RESEARCH ARTICLE

A REVIEW ON NON-CHEMICAL WEED MANAGEMENT IN MAIZE (*ZEA MAYS L.*)

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ARTICLE DETAILS

Article History:

Received 05 June 2021
Accepted 07 July 2021
Available online 12 July 2021

ABSTRACT

Weed is omnipresent species that compete with major crops for light, nutrients, space, and water for their growth and development and ultimately deteriorate the ideal environment for crops growth. In the present context, herbicide application is the easiest and seemingly economical approach for weed control in south-Asian countries. In contrary, the side effects of herbicide on health and environment impose to adopt for the non-chemical method of weed management. This paper reviewed the menace of herbicide, crop weed association, the critical period of crop-weed competition, and different methods of organic weed control implemented especially for maize. The main objective of this review is to maneuver a weed control strategy for maize other than the chemical application. The findings of different research suggested that a critical period of crop-weed competition in maize lies between 2 to 8 weeks after crop sowing. Many mechanical methods for weed control in maize proved efficient but seemed labour intensive and biological methods provided maximum security against specific weed species. The cultural method in combination with other methods effectively reduced the weed population in the maize field. It was found that, if various components of non-chemical weed management are implemented systematically, we can control the weed population with higher economic return and achieve the goal of organic food production with sustainable solutions. Weed control in the organic system focuses on management techniques designed to prevent weed emergence, give a competitive advantage to the main crop, and act for sustainable solutions. The non-chemical integrated weed management system is recommended to reduce the use of herbicide and for sustainable production. A review of non-chemical weed management in maize could be helpful for researchers to provide useful, sustainable, and environmentally friendly solutions to farmers to solve the problem of weed infestation in the maize crop along with substantial yield improvement.

KEYWORDS

maize, organic, sustainable, weed control

1. INTRODUCTION

Maize (*Zea mays L.*) is the second most important staple crop in Nepal. It is a versatile crop grown for grain and fodder purposes. Weed infestation during the growing period is a serious problem for higher production in the world as well as in Nepal. Weed are undesirable plants that infest different crops and inflict a negative impact on crop yield by competing for water, light, space, and nutrients (Reddy et al., 2011). Weed is a notorious competitor for the main crops and also harbors different insects, pests, and diseases. Weed is to be managed properly to avoid economical loss in crop production. In south-Asian countries, herbicide application seemed the easiest and economical practice for weed control but the impact of the chemical on the environment and human health has long-lasting negative effects. Maize crop has great sensitivity towards weed infestation. Weed infestation during the entire crop season can decrease the maize yield by up to 82% to 84% (Babiker et al., 2013). The use of various techniques for weed control is pivotal for crop cultivation. Weed management strategies comprise mechanical, physical, chemical, cultural, biological, and many more. The change of the focus from herbicide to non-chemical weed management was driven by the recent upsurge in environmental awareness of the public, and the problem with the side effect of the herbicides. The non-chemical approaches for weed management aim towards minimizing the reliance on pesticides and accentuate the focus on sustainable solutions.

2. MENACE OF HERBICIDE

In the past few decades, the use of herbicides in less developed countries has tended to increase faster than in industrialized countries (Moody, 1990). This trend creates a serious threat to the biodiversity of developing countries like Nepal. A glyphosate-based herbicide is the widely used broad-spectrum herbicide in the world. Due to its improper and excessive application practices, the widespread presence of glyphosate has been reported in the terrestrial and aquatic ecosystem (Hanke et al., 2010). Various cereal crops including maize, oilseed, alfalfa, and livestock feed have drastically increased the tolerance level towards glyphosate-based herbicides. Spray drift from glyphosate has been found to cause distorted fruit at a sublethal level of exposure (Laitinen et al., 2007). Besides its impact on the environment and non-targeted crops, it poses an immense treat both acute and chronic to human health. Various experts of the World Health Organization's International Agency for cancer research have concluded that glyphosate has a carcinogenic effect on humans (Myers et al., 2016). Furthermore, according to the annual financial report of 2016/17, Nepal has imported herbicides worth USD 6,690,997 (PMRD, 2018). This represents the wide impact of herbicide on the ecosystem, economy, and human health. This urges us to shift towards non-chemical plant cultivation practices in the future.

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DOI:
[10.26480/faer.01.2021.46.51](http://doi.org/10.26480/faer.01.2021.46.51)

3. WEED ASSOCIATED WITH MAIZE PLANT

Among the below-mentioned weed species, the most abundant weed species found in the Terai region of Nepal are *Ageratum conyzoides*, *Cynodon dactylon*, *Digitaria stramonium*, *Echinochloa* spp., *Brachiaria*

ramossa, and *Commelina benghalensis*, (Subedi, 2014). Bharati also observed the persistence infestation of *Cynodon dactylon*, *Commelina benghalensis*, and *Mariscus alterfolius* in the maize field at Orrisa, India (Bharati, 2016).

Table 1: List of different weed flora in the maize field in different countries of South Asia.

SN	Weed	Family	Season	Cited by
1	<i>Amaranthus spp</i> (Latte saag)	Amaranthaceae	Rabi	(Ndam et al., 2014)
2	<i>Cammelina</i>	Poaceae	Annual	(Subedi, 2014)
3	<i>Chenopodium album</i> (Bethe saag)	Amaranthaceae	Annual	(Tollenar et al., 1994)
4	<i>Chloris Virgata</i> (Finger grass)	Poaceae	Annual	(Ndam et al., 2014)
5	<i>Commelina benghalensis</i> (Kane ghas)	Commelinaceae	Rabi	(Ndam et al., 2014; Bharati, 2016)
6	<i>Avena fauta</i> (Jai)	Poaceae	Kharif	(Subedi, 2014)
7	<i>Solanum nigrum</i> (Kalo bihin)	Solanaceae	Annual	(Subedi, 2014)
8	<i>Cynodon dactylon</i> (Dubo)	Poaceae	Annual	(Ndam et al., 2014)
9	<i>Cyperus esculentus</i> (Mothe)	Cyperaceae	Annual	(Saini and Angiras, 1998)
10	<i>Cyperus rotundus</i> (Mothe)	Cyperaceae	Annual	(Ndam et al., 2014)
11	<i>Brachiaria ramossa</i> (Signalgrass)	Poaceae	Rabi	(Subedi, 2014)
12	<i>Lathyrus aphaca</i> (Grass pea)	Fabaceae	Annual	(Subedi, 2014)
13	<i>Dhatura stramonium</i> (Dhaturo)	Solanaceae	Annual	(Subedi, 2014)
14	<i>Digitaria sanguinalis</i> (Hairy crabgrass)	Poaceae	Annual	(Subedi, 2014)
15	<i>Equisetum arvense</i> (Sime jhar)	Equisetaceae	Kharif	(Chovancova et al., 2018)
16	<i>Mercurialis annua</i> (Annual mercury)	Euphorbiaceae	Annual	(Chovancova et al., 2018)
17	<i>Polygonum aviculare</i> (Knotgrass)	Polygonaceae	Kharif	(Chovancova et al., 2018)
18	<i>Stellaria media</i> (Armale jhar)	Caryophyllaceae	Annual and perennial	(Chovancova et al., 2018)
19	<i>Thlaspi arvense</i> (Chopda ghas)	Brassicaceae	Annual	(Chovancova et al., 2018)
20	<i>Urtica dioica</i> (Sisnu)	Urticaceae	Rabi	(Chovancova et al., 2018)
21	<i>Andropogon tectorum</i> (Beard grass)	Poaceae	Annual	(Ndam et al., 2014)
22	<i>Echinochloa</i> (Tuned saama)	Poaceae	Annual	(Tollenar et al., 1994)
23	<i>Setaria viridis</i> (green fox tail)	Poaceae	Annual	(Tollenar et al., 1994)
24	<i>Ageratum conyzoides</i> (Ganmane jhar)	Asteraceae	Kharif	(Saini and Angiras, 1998)
25	<i>Amaranthus spinosus</i> (Kande lundo)	Amaranthaceae	Rainy	(Ndam et al., 2014)
26	<i>Cyperus difformis</i> (Mothe)	Cyperaceae	Annual	(Chovancova et al., 2018)
29	<i>Phalaris minor</i> (Canary grass)	Poaceae	Annual	(Subedi, 2014)
30	<i>Anagalis arvensis</i> (Armale)	Primulaceae	Annual	(Subedi, 2014)

4. CRITICAL PERIOD OF CROP-WEED COMPETITION

Diverse weed species interfere with the crop in the standing field for a prolonged period resulting in the drastic reduction of grain yield. A group researchers defined that the critical period of crop-weed competition as the period at which weeds emerge soon after crop planting without affecting crop yield (Evans et al., 1997). During the winter season, a critical period for weed control were 2 to 8 week and in summer it was 2 to 9 weeks (Babiker et al., 2013). A group researchers reported that the critical period of weed control in maize was 2 to 6 weeks after sowing (Ghoshen et al., 1996). Krishnaprabhu opined that the critical period for crop weed competition is 15 to 45 days which results in yield loss if proper management is neglected (Krishnaprabhu, 2020). Imoloame and Omolaiye concluded the critical period of weed interference in maize was between 3 to 6 weeks and also recommend weed management practices at this time (Imoloame and Omolaiye, 2017). We can conclude that the critical period of crop-weed competition lies between 2 to 8 weeks and proper weed management strategy can minimize the yield loss of maize crops.

5. YIELD LOSS DUE TO WEED

Faulty weeding practice results from moderate to serious grain yield loss in the maize crop. Maize plant competes with a wide range of weeds during its lifetime and causes substantial yield loss. A study reported that maize

infested with diverse weed species from grasses to broadleaf and sedges in standing crops causes substantial yield losses (33-50%) (Hawaldar and Agasimani, 2012). Some researchers reported that the wide species of weed families interfere with the standing maize crop for a prolonged period and able to decrease ear number per plant and thousand seed weight linearly (Evans et al., 1997). Maize fields are usually infested with varying weed species and compete with maize crops in terms of moisture, nutrition, and so on. It has been observed that 65% yield loss with delay in weed control and 83% losses while weeding after the critical period of weed (Ehsas et al., 2016). Some researchers reported that yield loss due to weed infestation in maize crops is much greater than that of other agricultural diseases and pests, and depending upon nature, intensity and duration yield losses varying from 28-100% (Sharma et al., 2010). Saini and Angiras opined that the prolongation period of the diversity of weeds infestation on the main field of maize reduces grain yield by 28-100% (Saini and Angiras, 1998).

6. METHOD OF NON-CHEMICAL WEED MANAGEMENT

The non-chemical method of weed management is defined as the control of the weed in the field without using chemicals. Non-chemical weed management is broadly classified into the direct and indirect methods of management. The various non-chemical weed management and technologies applied in maize are listed below:

Figure 1: Diagram of different methods of non-chemical weed management (Bond & Grundy, 2001).

7. DIRECT WEED MANAGEMENT

7.1 Physical Weed Management

The physical method of weed management deals primarily with the killing and removing the weeds by direct physical means. This is the best pragmatic approach for the farmers in this present context. The method and implementation used in this approach depend upon the soil type, type of the main crop, the timing of weeding, and the socio-economic status of the farmers. On small farms, hand weeding remains a possibility but this is far beyond imagination on the large farm. The physical method encompasses manual and mechanical methods, thermal methods, pneumatic methods, and many more. This method of weed management is labor requiring and hectic as compared to other approaches of weed management.

7.2 Mechanical Weed Management

Mechanical weeding involves weeding the whole field or may be limited to selective row weeding. Mechanical weeders range from hand weeding to sophisticated weeding implements driven by tractors. Mechanical cultivating tools include hoes, harrows, tines, brush weeders, and cutting tools like mowers, sickle, etc. The choice of the implements depends on the crop, weed type, and the socio-economic status of the farmers. Farmers have been doing manual weeding with hand tools as a conventional method of weed management. Brush weeding has been used to pull out and bury the weed between crop lines and inter-rows. It is effective during wet conditions. Harrow weeding is a traditional method for weed control. It is mostly used at the pre- and post-emergence stage of maize seedlings. It is used in the hills of Nepal to give a competitive advantage to maize seedlings and to level the land for follow-up weeding practice. Also, heavy machinery like a mechanical hoe, mowing machines are used to control the weed.

The use of hoeing followed by two hand weeding has increased the grain yield by 0.36 ton/ha in Himanchal, India (Singh et al., 1991). The efficiency of hand weeding was found to be 91.9% (Sinha et al., 2003). Research has shown that hand weeding at 3 and 5 weeks after sowing has significantly reduced the weed infestation in Ranchi, India (Saha and Srivastava, 1992). Manual weeding was found to be most effective to reduce the weed dry biomass and population as compared to chemical applications because the effectiveness of chemicals decreased over time (Intodia et al., 1996). Various yield attributes were statistically significant in the weed-free plot managed by hand weeding than in control which assists in crop development and higher grain yield (Shrestha et al., 2018). This method of weed management is labor extensive and time-consuming but it is the foremost step for organic weed management.

7.3 Thermal Weed Management

Thermal weed control can be defined as the rapid heating of the living plant to destroy its cellular integrity (Cheng et al., 2007). Thermal weed management includes flaming, hot water, hot air, steaming, electrocution, infrared radiation, microwave, and so on. In flame weeding, the weed is heated at around 60°C to 70°C with a propane flame by using special equipment. In steam weeding, the weed is sprinkled with a mixture of vaporized water and steam in a fixed ratio. Hot foam can also be used to control weeds by keeping them in contact with high-stalked weeds for a long time. The concept of electrocution is to use electrical energy to control the weed and was developed in the late 19th century. Rahkonen and Vanhala observed that the *Chenopodium album*, *Matricaria inodora*, and *Phleum pratense* are highly susceptible to flame treatment at their early growth stages (Rahkonen and Vanhala, 1993).

Ascard found that *Stellaria media*, *Chenopodium album*, and *Urtica urens* were relatively susceptible to flaming as compared to perennial weed (Ascard, 1995). In the case of sweet-corn, flame weeding gave short-term weed control but could not control the germinating weed throughout the season (Rifai et al., 1996). A hand-held infrared weeder can be used for killing the rosettes of perennial broad-leaved weeds in various crops. The field study has proved that field steaming gave 90% protection against *Amaranthus retroflexus* and *Chenopodium album* up to 4-6 leaf stage of the crop (Kolberg and Wiles, 2002). Some researchers experimented with removing the seed of *Avena fatua* from the mixture of cereal grains by irradiation with 1 Kw 2450 Mhz energy (Diprose et al., 1978).

The germination of *Avena fatua* was greatly reduced while the germination of cereals remains unaffected. Soil solarization is one of the most cost-effective methods to control weed alongside pathogen control. A group researcher found that perennial grass weeds were killed by solarization but they regrew after some weeks (Elmore et al., 1993). All this above-mentioned thermal method of weed has no long-lasting negative impact on the environment and undergoes minimum soil disturbances. It is yet to be determined how effective this method is against maize crops particularly.

7.4 Pneumatic Weed Management

This is a new technology implemented to manage weed from the field. An implement has been developed that injects the compressed air into the soil and removes the small weed from either side of the crop row (Vale, 1998). A pneumatic drilling machine drills the pressurized air up to the soil depth of 15mm at a speed of 5-6 km/hr. The compressed air uproots the weeds from both sides of the crop furrow. This method of weed management has been a success in maize.

7.5 Biological Weed Management

Biological weed management can be defined as the control of the weed flora affecting the crop by the use of host-specific phytophagous animals and plant pathogenic micro-organisms (Geoden, 1988). It is a broad-spectrum approach that requires detailed knowledge about the ecology of the target weeds. The oldest example of a broad-spectrum biological control method was the use of cattle and birds to maintain the pasture. In cereals, sheep grazing in the off-season is a traditional practice for many farmers to aid weed control. In the year 1992, the biological control method was evaluated by 56 countries across the world for 144 weed species involving 370 biological agents (Igrc and Maceljski, 1993). The control of *Echinochloa* sp. and *Cyperus rotundus* has been observed by the release of bioagent *Emmalocera* sp and *Bactra verutana* respectively. The control of the notorious weed *Orobancha cerna* was found to be effective by the release of the bioagent *Sclerotinia* sp. in the U.S.

With the scope of the biological approach increasing, allelopathy can be the legit component of biological weed components (Lovett, 1991). Allelopathy refers to the direct or indirect chemical effects of one plant on the germination, growth, or development of other neighboring plants. The effect is mediated by the allelochemicals which are released by the plants or their residues. Various research on allelopathy has been conducted to study the effects of weed on the crop. Allelopathy could be used to manipulate the crop-weed balance by increasing the toxicity of the crop plants to the weed flora (Numata, 1982). Mulching of eucalyptus leaf has been found to inhibit seed germination and seedling growth of *Abutilon theophrasti*, *Datura tramonium* & *Ipomoea* spp weeds. Corn gluten meal has been believed to reduce the pre-emergence weed germination in a variety of crops (Gough and Carlstrom, 1999). The biological method of weed management is the perpetual mechanism for weed control and there is no substitute for this approach. Different research work has to be conducted in this approach to achieve the goal of organic weed management.

7.6 Integrated Weed Management

The integrated method of weed management comprises of combined application of preventive, direct, mechanical, biological, and non-chemical measures regarding the field, aimed to give sustainable weed management solutions for specific cropping systems (Swanton and Weise, 1991). Krishnaprabhu reported that mulching with fresh *Eupatorium* 10 t/ha and soybean green manuring in combination with one hand weeding showed the highest cob length and high grain yield with minimum weed density and weed biomass (Krishnaprabhu, 2020). A study reported the highest cob length with a profitable return was observed when two rows of pea were intercropped in between two rows of maize (75 cm x 20 cm) with two times hand weeding conducted at 20 and 40 DAS (Naher et al., 2018). Soybean intercropping with one mechanical weeding at 20 DAS revealed significantly lowest weed dry weight, higher yield attributes, and maize equivalent yield (Saini et al., 2013). Manual hand weeding at 20 DAS and earthing up at 30 DAS in maize-green gram system recorded significantly higher plant height, culm girth, and dry weight of maize crop (Verma et al., 2009). Some researchers observed that two mechanical weeding's at 20 DAS and 40 DAS in combination with mash intercropping were effective in controlling major and minor weed species due to their profused canopy (Ghosh et al., 2007).

8. MULCHING

Mulching the soil surface can substantially reduce the weed problem by preventing weed seed germination or by suppressing the growth of emerging seedlings. Mulch may be of different forms: a living mulch ground cover, organic matter, inorganic matter, sheets of artificial or natural materials spread on the soil. Some researchers found that short-term covering of the soil with black polyethylene reduces the subsequent weed emergence giving a competitive advantage to the cereal crop (Grundy et al., 1996). Various loose materials like straw, bark and compost manure provide effective weed control but the depth of mulch is needed to suppress weed emergence (Merwin et al., 1995). The maize field mulched with film plastic showed the highest growth rates, greater leaf area index, and substantially increased the grain yield by 28.3% as compared to the non-mulched crop field (Bu et al., 2013). Plastic film mulch is preferred in maize fields as compared to other in semi-arid condition. Plastic film mulch significantly increased the grain yield ($p < 0.001$) in maize because of improved soil moisture and temperature (Lee et al., 2018).

9. INDIRECT WEED MANAGEMENT

9.1 Cultural Weed Management

The cultural method of weed control comprises various agronomic practices like crop rotation, crop competition, mulching, intercropping, tillage, etc. According to intercropping of maize and legume can decrease the available light for weed (Bilalis et al., 2009). A group researcher opined that the incorporation of different crop residues and their associated weed helps in the establishment of mulches which reduced the weed population, increased the performance of maize, and enhanced land utilization (Hussain et al., 2013). Increasing the density of maize from 40,000 plants/ha to 1,00,000 plants/ha under normal intercultural operation reduces the weed density and biomass up to 25% and 50% (Tollenaar et al., 1994). According to Ford and Pleasant maize cultivar having traits such as large leaf area, vertical leaf orientation, and greater plant height exhibited weed suppressive potential under a high level of infestation (Ford and Pleasant, 1994).

Tharp and Kells reported that decreasing maize row spacing from 76cm to 56cm resulted in a 23% decrease in weed biomass while decreasing to 38cm resulted in a 27% decrease in weed biomass (Tharp and Kells, 2001). Narrow row spacing, high plant density, and fertilizer next to seed in maize resulted in a 60% reduction in weed compared with wide row spacing, lower maize density, and broadcasting of fertilizer (Anderson, 2000). Farhaad and Vahid found that the maximum yield of 4062.9kg/ha was obtained from the field using clover as a cover crop with minimum weed density and biomass (Farhaad and Vahid, 2014). A higher grain cob, thousand-grain weight, and grain yield were obtained from two hands weeding. We can say that the cultural method of weed control is the best solution in the long run as it is eco-friendly, helps in maintaining soil fertility, and easy to practice.

10. CONCLUSION

The various techniques for non-chemical weed management have been developed to reduce the chemical cost of conventional agriculture, reduce

the environmental and health impact, and move forward to organic food production. A mechanical method of weed control provides great security against the invasive weed population but it is labour-intensive. The cultural method that includes shifting in date of planting, bund check, crop rotation, etc. reduced the competition of weed and main crop. The biological method augments the competitiveness of the main crop against the weed population. For best results, non-chemical weed control relies on the cumulative approach of mechanical, thermal, biological, and cultural methods.

There is the problem of farmer's acceptability of this method in maize crops because of perceived ineffectiveness and inadequate information regarding the other non-chemical approach. We can conclude that if various components of non-chemical weed management are implemented systematically, we can provide complete weed control with higher economic returns and achieve the goal of organic food production with sustainable solutions. However, an in-depth study has to be carried urgently in non-chemical weed control in maize because a successful weed control mechanism requires an integrated system with detailed attention. Moreover, research on the biological and cultural methods of weed control specific to maize is also lacking.

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