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Weed management in vegetables and flowers crops in India

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Abstract
Vegetable and floricultural crops are major components of the horticultural industry in India. These horticulture crops generates foreign exchange, create employment and provide raw material for processing industries. The slow growing habit makes these crops susceptible to competition from weeds, which adversely affects yield and quality of these crops. Vegetables are a substantial part of our lives and possess great commercial and nutritional value Weed management is an important aspect in the successful production of these crops. Weeds reduce crop yields by 45%–95% in the case of weed–vegetable competition, lower their quality and increase costs of production. They host pests and diseases thereby raising the need to control them as well. Weed management may involve non-chemical and or chemical methods. The decision of method to be used depends on the environmental conditions, available labour, weed population, the crop, desired management practices and the cost of controlling weeds. The major aim is to manage the weed population to a level below that will cause a reduction in economic return for the farmer. An integration of different control methods, therefore, needs to be addressed in future research. Furthermore, specific researches on weed management in horticultural crops in India need to be addressed. This article attempts to highlight important weed flora of vegetables and flower crops in India and some of the management strategies that could be used to manage these weeds.

Keywords: critical period, herbicides, mulch, solarisation, weed competition

Introduction
Vegetable and floricultural crops are important among horticultural crops in India. Vegetable growing imposes a particular weed-management approach. Several production problems diminish the quality and yield of vegetables. Salinity, drought stress and climate changes are a few abiotic factors that decrease the yield of vegetables while the major biotic factors that reduce the yield include disease pathogens, insect pests, viruses, and weeds. Vegetables are rich sources of vitamins, minerals and fibres which provide food and nutritional security, and together these horticultural crops generate foreign exchange, create employment and provide raw materials for processing industries. Vegetable areas are usually small, but produce high-value crops that are commercially and gastronomically appreciated. Fruit and leaf crops provide important income for farmers and workers at local or regional levels. Weeds not only reduce the yield of vegetables but also decrease their quality and market value. Most of these crops are slow growing and have poor canopy development during the early stages. This habit makes them susceptible to competition from weeds, which adversely affect yield and quality of these crops. Product quality is a major aspect of horticultural industry. Generally, farmers do not understand the negative implications of weeds in term of yield losses and the cost of its control. Weed control has been observed as one of the most important practice in crop production because good weed control will ensure maximum yield and high quality of farm produce. Since most horticultural crops are very slow in growth, especially in the early stages of their establishment, it becomes imperative to begin weed control early enough in order to ensure high yield and quality. This paper reviews the common weeds problems and their control with particular reference to India.

Different Agro-climatic zones with commonly grown vegetable and flowers

Zones	States	Vegetable	Flowers
Western Himalayan Region	J&K, HP, Parts of UP	Cabbage, broccli, pea, radish, turnip, knol-khol	Marigold, gladiolus, lilium, rose, carnation and gerbera
Eastern Himalayan Region	Sikkim, Arunachal Pradesh, Manipur, Assam	Potato, Sweet Potato, chilly and turmeric	Cymbidium, Orchids
Lower Gangetic Plain	West Bengal	Tomato, Cabbage, Cauliflower, Peas, Brinjal, Onion and Cucurbits	Marigold, Rose, gerbera, jasmine
Upper Gangetic Plain	Remaining parts of UP	Okra, garlic, tomato	Chryasanthemum marigold
Transgangetic plain	Punjab Haryana and Shiwalik Region	Okra, bittergourd, brinjal	Lotus, lillium, candidum
Eastern Plateau and Hills	Hilly areas of MP,Orissa, Chottanagpur plateau	Onion, garlic, corainder, chillies	Lilium
Central Plateau and Hills	Chhatisgarh, UP and Rajasthan	Carrot, Sweet potato	Rajnigandha, tulip, lilium
Western Plateau and Hills	Main region of Maharashtra, major parts of MP, Part of Rajasthan	celery, leek, cabbage, cherry tomato, onion	Rose
Southern Plateau and Hills	Part of AP, Karnataka, Tamil Nadu	French bean, tomato, green leafy vegetables	Rose, lotus
East Coast Plains	East coast of Tamil Nadu, Andhra and Orissa	Onion, Brinjal, cabbage, cauliflower	Rose, lotus, Glory lily
West Coast plains and Ghats	West coast of Tamil Nadu, Kerala, Karnataka, Maharashtra and Goa	Drum stick, chillies, Brinjal, gourds	Rose, lotus
Gujarat plains and Hills	19 Districts of Gujarat	Onion, garlic, brinjal, okra	African marigold
Western Dry region	9 Districts of Rajasthan	Bottle gourd, bitter gourd	Roses, jasmine, gerbera
Islands Region	Island terriorties of Andman and Nicobar and lakashdeep	Radish, tomato, okra	Pyinma, cannonball flower

Weed competition

Weeds compete with crops for water, nutrients, space, light and oxygen resulting into a delay in maturity and low yield. Generally, these losses occur as a result of reduced yield, quality, harbouring of pests or diseases, allelopathic effects on crops etc. The extent of yield losses depends on the type of weed flora, their intensity and duration of weed competition and soil and climatic factors. Research studies demonstrated the yield losses of up to 66% in spring cabbage, 51% in cauliflower, 70% in pea, 40% in okra, 60% in tomato (Kaur *et al*., 2008) [10], 62-82% in potato, 95% in beetroot, 28-78% in carrot, 2-41% in root and 86% in radish seed yield, 42% in onion, and 60% in garlic (Sandhu *et al*. 2002, Kumar *et al*. 2001, Kaur *et al*. 2015) [25, 12, 11]. Reports from Rodenburg *et al*. (2009) have shown that weeds reduce onion bulbs, heads in lettuce and cabbage. Weeds serve as many hosts for pests and diseases, causing phyto-sanitary problems. The aphid (Aphis gossipi), which is known to transmit a viral disease 'potato leaf roll; and 'potato mosaic' has been found to live in Eleusine indica as a host (Rao 2006) [22]. Removal of such a weed has been found to reduce the incidence of this pest on potatoes. Weeds also carry pests over season to season. Some weeds exert allelopathic effects on some crops. Thus, to get maximum returns from inputs applied to these horticultural crops, there is a great need of proper weed control measures in these crops. Most of these weeds are not host specific because they infest both vegetables and flowers. It is, therefore, very difficult to draw a clear cut boundary between vegetable or flower weeds (Adeyemi and Olaniyi 2008) [1].

Weed control

Weed control is especially important early in the season when weed competition can substantially reduce vigour, uniformity and overall yield. The period from emergence to four weeks has been found to be critical in the competition of weeds in many row crops including vegetables. Only a few vegetables are good competitors with weed flora because they quickly cover the soil, topping the weed growth like potato, transplanted brinjal and cabbage. But most vegetables, such as carrots, turmeric or direct seeded vegetable crops like cabbage grow slowly and they cover the soil very sparsely, suffering strong weed competition not only for water, nutrients and light, but even for space. Thus, if weed control is not carried out timely, there will be no production at all. There are many examples of problems in crop-yield reduction that indicate the great sensibility of vegetables to early weed competition and the need to control weeds at early crop stages. Weed competition is more severe when a directseeded vegetable is grown.

Critical period of weed control

This period has been defined as an interval in the life-cycle of the crop when it must be kept weed free to prevent yield loss. Horticultural crops are very sensitive to weed competition and need to keep them weed-free, from planting, emergence or until the end of their critical weed free period. If the crop is kept weed-free for the critical period, generally no yield reduction would be there. Again, weeds emerging after the critical weed-free period will not affect yield, but control efforts after this time may make harvest more efficient, or reduce weed seed banks and reduce weed problems in subsequent years. The critical period of weed competition is usually longer in direct-seeded than in transplanted crops. For example, if transplanted pepper has to be weeded from the second week until the third month after transplant to prevent a 10% yield loss, directseeded pepper must be weeded during the first four months after emergence to prevent the same loss (Kumar *et al*., 2010) [14]. Some traditional techniques, viz. transplant, earthing-up as done in potato are thought to increase crop competitiveness. Obviously, weather conditions and weed density have a great influence on the length of critical periods.

Weed flora

Weeds in vegetable and flower fields are in different sizes, forms and behaviours. They belong to many families varying in physiology, morphology and habits of growth. The first step in weed management is to identify the weeds and

understand their lifecycles. Weeds can be categorised by their life-cycles and management strategies developed accordingly (Nwafor *et al*. 2010) [21]. Annual weeds complete their life-cycles in one year and reproduce solely by seeds. Annuals are divided into summer and winter groups depending on when they grow.

The perennial weeds live for more than two years and can reproduce by seed or vegetative structures such as stolons, rhizomes, tubers, bulbs and roots. Because perennial weeds are difficult to manage in vegetables, it is better not to use a field with severe perennial weed problems.

The composition of present weed flora in vegetables needs to be well determined. Based on this data, we shall then be able to prepare the best control methods to be implemented. It is well known that weeds are very well adapted to the crop that they infest, because of their morphological and phenological characteristics. An example of this situation is the case of carrots where umbelliferous species as *Ammi majus*, *Torilis* spp., *Scandix pecten-veneris*, *Daucus* spp. are the dominant ones (Singh *et al*., 2014) [29]. A spring crop can be infested by two generations of species: first by cold-temperature-adapted, such as *Capsella bursa-pastoris*, *Chenopodium album and Polygonum aviculare*, and later by the summer thermophiles *Portulaca oleraceae, Solanum nigrum, Cyperus rotundus* and *Amaranthus retroflexus.*

Some annual species with a short cycle such as *Sonchus oleraceus, Poa annua, Senecio vulgaris, Stellaria media* are also likely to create problems in some vegetables at certain stages of the crop rotation (Barman *et al*., 2005) [3].

Weed communities may have various species, but many of them are more adapted to a particular crop. For example: *Echinochloa crus-galli, Amaranthus* spp., *Chenopodium album, Polygonum aviculare, Portulaca oleracea* and *Solanum nigrum* are dominant in transplanted tomatoes. However if this crop is direct-seeded, early emergence grass weeds such as *Alopecurus myosuroides*, *Avena* spp., *Lolium* spp. and several species of *Brassicaceae* and *Asteraceae* are more frequent (Bhat *et al*., 2005) [4].

Similarly, frequent weeds in early-seeded onion are *Capsella bursa-pastoris, Sinapis arvensis, Poa annua, Sonchus* spp., *Polygonum aviculare.* In transplanted onion, or later seeded crops, *Echinochloa* spp., *Portulaca oleracea*, *Solanum* spp., *Setaria* spp. are also frequent. Parasitic weeds can be also a problem in vegetable crops (*Orobanche crenata* in legumes, *Apiaceae* and lettuce; O. ramosa in *Solanaceae* and cucurbits; *Cuscuta* spp. in legumes, tomato, carrots, onion, asparagus). (Menan *et al*., 2020) [19] Major problems in vegetables are caused by broadleaf weeds because grass weeds are much better managed in rotation or they can be successfully eliminated with the use of selective foliar-applied herbicides.

With a sound knowledge of weed phenology and other factors (temperature, rainfall and irrigation scheme) at the local level, it is possible to predict when and in which crop certain weeds will raise problems. Obviously, in a plastic-protected crop, weed emergence takes place earlier and weed growth tends to be greater.

The composition of present weed flora in vegetables needs to be well determined. Based on this data, we shall then be able to prepare the best control methods to be implemented. It is well known that weeds are very well adapted to the crop that they infest, because of their morphological and phonological characteristics. An autumn crop like onion and garlic can be infested by two generations of species, first by winter annuals such as Chenopodium album and Poa annua and perennials like Cirsium arvense, and later by the summer annuals like Amaranthus retroflexus, Dactyloctenium aegyptium. Weed communities may have various species, but many of them are more adapted to a particular crop. Parasitic weeds can also be a problem in vegetable crops (Orobanche crenata in legumes; Apiaceae in lettuce; O.ramosa in solanaceous crops and cucurbits; Cuscuta spp. in legumes, tomato, carrots, onion, and asparagus) with a sound knowledge of weed phenology and environmental factors at the local level, it is possible to predict when and where certain weeds will raise problems.

Methods of weed control

Weed control in vegetables especially important early in the season when weed competition can substantially reduce vigour, uniformity and overall yield. The period from emergence to four weeks has been found to be critical in the competition of weeds in many row crops including vegetables. The methods used for controlling weeds have been divided into two broad categories, non-chemical and chemical. Many non-chemical weed management methods are common sense farming practices. These practices are of increasing importance due to consumers' concerns about pesticide residues, potential environmental contamination from pesticides, and unavailability of many older herbicides.

Non-chemical methods

Weed management should start with nonchemical strategies. The aim should be to manage the weed population below a level that reduces economic return. In some instances, the cost of controlling weeds may be more than the economic return obtained from any yield increase. This situation occurs when a few weeds are present or the weeds germinate late in the season. In those instances, the best strategy may be to do nothing. In other situations, weed populations and other considerations may require combining herbicides with non-chemical approaches.

Preventive methods

These methods are closely connected with crop rotations and necessary when no direct measures of weed control can be taken for economic reasons. They are based on a reduction in the soil seed and propagule bank and the early awareness of the infestations. It is necessary to avoid the invasion of new species through the use of clean planting material and to prevent seed dispersal on the irrigation water, implements and machines. A written record of the history of weed infestation in the field is very useful. Another aspect is to impede perennial weed dispersal (or parasitic weeds) through the use of treatments and tillage and the use of drainage tillage to prevent propagation of some species (Phragmites spp., Equisetum spp., Juncus spp.) That need high moisture levels. It is also necessary to scout the field edges to prevent invasions, acting only when necessary, and bearing in mind the usefulness of the edges and borders to control erosion and hosting useful fauna (Zaragoza 2001) [34].

Cultural methods: One should aim to establish a vigorous crop that competes effectively with weeds. This approach starts with land selection. A general rule is not to plant vegetables on land with a history of heavy weed infestation, especially of perennial weeds.

Stale seedbed

Stale ('false') seedbeds are sometimes used for vegetables when other selective weed control practices are limited or unavailable. Many vegetables are grown in seed beds to develop suitable seedlings for transplanting in the field. Soils dedicated to seed beds are usually light, with good tilth, and fertilized to obtain a good plant emergence. Seed beds are usually flood-irrigated and plastic-protected. Success depends on controlling the first flush of emerged weeds before crop emergence, and on minimal disturbance, which reduces subsequent weed flushes. It consists of preparation of a seedbed 2-3 weeks before planting to achieve maximum weed-seed germination near the soil surface. These seedlings are killed by light cultivation or by applying non-residual herbicides glyphosate and paraquat just before or after planting, but before crop emergence. The crop is planted with minimum soil disturbance to avoid exposing new weed seed to favourable germination conditions. The pre-germination should occur as close as possible to the date of planting to ensure that changes in weather conditions do not have an opportunity to change the spectrum of weeds (cool vs. warm season) in the field.

Planting to moisture: The majority of small seeded weeds germinate in upper 1 to 2 inches of soil. This aspect of the germination ecology of weeds can be exploited for control of these weeds. After the weeds are killed by cultivation, the top 1 to 2 inches of soil are allowed to dry and form a 'dust mulch'. (Kalhapure *et al*., 2013) [8] At planting, the dust mulch is pushed away and largeseeded vegetables such as corn or beans can be planted into the zone of soil moisture. These seeds can germinate, grow, and provide partial shading of the soil surface without supplemental irrigations that would otherwise provide for an early flush of weeds.

Crop rotation: Crop rotation is a key control method to reduce weed problems in vegetables. It was considered for a long time to be a basic practice for obtaining healthy crops and good yields. This concept was mistakenly eliminated with the use of more agrochemicals. At present, however, crop rotation is gaining interest and is of value in the context of integrated crop management. Weeds tend to thrive with crops of similar growth requirements. Cultural practices designed to contribute to the crop may also benefit the growth and development of weeds. Monoculture results in a build-up of weed species that are adapted to the growing conditions of the crop. When diverse crops are used in a rotation, weed germination and growth cycles are disrupted by variations in cultural practices associated with each crop (tillage, planting dates, crop competition, and weed control methods). Traditionally, potato was included in the rotation to reduce weed problems before a less competitive crop was grown. Introducing a fallow in the rotation is essential to reduce difficult weeds like perennials. It is best to alternate legumes with grasses, row crops with close planted crops and heavy feeders with light feeders.

The broad principles and examples of ideal crop rotations are given below:

1. Alternating crops with a different type of vegetation: leaf crops (lettuce, spinach, cole), root crops (carrot, potato, radish) - bulb crops (onion, garlic) - fruit crops (squash, pepper, melon).
2. Alternating grass and dicot crops, such as maize and vegetables.
3. Alternating different crop cycles: winter cereals and summer vegetables.
4. Avoiding succeeding crops of the same family: apiaceae (celery, carrot)-solanaceae (potato, tomato).
5. Alternating poor (carrot, onion) and high weed competitors (maize, potato).
6. Avoiding problematic weeds in specific crops (e.g. mulvaceae in celery or carrots, parasitic and perennials in general).

Cover crops: Rapid development and dense ground covering by the crop will suppress weeds. The inclusion of cover crops such as clovers, oilseed radish, summer greengram, summer black gram, sunhemp, Sesbania or forages in the cropping system can suppress weed growth. Highly competitive crops may be grown as short duration 'smother' crops within the rotation. Additionally, cover crop residues on the soil surface will suppress weeds by shading and cooling the soil. When choosing a cover crop, consideration should always be given to how the cover crop will affect the succeeding crop. In addition, decomposing cover crop residues may release allelo chemicals that inhibit the germination and development of weed seeds. The cover-crop systems tend to control small seeded annual broadleaf weeds the best.

Planting patterns: Crop population, spatial arrangement, and the choice of cultivar (variety) can affect weed growth. Narrow row spacing and proper plant density assure that the crop rapidly closes the canopy. A closed canopy shades out late emerging weeds and prevents germination of weed seeds requiring light. Similarly, fast-growing cultivars can have a competitive edge over the weeds. Weeds seldom pose a problem once the canopy closure occurs. Weed management in vegetable and flower crop-based systems

Planting time: The crop planted at the right time showed more competitiveness towards weeds than late planted crop. Crops may be divided into warmand cool-season plants, depending on the optimal temperature for their growth. The planting date effects the time of emergence and early seedling vigour of the crop, which are important in determining crop competitiveness. Cool-season crops germinate at cooler soil temperatures and thus compete better against early emerging weeds than do warm-season crops. The crop should be planted at a time when the temperatures are favourable for crop growth.

Mulching: Mulching or covering the soil surface can prevent weed seed germination by blocking light transmission preventing seed germination. Mulches may be classified as either natural or organic (straw, bark, compost) or synthetic (plastic). As natural mulches are difficult to apply over large areas, they are best for small, specialized areas. Natural mulches should be spread evenly at least 1.5 inches thick over the soil to prevent light penetration; weeds can easily manage to reach the surface if the layer is not thick enough. Allelopathic chemicals in natural mulch also can physically suppress seedling emergence. Some manual weeding may be required along with the practice of mulching. Paddy straw mulch at 6 t/ha in potato and 9-10 t/ha in turmeric recorded effective control of mixed weed flora (Kaur *et al*. 2008, Anonymous 2015) [10, 2]. Natural mulch materials must be free of weed seeds and other pest organisms and be heavy enough that they are not easily displaced by wind or water. A major

advantage of natural mulches is their biodegradability adding organic matter to the soil. The use of plastic mulching is very popular in many vegetable-growing areas. 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. Synthetic mulches control weeds within the row, conserve moisture, increase soil temperature, and are easy to apply. Black plastic mulches are the most common and are particularly effective in improving early season growth of warm-season crops such as tomatoes, muskmelons, watermelons, and peppers. Better early season growth of these crops improves their competitive ability against weeds. Plastic mulches used in combination with trickle irrigation also improve water use efficiency. The biggest disadvantage of plastic mulch is disposal, as many landfills do not accept it. Photodegradable plastic mulches have been developed, but their season long persistence is a problem. Also, photodegradable mulches just degrade into smaller pieces of plastic that still contaminate the environment. Biodegradable plastic mulches are not yet widely available. Mulching generally prevents the germination of light sensitive weeds like Ageratum conyzoides, Portulaca oleraceae etc. (Adeyemi and Olaniyi 2008) [1]. Some perennial weeds are not controlled (e.g. Cyperus spp., Convolvulus arvensis) by this process and for them inter-row cultivation or herbicidal treatments are necessary.

Solarization

In this process, moist soil is covered with a clear, thin transparent plastic sheet, to trap the soil radiation for 30-45 days. Solarization works when the heat created under the plastic film becomes intense enough to kill weed seeds. The maximal soil temperature reaches nearly 60°C under polyethylene covered plots. The factors involved in solarization are soil temperature, moisture and probably gases due to which solarization reduces the germination, establishment and biomass of heat sensitive weed species. Results are often variable, depending on weather conditions. In Northern India, high soil temperature (50-60 °C) can develop in soil covered with transparent polyethylene sheets in May-June. Cold (high latitude) or cloudy places are usually not suitable for implementing solarization. Some species can tolerate solarization (e.g. deep rooted perennials, viz. Sorghum halepense, Cyperus rotundus, and also some big weed seeds such as legumes). After solarisation, the use of deep or mouldboard tillage must be avoided and the sowing should be done with minimal soil disturbance. This system is more suitable for small areas of vegetables, but is widely used under plastic greenhouse conditions.

Chemical control in seed beds

There are even less registered herbicides for seed beds than for planting crops. Some of the recommended herbicides are described by Labrada (1996) [17]. Table 1 shows some new additions.

There are several post-emergence grass-killers (usually known as ‘fop’ and ‘dim’ families) that could be used well in vegetable seedbeds, as for example, cycloxydim (for onion, cruciferous crops), cletodim (onion, tomatoes), fluazifop-butyl (tomato, pepper, lettuce, leek, onion). Rates must be low to avoid any problem of phytotoxicity (De Liñán, 2002) [5].

Herbicide treatments under plastic cover are always hazardous and careful application should be carried out. Under plastic, high levels of moisture and elevated temperature are common and plants grow very gently. Selectivity could be easily lost and phytotoxicity symptoms may occur, while sometimes they are just temporary. The effects are often erratic. The best way to deal with it is to be prudent and make some trials before a general treatment.

Table 1: Selective pre-emergence and early post-emergence herbicides for vegetable seedbeds.

a) Pre-emergence		
Herbicide	**Dose (kg a.i./ ha)**	Crop
Clomazone	0.18 - 0.27	Pepper, cucumber
DCPA	6.0 - 7.5	Onion, cole crops, lettuce
Metribuzin	0.15 - 0.5	Tomato
Napropamide	1.0 - 2.0	Tomato, pepper, eggplant
Pendimethalin Proanide	1.0 - 1.6 1.0 - 2.5	Onion, garlic Lettuce
Propachlor	5.2 - 6.5	Onion, cole crops
b) Post-emergence (crops with at least 3 leaves)		
Oxifluorfen	0.18 - 0.24	Onion, garlic
Rimsulfuron	0.0075 -0.015	Tomato
Clomazone	0.27 -0.36	Pepper
Ioxinil	0.36	Onion, garlic, leek
Linuron	0.5 - 1.0	Asparagus, carrots
Metribuzin	0.075 - 0.150	Tomato

Direct-seeded and transplanted crops

Crop rotation

Crop rotation is the programmed succession of crops during a period of time in the same plot or field. It is a key control method to reduce weed infestation in vegetables. Crop rotation was considered for a long time to be a basic practice for obtaining healthy crops and good yields. This concept was mistakenly eliminated with the use of more agrochemicals. At present, however, crop rotation is gaining interest and is of value in the context of integrated crop management. Classically, crop rotations are applied as follows:

1. Alternating crops with a different type of vegetation: leaf crops (lettuce, spinach, cole), root crops (carrots, potatoes, radish), bulb crops (leeks, onion, garlic), fruit crops (squash, pepper, melon).
2. Alternating grass and dicots, such as maize and vegetables.
3. Alternating different crop cycles: winter cereals and summer vegetables.
4. Avoiding succeeding crops of the same family: *Apiaceae* (celery, carrots), *Solanaceae* (potato, tomato).

5. Alternating poor- (carrot, onion) and high-weed competitors (maize, potato).
6. Avoiding problematic weeds in specific crops (e.g. *Malvaceae* in celery or carrots, parasitic and perennials in general).

Examples of crop rotations are as follow (Zaragoza *et al.* 2001) [34]:

Examples of crop rotations are as follow

In tropical regions:	Tomato - okra - green bean
	Sweet potato - maize - mung bean
In temperate regions:	Pepper - onion - winter cereal
	Melon - beans - spinach – tomato
	Tomato - cereal – fallow
	Lettuce - tomato – cauliflower
	Potato - beans - cole - tomato- carrots
	Melon - artichoke (x 2) - beans - red beet - wheat – cole

Introducing a fallow in the rotation is essential for the control difficult weeds (e.g. perennials), cleaning the field with appropriate tillage or using a broad-spectrum herbicide. It is also important to avoid the emission of weed seeds or other propagules.

Preventive measures

These can be very useful (but, unfortunately, are always forgotten), closely connected with crop rotations and necessary when no direct measures of weed control can be taken for economic reasons. They are based on a reduction in the soil-seed and propagules bank and the early awareness of the infestations.

It is necessary to avoid the invasion of new species through the use of clean planting material and to prevent seed dispersal on the irrigation water, implements and machines. A written record of the weed situation in the fields is very useful. Another aspect is to impede perennial weed dispersal (or parasitic weeds) through the opportune use of treatments and tillage and the use of drainage tillage to prevent propagation of some species that need high moisture levels. *(Phragmites* spp., *Equisetum* spp., *Juncus* spp.) It is also necessary to scout the field edges to prevent invasions, acting only when necessary, and bearing in mind the usefulness of the edges and borders to control erosion and hosting useful fauna (Zaragoza, 2001) [34].

Land preparation and tillage

As Labrada (1996) [17] stated, suitable land preparation depends on a good knowledge of the weed species prevalent in the field. When annual weeds are predominant (Crucifers, *Solanum*, grass weeds) the objectives are unearthing and fragmentation. This must be achieved through shallow cultivation. If weeds have no dormant seeds (*Bromus* spp.), deep ploughing to bury the seeds will be advisable. If the seeds produced are dormant, this is not a good practice, because they will be viable again when they return to the soil surface after further cultivation.

When perennial weeds are present, adequate tools will depend on the types of rooting. Pivot roots *(Rumex* spp.) or bourgeon roots *(Cirsium* spp.) require fragmentation and this can be achieved by using a rotovator or cultivator. Fragile rhizomes (*Sorghum halepense)* require dragging and exposure at the soil surface for their depletion, but flexible rhizomes *(Cynodon dactylon*) require dragging and removal from the field. This can be done with a cultivator or harrow. Tubers (*Cyperus rotundus)* or bulbs (*Oxalis* spp.) require cutting when rhizomes are present and need to be dug up for exposure to adverse conditions (frost or drought). This can done with mouldboard or disk ploughing. Chisel ploughing is useful for draining wet fields and reducing the infestation of deep-rooted hygrophilous perennials (*Phragmites*, *Equisetum*, *Juncus).* This is why reliable weed information is always necessary.

The success of many weed-control operations depends upon the timing of its implementation (Forcella, 2000). The opportunity for mechanical operation is indeed essential. Action must be taken against annual weeds before seed dispersion takes place. Tillage efficacy against perennials is higher when the plant reserves move up (e.g. *Convolvulus arvensis* in springtime. In autumm there are more fragment rootings).

Good practices in mechanical operations must look at optimal conditions, including the following:

- planting density must be in function of the weeding-tool working width;
- choice of adequate tools necessary for the work;
- paying attention to the weed and crop stage and avoiding delays in interventions;
- regulating the work depth, advance speed, attack angle;
- moisture content is important; look for the right tilth;
- do not increase the soil erosion: avoid parallel tillage to the slope direction line;
- foresee climatic conditions after completion of work. Avoid tillage if rainfall is expected.

In Germany, very limited negative side effects have been produced with the use of mechanical weed control. Average plant losses after hoeing, ridging plus harrowing time were 3.0-3.5 percent (Laber *et al.* 2000) [16].

Another typical operation that requires mechanical tillage is herbicide soil incorporation. Some very volatile herbicides commonly used in vegetables (e.g. trifluraline) must be thoroughly incorporated in the soil at an adequate depth (5-7 cm). The implement used for herbicide incorporation must be in good condition. For example, rotavator blades must be sharpened. L-shaped blades are the best choice for chemical incorporation. For correct incorporation the soil must be neither too wet nor too dry. In the first case it is convenient to change the rotavator by a flexible or rigid tine harrow. Unbroken pieces of manure or soil clods can reduce the treatment efficacy.

Mulching material

The use of plastic mulching is very popular in many vegetable-growing areas. A non-transparent plastic is used to impede the transmission of photosynthetic radiation through the plastic to the weeds so that the development of weeds is then arrested. Advantages are also a better moisture conservation as a reduction in irrigation needs means a reduction in nitrogen leaching, a better soil structure conservation, and an increase in the vegetable yield in an arid climate. Inconveniences are mainly the price of plastic (although it can be reused) as well as management costs. Some perennial weeds are not controlled (e.g. *Cyperus* spp., *Convolvulus arvensis*) and interrow cultivation or treatments are necessary. It is obligatory to remove the plastic residues from the field in the form of waste

(burning is prohibited). Black plastic mulching on the crop rows and interrow cultivation is a satisfactory option for organic tomato and melon growers in Southern Europe. Other organic materials (bark, straw, plant residues) can be used, especially if there is a cheap source available nearby. Their advantages are similar to plastic, but weeds can easily manage to reach the surface if the layer is not thick enough. Depending on the materials used, there can be specific problems (e.g. danger of fire with the use of straw, and wind or flooding can remove mulching materials). Some materials can increase the population of crop enemies: rodents, snails. Of course, some manual weeding is often still necessary (Nogueroles and Zaragoza, 2001).

Chemical weed control

The best approach to minimize inputs and to avoid any environmental problems is to apply herbicides in the crop row to a width of 10-30 cm. Band application reduces herbicide use by up to 75 percent compared to an overall application. Weeds along the cropping row are then controlled and the interrow ones can be removed through cultivation.

Diphenamid was a good herbicide for vegetables but is no longer commercialized. None of these herbicides are effective in the control of perennial weeds. Halosulfuron is a new compound selective on cucurbits and other vegetables with action against *Cyperus* spp. (Webster, 2002) [32].

Sometimes a combination of two herbicides having a different weed-control spectrum may be used. Mixtures of different herbicide are possible (e.g. isoxaben + trifluralin, DCPA + propachlor, bensulide + naptalam) to achieve better efficacy, but previous trials are necessary. Some herbicides can be tested against the parasitic *Cuscuta* spp., such as DCPA, pendimethalin, pronamide and imazethapyr.

For the selective control of grass weeds in vegetable crops the use some foliar active herbicides is recommended, such as cicloxidim (against annuals: 0.1-0.25 kg a.i./ha, perennials: 0.3-0.4), cletodym (0.1-0.2), fluazifop-butyl (annuals: 0.15-0.25, perennials: 0.5+0.25), haloxyfop-methyl (0.05-0.2), propaquizafop (0.1-0.2), quizalofop (annuals: 0.05- 0.125, perennials: 0.1-0.2). It should be noted that one application will not be sufficient against perennials. Their foliar activity is enhanced by adding a non-ionic surfactant or adjuvant (William *et al.* 2000; De Linan, 2002) [33].

The use of any herbicide in vegetables requires previous tests to verify its effectiveness in local conditions and selectivity to available crop cultivars.

Table 2: Effect of different weed management practices on yield and Weed control efficiency (%) in vegetables

Name of the crop	Location	Treatment	Yield (t/ha)	Weed control efficiency (%)	References
Brinjal	Raipur	Pendimethalin extra (0.64 kg/ha) Pre transplanting+1 hand weeding at 40 DAT +Pendimethalin extra (0.64 kg/ha) at 45 DAT	25.2	79.67	*Kunti at al.*, (2012) [15]
Garlic	Palampur	Pendimethalin 1.50 kg/ha + 3HW(30,60,90 DAP)	4.44	93.5	Kumar *et al*., (2013) [13]
Cabbage	H.P	Oxadiazon @0.75+ Pendimethalin @0.75	18.68	83	Nanda *et al.*, (2005) [20]
Garlic	SKUAST Jammu, Chatha.	Oxadiargyl 90 g/ha PE fb quizalofop –ethyl 50 g/ha POE	6.06	87.6	*Sampat et al.*, (2014) [24]
Potato	Ludhiana, Punjab;	Hand hoeing twice (20 and 40 DAP)	19.78a	86.4	*Bhullar et al* (2006 to 2010)
On Onion	Ludhiana	Pendimethalin @0.750 kg/ha Oxyflurofen0.250 kg/ha fb Quizalofop-ethyl0.050 kg/ha	43.93	86.10	*Singh et al.*, (2009) [28]

Carryover effects of residues in soil

Some herbicides have long persistence and may affect the succeeding crop in the rotation. To avoid this, the use is recommended of either mouldboard ploughing or two crossed cultivator passes after the crop harvest to mix the treated and non-treated soil layers and thus dissipate the herbicide residues. Product labels must always be consulted with regard to the planting of sensitive crops following herbicide treatments. In warm and wet climates the residues usually dissipate rapidly, but in all cases caution is necessary. Some examples of recommendations given in product labels are as follows:

Some examples of recommendations given in product labels are as follows:

Napropamide:	After a period of two months, and after tillage, it is possible to sow peas, green beans, faba beans, cereals, fodder grass, sugar beet and flax.
Metribuzin:	After a period of three months and after tillage, it is possible to sow several crops, except cucurbits, crucifers, lettuce, strawberry, sunflower, peas, beet and tobacco.
Trifluralin:	After tillage it is possible to sow: peas, French beans, faba beans, cole, lentils, artichoke, potato, barley, sunflower, alfalfa, clover and carrots. Spinach, beet, oats, maize and sorghum should not be sown before a period of 12 months.

Mechanical method

Mechanical removal of weeds is both time consuming and labor-intensive but is one of the most effective methods. Mechanical weed management starts with seedbed preparation. Moldboard plowing is usually the first step in mechanically managing weeds. It is particularly useful in controlling emerged annual weeds. An important second step is often rotary hoeing for mechanically managing weeds in large-seeded vegetable crops (sweet corn, snap beans and peas). Rotary hoeing needs to be done after the weeds germinate but before they emerge; it controls only small-seeded weeds. Once the crops have emerged or transplants are established, a row cultivator may be used to manage emerged weeds. Adjust the cultivator sweeps or teeth to dislodge or cover as many weed seedlings as possible. Seedling weeds can be killed by cultivating 1-2 inches deep. The best weed control is obtained with a row cultivator in relatively dry soils by throwing soil into the crop row to cover small weed

seedlings. Avoid crop injury from poor cultivation, which reduces crop yields. Relying entirely on mechanical practices to manage weeds is difficult on large acreages. Also, several weeds especially perennials, are extremely difficult to manage unless herbicides are combined with nonchemical approaches. The tillage operations for seed bed preparation should be planned keeping in view with the type of weeds present in the field. When annual weeds are predominant (crucifers, solanaceous, grass weeds) the objectives are unearthing and fragmentation. This must be achieved through shallow cultivation. If weeds have no dormant seeds (*Bromus* spp.), deep ploughing to bury the seeds will be advisable. If the seeds produced are dormant, this is not a good practice, because they will be viable again when they return to the soil surface after further cultivation. When perennial weeds are present, adequate tools will dependon the types of rooting. Pivot roots (*Rumex* spp.) or bourgeon roots (Cirsium spp.) require fragmentation and this can be achieved by using a cultivator. Fragile rhizomes (*Sorghum halepense*) require dragging and exposure at the soil surface for their depletion, but flexible rhizomes (*Cynodon dactylon*) require dragging and removal from the field. This can be done with a cultivator or harrow. Tubers (*Cyperus rotundus*) or bulbs (*Oxalis* spp.) require cutting when rhizomes are present and need to be dugup for exposure to adverse conditions (frost or drought). This can be done with the mouldboard or disk ploughing. Chisel ploughing is useful for draining wet fields and reducing the infestation of deep-rooted hygrophilous perennials (Phragmites, Equisetum, Juncus). This is why reliable weed information is always necessary.

Chemical method: Herbicides offer a great scope for minimizing the cost of weed control irrespective of the situation and offer a good weed control alternative to cultural or mechanical methods in horticultural crops. Chemical control, however, is relatively poorly developed in vegetable crops as they tend to be grown in relatively small areas, hence making use of herbicides expensive and uneconomical. With this method, less labour is required; this allows the transfer of labour to other activities. Usage of preemergence herbicides assumes greater importance in view of their effectiveness from the initial stages of crop growth, which is the most critical period of weed competition. The weeds emerging later also compete with the crop and reduce its productivity and need for post-emergence herbicides or other non-chemical approaches described above. However, the herbicides alone could not provide long term control of a wide range of weed flora present in a field. This necessitates the use of an integrated approach for long term control of weeds in vegetable crops. Several herbicides are often labeled for a crop. Scouting in your area to determine which weeds are present can allow you to select the herbicide that can give you the best control. Potential environmental hazards must be considered when selecting a herbicide.

Table 3: Effect of different weed management practices on yield and Weed control efficiency (%) in Flowers

Name of the crop	Location	Treatment	Yield (kg/ha)	Weed control efficiency (%)	References
Marigold	SKUAST Jammu, Chatha	Two hand weeding (20, 40 DAT)	29140	56.48	*Kumar et al.*, (2013) [13]
Marigold	Iraq	Black plastic mulch	905	59.09	Abass *et al.*, (2014)

Review of literature

The experimental study was conducted by Sharma *et al*., (2009) [26] comparative efficacy of pendimethaline and oxyflourfen for controlling weeds in onion (*Allium cepa* L.) nursery at Punjab Agricultural University Regional Station, Bathinda to evaluate the effect of different weed control treatments on germination, growth of onion seedlings and weed spectrum in onion nursery. All the treatments reduced weed growth significantly over the unweeded control except plastic mulching and oxyfluorfen at 0.062 kg/ha. Pendimethalin at all the three levels significantly reduced weed population but adversely affected the germination of onion seedlings. The most adverse effect of pendimethalin was observed at 1.0 kg/ha. However, partial control of weed was observed in case of oxyfluorfen. There was significant reduction in weight of 100 seedlings at all the oxyflourfen levels. So, pendimethalin at 0.5 kg/ha and oxyfluorfen at 0.125 kg/ha can be used for better weed control and higher seedling production in onion nursery.

A field experiment was conducted by Kalhapure *et al.*, (2014) [7] at Mahatma Phule Krishi Vidyapeeth, Rahuri, Maharashtra, in India to find out most suitable and efficient combination of different pre-plant and post-emergence herbicides to control weeds in onion seed production crop. Experiment was conducted in randomized block design with 9 treatments and three replications consisting of pre-plant application of pendimethalin, post-emergence application of oxyfluorfen and quizalofopethyl and their different combinations. The pre-plant application of pendimethalin 0.750 kg/ha followed by post-emergence application of oxyfluorfen 0.250 kg/ha mixed with quizalofop-ethyl 0.050 kg/ha resulted in effective control of various broad-leaf and grassy-weeds and recorded lower weed density, weed biomass, weed index and higher weed control efficiency. This treatment also produced higher number seed weight per umbel, 1000 seed weight, and diameter of umbel. It also produced higher seed yield (439.30 kg/ha).

A field experiment was conducted by Makhan *et al.,* (2015) [18] during the rainy (*kharif*) seasons of 2007, 2008 and 2009 to find out the relative efficiency of weed management practices in Okra (*Hibicus esculentus* L.). The result indicated that the highest weed control efficiency was achieved with the treatments fluchloralin 1.0 kg/ha preplant application+1HW followed by alachlor 2.0 kg/ha pre-emergence - application + 1HW. The data on yield attributing charaters *viz*, number of pods/ plant and plant height were significantly influenced by various weed management treatments. The highest fresh pod yield was recorded with the application of fluchloralin 1.0 kg/ha preplant application supplemented with 1HW. Significantly lowest fresh pod yield of okra was recorded in weedy check.

An experiment was carried out by Shalini and Patil (2006) at the Floriculture Unit, Division of Horticulture, Main Agricultural Research Station, University of Agricultural Sciences, Dharwad to study the effect of integrated weed management practices in vegetative, reproductive and yield parameters in gerbera (*Gerbera jamesonii H. Bolus*). The experiment consisted of seven different pre-emergence herbicides, two mulching materials and cultural practices as weed control treatments and were replicated thrice in

randomised block design. Better results were obtained significantly with different weed management practices. Among the treatments applied pendimethalin @ 1.0 kg a.i. ha-1, B.P (black polyethylene). Sheet treatment and alachlor @ 1.5 kg a.i. ha-1 showed better results with vegetative, reproductive and yield parameters.

A field study was conducted by Kumar *et al*., (2013) [13] at the experimental farm of CSIR-Institute of Himalayan Bioresource Technology, Palampur to assess the effect of different weed control methods *viz.*, chemical, physical and cultural on weed management and growth rate of damask rose (*Rosa damascena* Mill.) nursery. Atrazine @ 1.0 and 2.0 kg/ha and metribuzin @ 0.75 and 1.50 kg/ha were applied as pre emergence in combination with one hand weeding at 4 months after planting. Both the herbicides were effective in reducing the weed population and biomass. Black polythene mulch was quite effective in controlling weeds, improving establishment and growth of nursery plants. Higher weed control efficiency (97.6%) next to weed free treatment was recorded in black polythene mulch as compared to other treatments. Use of black polythene mulch provided higher value of increased yield (19.2 × 105/ha) while net income was higher due to application of atrazine @1.0 kg/ha+ 1 H.W.

A field experiment was carried out by Makhan *et al*., 2015 [18] during *Rabi* season from 2007-2010 at Chatha, Jammu to find out relative efficiency of weed management practices in gladiolus (*Tagets erecta* L.). Result revealed significant enhancement in spike yield with 2 hand weedings at 20 and 40 days after transplanting (6.05 t/ha) and pendimethalin 2 kg/ha + 1 hand weeding (5.79 t/ha), both of which were superior to weedy check (3.25 t/ha). The highest weed control efficiency (78.2%) was also achieved with 2 hand weedings, followed by pendimethalin + hand weding 76.9%). Application of pendimethalin along with hand weeding proved to be economical.

Integrated weed management strategy for specific vegetable crops

Some advanced agricultural areas have developed integrated weed management systems. Some general strategies are summarized here (William *et al.* 2000) [33].

Green beans and peas: Harvested legumes must be free of *Solanum* berries, thistle buds, *Amaranthus* stems, or crucifer pods. Crop rotations, close row spacings, early season weed control and cultivation (except in rocky or clod soils) are combined with herbicides to minimize weed competition and contamination of product. A single post-emergence treatment can suppress weed competition or potential contamination of harvested peas.

Carrots and celery: Carrots suppress weeds when row spacings, population densities, cultivation and application of a single herbicide are combined. Cultivation also prevents sunburnt or green carrots roots by throwing soil over the roots.

Table or red beets: A combination of early season weed control, closely spaced rows, dense population, and cultivation will suppress mid- to late-season weed emergence after the crop canopy develops.

Crucifer and cole crops: Weed suppression in crucifers begins by rotating crops that demand different weed control practices to disrupt weed life cycles. Row spacing and plant density vary both to achieve head size, depending on the market, and in order to suppress weeds. Early-season weed control includes applying a herbicide and/or cultivation (s).

Cucurbit crops: Weed management in cucurbits means planning and integrating several practices. Crop rotations and pre-planting control of susceptible weeds must be carried out. Many growers practise stale seed beds followed by cultivation, except in excessively wet seasons. Row spacings that enhance canopy development and cultivation may be supplemented with a herbicide application within the crop row. Often rye windbreaks are planted between rows and incorporated during the last cultivation.

Leaf crops (lettuce, escarole, spinach): Direct-seeded lettuce requires a couple of cultivations and a hand-thinning or weeding, whereas transplanted lettuce matures in 45 days following one or two cultivations with minor hand-weeding.

Garlic and onion: Garlic requires an almost perfect weed control since it emerges slowly, matures over a period of 10-11 months, and never forms a canopy with its short, vertical leaf arrangement. Growers, therefore, often control all weedy vegetation immediately prior to crop emergence, apply a selective soil-applied herbicide for winter weed control, and additional treatments are carried out during spring, depending on specific weed infestations. In onion, weeds are managed with selective herbicides combined with frequent cultivation. Winter cover crops enhance both soil and weed management.

Tomato and pepper: Weeds can be managed through preparatory tillage and a pre-planting herbicide in transplanted crops. Black plastic mulch can help to reduce the chemical need. Interrow tillage or post-emergence herbicide can control weeds later on. In direct-seeded crops, more intensive chemical treatments will be necessary. Management of *Solanum nigrum* (one of the worst weeds in tomato) should bear in mind the following points:

- chemical control in the previous crops where it is easier; (beet, carrot, celery, spinach);
- that it prevails more in transplanted than in direct-seeded tomatoes;
- stale seed bed before tomato planting is recommendable;
- row application of soil-acting herbicides at planting (pendimethalin, oxifluorfen) integrated by interrow hoeing and/or by split low-dose treatments with metribuzin + rimsulfuron against S. nigrum at very early stages (up to two leaves).

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Conclusion

From the research conducted by different scientist for weed management in vegetables and flowers. It was observed that in vegetable crops, among the chemical control methods, pre-emergence application of pendimethalin shows effective control of weeds followed by oxadiazon and atrazine. Further, weeds in flower crops can be suppressed by integrated approach of weed management i.e. Black plastic mulch, two hand weeding at 20 & 40 days after sowing/transplanting and pre-emergence application of pendimethalin

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