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Sustainable Weed Management in Climate-Smart Cropping Systems

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INTRODUCTION

Weeds are managed for the core reason that they compete with crop plants for nutrients, water, light, and space. Weeds constitute more yield loss than both pests and diseases combined. Weeds were managed by using herbicides. However, using herbicides in weed management poses concerns such as the development of herbicide resistance, environmental pollution, loss of biodiversity, and high production costs.

Climate change, which is evident through enhanced warming, changed rainfall regimes, increased CO2 concentration, and weather extremes, is an additional factor that has made weed management more complex. Some weed species are more adaptable to climate change induced stresses than crops, hence becoming more vigorous weeds. Therefore, climate-resilient cropping systems that incorporate sustainable weed management practices are critical in ensuring sustainability in food security.

2. Concept of Climate-Smart Cropping Systems

Climate-Smart Agriculture (CSA) is a technique that seeks to:

1. Enhance agricultural productivity in
2. Improve resilience and climate change adaptation
3. Reduce or get rid of greenhouse gas

Climate-Smart Cropping Systems: These cropping systems encompass climate-resilient agronomy, resource conservation, diversification, and resource management. Weed management in climate-smart cropping systems: It is more about controlling weed populations through effective means that are environmentally sustainable and economically feasible.

Source: https://saiwa.ai

3. Weed-Climate Change Inter

Climate change significantly affects weed dynamics in agricultural systems with respect to growth, distribution, competitiveness, and response to weed management practices. It creates new challenges for sustainable weed management practices.

3.1 Effect of Temperature:

This is because warmer temperatures support the growth of more heat-tolerant weed species that perform better in heat-stressed conditions compared to many cultivated crops. When temperature increases, it accelerates the weed growth cycle, including growth rates of weed seeds, allowing more life cycles of weeds to occur in a given year. This implies that with higher temperatures, the growth periods for weeds are also longer, an aspect that hinders the growth of agricultural crops.

3.2 Elevated CO2 levels

Higher concentration of CO2 in the atmosphere increases the efficiency of photosynthesis, especially in C_3 weeds, which often exhibit a better growth response compared to C_3 crops. At higher CO2 levels, weeds exhibit higher leaf area, biomass, and root growth, making it easier for them to compete for water or nutrients. Such competitiveness often results in reduced yields of crops.

3.3 Modified Rainfall Reg

Unpredictable rainfall regimes contribute to weed flushes through the season. Too much rainfall is ideal for perennial or aquatic weeds, while drought conditions are beneficial for deep-rooted weeds. These rainfall regimes contribute to weed diversity, making it difficult for effective weed control measures to be taken before the weed grows to its full potential.

Source: https://www.cimmyt.org

3.4 Herbicide

Climatic variability is an important factor in herbicide effectiveness, considering that it influences the herbicide processes of absorbance, translocation, volatilization, or degradation. Herbicides can be less taken up by crops if it is too hot or dry, or if it is too wet. Such factors contribute to low herbicide efficiency or herbicide resistance in most weed species.

4. Principles of Sustainable Weed Management

An effective weed management that is climate-resilient should be anchored on the following principles:

- Prevention over cure
- Multiple control techniques integration
- Less use of chemical herbicides
- Biodiversity & Soil Protection
- Long-term management of weed seed banks

5. Components of Sustainable Weed Management

Sustainable weed management is an integrated approach for effectively inhibiting weed growth with little risk of harm or damage to the environment and ensuring productivity, especially through climate-smart agricultural practices. Sustainable weed management is not dependent on a single means of weed control.

5.1 Preventive Weed Management

Preventive methods include avoiding the entry and spread of weeds. In fact, the use of clean seeds prevents the introduction of new weed species into the farm. It also prevents the spread of weed seeds through farm equipment if it is regularly sanitized. If farm manure is composted, it kills weed seeds, which would otherwise be spread into the farm through the farm manure. Weeds that often escape before the production of seeds are freed from the weed bank through their prompt removal before the

production of seeds. This is cheap and very effective.

5.2 Cultural Weed Management:

Cultural practices intervene in the cropping environment to improve crop competitiveness over weed growth. Crop rotation prevents weed life cycles by inhibiting the dominance of certain weed species that thrive in cropped agricultural systems. Planting competing cultivar species with high initial growth rates and larger canopies reduces the amount of light that reaches the ground, thereby inhibiting weed emergence. This is achieved through the establishment of the optimum plant density that allows for effective resource utilization by the crop while inhibiting weed growth or the production of weed seeds. Mulching and cover cropping reduce weed emergence, improve water-holding capacity of the soil, maintains soil temperature, and promotes healthy biotic communities, which are among the major practices of climate-smart agriculture.

5.3 Mechanical and Physical Weed Management:

Mechanical methods such as hand weeding, hoeing, inter-row cultivation, or the use of weeders eradicate weeds without the use of chemicals. Soil solarization, especially for valuable crops, utilizes the heat of the sun to destroy weed seeds and propagules. Despite the high labor involved, such methods are safe to the environment and ideal for small-scale or organic farming.

5.4 Biological Weed Management:

Biological control comprises using insects, pathogens, or allelopathic crops that naturally inhibit weed growth. Bioherbicides developed through microbial agents provide biodegradable alternatives to chemical herbicides. These methods are more climate-resilient and adaptable to sustainable organic agricultural practices.

5.5 Chemical Weed Management in a Sustainable Framework:

Herbicides are still a significant part of it but need to be employed wisely. When it comes to herbicides, application based on need, rotation of herbicide modes of action, development of safer molecules for herbicides with reduced dosages, or implementation of non-chemical methods can countervail challenges of environmental hazards and herbicide resistance.

6. Integrated Weed Management (IWM)

Integrated Weed Management (IWM) is a sustainable approach that focuses on both preventive as well as cultural, mechanical, biological, as well as judicious chemical practices for effective weed management. Instead of using a single weed control approach, IWM practices the complementary use of various approaches to achieve weed populations below the economic threshold levels. Climate-smart agricultural practices make IWM more effective for weed management by minimizing dependence on chemical herbicides with a view to reduce environmental pollution. Additionally, it helps make the agricultural systems more adaptable to climate change by ensuring their sustainability through IWM practices that ensure productivity as well as profitability for the farmer.

7. Role of Conservation Agriculture in Weed Management

This is conservation agriculture (CA) that practices low tillage, retention of residues, and crop rotation. Conservative agriculture is duality in weed management practices. Although low tillage enhances weed growth, sustainable conservation agricultural systems are effective in managing weeds through weed residue mulch, weed-suppressed biomasS>, and weed-suppressed cropping systems.

8. Technological Interventions in Climate-Smart Weed Management

- Modern technological advancements are playing an important role in ensuring sustainable weed management that is climate-smart.
- Precision weed control through the use of sensors, remote sensing, or drones makes it possible for weed outbreaks to be detected and mapped.
- Site-specific herbicide application targets herbicides only in areas where weeds exist, thereby reducing their consumption, cost of application, as well as environmental pollution.
- Robotics weeders and automated weeders are alternatives that provide non-chemical weed management through either mechanical or laser technology approaches.
- decision support systems (DSS) that combine data of weather conditions, weed biology, and crop growth models help farmers make informed decisions about appropriate times for weed control. All these methods contribute positively to climate adaptability, efficiency in weed control practices, and sustainable cropping systems.

9. Environmental & Socio-Economic Benefits

Sustainable weed management practices ensure the following:

- Fewer cases of
- Increased soil organic carbon and biodiversity
- Reducing production costs in the long term
- Improved farmer resilience and profitability

10. Challenges of Sustainable Weed Management

Despite the long-term effectiveness of sustainable weed management, there are some challenges that it encounters. Some of the techniques that are non-chemical or integrated are labor-intensive, which leads to an increase in production costs, especially for small-scale farmers. These techniques are also knowledge-intensive, meaning that the farmer would need adequate information about weed biology, crop-weed relationships, and the timing of interventions. While making the transition from the conventional to the sustainable approach, some initial yield losses encountered by the farmer could act as a deterrent. Moreover, the lack of access to advanced technology such as precision technology and robots would make it difficult for small-scale farmers to adopt sustainable weed management practices.

11. Future Prospects and Way Forward

The global Future approaches for achieving sustainable weed management practices in climate-smart agricultural systems would need to emphasize research on climate-resilient weed management practices related to understanding climate change impacts on weed species, herbicide resistance issues, and interactions between crops, weeds, and climate change. Improving extension support systems and training agricultural stakeholders is critical to enhance their capability for adopting practices that are more integrated, knowledge-intensive, and sustainable. Governments must emphasize policy support, such as the provision of subsidies, carbon credits, or conservation agriculture systems, to make sustainable weed management more feasible. Traditional practices could provide effective solutions by integrating with current advancements in science, ensuring sustainability of agricultural systems.

CONCLUSION

Sustainable weed management is an important part of climate-resilient agricultural systems. It involves the concept of diversified practices with the application of eco-logical principles and latest technology that helps in effective weed control without jeopardizing natural resources. It is important to incorporate sustainable approaches for managing weeds in order to get climate-resilient, productive, and sustainable agricultural systems in the wake of climate change.

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