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# Weed management in vegetable and flower crop-based systems

**Makhan S. Bhullar*, Tarundeep Kaur, Simerjeet Kaur and Ramawatar Yadav**
*Department of Agronomy, Punjab Agricultural University, Ludhiana, Punjab 141 004*

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**ABSTRACT**

Vegetable and floricultural crops are major components of the horticultural industry in India. Weed management is an important aspect in the successful production of these crops. Weeds reduce crop yields, 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.

**Key words:** Critical period, Herbicides, Mulch, Solarisation, Weed competition

Vegetable and floricultural crops are important among horticultural crops in India. 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 (Njoroge 1999). 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 (Roberts 1976). 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 (Njoroge 1999). 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.

## 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, 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 (Leela 1987, 1993, Sandhu *et al.* 2002, Kumar *et al.* 2001, Ahuja *et al.* 1999, Singh and Bhan 1999, Kaur *et al.* 2015). 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). Removal of such a weed has been found to reduce the incidence of this pest on potatoes (Gogoi *et al.* 1997). Weeds also carry pests over season to season. Some weeds exert allelopathic effects on some crops. For an example, *Centrosema* spp. has allelopathic effect on banana and plantain (Okezie 2000). 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).

***Corresponding author:** bhullarms@pau.edu

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 (Labrada 1996) 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 direct-seeded 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 (Table 1). 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, direct-seeded pepper must be weeded during the first four months after emergence to prevent the same loss (Medina 1995). 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 life-cycles. Weeds can be categorised by their life-cycles and management strategies developed accordingly (Nwafor *et al.* 2010). 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 (Njoroge 1999). Because perennial weeds are difficult to manage in vegetables, it is better not to use a field with severe perennial weed problems. A detailed list of annual and perennial weeds infesting different vegetable and flower crops during different growing seasons are presented (Tables 2 and 3).

**Table 1. Critical weed-free period for some vegetable crops**

| Crop | Critical weed-free Period |
|---|---|
| Beet | 2-4 weeks after emergence |
| Cabbage, early | 3 weeks after planting |
| Carrot | 3-6 weeks after emergence |
| Cucumber, pickling | 4 weeks after seeding |
| Lettuce | 3 weeks after planting |
| Onion | The whole season |
| Potato | 15-45 days after planting |
| Squash | Early plantings compete better |
| Tomato transplanted | 6 weeks after transplanting |
| Tomato seeded | 9 weeks after seeding |
| Chilli | 30-45 days after transplanting |
| Pea | 30-60 days after planting |
| Turmeric | 60-150 days after planting |

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 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) (García-Torres 1993). 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. Major problems in vegetables are caused

**Table 2. Commonly infested annual weeds of vegetable and flower crops in India**

| Weed | Grass | Broad-leaf |
|---|---|---|
| *Summer annuals* | | |
| *Setaria verticillata* | X | |
| *Dactyloctenium aegyptium* | X | |
| *Eleucine indica* | X | |
| *Digitaria sanguinalis* | X | |
| *Echinochloa colona* | X | |
| *Trianthema portulacastrum* | | X |
| *Cucumis callosus* | | X |
| *Amaranthus viridis* | | X |
| *Digera arvensis* | | X |
| *Euphorbia microphylla* | | X |
| *Phyllanthus niruri* | | X |
| *Portulaca oleracea* | | X |
| *Commelina benghalensis* | X | |
| *Cannabis sativa* | | X |
| *Setaria verticillata* | | X |
| *Winter annuals* | | |
| *Phalaris minor* | X | |
| *Avena ludoviciana* | X | |
| *Lolium temulentum* | X | |
| *Polypogen monspeliensis* | X | |
| *Poa annua* | X | |
| *Sonchus arvensis* | | X |
| *Rumex dentatus* | | X |
| *Euphorbia simplex* | | X |
| *Chenopodium album* | | X |
| *Melilotus alba* | | X |
| *Stellaria media* | | X |
| *Coronopus didymus* | | X |
| *Malva parviflora* | | X |

**Table 3. Commonly infested perennial weeds of vegetables and flower crops in India**

| Weed | Grass | Broad-leaf | Sedge |
|---|---|---|---|
| *Summer perennials* | | | |
| *Sorghum halepense* | X | | |
| *Cynodon dactylon* | X | | |
| *Cyperus rotundus* | | | X |
| *Parthenium hysterophorus* | | X | |
| *Winter perennials* | | | |
| *Convolvulus arvensis* | | X | |
| *Cuscuta reflexa* | | X | |
| *Cuscuta chinensis* | | X | |
| *Orobanche aegyptiaca* | | X | |
| *Cirsium arvense* | | X | |

by broad-leaf weeds because grass weeds are much better managed in rotation or they can be successfully eliminated with the use of selective foliar-applied herbicides. The choice of control method depends on environmental concerns, marketing opportunities, desired management intensity, labor availability, weed pressure, and the crop.

## 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 (Masiunas 2000).

### Non-chemical methods

Weed management should start with non-chemical 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).

**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. 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'. At planting, the dust mulch is pushed away and large-seeded 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.

**Planting time:** The crop planted at the right time showed more competitiveness towards weeds than late planted crop. Crops may be divided into warm- and 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 (Nogueroles and Zaragoza 1999). 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). 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). 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.

**Solarisation:** 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 (Kumar *et al.* 1993). 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.

**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 non-chemical 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 pre-emergence 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 (Bhutani *et al.* 1978). 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. Herbicide labels contain information on these hazards. The details of herbicides commonly used for weed control in vegetable crops (Table 4 ) and in flower corps are listed (Table 5). If an user is not familar with the use of herbicdes, it requires preliminary tests to verify its effectiveness in local conditions and selectivity to available crop cultivars.

**Good practices during the use of herbicides**

- A summary of a ‘decalogue’ of good practices in the use of herbicides in extensive vegetable crops (Zaragoza 2001) is provided below:
- Periodically inspect the fields and assess the weed of importance. Identify correctly the major weeds.
- The weed and crop stage of growth must be taken into account.
- Careful selection of the product and dosage, bearing in mind points one and two.
- Read the product label and follow the recommendations.
- Avoid adverse conditions at the time off application: wind, temperatures, rainfall. Do not delay treatment.
- Quality of the spraying is obtained by the correct calculation of dosage (surface to be treated must be well measured) and by the spraying equipment, which must be calibrated and in good condition (especially nozzles).
- Band or patch application to save herbicide and reduce residues.
- Keep to the environmental norms: avoid spills, drift, respect the edges, water ways, and sensitive areas. Rinse all empty cans or containers thrice and do not re-use them.
- To avoid propagation of resistant species, the same herbicide or herbicides with the same mode of action must not be used repeatedly.

**Table 4. List of herbicides for use in vegetable crops**

| Crop | Herbicide | Dose (kg/ha) | Time of application | Reference |
|---|---|---|---|---|
| Garlic | Pendimethalin | 0.75-1.25 | PRE | Madan*et al.* (1994), Suresh *et al.* (2013), Singh *et al.* (2002a), Anonymous (2009, 2015) |
| | Oxyfluorfen | 0.125-0.240 | PRI/Early POST | Madan*et al.* (1994), Suresh *et al.* (2013), Ramani and Khanpare (2010), Anonymous (2009, 2015) |
| | Metolachlor | 1.500 | PRE | Madan *et al.* (1994), Suresh *et al.* (2013), Kumar *et al.* (2013) |
| | Oxadiazon | 1.5 | PRE | Vermani *et al.* (2001), Singh *et al.* (2002a) |
| | Fluchloralin *fb* Oxadiazon/ Quizalofop-ethyl | 0.95 *fb* 1.0/0.05 | PPI *fb* POST | Sharma *et al.* (1983), Sampat *et al.* (2014) |
| | Oxadiargyl | 0.090- 0.667 | PRE/Early-POST/ POST | Ramani and Khanpare (2010), Anonymous (2009) |
| | Fenoxaprop-P-ethyl | 0.075 | POST | Ramani and Khanpare (2010) |
| Root crops (Carrot, Radish) | Trifluralin | 0.9-1.5 | PRE | Jadhao *et al.* (1999), Singh *et al.* (2009), Kumar *et al.* (2001) |
| | Pendimethalin | 0.75-1.87 | PPI/PRE | Sandhu *et al.* (2002), Singh *et al.* (2009), Sharma (2000), Reddy *et al.* (2002) |
| | Alachlor | 1.25-2.5 | PRE | Channappagoudar *et al.* (2007b), Singh Bakshish *et al.* (2009), Leela (1987, 1993), Reddy *et al.* (2002) |
| | Oxyfluorfen | 0.147-1.0 | PRE | Singh *et al.* (2009), Leela (1993) |
| | Butachlor | 1.0 – 2.0 | PRE | Leela 1987, (1993), Channappagoudar *et al.* (2008) |
| | Metolachlor | 2.0 | PRE | Sharma (2000) |
| | Sethoxydim | 0.8 | POST | Reddy *et al.* (2002) |
| | Fluazifop-butyl | 0.75 | POST | Leela (1987) |
| Potato | Isoproturon | 0.94 | PRE | Anonymous (2009, 2015) |
| | Alachlor | 2.5 | PRE | |
| | Alachlor + Atrazine | 1.25+0.125 | PRE | |
| | Paraquat | 0.25 – 0.375 | at 5-10% of crop emergence | |
| | Metribuzin | 0.250 -0.750 | PRE | Channappagoudar *et al.* (2007a), Anonymous (2009, 2015) |
| | Atrazine | 0.35-1.0 | PRE | Bhullar *et al.* (2015), Anonymous (2015) |
| | Pendimethalin | 0.75-1.5 | PRE | Shekhawat and Maliwal (1991), Patel *et al.* (1995), Anonymous (2015) |
| | Diuron | 1.0 | PRE | Channappagoudar *et al.* (2007b) |
| Brinjal | Oxyfluorfen | 0.10-0.15 | PRE | Singh (2014), Reddy *et al.* (2000) |
| | Butachlor | 1.0 | PRE | Reddy *et al.* (2000), Bangi *et al.* (2014) |
| | Pendimethalin | 1.0-1.5 | PRE | Reddy *et al.* (2000), Kunti *et al.* (2012), Anonymous (2009) |
| | Metolachlor | 1.0 | PRE | Reddy *et al.* (2000) |
| | Alachlor | 1.0 | PRE | |
| | Oxadiazon | 1.25 | PRE | Nandal and Pandit (1988) |
| | Quizalofop | 0.040 | POST | Meena *et al.* (2006) |
| Cabbage | Pendimethalin | 0.75-2 | PRE | Noonia *et al.*(1992), Kaur *et al.* (2015) |
| | Sethoxydim | 1.5 | POST | Singh and Tripathi (1988) |
| | Alachlor | 1.0 | PRE | Nandal *et al.* (2005), Dhiman *et al.* (2005) |
| | Oxadiazon | 1.0 | PRE | Nandal *et al.* (2005), Dhiman *et al.* (2005) |
| | Oxyfluorfen | 0.09-0.234 | PPI/PRE | Nandanwar *et al.* (2006), Kaur *et al.* (2015), Kaur (2012) |
| | Trifluralin | 0.90 | PRE | Kaur (2012) |
| Cauliflower | Fluchloralin | 0.84-1.5 | PPI | Porwal and Singh (1993), Anonymous (2015) |
| | Alachlor | 2.0 | PRE | Govindra *et al.* (1983) |
| | Pendimethalin | 0.50-1.0 | PPI/PRE | Anonymous (2009, 2015) |
| **Broccoli** | Pendimethalin | 0.50-1.0 | PPI/PRI | |
| Onion | Pendimethalin *fb* Oxyfluorfen + Quizalofop-ethyl | 0.750-1.5 *fb* 0.12-0.85+0.037-0.050 | PPI *fb* POST | Kalhapure *et al.* (2013, 2014), Ved Parkash *et al.* (2000), Bhat and Bhushan (2005), Sardhar and Guggari (2015), Anonymous (2009, 2015) |
| | Alachlor | 2.0 | PRE | VedParkash *et al.* (2000) |
| | Fluchloralin | 1.12 | PPI | Bhat and Bhushan (2005) |
| | Metolachlor | 1.0 | PRE | Shekar *et al.* (2002) |
| | Oxadiargyl | 0.667 | PRE | Anonymous (2009) |
| Transplanted onion | Oxyflourfen | 0.12 | PRE | Shekar *et al.* (2002) |
| | Metolachlor | 1.0 | PRE | |
| | Pendimethalin | 1.0 | PRE | |
| Onion nursery | Pendimethalin | 0.5 | PRE | Sharma *et al.* (2009) |
| | Oxyfluorfen | 0.125 | PRE | |
| Chilli | Pendimethalin | 0.75-3.0 | PPI/PRE | Mukund *et al.* (1995), Kaur (2002), Patel *et al.* (2004), Anonymous (2009, 2014), Prakash *et al.* (1999) |
| | Fluchloralin | 1.0 | PRE | Singh *et al.* (1985), Anonymous (2014) |
| | Oxyfluorfen | 0.10-1.25 | PRE | Kumar and Thakral (1993), Kumar *et al.* (1995), Shaikh *et al.* (2005) |
| | Alachlor | 3.0 | PRE | Prakash *et al.* (1999) |
| | Oxadiazon | 1.0 | PRE | Singh *et al.* (1985), Anonymous (2014) |
| Bell pepper | Pendimethalin + Oxyfluorfen | 1.00 + 0.15 | PPI | Singh *et al.* (1991, 1992) |

| Crop | Herbicide | Dose (kg/ha) | Time of application | References |
|---|---|---|---|---|
| Chilli (seeded) | Pendimethalin | 1.0 | PRE | Agasimani and Channappagoudar (2005) |
| | Oxadiargyl | 0.09 | PRE | |
| Tomato | Pendimethalin | 0.56-1.0 | PRE- transplant | Sandhu *et al.* (1993) |
| | Metribuzin | 0.37- 0.525 | PRE- transplant | Rana and Barevadia (1995) |
| | Isoproturon | 0.62- 1.25 | PRE- transplant | Anonymous (2009, 2014) |
| | Sulfosulfuron | 0.75 | PRE | Dinesha*et al.* (2012) |
| Chilli + Coriander | Pendimethalin | 1.0 | PRE | Muthusankaranarayanan *et al.* 1997 Parkash *et al.* (1999) |
| Peas | Pendimethalin | 1.20-1.50 | PRE | Rana 2002; Anonymous (2009) |
| | Imazethapyr | 0.15-1.5 | POST | Singh *et al.* (2014), Rana *et al.* (2013) |
| | Quizalofop-ethyl | 0.050 | POST | Singh *et al.* (2014) |
| | Trifluralin | 0.75 | PPI | Banga *et al.* (1998). Anonymous (2015) |
| Okra | Pendimethalin | 0.50-0.75 | PRE | Anonymous (2015) |
| | Alachlor | 2.5 | PRE | |
| | Metolachlor | 0.75 | PRE | Anonymous (2014) |
| | Oxyflourfen | 0.15 | PRE | |
| Coriander | Pendimethalin | 1.0 | PRE | Anonymous (2009) |
| Turmeric | Pendimethalin | 0.975 | PRE | Kaur *et al.* (2008) |
| | Metribuzin | 0.70 | PRE | Anonymous (2015) |
| | Atrazine | 0.75 | PRE | |

PP- Pre-plant incorporation; PRE- Pre-emergence; POST- Post-emergence; *fb*- followed by. The above herbicides, especially at their lower doses, should be integrated with hand weeding to remove the weeds escaped/emerged after the application of herbicides.

**Table 5. List of herbicides for use in flower crops**

| Crop | Herbicide | Dose (kg/ha) | Time of application | Reference |
|---|---|---|---|---|
| Gladliolus | Oxyfluorfen | 0.25 | PRE | Manuja *et al.* (2005) |
| | Alachlor | 1.0 | PRE | Manuja *et al.* (2005) |
| | Atrazine | 1-2 | PRE | Chahal *et al.* (1994) |
| | Pendimethalin | 0.75-1.0 | PRE | Bhat and Sheikh (2015) |
| | Metribuzin | 0.5 | PRE | Rao *et al.* (2014) |
| | Butachlor | 1.5 | PRE | Rao *et al.* (2014) |
| | Pendimethalin + Metribuzin | 0.75+0.3 | PRE | Jankiram*et al.* (2014) |
| | Oxyfluorfen | 0.5 | PPI | Yadav and Bose (1987) |
| | Glyphosate | 1.0 | POST-directed | Manuja *et al.* (2005) |
| Gerbera | Pendimethalin | 1.0 | PRE | Shalini and Patil (2006) |
| | Alachlor | 1.5 | PRE | Shalini and Patil (2006) |
| Rose | Diuron | 2-2.5 | PRE | Yaduraju *et al.* (1997), Rajamani *et al.* (1992) |
| | Glyphosate | 0.5 | POST-directed | Rajamani*et al.* (1992) |
| | Oxyfluorfen | 1.0 | PRE | Rajamani (1992) |
| | Atrazine | 1.0-2.0 | PRE | Kumar and Singh (2013) |
| | Metribuzin | 0.75-1.50 | PRE | Kumar and Singh (2013) |
| China aster | Oxyfluorfen | 0.1 | PRE | Kumar and Gowda (2010) |
| | Metolachlor | 1.0 | PRE | Kumar and Gowda (2010) |
| Marigold | Trifluralin | 1.0 | PPI | Kumar *et al.* (2010) |
| Tuberose | Metolachlor | 2.0 | PRE | Murthy and Gowda (1993) |
| | Pendimethalin | 1.25 | PRE | Murthy and Gowda 1993 |
| Winter annuals | Pendimethalin | 0.50 | PRE | Badhesha (2003) |
| *(Helichrysum-bracteatum, Coreopsis lanceolata Chrysanthemum carinatum)* | | | | |

PP- Pre-plant incorporation; PRE- Pre-emergence; POST- Post-emergence

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