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Integrated weed management in vegetables: A review

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Abstract
Vegetables are very slow growing during the initial growth period. In vegetables, weeds caused 70 to 80 per cent yield reduction and hence it is very inevitable to control weeds during the critical weed free period. Integrated weed management (IWM) is a system approach to maintain the weed population below the economic threshold level. Adoption of cultural practices minimized the crop-weed competition. Mechanical methods and herbicidal management of weeds are also recommended in vegetables. Biological control is exploited to a limited extend. Dependence on any single method of weed control may lead to various problems such as shift in weed flora, development of herbicide resistance, emergence of perennial weeds etc. and these problems can be overcome by adopting IWM, since it integrates the use of different methods in a balanced way by managing the weeds effectively to a level that do not pose any significant reduction in yield and harmful effect on environment.

Keywords: allelopathy, biological method, biotechnological method cultural methods, chemical method and mechanical methods

Introduction

There are about 374000 plant species currently known in the world. When one grows any of the economic species of plants, invariably a variety of undesirable vegetation come up simultaneously which competes with the crop for all growth factors. These undesirable and competitive plants are known as "*weeds*". Out of all the pests, weeds alone caused 45 per cent yield reduction in the world context (Katiyar and Singh, 2015) [22]. In India, the loss caused by weeds accounts for 37 per cent, insects 29 per cent, diseases 22 per cent and others 12 per cent (Yaduraju, 2006) [55]. Gharde *et al*. (2018) [16] reported an yield loss of about USD 11 billion due to weeds alone in India.

Our country has achieved self-sufficiency in food production, but the true sense of self sufficiency can be achieved only through assuring a balanced diet to everyone. Vegetables form the most important component of a balanced diet. They are rich sources of vitamins, minerals and fibres which provide food and nutritional security, generate foreign exchange, and provide raw materials for processing industries. India is ranked second in vegetable production. The production of vegetables has increased from 101.2 Mt to 184.40 Mt since 2004-05 to 2017-18 and among the horticultural crops the highest contribution is from vegetables (59-61%).

Importance of Weed Management In Vegetables

Most of the vegetables are slow growing during the initial stage of development. This habit makes them vulnerable to weed competition, which has a negative impact on the quantity as well as the quality parameters. In vegetables, weeds caused 70 to 80 per cent yield reduction (Rana *et al*., 2011)[37]. Manual method is commonly practiced to get rid of weeds in vegetables. Non availability of labour at right time, hike in wage rate and aberrant weather conditions limit its efficacy and affect the yield of the crop. Chemical weed control is a reliable and simple choice to manage this situation. However, dependence on herbicides alone for weed management is not encouraged due to the problems on environment and resistance development in weeds. Therefore, a system that combines herbicides with cultivation and other good crop husbandry practices should be practiced. Chakraborthy (2000) [10] opined that integrated weed management is a cost effective, sound, reliable practice that can be easily and effectively adopted by a farmer as a part of any sound management practice.

Crop Weed Competition

On account of the early establishment and faster growth characteristic, weeds gain competitive advantage over the crop. Allelochemicals from some weeds adversely affect the germination and root shoot growth of crop seedlings. The aqueous leaf extracts of *Cynodon dactylon, Cyperus rotundus, Parthenium hysterophorus* etc. are found to inhibit the germination of tomato seeds (Sannigrahi and Chakraborty, 2005) [42]. Ameena *et al*. (2014) [2] also observed that the root exudates of *Cyperus rotundus* inhibited the growth of cowpea, okra, and brinjal due to the inhibitory substances present. Weeds compete with crops for growth factors resulting into a maturity delay and yield reduction. The extent of yield losses depends on the type of weed flora, intensity and duration of weed competition and soil and climatic factors. The reduction in the economic yield of vegetables due to crop weed competition is presented below (Table 1).

Table 1: Yield loss due to weeds in different vegetables

Crop	Reduction in Yield (%)
Okra	40 -80 % (Patel *et al*., 2017) [33]
Potato	52% (Singh *et al*., 2005) [51]
Bottle gourd	40% (Dash and Mishra, 2014) [14]
Onion	40 -80 % (Channapagoudar and Biradar, 2007) [11]
Cabbage	45 – 80 % (Akshatha *et al*., 2018) [4]
Carrot	90 % (Singh *et al*., 2017) [49]
Tomato	92-95% (Bakht and Khan, 2014) [6]
Brinjal	30 -35 % (Syriac and Geetha, 2007) [53]
Chilli	60 -70 % (Khan *et al*., 2012) [24]
Garlic	94.8 % (Sanjay *et al*., 2009) [41]
Radish	86 % (Singh *et al*., 2009) [50]

Weeds removed substantial amount of nutrients from the soil. Maheswari and Arthanari (2017) [29] observed that weeds removed about 90.50, 22.70 and 62.70 kg ha^{-1} of N ,P and K from unweeded plot and also observed that adoption of weed management practices significantly increased the nutrient uptake in brinjal. Sinchana (2020) [45] also reported that in bush type vegetable cowpea weeds removed 53.37, 4.23 and 43.44 kg ha^{-1} of N,P, and K respectively from unweeded plot and weed removal significantly increased the green pod yield.

Strategies For Weed Management In Vegetables

It is necessary to understand the biology and ecology of the weeds and the time period of crop weed competition for successful weed management in vegetables. The selection of suitable weed management method depends on local situations, environmental conditions, labour availability, weed pressure and nature of the crop.

Critical Period of Crop Weed Competition

The critical period of competition for weeds has been described as an interval in the crop life-cycle during which weeds are managed in order to avoid yield losses. Knowledge of critical period of weed control is helpful in taking decisions on timing of weed control and reducing the herbicide use. Vegetables are vulnerable to weed competition and it is inevitable to get rid of weeds during this period. If the crop is kept weed-free during the critical period there would be no yield reduction generally. Weeds emerging after the critical weed-free period will not affect yield, but control efforts after the critical weed free period may make harvest more efficient, reduce weed seed bank and reduce weed problems in subsequent years.

The critical period for crop-weed competition is different for different vegetables. The critical period for weed control in vegetables is presented below in Table 2.

Table 2: Critical period of crop weed competition in vegetables

Crops	Critical period of crop weed competition
Okra	2-4 weeks after emergence
Cabbage	2-4 weeks after emergence
Cauliflower	0-30 days after sowing
Brinjal	20-60 days after sowing
Carrot	3-6 weeks after emergence
Turnip	15-20 days after sowing
Radish	25-30 days after sowing
Cucumber	4 weeks after seeding
Peas	30 -60 days after planting
Lettuce	3 weeks after planting
Onion	The whole season
Chilli	30 – 45 days after transplanting
Potato	15-45 days after planting
Squash	Early planting competes better
Tomato transplanted	6 weeks after planting
Tomato seeded	9 weeks after seeding

(Rana *et al*., 2011; Bhullar *et al*., 2015) [37, 8]

Weed Flora in Vegetables

In general, weeds in vegetables are periodical in nature as they finishes the life cycle in a short span of time. Syriac and Geetha (2007) [53] reported that the common grassy weeds found in brinjal raised in the reclaimed alluvial soils of Kuttanad were *Eleusine indica, Digitaria sanguinalis, Paspalum* spp. and *Eragrostis* spp., broad leaved weeds were *Ageratum conyzoides, Leucas aspera, Ludwigia perennis, Commelina benghalensis, Cleome viscosa, Phyllanthus niruri* and *Vernonia cinerea*, and sedges were *Cyperus rotundus, Cyperus iria* and *Kyllinga monocephala*. Shamla *et al*. (2017) [43] revealed that the major grassy weeds found along with okra were *Digitaria ciliaris* and *Panicum maximum* and the broad leaved weeds were *Cleome burmanii, Euphorbia geniculata, Borreria hispida, Phyllanthus amara, Sida acuta,* and *Alternanthera bettzickiana*. Sinchana (2020) [45] reported that *Setaria barbata and Digitaria sanguinalis* were the major grassy weeds and *Spermacoce latifolia, Alternanthera sessilis, Phyllanthus niruri* and *Synedrella nodiflora* were the major broad leaved weeds and *Cyperus rotundus* was the only sedge found in association with bush type vegetable cowpea.

Parasitic weed, Orobanche was also found along with solanaceous vegetables. Ramachandraprasad (2011) [36] reported that *Orobanche* was found in tomato, potato and brinjal. Akhter and Khan (2020) [3] also reported three species of Orobanche *viz.*, *Orobanche aegyptiaca*, *Orobanche cernua and Orobanche ramose* in association with brinjal.

Integrated Weed Management

The repeated application of the same chemical herbicide and routinely repeated cultivation practices caused modification in weed communities. Integrated weed management (IWM) is an important method to shift crop weed competition in favor of crop (Shweta and Singh, 2005) [44]. Lamichhane *et al*. (2017) [27] stated that integrated weed management was more effective than any single method in alleviating the buildup of weeds in crops. It is a system approach to maintain the weed population below the economic threshold level by adopting all available means of weed control (Pooniya *et al*., 2017) [35]. It includes cultural, mechanical, chemical, biological and biotechnological practices.

Cultural Methods of Weed Management

Weeds can be effectively controlled or their population pressure can be reduced with the adoption of following cultural practices.

Optimum Time of Sowing

Weed density and biomass can be reduced significantly by planting at optimum time. The crop must be planted at an optimum time when the soil and climatic conditions are favourable for crop growth. The crop sown at the ideal time expressed more competitiveness against weeds than lately sown crops (Bhullar *et al*., 2015) [8].

Proper Row Spacing

Manipulation of row spacing is a simple management practice that can brought significant impact on weeds in vegetable crops. Row spacing and fast canopy closure are the important factors for critical period of crop weed competition. Closer row spacing and sufficient plant density allow the crop to easily cover the land. Compared to 60 and 80 cm row spacing (4.19 and 4.53 no. m- 2), the lowest density of weeds was observed in 40 cm row spacing in tomato (3.39 no. m-2) (Bakht and Khan, 2014) [6]. Early canopy formation blocks sunlight, decreases weed seedling emergence and suppresses the growth of emerged seedling. Narrow row spacing shortened the critical period of weed control and reduce the reliance on herbicides.

Weed Competitive Cultivar

Weed competitive cultivars is one of the most efficient components of IWM program. Quickly growing cultivars can have a competitive advantage over the weeds. The competitive cultivar SJKG-1 recorded lower weed density and weed dry matter and higher weed control efficiency than the non- competitive cultivar SJKG-2 in garlic (Sampat *et al*., 2014) [40]

Crop Rotation

Crop rotation is considered to be the vital tool for weed management in vegetables. Because crops in rotation vary in the time of planting, rate of canopy development, canopy height, row spacing, fertility management and harvest time. Crop rotation allows the usage of herbicides with different mode of action which will prevent the development of herbicide resistance in crops. Different cultivation practices also disrupt the buildup of problematic weeds. General principles to be followed in crop rotation are

1. Following rotation with different type of crops eg. leafy vegetables (lettuce, spinach, cole), root crops (carrots, potatoes, radish), bulb crops (leeks, onion, garlic), fruit crops (squash, pepper, melon).
2. Following rotation with monocots and dicots such as cereals and vegetables.
3. Following rotation with crops with different cycles eg. winter cereals and summer vegetables.
4. Following rotation with crops of different family; Apiaceae (celery, carrots), Solanaceae (potato, tomato)
5. Following rotation with crops of different competitive ability eg. growing poor weed competitors (carrot, onion) and high-weed competitors (maize, potato) in rotation.

Crop rotation breaks the weed seed cycle and prevents the development of weed population. It adds various economic and environmental benefits. In addition, crop rotation is helpful in sustainable soil and farm management. Reddy (2019) [38] reported that strong competitive crops were to be grown in each part of the rotation for efficient management of weeds in vegetable crops.

Soil Solarization

Soil solarization is a low-cost technique that involves covering the moist soil surface with a 25 to 50 mm polyethene sheet (LDPE film) to trap solar radiation during the summer season. This would raise the soil temperature by 8 to 10 ºC as compared to non-solarized soils and resulted in killing of soil borne pests as well as weeds. Compared to light soil, this technique works well on heavy soil, as heavy soil retains more water and produces sufficient steam every day. A time span of 4-6 weeks is needed for satisfactory control of weeds. The other beneficial effects include improving the soil structure, increasing the availability of nutrients especially N and controlling soil-borne fungi. Weeds belongs to the genera *Amaranthus, Anagallis, Chenopodium, Convolvulus, Digitaria, Lactuca, Portulaca, Solanum* etc. can be effectively controlled by this method. Perennial weeds such as *Cyperus rotundus* and *Cynodon dactylon* and annual/ biennial weed *Melilotus* spp. cannot be controlled by soil solarization (Patel *et al*., 2005) [32]. Syriac and Geetha (2007) [53] conducted an experiment in brinjal in the reclaimed alluvial soils of Kuttanad and revealed that soil solarization for one month as well as use of pre-emergence herbicides *viz*., alachlor (2.0 and 2.5 kg ha-1) and oxadiazon (0.5 and 0.75 kg ha-1) were adjudged as the best alternative to hand weeding on the basis of fruit yield and weed control efficiency. Carrot yield and weed control were higher in treatments, where the soil was solarized for 3 to 9 weeks, compared to non-solarized control plot (Maheswari and Karthik, 2019) [30].

Mulching

Mulching helps to manage weeds by preventing the germination of weed seeds, smothering weeds and promoting crop growth by retaining soil moisture and controlling soil temperature. It is possible to use natural materials and plastic sheets as mulch. Both annuals as well as perennial weeds were controlled by mulching. Anzalone *et al.* (2010) [5] stated that 1 kg m-2 of 10 to 15 cm thick organic mulch was adequate to cover the soil to reduce the weed density. Pereira *et al.* (2011) [34] pointed out that in addition to the weed suppression effect in the initial crop growth period, mulches add organic matter to the soil and prevents soil loss due to erosion, Black polyethene mulches are the most commonly used mulch material in warm-season crops such as tomato, muskmelon and watermelon. Muhammed (2015) [31] conducted an experiment in okra and observed that compared to organic mulches, mulching with black polythene significantly reduced the weed density and dry weight and recorded lower weed index and higher yield. Mulching with silver-black polythene alone maintained a weed free condition and resulted in superior yield characters such as head length, head breadth and gross and net head weight in cabbage (Akshatha *et al*., 2018) [4]. Sinchana (2020) [45] observed that mulching with dried banana leaves registered higher weed control efficiency and yield than non-mulched plots in bush type vegetable cowpea

Stale Seedbed

Stale seedbed (SSB) is based on the principle that germinal weed seeds are flushed out before the crop is planted, so that the weed seed bank in the top layer of the soil is depleted and the occurrence of weeds are reduced (Johnson and Mullinix, 2000) [21]. Gnanavel and Kathiresan (2014) [17] and Singh (2014) [48] reported that, in stale seedbed seeds were allowed to germinate after giving a pre sowing germination and the germinal weeds were killed by the application of non-selective herbicides or pre-plant tillage.

Standifer (1980) [52] reported that stale seedbed significantly reduced *Digitaria sanguinalis, Poa annua and Eleusine indica*, since the seeds of these weeds were mostly present on the upper 2 cm of soil. Sambagavalli *et al*. (2016) [39] opined that weed seeds present on the top 5 cm of soil can only be effectively controlled by adopting stale seedbed technique. Weed species that need light to germinate, have low initial dormancy and are present in the top layer (3-5 cm) of the soil are vulnerable to seedbed technique (Chauhan *et al.*, 2010) [12]. Stale seedbed caused the reduction in weed population by 53 per cent compared with the treatments in which this practice was not adopted (Singh *et al.*, 2009) [50]. Stale seedbed prepared 10 to 30 days before planting registered higher cucumber yield than the seedbed prepared on the day of planting (Lonsbary *et al*., 2003) [28].

Ameena *et al*. (2013) [1] reported that a combination of stale seedbed with glyphosate *fb* mulching with black polyethene cover was the best method for purple nut sedge management in okra. Sinchana (2020) [45] observed that stale seedbed registered lower weed density, dry weight and higher weed control efficiency in bush type vegetable cowpea compared to normal seedbed.

Irrigation

Different methods of irrigation are adopted in vegetables. Drip irrigation results in minimum weed population and maximum yield in cabbage than other irrigation methods (Singh *et al*., 2019) [47].

Allelopathic Weed Management

The term allelopathy includes both harmful and beneficial biochemical interactions between all types of plants including microorganisms through the release of chemical compounds from plant parts by leaching, root exudation, volatilization, residue decomposition and other processes. Zeng (2014) [57] pointed out that suppressing weed growth by utilizing the allelopathic potential of crops/ crop residue is a promising innovative weed control method. Allelochemicals offer excellent potential as herbicides. Jabran *et al*. (2015) [20] reported that use of allelopathic cover crops and intercrops, allelopathic crops in rotation and the use of allelopathic plant residues as mulches are important for weed management in sustainable agricultural systems. Cheema *et al*. (2009) [13] observed that sorghum allelopathy can be employed effectively to manage purple nut sedge under field conditions. Allelochemicals present in sesame leachate inhibited the sprouting of tubers of purple nut sedge (Hussain *et al*., 2017) [19]. Allelopathic activity of berseem can be exploited through intercropping to suppress *Orobanche* spp.

Mechanical Methods of Weed Management

Mechanical methods involve physical removal of weeds or by tools or implements. It is the oldest method adopted for weed control. Different methods are as follows;

Tillage

Tillage helps to uproot the weeds and to pulverize the soil to create ideal conditions for the crop seeds to germinate. Deep tillage helps to significantly reduce the soil weed seed bank by burying the weed seeds to lower depths Yaseen *et al*. (2015) [56] revealed that deep tillage recorded the lowest weed density and dry weight in tomato due to the prevention of weed seeds reaching the surface of the soil.

Hand Hoeing

It is a widely used method of weed control in vegetables. The time of hoeing should be determined in consideration with critical period of crop weed competition.

Hand Pulling

Hand pulling of weeds before flowering or seed setting along with roots reduced the weed seed bank (Walia, 2014) [54]. In carrot, two hand weeding at 30 and 60 DAS recorded the maximum length, girth, fresh weight of roots and yield (19.92 t ha-1) (Chaitanya *et al*., 2014) [9]. Baraiya *et al*. (2017) [7] revealed that two hand weeding at 30 and 60 DAS recorded minimum weed density and higher WCE (97.67 %) in okra.

Flame Weeding

Flame weeding is a thermal technique which works by killing the weeds by heat. Cell membrane function is disrupted by heat, which either kills the weed or reduce its ability to compete. Usually, it involves the use of burners at temperatures of 1500 degree fueled with propane, that are pulled through the field. Different models and types are available to fit to the scale of operation from back pack single torch model to multiple burners to tractor mounted implements. It is very well practiced in European countries. It is most effective on emerging annual broad- leaved weeds with growing points which are not protected by soil or vegetation. Flaming is more effective during the afternoon hours due to relative low leaf water content compared to morning hours. Klodd and Rohwer (2019) [25] claimed that two flaming per season will provide a weed control comparable with that of two applications of propachlor in cabbage. The main advantages of flame weeding are, it can be recommended in organic vegetable crop production, it can be used as an alternative to cultivation if the soil is too wet and can help to manage herbicide resistant weeds in conventional systems.

Chemical Method of Weed Management

Chemical control with herbicides is considered as the easiest and most attractive method of weed control in vegetables**.** Pre emergence as well as post emergence application of herbicides were done before critical period of crop-weed competition. So, chemical method of weed control provides good environment for the initial growth and development of crops. Effective control of morphologically similar weeds, intra row weeds, problematic weeds etc. are possible by this method.

Table 3: Herbicides commonly used in vegetables

Herbicide	Trade name	Dose (kg ha $^{-1}$)	Time of application	Crops
Fluchloralin	Basalin	0.85 – 1	Pre plant incorporation	Tomato, okra, garlic, cabbage, cauliflower
Trifluralin	Crisalin	0.75 -0.9	Pre plant incorporation	Transplanted tomato, brinjal, potato, okra, brassica crops, legumes etc.
Pendimethalin	Stomp	0.75- 1.5	Pre emergence	Carrot, radish, potato, garlic, chilli, okra, tomato, brinjal, cabbage, cauliflower etc.
Alachlor	Lasso	2-3	Pre emergence	Potato,
Butachlor	Machete	2.0	Pre emergence	Transplanted tomato and cucurbits
Metribuzin	Lexone, sencor	0.2-0.35	Pre or early post emergence	Direct seeded and transplanted tomato and potato
Oxyfluorfen	Goal	0.24- 0.36	Early post emergence	Direct seeded and transplanted onion and potato
Oxadiazon	Ronstar	0.75 -4	Post emergence	Onion, garlic
Quizalofop – p- ethyl	Targa super	0.04-0.05	Post emergence	Tomato, brinjal, chilli
Fenoxaprop- p- ethyl	Puma super	0.05-0.075	Post emergence	Carrot, radish

The pre-emergence application of butachlor @ 1.5 kg ha-1 recorded higher weed control efficiency and higher root yield in radish under Karnataka conditions (Singh *et al*., 2008) [46]. Singh *et al*. (2017) [49] stated that flurochloridone 625 g ha-1 as pre-emergence can be recommended for weed control in vegetables. Post emergence application of halosulfuron methyl 52.5 g ha -1 controlled sedges and enhanced the yield of bottle gourd (Dash and Mishra, 2014) [14]. Sequential application of pre- and post-emergence herbicides was more effective in controlling weeds in okra than pre-emergence application of herbicides (Patel *et al*., 2017) [33].

Biological Method of Weed Control

Biological control involves the use of living organisms such as insects, other animals and competitive plants for weed control. Two approaches commonly employed in the biological control of weeds are classical approach and the augmentative or bioherbicide approach. Biological control is found to be an inexpensive method and did not pose any threat to the environment, non-target organisms and biodiversity. Kumar (2009) [26] reported that *Zygogramma bicolorata* was the only effective insect bioagent against parthenium. Kaur *et al*. (2014) [23] reported the rust fungi, *Puccinia abrupta* var. *partheniicola* and *Puccinia xanthii* var. *parthenii-hysterophorae*, can be used to control parthenium. *Bactra verutana* was another insect bioagent used against *Cyperus rotundus*.

Biotechnological Method of Weed Control.

Biotechnological tool in weed management are herbicide resistant crops. Herbicide resistance is the ability of a plant population to withstand a greater dose of a particular herbicide than the wild type of that plant. Several biotechnological techniques have been adopted for developing herbicide resistance in crop plants. Plant transformation by transfer of cloned genes in susceptible plants through engineered vector technique is a common method.

Resistance Development in Crops Against Various Herbicides

1. Glyphosate: Herbicide tolerant crops like sugar beet, soyabean etc are genetically engineered to develop resistance against herbicide glyphosate. Glyphosate (Round Up) is a systemic herbicide which inhibits 5- enol pyruvyl shikimate 3 - phosphate (EPSP) synthase. EPSP synthase uses phosphoenol pyruvate (PEP) and shikimate-3-phosphate as substrates to make EPSP. EPSP is essential for Shikimic acid pathway to produce aromatic amino acids. Glyphosate competitively interferes with the binding of PEP to the active site of EPSP synthase. Sugar beet are genetically engineered to be resistant to glyphosate through the insertion of a gene from *Agrobacterium* sp. strain CP4 that encodes the enzyme (EPSPS) into the sugar beet genome. (Gurel *et al*., 2008)[18]
2. Glufosinate: Bialaphos is a pro-herbicide that is converted by the plants into Glufosinate or its ammonium salt L-phosphinothricin (PPT) which is an active ingredient in several nonselective herbicides such as sweep power. The herbicide acts by inhibiting the essential ammonia assimilation enzyme glutamine synthetase (GS). Bar (bialaphos resistance) gene was isolated from *Streptomyces* spp. which encodes a phosphinothricin acetyl transferase (PAT) that converts the herbicidal molecule to a non-toxic acetylated form. For example, phosphinothricin resistant potato and tomato were developed (Duke *et al*., 2012) [15].
3. Sulfonylurea herbicides inhibit Acetolactate synthase (ALS) in plants is involved in the biosynthesis of the amino acids like leucine, isoleucine and valine. Mutant genes that exhibit resistance to sulfonylureas are present in some microorganisms and plants like *Arabidopsis thaliana*. These mutant ALS genes can be isolated and transferred in crops for imparting sulfonylurea resistance. For example, sulfonylurea resistant soybeans, canola etc (Gurel *et al*., 2008) [18].

Conclusion

Weed interference cause substantial reduction in yield in vegetable crops. It is very imperative to keep the density of weeds below the threshold level to minimize the yield loss. Dependence on any one method may lead to various problems such as shift in weed flora, development of herbicide resistance, emergence of perennial weeds etc. Integrated weed management can overcome these problems, since it integrates the use of different methods of weed control (cultural/mechanical/ mechanical/biological) in a balanced way without any harmful effect on environment at the same time managing the weeds effectively to a level that do not pose any significant damage to the crop. It also effectively reduced the weed seed bank, the main hidden foes of crop production. Thus, integrated weed management is the most suitable option for sustainable agriculture.

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