaranthaceae	Broad-leaf weed			*
Anagallis arvensis	Myrsinaceae	Broad-leaf weed		*	
Argemone maxicana	Papaveraceae	Broad-leaf weed		*	
Asphodelus tenuifolius	Asphodelaceae	Broad-leaf weed		*	
Avena ludoviciana	Poaceae	Narrow-leaf weed		*	
Carthamus oxycantha	Asteraceae	Broad-leaf weed		*	
Celosia argentea	Amaranthaceae	Broad-leaf weed	*		
Chenopodium album	Chemopodiaceae	Broad-leaf weed		*	*
Cleome viscose	Capparaceae	Broad-leaf weed	*		
Commelina benghalensis	Commelinaceae	Broad-leaf weed	*		
Convolvulus arvensis	Convovulaceae	Broad-leaf weed		*	
Coronopus didymus	Brassicaceae	Broad-leaf weed		*	
Cucumis trigonus	Cucurbitaceae	Broad-leaf weed	*		*
Cynodon dactylon	Poaceae	Narrow-leaf weed	*		*
Cyperus difformis	Cyperaceae	Sedge	*		
Cyperus iria	Cyperaceae	Sedge	*		
Cyperus rotundus	Cyperaceae	Sedge	*	*	*
Dactyloctenium aegyptium	Poaceae	Narrow-leaf weed			*
Digera arvensis	Poaceae	Narrow-leaf weed	*		
Digitaria sanguinalis	Poaceae	Narrow-leaf weed			*
Echinochloa colona	Poaceae	Narrow-leaf weed	*		
Echinochloa crus-gall	Poaceae	Narrow-leaf weed	*		
Eclipta alba	Asteraceae	Broad-leaf weed			*
Eleusine indica	Poaceae	Narrow-leaf weed			*
Eragrostis tenella	Poaceae	Narrow-leaf weed	*		
Euphorbia hirta	Euphorbiaceae	Broad-leaf weed	*		
Fimbristylis spp.	Cyperaceae	Narrow-leaf weed	*		
Fumaria parviflora	Papaveraceae	Broad-leaf weed		*	
Gnaphalium indicum	Asteraceae	Broad-leaf weed		*	
Lathyrus aphaca	Fabaceae	Broad-leaf weed		*	
Launaea nudicaulis	Asteraceae	Broad-leaf weed		*	
Lolium temulentum	Poaceae	Narrow-leaf weed		*	
Medicago denticulate	Fabaceae	Broad-leaf weed		*	
Melilotus alba	Fabaceae	Broad-leaf weed		*	

Weeds	Family	Types	Seasons		
			Kharif	Winter	Spring/ Summer
Panicum maximum	Poaceae	Narrow-leaf weed			*
Phalaris minor	Poaceae	Narrow-leaf weed		*	
Phyllanthus niruri	Phyllanthaceae	Broad-leaf weed	*		
Physalis minima	Solanaceae	Broad-leaf weed			*
Poa annua	Poaceae	Narrow-leaf weed		*	
Polygonum plebejum	Polygonaceae	Broad-leaf weed			*
Polypogon monspeliensis	Poaceae	Narrow-leaf weed		*	
Portulaca quadrifida	Portulacaceae	Broad-leaf weed			*
Rumex dentatus	Polygonaceae	Broad-leaf weed		*	
Saccharum spontaneum	Poaceae	Narrow-leaf weed	*		
Setaria glauca	Poaceae	Narrow-leaf weed	*		*
Solanum nigrum	Solanaceae	Broad-leaf weed		*	*
Sorghum halepense	Fabaceae	Narrow-leaf weed	*		
Spergula arvensis	Caryophllaceae	Broad-leaf weed		*	
Trianthema monogyna	Aizoaceae	Broad-leaf weed	*		*
Vicia hirsute	Fabaceae	Broad-leaf weed		*	
Vicia sativa	Fabaceae	Broad-leaf weed		*	

**Indicates the active season for the corresponding weeds. Source: [9].*

Table 1.
Significant weeds and their growing seasons associated with pulses.

Pulses	Critical period [15]	Yield loss (%)	
		Ali M. et al. [8]	Other references
Pigeon pea	15-60 DAS	21-97	31.0-52.8 [16]
Green Gram	15-30 DAS	40-50	38.6 [17]
Black gram	15-30 DAS	44-83	43.3 [18]
Chickpea	30-60 DAS	29-70	77.8 [19]
Lentil	30-60 DAS	70-87	37.7 [20]
Pea	30-45 DAS	25-35	50 [21]

Table 2.
Critical period and yield loss associated to major pulses.

2. Weed Management practices

Understanding weed biology and ecology is essential for developing a sustainable weed management program. We still lack fundamental information on many important species, necessitating additional research. Nevertheless, there are many approaches that have been put into practice in farmers' fields with the intention of limiting the effects of weeds in effective and economically sound ways.

2.1 Tillage

It is one of the oldest preventive measures to avoid weed infestation. It uproots and leaves weeds exposed, taking control of weeds by burying their seeds deep enough to impede their germination and altering the soil-based growing environment. Taking an effective approach to controlling perennial weeds requires covering them deeply in the soil or drying them out by starving tactics [22]. There are several methods of tillage that are applicable to pulses. However, the efficacy of tillage varies with its methods, as we can observe in **Table 3**.

The use of moldboard plows prior to sowing had no discernible impact on chickpea yield, as demonstrated by Barzegar et al. [24]. Their findings state that, compared to moldboard, disk harrows were more effective against yield loss. Nighttime (photocontrol) tillage has been proven to be advantageous over weed management; nonetheless, due to its inconsistent results, questions have arisen about its effectiveness [25].

2.2 Intercropping system

Intercropping has been identified to be an effective approach in establishing agricultural systems and enabling sustainable agriculture goals. Hiltbrunner et al. [26] concluded that one of the greatest benefits of intercropping systems is weed control. Intercropping increases soil surface cover and plant diversity, two principles that control weeds better than monocropping. It has been shown in several studies that intercropping improves yields and eliminates weeds. Banik et al. [27] found that planting wheat and chickpeas together increases total yield productivity, makes better use of the land, and keeps weeds from growing. **Table 4** shows the efficiency of different inter-cropping systems in managing weeds in pulses [28].

Furthermore, according to Rai et al. [29], in pigeonpea + blackgram, and pigeonpea + greengram intercropping systems, weed suppression efficiency was found to be 69.6% and 69.4%, respectively, which were significantly higher than that of pigeonpea monocropping. This finding also concurs with the conclusion that intercropping is superior to monoculture for reducing weed damage to crops.

Treatments	Weed density(No./0.25m^2)			Weed control efficiency (%)	
	Broad- leaf weeds	Grasses	Sedges		
Zero tillage	6.52	6.58	1.31	6.6	49.6
Conventional Tillage	12.13	9.4	1.73	10.28	40.8

Source: [23].

Table 3.
Effect of different tillage practices for weed management in mung bean.

Intercropping systems	WSE (%)
Pigeon pea + Black gram	32.8
Pigeon pea + Green gram	31
Pigeon pea + Cowpea	39.1
Pigeon pea + Sesame	36.6
Pigeon pea + Pearlmillet	50.8
Black gram + Maize	17.3
Pigeon pea + Maize	16.4

Source: [28].

Table 4.
Weed-Smothering Efficiency (WSP) of different pulse-based intercropping systems.

2.3 Herbicides

Herbicides are a significant piece of agricultural technology that has contributed, at least in part, to the agricultural revolution that has occurred in recent decades and to the accompanying rise in the amount of food that has been produced. Herbicides, a major component of pesticides, are one of the external factors and a group of synthetic chemical and biochemicals used to suppress or kill unwanted vegetation [30]. Increasing labor shortages in agriculture, coupled with the need to maximize crop productivity to meet the needs of a growing global population, have led to the widespread use of herbicides for weed control, leading to their adoption as one of agriculture's most popular weed control strategies [31]. An author [32] added that reducing soil erosion resulting from tilling is another advantage of the approach. Nevertheless, maintaining the efficiency of existing weed control options necessitates that herbicide use practices and recommendations be regularly updated and revised to keep up with the ever-changing weed ecology (**Table 5**).

It is imperative that herbicides be applied only at the time specified on the label and in accordance with the recommended intervals between the time of treatment and the time of planting or harvesting the crops. Whenever there is a possibility of rain within 2–4 hours of application, it is best to avoid herbicide applications. The use of herbicides requires a great deal of caution from us [34]. Several countries have restricted the use of some herbicides because of the health risks they pose. Paraquat, for example, is restricted in some countries due to its acute toxicity and association with Parkinson's disease. That means, the aforementioned chemical can only be applied by certified applicators for the purposes of scientific research and observation.

2.4 Integrated Weed management

Herbicidal technology has faced significant shifts in its effectiveness in agricultural systems, which can, in some instances, result in the failure of weed control applications. This is primarily attributable to the perpetuating development of weed tolerance and resistance, as well as the development of the herbicide industry and its associated limitations. We have some data on cases of herbicide-associated resistance as expressed in **Figures 1** and **2** [35].

Herbicides	Trade names	Active ingredients (lb a.i)	Site of action	Application Time	Targets
Pendimethalin	Acumen	0.95-1.43	3	PPI	Annual grasses, small-seeded annual broadleaf weeds
Trifluralin	Treflan	0.5-1	3	PPI	Grasses and some small-seeded broadleaf weeds
Ethalfluralin	Sonalan	0.55-0.75	3	PPI	Certain grasses and broadleaf weeds
S-metolachor	StreliuS II	0.95-1.9	15	PPI or PRE	Annual grasses and some broadleaf weeds
Saflufenacil	Sharpen	0.02-0.04	14	EPP or PRE	Broadleaf weeds
Imazethapyr	Praxis	0.03-0.047	2	PRE, EPOST	Several annual broadleaf weeds and some foxtail
Dimethenamid-p	Slider	0.56-1	15	PPI & PRE	Annual grasses
Carfentrazone	Aim	0.008-0.031	14	EPP	Small weeds
Flumioxazin	Flumi	0.095	14	POST	Various grasses and boardleaf weeds
Quizalofop	Targa	0.035-0.08	1	POST	Annual grasses and quack grass
Glyphosate	Roundup PowerMAX	5.5	9	POST	Wide range
Triallate	Avadex MinTill	1.5	8	PPI	Wild oat
Sethoxydim	Poast	0.1-0.5	1	POST	Actively growing grasses
Clethodim	Tapout	0.07-0.25	1	POST	Annual grasses
Imazamox	Beyond	0.031-0.047	2	EPOST	Actively growing small broadleaf and grasses
Sulfentrazone	Sulfin	0.07-0.25	14	EPP or PRE, PPI	Annual broadleaf weeds including pigweed
S-metolachor + Glyphosate	Sequence	0.75-1.5 + 0.56-1.13	15+9	EPP or PRE	Grasses and some broadleaf weeds
Paraquat*	Paraquat	0.3-0.5	22	POST	For harvest aid and desiccation of green weed foliage

lb a.i. = *Pounds active ingredient,* **EPP** = *Early Preplant,* **PPI** = *Preplant Incorporated,* **PRE** = *Preemergence,* **EPOST** = *Early Postemergence,* **POST** = *Postemergence*
Sites of action (groups): **1** = *ACCase Inhibitor,* **2** = *ALS Inhibitor,* **3** = *Microtuble Inhibitor,* **8** = *Lipid Synthesis Inhibitor,* **9** = *EPSP Inhibitor,* **14** = *Cell Membrane Disruptor (PPO Inhibitor),* **15** = *Seedling Shoot Inhibitor,* **22** = *Cell Membrane Disruptor (PSI Inhibitor)*indicates Restricted Use Herbicide.*

Table 5.
Environmental Protection Agency (EPA)-approved herbicides recommended for pulse crops by Johnson et al. [33] based on research conducted at the South Dakota Agricultural Experiment Station and other studies.

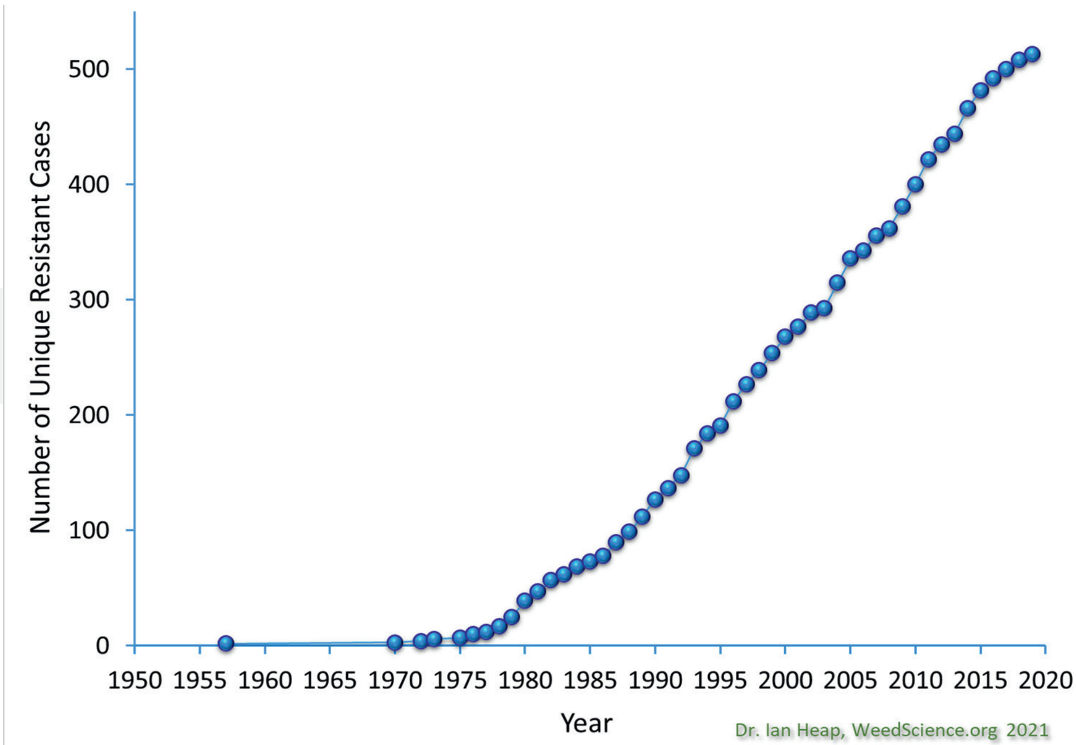

Figure 1.
A global increase in unique resistant cases at different years.

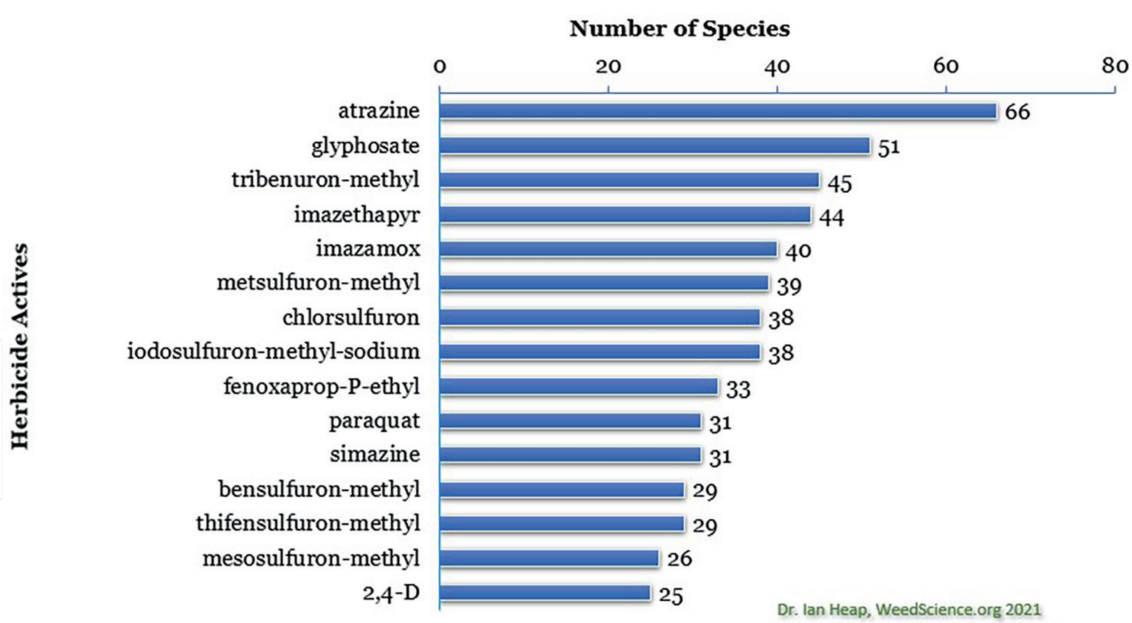

Figure 2.
The top 10 herbicides, along with the number of associated resistant species. Source: [35].

The widespread use of herbicides that primarily have the same or a similar mode of action is hamstrung by the emerging risks of environmental hazards, the introduction of herbicide resistance in various biotypes of weeds, and the nonselectivity and narrow spectrum of herbicides, all of which contribute to limiting the scope of herbicide use. To develop an effective and sustainable weed management strategy, it is essential to first comprehend the selection pressure of an organism. Selection pressure is an outcome of virtually anything as long as the survival and reproductive pattern of a species are influenced, provided that it acts in a relatively consistent manner over and over again [36]. It is worth pointing out that this is the case with herbicide resistance. The repeated use of the same active ingredient or of the same mode of action eliminates susceptible weeds from a population, leaving only the resistant ones, which become dominant species over time; the development of herbicide resistance can be considered an evolutionary process [37].

The development of herbicide-resistant weeds is associated with several factors, including selection pressure, the weed's genetic variability, inheritance patterns, gene flow, herbicides' nature, agro-ecosystem factors, and others [38]. In light of this, it is not always possible to come up with a single management strategy for controlling and preventing the spread of herbicide-resistant weeds; instead, an integrated weed management (IWM) approach is required.

Integrated weed management (IWM) strategies for managing resistant weeds:

1. Regularly scout fields and identify weeds, as well as respond swiftly to changes in weed populations, to prevent the spread of weeds.

2. Choose herbicides based on the types of the target weeds present and use it prudently.

3. Crop rotation is an effective method for interrupting the life cycles of weeds, and certain weed problems are more easily managed in certain crops than in others.

4. Refrain from using the same herbicide or another herbicide with the same mode of action for 2 years or more in a row in the same field.

5. Consider using a tank mixture or sequential applications of herbicides with varying modes of action.

6. Keep tillage and harvesting equipment clean to avoid spreading weeds from field to field.

2.5 Modeling and robotics for SSWM

Site-specific weed management (SSWM) is a state-of-the-art weed management approach that allows optimization of weed treatment for each unique agronomical site, with precise and continuous monitoring and mapping of weed infestations, which has been proven highly efficient and environmentally safe for control of weed populations [39, 40].

This system relies on multidisciplinary technologies such as image sensing techniques (multiple-dimensional cameras and multispectral imaging), GPS, remote sensors, artificial intelligence (AI), and machine learning algorithms for discerning a specific weed and its population, thereby allowing unmanned vehicles for weed management via targeted spraying, automated hoeing, or other techniques. In conjunction with the new sensor technologies, decision support systems (DSS) can help farmers apply weed control treatments at the right time, with the right intensity, and in the right places [41].

2.5.1 Drones

Precision agriculture has adopted unmanned aerial vehicles (UAVs), primarily drones, as a common tool [42, 43]. Due to their affordability, user-friendliness, and adaptability, UAVs are frequently the preferred option for rapid and accurate in situ remote sensing or survey operations. Despite their adaptability, these systems can serve a variety of purposes depending on the sensors they carry. UAVs, as one of the most effective tools for weed mapping, are critical for SSWM. The workflow consists of three significant phases: 1) collection of field images, via sensor cameras, 2) image processing, which recognizes weeds and pinpoints their whereabouts and patches via deep neural networks or other AI techniques, 3) training-specific algorithms to eliminate the targeted weeds with herbicide spraying by drones or mechanically with unmanned terrestrial vehicles (UTVs). There are three types of sensors attached to UAVs, depending on the payload and weed/crop recognition system and other purposes: 1) RGB (Red, Green, and Blue) or VIS (visible) sensors, 2) multispectral sensors, and 3) hyperspectral sensors. With up to 80% precision, hyperspectral sensors can differentiate between glyphosate-resistant and glyphosate-susceptible Kochia biotypes [44]. And the accuracy rate is 96% for *Amaranthus palmeri* in real field bases [45]. A novel alternative to UAVs could be laser-equipped robots.

2.5.2 Autonomous laser weeding

Andreasen et al. [46] highlighted that Autonomous Laser Weeding is a cutting-edge technique for weed management that is a prototype, not yet widely used or sold commercially. Artificial intelligence and deep learning are being deployed to precisely locate and distinguish weeds [47, 48] and burn the meristems of the targets with laser beams released by robotic actuators for real-time weed control. Beam quality is a crucial parameter for laser applications, particularly weeding, as it determines the maximum power density that can be achieved. At least 54 joules of laser energy per plant were required to cause lethal damage to each treated plant with a 95% probability. Lethal damages are contingent upon weed species, growth stage, laser spot position and area, and laser energy (J) applied [49–51]. Papadopoulos [52] reported that LaserWeeder, a product of Carbon Robotics, is an autonomous laser robot that has the capacity of eliminating 200,000 weeds per hour by incinerating active ones, with a performance increase of 100 percent over the system's first version.

Need-based spatial spraying minimizes selection pressure on herbicide-resistant weeds and herbicide diffusion with only minimal interference with nontargeted plants. Importantly, laser robots offer substantially less interference with biodiversity and the environment, achieving the goal. Due to their lighter weight, UTVs perform site-specific weeding with acceptable soil impacts, creating a more favorable environment for crop growth. There have been positive impacts on ecological and agro-economic aspects, as depicted in **Figure 3**. It is possible for these robotic devices to replace organic growers' manual weeding practices. However, it can be challenging or may take some time, particularly for developing countries, to introduce and adopt such a novel approach.

3. Conclusion

To overcome the weed infestation, farmers have been using different tools and methods, and among them, the herbicide-use approach is widely adopted due to

DOI: http://dx.doi.org/10.5772/intechopen.110208

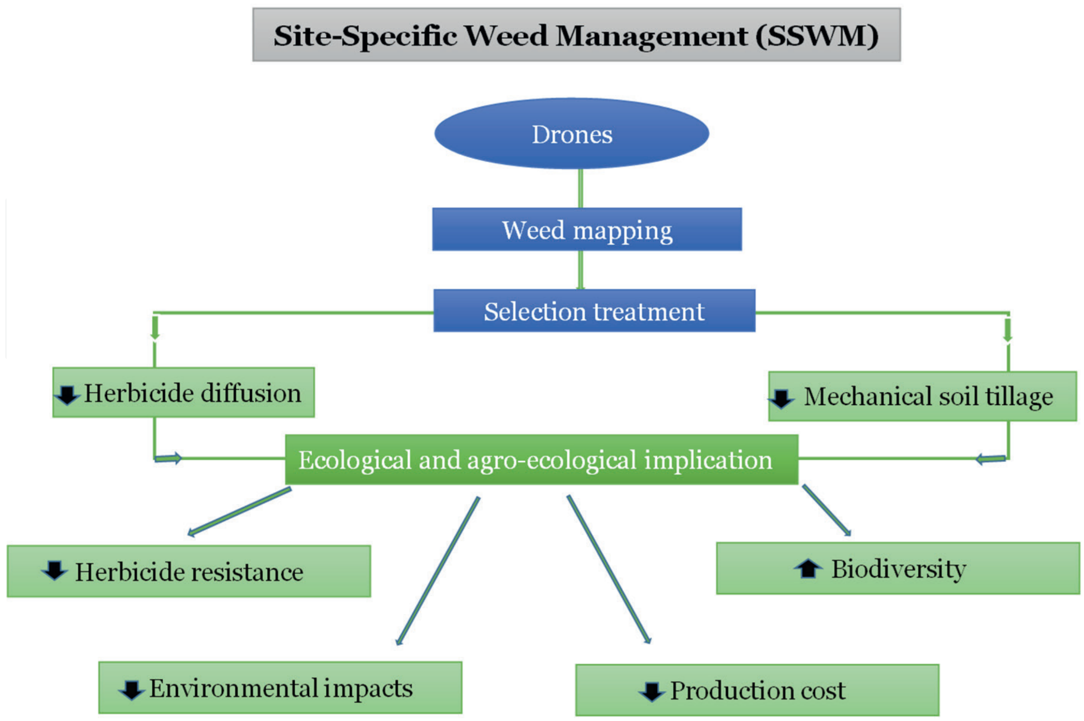

Figure 3.
Drone-based site-specific weed management (SSWM) and its impact on the Agri-economy and ecology. Source: [53].

its ease of use and labor shortage. Long-term weed management is unlikely to be achieved through the use of a single method of weed control, since this approach often leads to the development of weed resistance. This is not only the case with herbicides; even repetitive hand hoeing over and over may force weeds to adapt to such a stressed environment and build resistance/tolerance. Over the past few years, herbicide resistance and resistance management have been of great interest to weed scientists. Site-specific weed management (SSWM) is likely to improve the sustainability of weed management by treating only the weed species community, using image analysis and machine learning techniques. Further studies are crucial and in high demand to make this novel approach applicable in real agricultural situations.

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