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Eco-friendly weed management for sustainable crop production-A review

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ABSTRACT

Ecological weed management differs from traditional weed management in several ways. Ecological weed management strategy is to integrate the options and tools, rather than on specific control practices which are available to make the crops and cropping system unfavorable for weeds and to minimize the impact of any weed that survive. Maintaining appropriate crop rotation with legume and non-legume crops, and growing of cover crop helps to suppress weeds by smothering and allelopathic effects. Growing competitive cultivars, modifying in sowing and planting techniques, changing sowing and planting time, mulching with organic residues, green and brown manuring and the adoption of reduced or zero tillage makes an inappropriate environment for weed seed germinations and their growth. It also stores a higher amount of organic matter by reducing the mineralization rates and subsequently decreases energy consumption and carbon oxide emission. Herbicide use has been a valuable asset for modern agriculture; however, prudent use of chemicals for weed control is essential to fulfilling the goals of sustainable crop production, by reducing detrimental environmental impact, and delaying herbicide resistance development. Further development and testing of alternative weed management practices that can be utilized along with herbicide applications must be pursued in order to make the practice sustainable and successful.

Keywords: Bioherbicide, crop rotation, cultural practices, sustainable crop production, weed

Weeds are unwanted plants playing a very significant role in different agro-eco-systems and many of them cause direct and indirect losses. Weeds not only cause huge reduction in crop yields but also increase cost of cultivation, reduce input use efficiency, loss of potentially productive lands, loss of grazing areas and livestock production. It also results heavy erosion following fires heavily invaded areas, choking of navigational and irrigation canals and reduction of available weeds in water bodies. Interfere with crops, reduce quality, responsible for alternate hosts for several insect-pests, diseases, reduces aesthetic picture of ecosystem, loss of biodiversity, as well as affect human and cattle health. In India, presence of weeds in general reduces crop yields by 37-45% and in some cases can cause complete crop failure, when compared to 25 % due to diseases, 20% due to insects, 15% due to storage and miscellaneous pests and 6% due to rodents. Weed management takes away nearly one third of total cost of production of field crops. In India, the manual method of weed control is quite popular and effective. Of late, labour has become non-available and costly, due to intensification, diversification of agriculture and urbanization. The use of herbicides in India and elsewhere in the world is increasing due to possible benefits to farmers. At the same time, the continuous use of the same group of herbicides over a period of time on a same piece of land leads to ecological imbalance in terms of weed shift, herbicide resistance in weeds and environmental pollutions (Gnanavel *et al*., 2014, Sharma, 2014 and Kumar, 2014). Application of herbicides for controlling aquatic weeds in a pond also reduce dissolved oxygen and pH and increase biological oxygen demand. Herbicide application may also kill bacteria, fungi and protozoa that combat disease causing microorganisms, thereby upsetting the balance of pathogens and beneficial organisms and allowing the opportunist, disease causing organisms to become a problem (Kalia and Gupta, 2004). The complexity of these situations has resulted in a need to develop a holistic sustainable eco-friendly weed management programme throughout the farming period. Sustainable development is the management and conservation of the natural resource base and the orientation of technological and institutional change in such a manner as to ensure the attainment and continued satisfaction of human needs for present and future generations. Such sustainable development conserves land, water, plant and animal genetic resources, is environmentally non-degrading, technically appropriate, economically viable and socially acceptable (FAO, 1994).

Approaches involved in sustainable weed management

A single weed control approach may not be able to keep weeds below the threshold level of economic damage which demands adoption of diverse technology

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for weed management. Therefore, all the methods which are ecologically and economically feasible should be integrated in a comprehensive way for sustainable weed management (Buchanan, 1976). There are three different approaches are involved in sustainable weed management are as follows.

A. Cultural approaches

Cultural practices are aimed to ensure better soil and crop management. There are several ways to handle weeds through proper cultural management practices. Time and method of fertilizer application and effective water management plays a vital role in weed management (Kumar, 2014). The irrigation and drainage may be done in such a way as to reduce weed pressure in arable crops. Crop rotation is a well-known and proven weed management strategy in many crops and cropping systems. Some of the cultural practices are given below:

Proper crop stand

Adequate plant population along with its spatial arrangement, method and time of sowing, adequate seed rate and selection of variety are essential to limit the weed growth. Any crop variety that is able to quickly shade the soil between the rows and is able to grow more rapidly than the weeds will have an advantage in weed management (Verma and Singh, 2008). Studies have shown that narrow row widths and a higher seeding density will reduce the biomass of later-emerging weeds by reducing the amount of light available for weeds located below the crop canopy. Similarly, fast growing cultivars can have a competitive edge over the weeds (Verma *et al*., 2008). Planting pattern is a cost effective technique that modifies the crop canopy structure and micro- climate enhances crop competitiveness in weed suppression, improves the resource use efficiency and maximizes crop productivity (Sumathi *et al*., 2010).

Green manure crops

Green manure crops are those that are either turned under or incorporated into soil while green or soon after maturity in order to enrich the agricultural soil. Green manure crops are commonly associated with organic agriculture, and are considered essential for annual cropping systems that wish to be sustainable. One of the major benefits of green manures is their ability to suppress weeds (Blackshaw *et al*., 2001 and Mohler *et al*., 2012). Green manuring enriches diversity of the rotation and reduces the opportunities for weeds to become adapted to a particular cropping pattern. Some green manures also secrete specific chemicals into the soil that inhibit weed seed germination (Das, 2008).

Intercropping

Growing of two or more generally dissimilar crops simultaneously on the same piece of land, in distinct row arrangement is known as intercropping. Intercropping and cover cropping are practices that increase diversity in the cropping system and enhance the utilization of resources such as light, heat and water. These practices can also help to suppress weeds and increase the likelihood of being able to reduce herbicide use in the cropping system. Alternatively, in organic or other systems where herbicides are not used, intercropping and cover cropping can reduce the yield loss potential and provide stability in the system (Bhullar *et al*., 2006).

Selection of competitive cultivars

The role of crop genotype in weed management has received growing attention over the past several years. Select a weed-competitive variety with early seedling vigor, and high tillering to suppress weeds. Competitive cultivar can suppress weed seed production, limit future weed infestation, and become a safe, environmentally benign and low cost tool for weed management (Kumar *et al*., 2013). Transplanted crops tend to have fewer weeds and less yield loss than direct seeded crops. Transplant healthy, vigorous seedlings that can better compete with weeds in early stages.

Crop establishment methods

Crop establishment methods adversely affect the weed population and its dry weight. Zero-till and FIRB sowing recorded lower weeds density with higher grain yield in wheat over conventional tillage and strip till drill system (Jat *et al*., 2013), in maize (Chopra and Angiras, 2008) over conventional tillage and flat bed system and in lentil (Manjunath *et al*., 2010) over flat sowing. This is because of avoidance of wetting of whole cropped soil surface in bed sowing and the weed did not find congenial moisture conditions at the surface to germinate (Sharma, 2014). In zero till seeding by Happy Seeder machine with stubble mulching, undisturbed inter row space, where seeds lying at lower depths did not germinate and it saves time and energy. BBF method of sowing provides favorable environment for the growth and development of crop and reducing weed population over flat bed and ridge furrow methods (Jha and Soni, 2013). Bidirectional sowing in wheat gives fewer weeds compared to unidirectional sowing although seed rate is same (Singh *et al*., 2012).

Planting techniques

Planting techniques, which modifies the crop canopy structure and micro climate, in combination with weed management practices, may influence the weed infestation to a great extent and hypothesized that increased crop density, reducing row spacing and spatial uniformity can increase weed suppression, because the competitive ability of crops with weeds is improved (Singh, 2014). Closer row spacing will improve crop competition for limited resources due to a rapid canopy closure, reducing weed seedling growth and soil weed seed bank. Dry matter accumulation of weeds in wheat was significantly the lowest under bi-directional row orientation followed by North-South row orientation, cross sowing at 22.5 x 22.5 cm and highest under normal 22.5cm (Chaudhary *et al*., 2013), this might be due to better smothering effect.

Seed rate

Maintaining optimum plant population is the important component of the crop's ability to compete with weeds. Variation in the seed rates and high seed rate significantly influenced weed population and their dry weight by securing an optimum plant population (Meena *et al*., 2010), which shows excellent smothering effect on weeds (Sharma and Singh, 2011) and improving productivity and profitability of the crop.

Water management

Water is the best control method for weeds. Optimum time and number of irrigation reduces the density and weight of weeds (Das and Yaduraju, 2007). Many weeds cannot germinate or grow under flooded conditions (*e.g.* most grasses and some sedges). Maintaining a 2 to 5 cm water level in the field to minimize weed emergence and lower weed pressure. If water is sufficient, field can be continuously flooded from the time of transplanting to when crop canopy covers the soil completely. Good land leveling is critical to avoid high spots where weeds can become established.

Cover/smother crops

Cover crops are grown between periods of regular cropping and are also known as smother crops due to their overshadowing effect caused by thick stands and fast growth (Mohler *et al*., 2012). They are not only grown for the purpose of harvest but also for the conservation of soil and moisture, improvement of nutrient cycling, lowering of temperature, supplying forages in emergency, protection of cash crops from winds, suppression of weed growth due to allelopathic effects (Das, 2008) or by shading and increase in crop production Besides the allelopathic effects, crop covers reduces the sunlight exposure of weeds and compete with the weeds for water, nutrient and space (Singh *et al*., 2012).

Crop rotation

Crop rotation is an important component of integrated weed management. The choice and sequence of crops affect long term weed population dynamics, and consequently weed management. Rotating crops with different life cycles can disrupt the development of weed crop associations, through different planting and harvest dates preventing weed establishment and therefore weed seed production (Das *et al*., 2012), mainly by smothering and allopathic effect (Dwivedi *et al*., 2012).

Nutrient management

Fertilizers alter the nutrient level in the agro-ecosystems and therefore they may directly affect weed population dynamics and crop weed competitions Nevertheless, nutrients clearly promote crop growth but benefit weeds more than crops (Sharma, 2014). Strong effects can be observed by manipulating fertilizer timing, dosage, and placement in order to reduce weed interference in crops (Dubey, 2014). Placement of fertilizer significantly reduced the density and dry biomass of weed and produced higher grain yield than broadcast method of fertilizer application (Lodha *et al*., 2010).

Organic manures

A byproduct of the processing of plant and animal matter that has sufficient nutrient capacity to have value as fertilizer. Press mud is one of the byproducts of the sugar industry. Press mud is obtained in sugar factories to a tune of 2 per cent of the weight of sugarcane crushed. Press mud contains sizable quantity of macro and micro nutrients, besides 20-25 per cent of organic carbon. In addition to the manurial value of press mud, it destroys the weed seeds and seedlings due to reduced soil pH and allelochemicals produced from the native microbes of press mud. Application of sugarcane press mud and neem cake reduced the weed seed bank of *Cyperus rotundus, Echinochloa colonum* and *Trianthema portulacastrum* in maize, due to reduced pH and phytonicidal properties of organic manures (Parthiban and Kathiresan, 2002 and Geetha and Kathiresan, 2008).

B. Physical methods of weed management

Physical force either manual, animal or mechanical power is used to pull out or kill weeds. Depending on weed and crop situation one or combination of these methods are used. Most mechanical weed control methods, such as hoeing, tillage, harrowing, torsion weeding, finger weeding and brush weeding, are used at very early weed growth stages (Kewat, 2014). Physical control is eco-friendly but tedious and labour-intensive. Off-season ploughing operations carried out with the help of tractors or bullock drawn implements is was very effective in reducing the weed population in succeeding crop as tubers and weed seeds are exposed to scorching sun and a highly unfavorable environment, with eventual destruction of their perennation. Summer ploughing increased the total buried weed seed population by 3-4 times compared to no ploughing. Off-season ploughing twice at 45 days interval was found to be superior in reducing the population of weeds; *Cyperus rotundus, C. difformis, Sphenoclea zeylanica* and *Fimbristylis littoralis* succeeding crops. Mechanical destruction of existing weed in the summer and exposure of reserves of weed seeds or propagules and subsequent scorching contributed for superior performance of summer ploughing in controlling weeds in succeeding crops (Gnanavel and Kathiresan, 2002).

Soil solarization

Soil solarization is a novel technique of controlling weeds, under this method covering moist soil with a thin transparent polyethylene sheet during the summer months (Patel *et al*., 2005). The process would raise the surface soil temperature by 8 to 12°C as compared to non-solarized soils. Transparent polyethylene was found highly effective for heating the soil than black polyethylene. Duration of 4 to 6 weeks is sufficient to give satisfactory control of most of the weeds. Many annuals, some perennials and parasitic weeds are highly sensitive to solar heating of the soil. However, weeds such as *Cyperos rotundus* (tubers), *Melilotus* spp. (hard seed coat) and *Cynodon dactylon* (rhizomes) are not controlled easily by solarization. Solarization, thus proved to be not only as an efficient method of weed control but was also safe to the crop as well as invariably it produced healthy and vigorous seedlings and eventually resulted higher yield in all crops as compared non solarized plots even treated with herbicides.

Use of weeders

Now days, use of mechanical weeders in agricultural operations is increasing because of non-availability of labours for weeding. The cost of the weeding operations is also reduced by using the machineries for weeding. The machineries like mini-weeders, power tillers, mini-tractor drawn rotavator are used for weeding in wider spaced crops like sugarcane, cotton, and orchards. Since the wider spacing of 5-6 feet is practiced sustainable sugarcane initiatives (SSI), mini-tractor drawn rotavator can be used for effective controlling all types of weeds in sugarcane. Cono-weeder is used for controlling the wet land weeds and getting more yields in the system of rice intensification. The mini weeder and power tillers are used for controlling different types of weeds in cotton crop. Moreover, different types of weeding implements are available for weeding operations in various field and horticultural crops. Small farm implements and machine *i.e.* power tiller, marker and cono-weeder played very imperative role in controlling weeds, enhancement of productivity and reduction in drudgery (Deshmukh and Tiwari, 2011). In case of cono-weeder, incorporation of *Daincha* and *Azolla* resulted in higher weed control during early stages of rice crop particularly for *SRI*.

Hand pulling and digging

Hand pulling aims to remove the entire weed, including its roots, from the soil. This method is useful for small-scale infestations. It is best to hand-pull weeds after rain, when soil is moist. Sturdy gloves should be worn to avoid prickles, blisters or sap burns to the skin. It is not appropriate for all weed species, such as those with underground bulbs. Hand tools such as broad knives and trowels can be used to remove underground parts of weeds (such as bulbs) that may reshoot. In some cases it is necessary to dig out the crown of the weed. This requires the growing part of the weed to be cut beneath the ground using a knife.

Weeds are removed by digging up to deeper layers so as to remove underground storage organs. It is very helpful in the case of perennial weeds and it is done with the help of pick axes or crow bars. *Cynodan dactylon, Imperata cylindrica* and *Saccharum spontaneum* are effectively controlled by this method (Das, 2008).

Burning

In situations when seed production has already occurred, some of the seeds can be destroyed by burning. The effectiveness of burning depends on the duration and intensity of heat produced, plus the maturity and location of the weed seeds. Mature and dry seeds are more heat resistant than green seeds, which have high moisture content. Although intense heat will destroy most seeds remaining in plant heads, only a relatively small number of seeds on or below the soil surface can be destroyed by burning surface trash. Burning weeds over an extended area destroys valuable surface trash that would normally be returned to the soil through decay or cultivation. (Sharma, 2014)

Mulching

The word mulch has been probably derived from the German word "*molsch*" means soft to decay, which apparently referred to the use of straw and leaves by gardeners as a spread over the ground as mulch.

Mulches are coverings placed on the surface of the soil. Mulching smothers the weeds by excluding light and providing a physical barrier to impede their emergence. Any material such as straw, plant residues, leaves, loose soil or plastic film can be used as a mulching material. Such materials as straw, bark, and composted material can provide effective weed control. Mulching reduces the deterioration of soil by way of preventing the runoff and soil loss, minimizes the weed infestation and reduces water evaporation. Thus, it facilitates more retention of soil moisture and helps in control of temperature fluctuations, improves physical, chemical and biological properties of soil, as it adds nutrients to the soil and ultimately enhances the growth and yield of crops (Kumar *et al.,* 1990). Materials such as black polyethylene have been used for weed control in a range of crops in organic production systems. Plastic mulches have been developed that filter out photosynthetically active radiation, but let through infrared light to warm the soil. These infrared transmitting mulches have been shown to be effective at controlling weeds. Surface mulches increase the soil temperature, retard the loss of soil moisture, and check the weed growth, which are the key factors contributing to the crop production (Ramakrishna *et al*., 2006 and Verma *et al*., 2008). Black polythene (Goswami and Saha, 2006) and news paper (Singh, 2014) mulch recorded significantly lower density and dry biomass of weeds over water hyacinth, paddy straw and wheat straw mulch, respectively.

C. Biological approaches

Biological control involves the use of insects or pathogens (diseases) that affect the health of the weed. On the other hand biological weed control involves using living organisms, such as insects, nematodes, bacteria, pathogens, or fungi that affect the health of the weed or reduce weed populations. Usually, these bio-control agents are from the same country of origin as the weed species. Plants become pests and are weeds when they run rampant because their natural enemies become ineffective or are nonexistent. The natural cycle may be interrupted when a plant is introduced into a new environment, or when men disrupt the ecological system. When we purposefully introduce biological control agents, we are attempting to restore or enhance nature's systems (Tiwari *et al*., 2013). Pioneering works on biological control of weeds was carried in India for control of *Parthenium hysterophorus* (Kumar and Ray, 2011). The primary focus of the biological weed management efforts in South-East Asia has been on two aquatic weeds, water hyacinth (Ray *et al*., 2009) and water fern.

Allelopathic plants

Allelopathy is any direct or indirect effect by one plant, including micro-organisms, on another through

Table 1: Allelopathic weeds to interfere with other weeds

Acalypha indica, Trianthema portulacastrum,	*Eichhornia crassipes*
Parthenuim hysterophorus,	*Cyperus rotundus*
Argemone maxicana	*Lantana camara*
Eupatorium adenophorus	*Cyperus sp., Imperata cylindrical*
Mikania micrantha	*Echhinochloa colonum, Phalaris minor*
Imperata cylindrical	*Portulaca oleracea*

Table 2: List of weed species controlled by insect agents

Weed species	Agents used to control
Salvinia molesta	*Cyrtobagous salviniae, Paulinia acuminata*
Alternanthera philoxeroides	*Agasicles hygrophila*
Opuntia spp	*Dactylopius ceylonicus, D. opuntiae, D. tomentosus, D. indicus*
Lantana camara	*Ophiomyia lantanae, Crocidosema lantana*
Parthenium hysterophorus	*Zygogramma bicolorata*
Cyperus rotundus	*Bactra verutana, Athesapaeuta cyperi*
Orabanche spp.	*Phytomyza orobanche*

Table 3: List of microorganisms used in bio-herbicides and their target weeds and ecosystems

Microorganism	Target weed	Crops	Commercial product
Colletotrichum gleosporioides	*Aeschynomene viriginica*	Rice, soybean	Collego
Phytopthora palmivora	*Morrenia odorata*	Citrus groves	De Vine
Alternaria cassiae	*Cassia obtusifolia*	Soybean	CASST
Alternaria destruens	*Dodders*	Cranberry	Smolder
Biopolaris sorghicola	*Sorghum halepense*		

production of chemical compounds that escapes into the environment to influence the growth and development of neighboring plants (Rice, 1974). Plant releases chemicals that show allelopathic potentiality are called allelochemicals or allochemicals. It covers a wide range of chemicals used by plants or organisms. Generally different plant organ such as plant tissues, including leaves, flowers, fruits, stems, roots , rhizomes, seeds and pollen are the main sources of allelochemicals of donor plants are competing with neighboring plants, that released through crop-environmental ecological process. Allelochemicals or natural compounds have more benefits over synthetic compounds as they have novel structure and short half-life, therefore considered safe of environmental toxic (Duke *et al*., 2002). Therefore allelopathy mechanism can be applicable as a component of sustainable weed management. There are many plant species have allelopathic potential to control the aquatic weeds effectively. The list of allelopathic crops and weeds to interfere with different weeds are given in the table 1.

Bio-fertilizers

Bio-fertilizers are defined as preparations containing living cells or latent cells of efficient strains of microorganisms that help crop plants' uptake of nutrients by their interactions in the rhizosphere when applied through seed or soil. They accelerate certain microbial processes in the soil which augment the extent of availability of nutrients in a form easily assimilated by plants. *Azolla* is a free-floating water fern that floats in water and fixes atmospheric nitrogen in association with nitrogen fixing blue green alga *Anabaena azollae*. *Azolla* fronds consist ofsporophyte with a floating rhizome and small overlapping bi-lobed leaves and roots. Dual culturing of azolla in rice fields had the added benefit of suppressing weed growth besides fixing atmospheric nitrogen. Since it forms a mat over the surface, it reduced the entry of sunlight and aeration into soil thereby suppressing weed growth. The addition of azolla in rice fields suppresses the weeds *Eichinochloa crusgalli* and *Cyperus difformis* and the degree of suppression increased with increase in per cent of azolla cover and water depth (Sivakumar *et al*., 1999). The list of weed species controlled by insect agents is given in table 2.

Bio-herbicides

Weeds can be controlled by pathogens like fungi, bacteria, viruses and other biological agents. Among the classes of plant pathogens, fungi have been used to a larger extent than the bacteria and viruses or nematode. A bio-herbicide is a preparation of living inoculums of plant pathogens formulated and applied in a manner analogous to that of an herbicide in an effort to control or suppress the growth of weed species. The list different bio-herbicides available for controlling weeds are given in the table 3.

Herbicide resistant crops

Herbicide resistance is the inherited ability of the plant to survive and reproduce following exposure to a dose of herbicide that would normally be lethal to the wild type. In a plant, resistance may occur naturally due to selection or it may be induced through such techniques as genetic engineering. The adoption of genetically modified (GM) crops has increased dramatically during the last 10 years and currently over 52 million hectares of GM crops are planted world-wide. Approximately 41 million hectares of GM crops planted are herbicide-resistant crops, which includes an estimated 33.3 million hectares of herbicide-resistant soybean. Herbicide resistant maize, canola, cotton and soybean accounted for 77% of the GM crop hectares in 2001. However, sugarbeet, wheat, and as many as 14 other crops have transgenic herbicide resistant cultivars that may be commercially available in the near future. There are many risks associated with the production of GM and herbicide-resistant crops, including problems with grain contamination, segregation and introgression of herbicide-resistant traits, market place acceptance and an increased reliance on herbicides for weed control.

D. Integrated weed management

IWM includes more than one method of control *viz.,* seed purity, crop varieties, spacing and methods of planting, cultivations, soil solarization, intercropping, crop rotation, water management, manure application, biological control and herbicides (Sanyal, 2008). According to FAO, the integrated campaign against pests is a method whereby all economically, ecologically, and toxicologically justifiable methods are employed to keep the harmful organisms below the threshold level of economic damage, keeping in the foreground the conscious employment of natural limiting factors. By using different appropriate management practices against weeds, farmers have more options for controlling weeds, thereby reducing the possibility of escaping and weed adaptation as compared to any single weed management tactic. For example, the traditional practice of puddling soil to kill existing weeds and aid water retention, transplanting rice seedlings into standing water to achieve an optimum stand density, and maintaining standing water to suppress weeds, followed by one or several periods of manual weeding, is a well established example of integrated weed management (IWM) (Rao *et al*., 2007). Integrating fish culture and dual culture of azolla in transplanted rice is observed to compliment weed control in transplanted rice (Kathiresan *et al*., 2001). Off-season ploughing and mulching the inter row space enhances the weed control in combination with herbicide in cotton (Vijayabaskaran and Kathiresan, 1993).

In modern agriculture non chemical method have been ignored old practice such as crop rotation, tillage inter cultivation and intercropping have been forgotten; due to use of chemical method. It causes soil erosion, increase in chemical residue in harvested produce of crop if such type of food eaten by human being it causes harmful effect on health due to disturbance of food chain. To eliminate all the above harmful effects of chemical methods of weed control there is one option that is eco-friendly weed management for sustaining ever growing population. Maintaining appropriate crop rotation with legume and non-legume crops, and growing of cover crop helps to suppress weeds by smothering and allelopathic effects. Growing competitive cultivars, modifying in sowing and planting techniques, changing sowing and planting time, mulching with organic residues, green and brown manuring and the adoption of reduced or zero tillage makes an inappropriate environment for weed seed germinations and their growth. It also stores a higher amount of organic matter by reducing the mineralization rates and subsequently decreases energy consumption and carbon oxide emissions and finally save the environment. It is therefore suggested to grow crops following non chemical method of weed management as for as practicable.

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