# Weed Management Under Variable Crops grown in Diverse Environments

Abdul Baqi[1], Noor ul ain[2]
[1]Government Boys Postgraduate College, Sariab Road Quetta
[2]Lahore Collage for Women University
*Email: baqiaziz7@gmail.com

**Citation** | Abdul Baqi, Noor ul ain, “Weed Management Under Variable Crops grown at Diverse Environments,” *Int. J. Agric. Sustain. Dev.*, vol. 5, no. 1, pp. 01- 14, 2023.
**Received** | Dec 28, 2022; **Revised** | Jan 16, 2023; **Accepted** | Jan 22, 2023; **Published** | Jan 27, 2023.

Weeds are a significant problem for the efficiency and profitability of crop production systems worldwide. Since the introduction of herbicide-resistant crops, the use of herbicides as a weed control method has risen steeply because they are among the most effective among available methods. Weeds that are resistant to herbicides and other negative consequences for human and environmental health are a direct result of overusing herbicides. Sustainable weed management in major crop production systems can be aided by crop diversification. It provides a framework for integrating scientific discoveries and ecological understanding into weed management strategies for the long term. In order to increase the reliability and efficiency of ecosystem services, "diversified cropping" refers to the deliberate use of functional biodiversity at the temporal and/or spatial levels. Reduced weed density can be achieved through crop diversification's inhibitory effect on weed seed germination and weed growth. Furthermore, diversified farming systems are more resistant to climate change and produce higher crop yields than monoculture systems. The adoption of a diversified cropping system, however, faces a number of obstacles. These include, but are not limited to, changes in technology, government policies, farm-level decisions, climate, and market conditions. This review looks at the ways in which crop diversification helps with weed management, the difficulties that come along with it, and the prospects for weed control in light of the diversification idea.

**Keywords:** Climate change; Variable Climate; Sustainability; Rotation of Crops; Crop Cover.

## Introduction

The term "weed" is commonly used to refer to any unwanted plant that poses a threat to human health or disrupts human activities [1]. Due to competition for water, nutrients, sunlight, and space in a crop production system, weeds reduce crop yields [2]. The aggressive competition from weeds greatly reduces crop yield and increases the cost of producing crops [3]. Variables such as weed density, emergence timing, weed type, and crop type all play a role in the amount of yield loss due to weeds [4]. It has been estimated that weeds cause a worldwide yield loss of up to 40% [5]. Yield loss due to weeds is estimated to cost over $8.2 billion per year in the United States alone [6]. When it comes to major crops, weeds have the most devastating effect on corn and soybean production in the United States. Weed interference decreased corn and soybean yields by 50 and 52 percent, respectively, in the US and Canada between 2007 and 2013. It is estimated that weeds cost Australia $2.52 billion and India $11 billion annually in lost yields. About 3 million metric tons of China's annual grain production is lost due to weeds. According to the data provided here, weeds continue to be a major cause of economic output and crop yield losses all over the world.

The majority of weeds are removed by hand in developing countries where subsistence farming is practiced. People are increasingly turning to chemical methods of weed control due to rising urbanization, rising labor costs, and a shrinking agricultural workforce. An increase in the haphazard use of herbicides for weed control in subsistence farming systems in Southeast Asian countries like Nepal, Bhutan, Bangladesh, and Thailand has raised health and environmental concerns [7]. Farmers in developed nations like the United States, China, and Brazil practice specialized agricultural production systems that make extensive use of synthetic fertilizers and herbicides. China, the United States of America, Argentina, Thailand, Brazil, Italy, France, Canada, Japan, and India are the top ten consumers of pesticides worldwide, according to a recent study [8]. There were roughly 2 million tons of chemical pesticides used worldwide in agriculture in 2014, with herbicides making up about 48% of that total [9]. Herbicide-resistant weeds, herbicide drift, environmental and health problems, and the extinction or decline in the population of segetal species are just some of the issues that have resulted from the overuse and misuse of herbicides to control weeds [10][11]. Roughly 500 different types of herbicide-resistant weeds have been documented so far [12]. The United States has the highest number of cases of herbicide-resistant weeds, followed by Australia, Canada, China, and Brazil [12]. Some weeds are now resistant to herbicides that work through multiple mechanisms of action, while others are now less sensitive to the effects of herbicides [13][14]. Herbicide-resistant weeds have undergone mutations at both the target site and off-target sites [15][16]. Based on these findings, it's clear that relying too heavily on herbicides to keep weeds at bay isn't a viable strategy. Herbicide resistance management relies heavily on the discovery of new herbicides with novel modes of action; however, no new mode of action has been discovered in the past three decades [17][18].

A rising number of cases of crop damage have been attributed to herbicide drift in recent years. 2,4-dichloro phenoxy acetic acid (2,4-D) is one of the most widely used herbicides for controlling broadleaf weeds in agriculture; however, it often damages the adjacent 2,4-D sensitive cotton fields, resulting in the loss of millions of dollars. [19]. Off-target movement of dicamba has also been linked to serious crop injury in nearby fields growing crops that are not resistant to the chemical [20]. Additionally, arsenic, cadmium, lead, and mercury, which are all used as herbicides, have built up in soil and water resources [21]. Samples taken from streams near agricultural areas contained pesticides in 97% of cases, according to a study of 51 major river basins in the United States [22]. There is evidence that working with agricultural chemicals can have both immediate and delayed consequences for human health [23]. Excessive use of herbicides can cause herbicide resistance in weeds, water and soil pollution, and herbicide drift, as seen in the aforementioned examples. The extensive use of herbicides has negative ecological, environmental, and social externalities that must be reduced or eliminated, making the development and dissemination of viable alternatives to conventional herbicide weed control methods an urgent priority.

Increasing crop diversity has been shown in studies [24] to increase the number of stresses applied to weeds, resulting in less need for chemical weed/pest control. Crop diversification can be thought of as the deliberate incorporation of functional biodiversity at the temporal and/or spatial levels in order to increase the productivity and stability of ecosystem services. A diversified cropping system is more complex than a monoculture system because it uses a wider variety of crop combinations.[25]. As a result of advancements in agricultural technology, major crops, and livestock are now more profitable than ever before. In contrast, the goal of a diversified cropping system is to construct global food systems that are long-lasting, robust, and equitable. Examples of diversified cropping systems include I growing several varieties of the same crop or different crops in polyculture (ii) incorporating legumes into cereal-dominated systems (iii) rotating crops over time and space (cover crops, trap crops, hedgerows, fallow fields, etc.) [26]. When deciding what crops to grow on a diversified farm, it's important to adhere to certain guidelines (for instance, Liebman and Dyck discuss crop rotation and intercropping strategies in the context of weed management) [27]. One of the results of diversification is, but is not limited to, benefits that include, but are not limited to, pollination, increased water use efficiency, reduced pest and disease populations, and recycled soil nutrients [28]. Crop diversification has been emphasized as an essential component of environmentally responsible farming in numerous previous studies [29]. It is not well understood, however, how various methods of crop diversification affect weed management, nor what kinds of limitations exist for adopting such methods in the current agricultural context [30]. This literature review will focus on the role of crop diversification in modern agriculture, specifically as it relates to weed management [26]. This information will shed light on how sustainable weed management can be achieved by incorporating crop diversification into the current agricultural system.

There are two main strategies for crop diversification that have been identified by numerous studies: (a) arranging crops of different species and management techniques to expose weeds to a variety of stress and mortality factors; and (b) planning diversification to maximize crop capture of light, nutrients, and water and minimize the loss to weeds. These guidelines should be the foundation of any plan to increase agricultural variety (e.g., crop rotation, cover cropping, and intercropping). Contrary to popular belief, weed diversification techniques focus on weed control rather than weed eradication. In other cases, weeds can benefit people and outcrops by supporting vital biological processes. [30][31].

**Crop Cycle**

Crop rotation, in which different crops are grown consecutively on the same land at different times, provides diversity in terms of time [32]. By alternating which crops are harvested each year, crop rotation is a sustainable farming method that maximizes profit with low input costs [33] [34]. Recently, a meta-analysis by a researcher looked at 45 studies and found that rotating crops increases yields by 20%. More than half (49%) of weed density can be reduced by rotating crops, according to a meta-analysis of 54 studies. Reduced weed pressure and increased crop yield are two of the many benefits of crop rotation.

Low crop yields and an increase in weed-resistant weed species are common results of growing crops in monocultures (e.g., herbicide resistance, early seed shattering, and crop mimicry). By alternating between no-till and conventional tilling, as well as using a wide range of herbicides, planting dates, and fertilization strategies, crop rotations reduce the likelihood that weeds will adapt to and thrive in a given environment. Alternating the timing, pattern, and degree of soil disturbance, light penetration, and nutrient availability is how crop rotation reduces the selective pressures that favor weed growth [35]. As a result, crop rotation encourages the development of a weed flora that is not dominated by one or a small number of weed species, which can result in lower input costs (such as less herbicide use) [36][37] [38].

Weed biomass, density, and abundance can all be decreased by rotating crops. For instance, in Serbia, switching from continuously growing corn to growing corn, soybeans, and winter wheat reduces weed species and biomass (CC). In addition, compared to CC, the yield increases by 30%. Similarly, replacing rice and wheat with winter corn in India increased dry biomass by 11% and reduced weed growth by 75%. Unlike with herbicides, altering the weed community and density is a process that takes time, so it's important to think about the long-term effect. When corn is rotated with winter wheat, weed biomass is reduced by 92%, according to research by the researcher [39] [40][41]. This study, which included a rotation of corn and soybeans (CS), was conducted continuously over the course of 11 years. However, long-term experiments aren't always feasible. Modeling simulations are used in this case, taking into account all relevant growth and environmental factors [42]. In their study, researchers modeled the dynamics of the giant ragweed population under different crop rotation scenarios. They hypothesized that limiting the number of the giant.

In a two-year corn-soybean system, ragweed density could be controlled by herbicides or cultivation to at least 99 percent, and in a five-year corn-soybean-rye-alfalfa system, it could be controlled to at least 91 percent. Therefore, rotations with a wider range of crop types have a better chance of reducing the spread of giant ragweed. Several other models [43][44][45] can be used to help determine crop rotations according to location and resource availability.

Weed seeds collected from the ground are collected and stored in seed banks so that future generations can benefit from the traits present in the original crop [46]. These characteristics make weeds resilient to a wide range of stresses, including those posed by management strategies and natural adversities. The seed bank of soil can be managed in a number of ways, and crop rotation is one of them. Anderson et al. provided a concrete example of how crop rotations can help diminish the seed bank of annual weeds by balancing the frequency of seed production [47] [48]. A researcher [45] stated that a more even distribution of crop growth between successive plantings could help control weed populations. Weed diversity is increased while weed seed viability in the soil seed bank is decreased when warm-season crops with different planting dates (like corn and sunflower) are rotated over a two-year period. Crop rotations with four different crops, ideally two warm-season crops followed by two cool-season crops, are effective for weed seed management. While a cool-season crop is growing, the next generation of warm-season weeds can be stunted or stopped entirely with this strategy [49] [50]. Diluting the seed bank is another benefit of crop rotation (see, for example, the findings of a study on CC, CS, and corn-oats-hay rotation and another study on CS, rotation) [51].

Parasitic weed seed banks can be diminished by rotating crops with non-host species. The non-host plant, also called a trap crop, can be used to encourage the germination of parasitic seeds without harming the host plant. Researchers found that crop rotation was one of the most effective ways to reduce Striga infestations in maize and boost yields. Similar findings were found by researcher. while using Striga hermonthica L. in the common millet and cowpea cycle. Because of this genetic diversity, parasitic weeds may have varying germination responses to specific environmental cues. Hayat et al. demonstrated that alternating years of sugar beet, pepper, and wheat with sunflower and tomato affect the germination of broomrape species differently. [52] [53]. Herbicide-resistant weeds pose a greater threat in unrotated fields. Reducing glyphosate-resistant Palmer amaranth by a factor of two, for example, can be accomplished through crop rotation involving glyphosate-tolerant (GR) cotton and corn [54] [55]. Likewise, blackgrass is an important grass weed of winter cereal crops across the pond. Overuse of herbicides has led to blackgrass's widespread resistance. Spring crop rotation is an effective method of long-term blackgrass management in agricultural settings. A balanced crop rotation that includes spring cropping can reduce blackgrass populations by between 78 and 96 percent. Due to the fact that roughly 80% of blackgrass germinates in the autumn, spring-sown crops are much less susceptible to blackgrass infestation [56] [57]. Therefore, reducing the use of herbicides while still maintaining effective weed management can be accomplished through education about weed ecology and the adoption of appropriate cultural practices. According to one survey [58], crop rotation is used by 89% of German farmers to reduce or prevent the development of herbicide resistance [59]. Similarly, a 2015 survey of Canadian farmers found that 80% of them use crop rotation to prevent the development of herbicide-resistant weeds. Some farms implement crop rotations to increase productivity. It has the potential to significantly improve farmers' bottom lines. When dealing with herbicide-resistant giant ragweed, a crop rotation of alfalfa, alfalfa, and corn (AAC) produced a net return of $919 per hectare, per year (compared to a net return of $247 per hectare, per year for CC. Plus, annual alternative crop (AAC) rotations over several years depleted the herbicide-resistant giant ragweed seed bank [60]. Generally speaking, crop rotation can reduce the likelihood of herbicide resistance by increasing weed diversity and decreasing the seed bank.

**Methods**

One method of integrated weed management is intercropping, in which two or more crop species or genotypes are planted side by side. It's a frequent farming technique in places with high labor costs and limited resources. Relay intercropping, in which a second crop is planted before the first is mature; mixed intercropping, in which two or more crops are cultivated at the same time; and strip cropping, in which two or more crops are grown in strips, are the three basic types of intercrops.[61]. There are advantages to each type of intercropping, but when compared to mono-cropping, it results in stable aggregate food yields per unit area with fewer inputs and fewer problems caused by pests (including weeds, diseases, and insects) [62].

Intercropping helps when it comes to weed control because it lessens the number of weeds growing among crop plants. This technique increases crop resource use while reducing weed pressure by limiting weed access to space, water, and nutrients. It does this by using the idea of resource partitioning across co-occurring crop species with different resource acquisition strategies [63]. Increased availability of shared constraints on the crop is one effect of intercropping [64]. When crops with different functions are planted together, resource partitioning becomes more likely [65]. Improved nitrogen fixation, enhanced weed control, and increased yields are just a few of the benefits of intercropping cereals and legumes [66]. The weed biomass can be reduced by a factor of three when barley is intercropped with peas [67] [68]. Researcher found that the intercropping of peas and flax significantly reduced weed growth compared to either crop grown alone [69]. When used in drylands, intercropping is an effective method of reviving soil fertility and reducing weed infestation [70]. Short-duration legume crops, such as black gram and green gram, can be intercropped with pearl millet to boost yield, reduce weed density, and reduce dry weight.

**Spatial Arrangements.**

The spatial arrangement of the intercrops can also have a major effect on yield and weed control. According to reports, sunflower (2018) and buckwheat in 2019 provide the best weed control while keeping soybean yields stable. Soybean and lentils were intercropped in alternating rows for maximum yield. Crop and intercrop plant densities can also have an effect on weed suppression; for example, compared to monoculture corn, weed suppression is greatly improved when planting corn at a density of 9 plants/m2 and intercropping with cowpea at a density of 30 plants/m2. [71].Intercropping can also involve allelopathic interactions, which are beneficial to the environment and provide cost-effective weed control

[72]. Allelopathy is a phenomenon in which neighboring plants interact in a way that either inhibits or stimulates one another's growth and development [73].

There has been a great deal of research into the allelopathic potential of sorghum species and the characterization of allelochemicals associated with weed suppression. Growing sorghum alongside other crops has been shown to improve yields and decrease weed growth compared to growing either crop alone [74] [75]. Striga populations may have decreased because of factors like shading, higher humidity, and cooler temperatures in the intercrop areas, as was hypothesized [76]. The control of Orobranchial spp. has been demonstrated to be possible through the use of allelopathic compounds from the Brassicaceae family [77] . A similar effect is seen in witchweed, where an aqueous solution derived from Silverleaf reduces the development of haustoria. Also, when D. uncinatum was grown alongside corn as an intercrop, the S. harmonica infestation was reduced. Thus, intercropping is a viable strategy for eradicating parasitic weeds, and additional study of allelopathic exudates will lead to the development of cutting-edge bio-herbicides [78] [79].

**Results**

Masking Crops Soil moisture retention, erosion control, and pest control are all improved by planting cover crops during the off-season. Cover crops compete with weeds for resources like light, space, water, and nutrients, which help keep weeds at bay. If you leave the crop residue on the soil after harvesting, it will break down into a mulch that will prevent weeds from germinating, emerging, and establishing [80] [81]. Experiments have shown that mulch and cover crops release allelochemicals that prevent weed growth. A recent meta-analysis of 15 studies found that cover crop treatment in corn-soybean rotations significantly reduced the weed biomass, but had no effect on weed density. A cover crop dose of at least 5 mg ha1 is required to decrease weed biomass by 75%.

Cover crops need adequate soil water, moderate temperature, and a properly prepared seedbed for rapid emergence and robust growth. Therefore, field conditions, desired outcomes, and cost should all be considered when deciding which cover crops to use [82]. In a survey of 759 farmers in North Carolina, 46% said that the extra work required by cover crops dissuaded them from using them [83]. They also discovered that 28.1% of farmers are using cover crops to combat weed growth. Grass cover species provide greater weed suppression than broadleaf, according to a meta-analysis of 53 studies conducted by Osipitan et al. Similarly, cover crops sown in the fall provide greater weed suppression than those planted in the spring. Increasing the cover crop seedling rate from 1 to 3 also improved weed suppression. As a result, careful deliberation should be given to cover crop selection and management practices in light of the time and money involved [84].

Different species are combined to form a single crop with a wide range of useful characteristics [85]. However, biomass is a major predictor of weed suppression, and weed management studies have shown that mixtures perform better when made up of highly competitive species. Cover crop performance between mixtures and monocultures was found to be equivalent across seven metrics in a meta-analysis of 27 studies conducted by Florence and McGuire (biomass, N, weed, water, biology, yield, and stability). Weed establishment may be promoted, diminished, or unaffected, depending on when and how the cover crop is cut back [86]. Delaying the end of a cover crop, as Wallace et al. [87] noted, can increase crop biomass and thus aid in weed suppression. Depending on the goal of farm management, cover crops can be removed in one of three ways: by weather, chemicals, or machinery [88]. Because of this, cover crop selection, diversity, termination timing, and cover crop strategy can have a significant effect on weed suppression.

Herbicide-resistant weeds can be managed and prevented with the help of cover crops, which are part of an integrated weed management strategy. Researcher [89] found that glyphosate-resistant Canada fleabane is reduced in density and biomass when annual ryegrass is present, either alone or in combination with red clover. There are situations where cover crops alone are not enough to deal with weeds that have become resistant to herbicides. For instance, residues from early-planted hairy vetch and crimson clover can prevent the emergence of glyphosate-resistant Palmer amaranth. While Palmer amaranth has developed a high tolerance to the herbicide glyphosate, its resistance can be slowed by using herbicide mixtures with multiple sites of action in conjunction with cover crops. Long-term intensified cover crops may be useful in the management of herbicide resistance, according to a study, because they reduce the selection pressure for herbicides.

The success of weed management is significantly affected by the size and diversity of the weed seed bank. Cover crops can aid in the reduction of weed seedbanks by preventing the spread of weed seeds and preventing the germination and subsequent emergence of weed seedlings. Using a cover crop as a pre-crop to cash crops can eventually deplete the weed seed bank. In the corn-soybean system, for instance, a 5-year study found that weed seedbanks might be diminished by alternating winter rye and winter follows. Researchers found that after seven years, the rye seed bank density in corn was lower than the crop residue [86][89]. Studies have shown no significant change in the weed seed bank, but this may simply be a fluke. More research is needed to fully understand how cover crops and the weed seed bank work together.

Modern Farming's Major Obstacles to Crop Diversification 3Globalization has resulted in the widespread adoption of a monoculture agricultural system, making it more challenging for diverse farming methods like organic farming to gain traction. It's possible that the commercial farming community's reluctance to adopt crop diversification stems from a lack of familiarity with alternative farming models and the scientific mechanisms governing their various benefits, or from a failure to recognize the significance of ecology. Given the gaps in their education and training, it is understandable that farmers would be skeptical of the commercial viability of relatively complex farming systems at a massive scale. Moreover, the focus of current agricultural technology development is on monoculture. Specialization and loss of genetic diversity are two outcomes of plant breeding tools that emphasize the improvement of a small number of key traits. Furthermore, farmers' willingness to adopt a diversified cropping system to build crop resilience is hampered by stresses, and too much attention has been paid to protecting plants from biotic and abiotic threats. Although diversified farming makes more efficient use of agricultural inputs and may be less expensive overall, it can be difficult for small-scale farmers to set up a diverse agriculture farm due to the higher initial investment required. It took longer for Danish farmers to see a return on their investment after adopting a diversified cropping system because doing so required them to acquire more specialized knowledge, more expensive equipment, a larger labor force, and the help of experts in the field, among other things. Therefore, farmers who rely solely on one type of income will be averse to taking the risk associated with a diversified strategy. Produce grown in a more sustainable manner commands a premium, and hedging against price fluctuations can be accomplished through increased diversification. Farmers may have trouble transporting and marketing a limited number of diverse products in countries like the United States, where markets are concentrated among a handful of large food-processing, distributing, and retailing firms.

Furthermore, crop diversification is hindered by agricultural policies that favor industrialized and intensive agriculture. Most government subsidies and incentives work against diversification by encouraging farmers to increase the output of a small number of agricultural commodities. The top five crops in the United States received 89% of all subsidies between 1995 and 2005 [82]. Farmers in different regions who practice complex agricultural systems are the experts because they have lived and worked in those areas longer and have more direct experience with the land. Another barrier to crop diversification is the absence of rules and methods to transfer farmer information to extension workers and researchers. You should also know that the legislation in Denmark isn't up to par with what's needed for sustainable farming. New restrictions on the application of certain species or cultivars emerged, serving as a roadblock to the creation of new varieties. Most countries current laws do not require organic farmers to conserve weed biodiversity in order to meet certification standards. Species in the genus Aegilops L., the ancestor of cultivated wheat, are a good example of a Crop Wild Relative that can be bred with domesticated varieties to create hardier offspring.

The previous section demonstrated that the substantial investment of both time and labor required for crop diversification is a significant barrier to its widespread adoption. The challenge of assisting farmers in improving their knowledge and techniques of diversified farming is made more difficult by the lack of adequate research in this area. However, due to the development of several precision agriculture (PA) tools, a number of problems with conventional techniques of field inspections have been resolved, potentially paving the way for more widespread adoption of crop diversification. Modern technology includes, but is not limited to, satellite-based global positioning systems (GPS) devices, geographic information systems (GIS) data repositories, remote sensing tools, artificial intelligence (AI) platforms, machine learning (ML) algorithms, and simulation models.

Location-based sampling and treatment are made possible when GPS is embedded in other systems. Your precise location can be determined via satellite thanks to GPS. A GIS, on the other hand, is a combination of computer hardware and software that generates maps based on specific geographic information and user-specified characteristics. These two tools can be used to make maps with different kinds of agronomic data and other information, which can help researchers better understand the spatial and temporal variability of a region. After creating these maps, farmers will be better able to incorporate plans for diversified cropping into their efforts to boost productivity and income.

The term "remote sensing," which refers to the process of gathering data at a distance, is frequently used in PA. Radiation reflected from the ground or vegetation is typically detected using this method. Such radiations can be characterized across a broad range of wavelengths.

Precision agriculture on a diversified farm can also aid in cost reduction by maximizing the efficiency of agricultural inputs. Selective fertilizer applications and selective weed control are two examples of how to limit treatment overuse and waste. For targeted weed control, autonomous spraying UAVs have been developed using data from remote weed mapping. Field nutrient maps have also prompted the creation of variable-rate fertilizer application strategies. These practices would reduce greenhouse gas emissions, save money for farmers, and mitigate environmental damage. In this way, precision agriculture tools not only contribute to the goal of sustainable, diversified farming but also optimize the use of agricultural inputs and cut down on labor needs.

Recent advancements have made it abundantly clear that PA technologies are more practical, precise, and potent than ever before. Despite the fact that PA tools are only used by large, well-funded farms in developed countries at the moment, incorporating PA into diversified farming could lead to resilient cropping systems that are both sustainable and productive. Future precision agriculture technology development efforts should prioritize both diversified farming and, if at all possible, small-scale farmers.

**Conclusion**

Concerns for human health, environmental quality, and ecological sustainability are raised by the widespread use of chemicals in today's monoculture system, despite its high yields and low input costs. The growth of weeds resistant to herbicides increased health issues related to agricultural chemicals, and water and soil pollution are three primary negative aspects of contemporary agriculture. Before irreversible harm to people and the environment occurs, innovative and cutting-edge approaches for sustainable weed management must be developed. Using varied farming practices and ecological weed management strategies is the best way to build a robust and sustainable production system. Because it will take more time and money to accomplish the shift, farmers are reluctant to transition to a more diverse agricultural system. Public and private organizations must endeavor to encourage commercial and small-scale farmers to practice varied agricultural methods in order to develop the farming systems of the future.

**References**


[1] J. F. Egan and D. A. Mortensen, "Quantifying vapor drift of dicamba herbicides applied to soybean," *Environ. Toxicol. Chem.*, vol. 31, no. 5, pp. 1023–1031, May 2012, doi: 10.1002/ETC.1778.

[2] E. V. Perrino and G. Calabrese, "Endangered segetal species in southern Italy: distribution, conservation status, trends, actions and ethnobotanical notes," *Genet. Resour. Crop Evol.*, vol. 65, no. 8, pp. 2107–2134, Dec. 2018, doi: 10.1007/S10722-018-0678-6/METRICS.

[3] S. Shrestha, G. Sharma, N. R. Burgos, and T. M. Tseng, "Response of weedy rice (Oryza spp.) germplasm from Arkansas to glyphosate, glufosinate, and flumioxazin," *Weed Sci.*, vol. 67, no. 3, pp. 303–310, May 2019, doi: 10.1017/WSC.2018.92.

[4] Q. Yu, A. Cairns, and S. Powles, "Glyphosate, paraquat and ACCase multiple herbicide resistance evolved in a Lolium rigidum biotype," *Planta*, vol. 225, no. 2, pp. 499–513, Jan. 2007, doi: 10.1007/S00425-006-0364-3/METRICS.

[5] M. J. Owen *et al.*, "Widespread occurrence of multiple herbicide resistance in Western Australian annual ryegrass (Lolium rigidum) populations," *Aust. J. Agric. Res.*, vol. 58, no. 7, pp. 711–718, Jul. 2007, doi: 10.1071/AR06283.

[6] T. M. Tseng, S. Shrestha, J. D. McCurdy, E. Wilson, and G. Sharma, "Target-site Mutation and Fitness Cost of Acetolactate Synthase Inhibitor-resistant Annual Bluegrass," *HortScience*, vol. 54, no. 4, pp. 701–705, Apr. 2019, doi: 10.21273/HORTSCI13512-18.

[7] J. S. Yuan, P. J. Tranel, and C. N. Stewart, "Non-target-site herbicide resistance: a family business," *Trends Plant Sci.*, vol. 12, no. 1, pp. 6–13, Jan. 2007, doi: 10.1016/j.tplants.2006.11.001.

[8] S. O. Duke, "Why have no new herbicide modes of action appeared in recent years?," *Pest Manag. Sci.*, vol. 68, no. 4, pp. 505–512, Apr. 2012, doi: 10.1002/PS.2333.

[9] J. R. Harlan and J. M. J. de Wet, "Some thoughts about weeds," *Econ. Bot.*, vol. 19, no. 1, pp. 16–24, Jan. 1965, doi: 10.1007/BF02971181/METRICS.

[10] R. COUSENS, "A simple model relating yield loss to weed density," *Ann. Appl. Biol.*, vol. 107, no. 2, pp. 239–252, Oct. 1985, doi: 10.1111/J.1744-7348.1985.TB01567.X.

[11] S. Fahad *et al.*, "Weed growth and crop yield loss in wheat as influenced by row spacing and weed emergence times," *Crop Prot.*, vol. 71, pp. 101–108, May 2015, doi: 10.1016/J.CROPRO.2015.02.005.

[12] N. Soltani *et al.*, "Perspectives on Potential Soybean Yield Losses from Weeds in North America," *Weed Technol.*, vol. 31, no. 1, pp. 148–154, Jan. 2017, doi: 10.1017/WET.2016.2.

[13] N. Soltani *et al.*, "Potential Corn Yield Losses from Weeds in North America," *Weed Technol.*, vol. 30, no. 4, pp. 979–984, Dec. 2016, doi: 10.1614/WT-D-16-00046.1.

[14] Y. Gharde, P. K. Singh, R. P. Dubey, and P. K. Gupta, "Assessment of yield and economic losses in agriculture due to weeds in India," *Crop Prot.*, vol. 107, pp. 12–18, May 2018, doi: 10.1016/J.CROPRO.2018.01.007.

[15] ákos Mesterházy, J. Oláh, and J. Popp, "Losses in the Grain Supply Chain: Causes and Solutions," *Sustain. 2020, Vol. 12, Page 2342*, vol. 12, no. 6, p. 2342, Mar. 2020,

doi: 10.3390/SU12062342.
[16] K. Ramesh, A. Matloob, F. Aslam, S. K. Florentine, and B. S. Chauhan, "Weeds in a changing climate: Vulnerabilities, consequences, and implications for future weed management," *Front. Plant Sci.*, vol. 8, p. 95, Feb. 2017, doi: 10.3389/FPLS.2017.00095/BIBTEX.
[17] L. P. Gianessi, "The increasing importance of herbicides in worldwide crop production," *Pest Manag. Sci.*, vol. 69, no. 10, pp. 1099–1105, Oct. 2013, doi: 10.1002/PS.3598.
[18] S. Asghar *et al.*, "Management of Weeds &Sustainable Technique," *Int. J. Agric. Sustain. Dev.*, vol. 4, no. 2, pp. 1–6, 2022.
[19] A. M. De Oca, L. Arreola, A. Flores, J. Sanchez, and G. Flores, "Low-cost multispectral imaging system for crop monitoring," *2018 Int. Conf. Unmanned Aircr. Syst. ICUAS 2018*, pp. 443–451, Aug. 2018, doi: 10.1109/ICUAS.2018.8453426.
[20] D. N. Burrows, A. Wolszczan, and A. M. Moore, "The WSPC Handbook of Astronomical Instrumentation," vol. 3, Jul. 2021, doi: 10.1142/9446.
[21] J. M. Meynard *et al.*, "Socio-technical lock-in hinders crop diversification in France," *Agron. Sustain. Dev.*, vol. 38, no. 5, pp. 1–13, Oct. 2018, doi: 10.1007/S13593-018-0535-1/TABLES/3.
[22] C. Blaix *et al.*, "Quantification of regulating ecosystem services provided by weeds in annual cropping systems using a systematic map approach," *Weed Res.*, vol. 58, no. 3, pp. 151–164, Jun. 2018, doi: 10.1111/WRE.12303.
[23] C. Kremen and A. Miles, "Ecosystem Services in Biologically Diversified versus Conventional Farming Systems: Benefits, Externalities, and Trade-Offs," *Ecol. Soc. Publ. online Dec 18, 2012 | doi10.5751/ES-05035-170440*, vol. 17, no. 4, Dec. 2012, doi: 10.5751/ES-05035-170440.
[24] R. J. Gilliom, "Pesticides in U.S. streams and groundwater," *Environ. Sci. Technol.*, vol. 41, no. 10, pp. 3409–3414, May 2007, doi: 10.1021/ES072531U/ASSET/ES072531U.FP.PNG_V03.
[25] R. Bommarco, D. Kleijn, and S. G. Potts, "Ecological intensification: harnessing ecosystem services for food security," *Trends Ecol. Evol.*, vol. 28, no. 4, pp. 230–238, Apr. 2013, doi: 10.1016/J.TREE.2012.10.012.
[26] M. Liebman and E. Dyck, "Crop Rotation and Intercropping Strategies for Weed Management," *Ecol. Appl.*, vol. 3, no. 1, pp. 92–122, Feb. 1993, doi: 10.2307/1941795.
[27] M. Liebman and C. P. Staver, "Crop diversification for weed management," *Ecol. Manag. Agric. Weeds*, pp. 322–374, Dec. 2001, doi: 10.1017/CBO9780511541810.008.
[28] T. D. Sterling and A. V. Arundel, "Health effects of phenoxy herbicides. A review.," *Scand. J. Work. Environ. Health*, vol. 12, no. 3, pp. 161–173, 1986, doi: 10.5271/sjweh.2160.
[29] A. H. C. Van Bruggen *et al.*, "Environmental and health effects of the herbicide glyphosate," *Sci. Total Environ.*, vol. 616–617, pp. 255–268, Mar. 2018, doi: 10.1016/J.SCITOTENV.2017.10.309.
[30] T. K. Udeigwe *et al.*, "Implications of leading crop production practices on environmental quality and human health," *J. Environ. Manage.*, vol. 151, pp. 267–279, Mar. 2015, doi: 10.1016/J.JENVMAN.2014.11.024.
[31] J. Zhang, Y. Huang, K. N. Reddy, and B. Wang, "Assessing crop damage from dicamba on non-dicamba-tolerant soybean by hyperspectral imaging through machine learning," *Pest Manag. Sci.*, vol. 75, no. 12, pp. 3260–3272, Dec. 2019, doi: 10.1002/PS.5448.
[32] J. F. Egan, K. M. Barlow, and D. A. Mortensen, "A Meta-Analysis on the Effects of 2,4-D and Dicamba Drift on Soybean and Cotton," *Weed Sci.*, vol. 62, no. 1, pp. 193–

206, Mar. 2014, doi: 10.1614/WS-D-13-00025.1.

[33] J. S. Mishra, R. Kumar, R. Kumar, K. K. Rao, and B. P. Bhatt, "Weed density and species composition in rice-based cropping systems as affected by tillage and crop rotation," *Indian J. Weed Sci.*, vol. 51, no. 2, p. 116, 2019, doi: 10.5958/0974-8164.2019.00027.3.

[34] M. S. Simić, V. Dragičević, D. Chachalis, Ž. Dolijanović, and M. Brankov, "Integrated weed management in long-term maize cultivation," *Zemdirbyste*, vol. 107, no. 1, pp. 33–40, 2020, doi: 10.13080/Z-A.2020.107.005.

[35] E. H. Satorre *et al.*, "Crop rotation effects on weed communities of soybean (Glycine max L. Merr.) agricultural fields of the Flat Inland Pampa," *Crop Prot.*, vol. 130, p. 105068, Apr. 2020, doi: 10.1016/J.CROPRO.2019.105068.

[36] M. Liebman *et al.*, "Fates of Setaria faberi and Abutilon theophrasti seeds in three crop rotation systems," *Weed Res.*, vol. 54, no. 3, pp. 293–306, Jun. 2014, doi: 10.1111/WRE.12069.

[37] R. L. Anderson, "Managing weeds with a dualistic approach of prevention and control. A review," *Agron. Sustain. Dev.*, vol. 27, no. 1, pp. 13–18, Jan. 2007, doi: 10.1051/AGRO:2006027/METRICS.

[38] D. Weisberger, V. Nichols, and M. Liebman, "Does diversifying crop rotations suppress weeds? A meta-analysis," *PLoS One*, vol. 14, no. 7, p. e0219847, Jul. 2019, doi: 10.1371/JOURNAL.PONE.0219847.

[39] J. Zhao, Y. Yang, K. Zhang, J. Jeong, Z. Zeng, and H. Zang, "Does crop rotation yield more in China? A meta-analysis," *F. Crop. Res.*, vol. 245, p. 107659, Jan. 2020, doi: 10.1016/J.FCR.2019.107659.

[40] T. M. Bowles *et al.*, "Long-Term Evidence Shows that Crop-Rotation Diversification Increases Agricultural Resilience to Adverse Growing Conditions in North America," *One Earth*, vol. 2, no. 3, pp. 284–293, Mar. 2020, doi: 10.1016/j.oneear.2020.02.007.

[41] L. F. Amato-Lourenco, G. R. Ranieri, V. C. de Oliveira Souza, F. B. Junior, P. H. N. Saldiva, and T. Mauad, "Edible weeds: Are urban environments fit for foraging?," *Sci. Total Environ.*, vol. 698, p. 133967, Jan. 2020, doi: 10.1016/J.SCITOTENV.2019.133967.

[42] O. G. Mouritsen, "Those tasty weeds," *J. Appl. Phycol.*, vol. 29, no. 5, pp. 2159–2164, Oct. 2017, doi: 10.1007/S10811-016-0986-1/METRICS.

[43] B. M. Smith, N. J. Aebischer, J. Ewald, S. Moreby, C. Potter, and J. M. Holland, "The Potential of Arable Weeds to Reverse Invertebrate Declines and Associated Ecosystem Services in Cereal Crops," *Front. Sustain. Food Syst.*, vol. 3, p. 118, Jan. 2020, doi: 10.3389/FSUFS.2019.00118/BIBTEX.

[44] V. Bretagnolle and S. Gaba, "Weeds for bees? A review," *Agron. Sustain. Dev.*, vol. 35, no. 3, pp. 891–909, Jul. 2015, doi: 10.1007/S13593-015-0302-5/FIGURES/2.

[45] J. L. Capinera, "Relationships between insect pests and weeds: an evolutionary perspective," *Weed Sci.*, vol. 53, no. 6, pp. 892–901, Nov. 2005, doi: 10.1614/WS-04-049R.1.

[46] J. Hufnagel, M. Reckling, and F. Ewert, "Diverse approaches to crop diversification in agricultural research. A review," *Agron. Sustain. Dev.*, vol. 40, no. 2, pp. 1–17, Apr. 2020, doi: 10.1007/S13593-020-00617-4/FIGURES/9.

[47] R. G. Smith and K. L. Gross, "Assembly of weed communities along a crop diversity gradient," *J. Appl. Ecol.*, vol. 44, no. 5, pp. 1046–1056, Oct. 2007, doi: 10.1111/J.1365-2664.2007.01335.X.

[48] J. Dury, N. Schaller, F. Garcia, A. Reynaud, and J. E. Bergez, "Models to support cropping plan and crop rotation decisions. A review," *Agron. Sustain. Dev.*, vol. 32, no. 2, pp. 567–580, Apr. 2012, doi: 10.1007/S13593-011-0037-X/METRICS.

[49] M. Schönhart, E. Schmid, and U. A. Schneider, "CropRota – A crop rotation model to support integrated land use assessments," *Eur. J. Agron.*, vol. 34, no. 4, pp. 263–277, May 2011, doi: 10.1016/J.EJA.2011.02.004.
[50] S. Dogliotti, W. A. H. Rossing, and M. K. Van Ittersum, "rotat, a tool for systematically generating crop rotations," *Eur. J. Agron.*, vol. 19, no. 2, pp. 239–250, May 2003, doi: 10.1016/S1161-0301(02)00047-3.
[51] N. Colbach, F. Colas, O. Pointurier, W. Queyrel, and J. Villerd, "A methodology for multi-objective cropping system design based on simulations. Application to weed management," *Eur. J. Agron.*, vol. 87, pp. 59–73, Jul. 2017, doi: 10.1016/J.EJA.2017.04.005.
[52] M. Liebman and V. A. Nichols, "Cropping System Redesign for Improved Weed Management: A Modeling Approach Illustrated with Giant Ragweed (Ambrosia trifida)," *Agron. 2020, Vol. 10, Page 262*, vol. 10, no. 2, p. 262, Feb. 2020, doi: 10.3390/AGRONOMY10020262.
[53] S. C. Haring and M. L. Flessner, "Improving soil seed bank management," *Pest Manag. Sci.*, vol. 74, no. 11, pp. 2412–2418, Nov. 2018, doi: 10.1002/PS.5068.
[54] R. Anderson, "An ecological approach to strengthen weed management in the semiarid great plains," *Adv. Agron.*, vol. 80, pp. 33–62, Jan. 2003, doi: 10.1016/S0065-2113(03)80002-0.
[55] R. L. ANDERSON, "Sequencing Crops to Minimize Selection Pressure for Weeds in the Central Great Plains1," *https://doi.org/10.1614/WT-03-090R*, vol. 18, no. 1, pp. 157–164, Jan. 2004, doi: 10.1614/WT-03-090R.
[56] A. Kumar, T. Choudhary, S. Das, and S. K. Meena, "Weed seed bank: Impacts and management for future crop production," *Agron. Crop. Vol. 2 Manag. Pract.*, pp. 207–223, Jan. 2019, doi: 10.1007/978-981-32-9783-8_12/COVER.
[57] P. R. Westerman, M. Liebman, F. D. Menalled, A. H. Heggenstaller, R. G. Hartzler, and P. M. Dixon, "Are many little hammers effective? Velvetleaf (Abutilon theophrasti) population dynamics in two- and four-year crop rotation systems," *Weed Sci.*, vol. 53, no. 3, pp. 382–392, May 2005, doi: 10.1614/WS-04-130R.
[58] A. Oswald and J. K. Ransom, "Striga control and improved farm productivity using crop rotation," *Crop Prot.*, vol. 20, no. 2, pp. 113–120, Mar. 2001, doi: 10.1016/S0261-2194(00)00063-6.
[59] O. Samaké, T. J. Stomph, M. J. Kropff, and E. M. A. Smaling, "Integrated pearl millet management in the Sahel: Effects of legume rotation and fallow management on productivity and Striga hermonthica infestation," *Plant Soil*, vol. 286, no. 1–2, pp. 245–257, Aug. 2006, doi: 10.1007/S11104-006-9041-3/METRICS.
[60] J. K. Norsworthy *et al.*, "Reducing the Risks of Herbicide Resistance: Best Management Practices and Recommendations," *Weed Sci.*, vol. 60, no. SP1, pp. 31–62, 2012, doi: 10.1614/WS-D-11-00155.1.
[61] P. Neve, J. K. Norsworthy, K. L. Smith, and I. A. Zelaya, "Modeling Glyphosate Resistance Management Strategies for Palmer Amaranth (Amaranthus palmeri) in Cotton," *Weed Technol.*, vol. 25, no. 3, pp. 335–343, Sep. 2011, doi: 10.1614/WT-D-10-00171.1.
[62] P. J. W. Lutman, S. R. Moss, S. Cook, and S. J. Welham, "A review of the effects of crop agronomy on the management of Alopecurus myosuroides," *Weed Res.*, vol. 53, no. 5, pp. 299–313, Oct. 2013, doi: 10.1111/WRE.12024.
[63] L. Ulber and D. Rissel, "Farmers' perspective on herbicide-resistant weeds and application of resistance management strategies: results from a German survey," *Pest Manag. Sci.*, vol. 74, no. 10, pp. 2335–2345, Oct. 2018, doi: 10.1002/PS.4793.
[64] J. J. Goplen *et al.*, "Seedbank Depletion and Emergence Patterns of Giant Ragweed

(Ambrosia trifida) in Minnesota Cropping Systems," *Weed Sci.*, vol. 65, no. 1, pp. 52–60, Jan. 2017, doi: 10.1614/WS-D-16-00084.1.

[65] H. J. Beckie and K. N. Harker, "Our top 10 herbicide-resistant weed management practices," *Pest Manag. Sci.*, vol. 73, no. 6, pp. 1045–1052, Jun. 2017, doi: 10.1002/PS.4543.

[66] A. R. Ngwira, J. B. Aune, and S. Mkwinda, "On-farm evaluation of yield and economic benefit of short term maize legume intercropping systems under conservation agriculture in Malawi," *F. Crop. Res.*, vol. 132, pp. 149–157, Jun. 2012, doi: 10.1016/J.FCR.2011.12.014.

[67] R. W. Brooker *et al.*, "Improving intercropping: a synthesis of research in agronomy, plant physiology and ecology," *New Phytol.*, vol. 206, no. 1, pp. 107–117, Apr. 2015, doi: 10.1111/NPH.13132.

[68] R. J. Pakeman *et al.*, "Increased crop diversity reduces the functional space available for weeds," *Weed Res.*, vol. 60, no. 2, pp. 121–131, Apr. 2020, doi: 10.1111/WRE.12393.

[69] K. Ann Bybee-Finley, S. B. Mirsky, and M. R. Ryan, "Crop Biomass Not Species Richness Drives Weed Suppression in Warm-Season Annual Grass–Legume Intercrops in the Northeast," *Weed Sci.*, vol. 65, no. 5, pp. 669–680, Sep. 2017, doi: 10.1017/WSC.2017.25.

[70] L. Stefan, N. Engbersen, and C. Schöb, "Crop–weed relationships are context-dependent and cannot fully explain the positive effects of intercropping on yield," *Ecol. Appl.*, vol. 31, no. 4, p. e02311, Jun. 2021, doi: 10.1002/EAP.2311.

[71] J. Smith, B. D. Pearce, and M. S. Wolfe, "Reconciling productivity with protection of the environment: Is temperate agroforestry the answer?," *Renew. Agric. Food Syst.*, vol. 28, no. 1, pp. 80–92, Mar. 2013, doi: 10.1017/S1742170511000585.

[72] J. J. Goplen *et al.*, "Economic Performance of Crop Rotations in the Presence of Herbicide-Resistant Giant Ragweed," *Agron. J.*, vol. 110, no. 1, pp. 260–268, Jan. 2018, doi: 10.2134/AGRONJ2016.09.0536.

[73] V. Verret, A. Gardarin, E. Pelzer, S. Médiène, D. Makowski, and M. Valantin-Morison, "Can legume companion plants control weeds without decreasing crop yield? A meta-analysis," *F. Crop. Res.*, vol. 204, pp. 158–168, Mar. 2017, doi: 10.1016/J.FCR.2017.01.010.

[74] C. Rodriguez *et al.*, "Grain legume-cereal intercropping enhances the use of soil-derived and biologically fixed nitrogen in temperate agroecosystems. A meta-analysis," *Eur. J. Agron.*, vol. 118, p. 126077, Aug. 2020, doi: 10.1016/J.EJA.2020.126077.

[75] G. Corre-Hellou *et al.*, "The competitive ability of pea–barley intercrops against weeds and the interactions with crop productivity and soil N availability," *F. Crop. Res.*, vol. 122, no. 3, pp. 264–272, Jun. 2011, doi: 10.1016/J.FCR.2011.04.004.

[76] H. Saucke and K. Ackermann, "Weed suppression in mixed cropped grain peas and false flax (Camelina sativa)," *Weed Res.*, vol. 46, no. 6, pp. 453–461, Dec. 2006, doi: 10.1111/J.1365-3180.2006.00530.X.

[77] R. K. Mathukia, P. R. Mathukia, and A. M. Polara, " Intercropping and weed management in pearlmillet ( Pennisetum glaucum ) under rainfed condition ," *Agric. Sci. Dig. - A Res. J.*, vol. 35, no. 2, p. 138, 2015, doi: 10.5958/0976-0547.2015.00025.7.

[78] T. Cheriere, M. Lorin, and G. Corre-Hellou, "Species choice and spatial arrangement in soybean-based intercropping: Levers that drive yield and weed control," *F. Crop. Res.*, vol. 256, p. 107923, Oct. 2020, doi: 10.1016/J.FCR.2020.107923.

[79] K. Jamshidi, A. R. Yousefi, and M. Oveisi, "Effect of cowpea (Vigna unguiculata) intercropping on weed biomass and maize (Zea mays) yield,"

*https://doi.org/10.1080/01140671.2013.807853*, vol. 41, no. 4, pp. 180–188, Dec. 2013, doi: 10.1080/01140671.2013.807853.
[80] M. Farooq, K. Jabran, Z. A. Cheema, A. Wahid, and K. H. Siddique, "The role of allelopathy in agricultural pest management," *Pest Manag. Sci.*, vol. 67, no. 5, pp. 493–506, May 2011, doi: 10.1002/PS.2091.
[81] F. Tesio and A. Ferrero, "Allelopathy, a chance for sustainable weed management," *http://dx.doi.org/10.1080/13504509.2010.507402*, vol. 17, no. 5, pp. 377–389, Oct. 2010, doi: 10.1080/13504509.2010.507402.
[82] J. H. J. R. Makoi and P. A. Ndakidemi, "Allelopathy as protectant, defence and growth stimulants in legume cereal mixed culture systems," *http://dx.doi.org/10.1080/01140671.2011.630737*, vol. 40, no. 3, pp. 161–186, 2012, doi: 10.1080/01140671.2011.630737.
[83] L. Głąb, J. Sowiński, R. Bough, and F. E. Dayan, "Allelopathic Potential of Sorghum (Sorghum bicolor (L.) Moench) in Weed Control: A Comprehensive Review," *Adv. Agron.*, vol. 145, pp. 43–95, Jan. 2017, doi: 10.1016/BS.AGRON.2017.05.001.
[84] J. Sowiński, F. E. Dayan, L. Głąb, and K. Adamczewska-Sowińska, "Sorghum Allelopathy for Sustainable Weed Management," pp. 263–288, 2020, doi: 10.1007/978-3-030-51034-3_11.
[85] S. Arowosegbe and A. J. Afolayan, "Assessment of allelopathic properties of Aloe ferox Mill. on turnip, beetroot and carrot," *Biol. Res.*, vol. 45, no. 4, pp. 363–368, 2012, doi: 10.4067/S0716-97602012000400006.
[86] A. Mahmood, Z. A. Cheema, M. N. Mushtaq, and M. Farooq, "Maize–sorghum intercropping systems for purple nutsedge management," *http://dx.doi.org/10.1080/03650340.2012.704547*, vol. 59, no. 9, pp. 1279–1288, Sep. 2012, doi: 10.1080/03650340.2012.704547.
[87] S. K. Dhungana, I. D. Kim, B. Adhikari, J. H. Kim, and D. H. Shin, "Reduced Germination and Seedling Vigor of Weeds with Root Extracts of Maize and Soybean, and the Mechanism Defined as Allelopathic," *J. Crop Sci. Biotechnol.*, vol. 22, no. 1, pp. 11–16, Mar. 2019, doi: 10.1007/S12892-018-0251-0/METRICS.
[88] K. Jabran, "Sorghum Allelopathy for Weed Control," pp. 65–75, 2017, doi: 10.1007/978-3-319-53186-1_8.
[89] R. C. dos Santos, G. de M. G. Ferraz, M. B. de Albuquerque, L. M. de Lima, P. A. de Melo Filho, and A. de R. Ramos, "Temporal expression of the sor1 gene and inhibitory effects of Sorghum bicolor L. Moench on three weed species," *Acta Bot. Brasilica*, vol. 28, no. 3, pp. 361–366, Jul. 2014, doi: 10.1590/0102-33062014ABB3238.