www.ThePharmaJournal.com

The Pharma Innovation

ISSN (E): 2277- 7695
ISSN (P): 2349-8242
NAAS Rating: 5.23
TPI 2022; 11(3): 633-641

www.thepharmajournal.com
Received: 18-01-2022
Accepted: 28-02-2022

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Promising cultural weed management practices to limit crop-weed competition in Peas (*Pisum sativum* L.) in the North-western Himalayan Region

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Abstract
Garden pea is an important offseason vegetable, which is widely grown as cash crop during winter and summer in north-west Himalayan region. Among the several factors responsible for low yield of winter legumes, competition due to weeds is the important one. Uncontrolled weed growth in pea has been reported to cause yield reductions from 37.3 to 64.4%. Slow initial growth, wider spacing and fairly good application of FYM along with inorganic fertilizers provide congenial environment for weeds. The dominant weed species in pea crop were *Stellaria media*, *Phalaris minor*, *Vicia sativa*, *Tulipa asiatica*, *Vicia hirsuta*, *Avena ludoviciana*, *Poa annua* and *Anagallis arvensis.* Since environmental protection is a global concern, the age-old agronomic manipulations, *viz.* tillage and inter-cultivation, inter cropping, mulching, cover crops, crop rotation, higher seed rate or plant populations, planting at closer spacing, nutrient management, planting methods, and other agro-techniques are used for weed management. Therefore, a review based on cultural weed management practices in organically managed pea was done.

Keywords: Pea, weeds, weed management practices, crop-weed competition

1. Introduction

In Himachal Pradesh 70-75% area is rainfed. Maize - wheat is the major cropping system in these areas. The system is over exploitative of resources. Thus some remunerative crops like pea can be grown as an alternative to wheat in the system. Pea is cultivated in 23.65 thousand ha area with production of 277.2 thousand MT (Horticulture Statistics at a Glance, 2017, Horticulture Statistics Division, Ministry of Agriculture and Farmers Welfare, GOI). However, cultivation is limited to garden peas only with no cultivation of field peas. The main problem in its production is the occurrence of weeds which interfere with the crop and cause huge losses in yield. Of the total losses caused by pests, weeds have a major share (30%). In India, weeds, generally, reduce crop yields by 36.5% during rainy-season and 22.7% during winter, and in some cases, cause complete crop failure. The battle against weeds is never ending and often the costliest agronomic input for successful crop production. Concern about potential increases in weed populations without the use of herbicides has limited the uptake of organic farming. However, as both public demands for organic produce and the profile of organic farming have increased in recent years, so too has the range of weed control options. Thus, a dire need was felt to discover the agronomic manipulations for weed management which are environmentally safe. Progress in cultural methods of weed control has included the use of novel weed-suppressing cover crops and the identification of specific crop traits for weed suppression. Direct weed control has also seen developments, with new implements appearing on the market that could benefit in the future from sophisticated machine guidance and weed detection technology. Many weed control operations in organic systems present the grower with conflicts and both these and many of the most recent developments in organic weed control are reviewed (Bond *et al.* http://www.organicweeds.org.uk). An increase in our understanding of weed biology and population dynamics underpins long-term improvements in sustainable weed control. Emphasis is required to be given for flexibility and a combination of weed biology knowledge, cultural methods and direct weed control to maintain weed populations at manageable levels. Further, since environmental protection is a global concern, the age-old agronomic manipulations, *viz.* tillage and inter-cultivation, inter cropping, mulching, cover crops, crop rotation, higher seed rate or plant populations, planting at closer spacing, nutrient management, planting methods, and other agro-techniques are used for weed management.

Stale seed bed in which one or two flushes of weeds are destroyed before sowing of the crop reduces weed seeds bank (Sindhu *et al.* 2010) [53] and its emergence (Singh *et al.* 2012) [59] in the crop and thus delays early crop-weed competition. Raising of the stale seed beds to their in-ground counterparts have an added advantage of quicker heating up and improved drainage for plants' roots. Using the lean period between the two crops by way of cultivation of short duration crops not only gives additional income but minimizes weed infestations due to extensive ground cover. However, intensive agriculture, because of its high potential has to be developed in resource-rich areas. Therefore, the present review on cultural weed management practices in organically managed pea was done.

2. Crop-weed competition

Crop-weed competition indicates the contest between crops and weeds in agro-ecosystems for their survival, existence and superiority in response to limited resources. If resources are plentiful there is no question of competition. The weeds compete with crop plants for space, moisture, light, carbon dioxide and take away a major share of native and applied plant nutrients that otherwise would have been utilized by the crop plants. It is well established that losses caused by weeds exceeds the losses from any other category of agricultural pests. Therefore, better understanding of crop-weed interactions can provide weed management options that optimize yield while reducing production costs (Mohler and Staver 2001) [39, 40].

Weeds caused 37.3 to 64.4 per cent reduction in pea yield (Tewari *et al*., 1997; Banga *et al*.; 1998 and Harker, 2001) [17]. Peas are poor competitors, particularly at the seedling stage, avoiding early season weed interference is thus critical.

2.1 Crop-weed association

Salonen *et al*. (2008) [50] while working on the composition of weed flora of dry pea (*Pisum sativum* L.) fields and cropping practices in 119 conventionally cropped fields and 64 fields under organic cropping in Southwestern Finland, found that average number of weed species per field was 10 under conventional cropping and 18 under organic cropping. Under organic cropping, the age of crop stand and field location, respectively, explained best the variation. Mixed cultivation of pea with cereals was recommended, particularly for organic cropping as it favoured crop competition against weeds. A field experiment at Saskatchewan in Canada was carried out by Alba (2019). He noticed weed species composition in field pea was represented mainly by: green foxtail (*Setaria viridis* L.), wild mustard (*Sinapis arversis* L.), common lambsquarters (*Chenopodium album* L.), redroot pigweed *(Amaranthus retroflexus* L.) and wild buckwheat (*Polygonum convolvulus* L.). Stinkweed (*Thlapsi arvense* L.), wild oat (*Avena fatua* L.), flixweed (*Descurainia sophia* L.), smartweed (*Polygonum aviculare* L.), annual sowthistle (*Sonchus oleraceus* L.*)* and field horsetail (*Equisetum arvense* L.) were also present in some plots, however, they were less common.

Mathukia *et al*. (2015) [36] found *Asphodelus tenuifolius, Brachiaria, Chenopodium album, Cyperus rotundus, Dactyloctenium aegyptium, Digera arvensis, Euphorbia hirta, Indigofera glandulosa, Leucas aspera, Physalis minima* and *Portulaca oleracea* were the major weeds infesting field pea under clay soils at Junagarh, Gujarat. Singh *et al*. (2010) observed *Melilotus indica* (38%), *Fumaria parviflora* (20%), *Coronopus didymus (*19.5%), *Cyperus rotundus* (12.5%), *Avena ludoviciana* (11.5%), *Anagallis arvensis* (9%), *Convolvulus arvensis* (6.5%) and *Chenopodium album* (6.5%), the predominant weed species at Hisar, Haryana.

Singh (2003) [55], at Ludhiana found that important weeds associated with pea were *Anagalis arvensis, Avena ludoviciana, Chenopodium album, Convolvulus arvensis, Cyperus rotundus, Fumaria parviflora, Galium aparine, Lepidium sativum, Medicago denticulata, Melilotus alba, Phalaris minor, Poa annua, Polygonum, Rumex dentatus, Spergula arvensis, Stellaria media* and *Trigonella polycerata.* The predominant weed species infesting the crop were *Anagallis arvensis* (25%), *Fumaria parviflora* (15%), *Melilotus indica* (12%), *Cynodon dactylon* (11%), *Convolvulence arvensis* (10%), *Avena fatua* (6%), *Vicia sativa* (7%), *Cornopus didymus* (5%), *Trianthema monogyna* (3%) and *Medicago denticulata* (2%) under rainfed subtropical conditions of Kandi belt of Jammu as reported by Kumar *et al.* (2009) [26]. The other weeds were *Euphorbia helioscopia* (1.5%), *Cannabis sativa* (1.5%) and *Chenopodim album* (1%). Mawalia *et al*. (2015) [37] observed that the weed flora was mainly composed of *Phalaris minor*, *Alopecurus myosuroides, Avena ludoviciana, Lolium temulentum and Vicia sativa* in field pea at Palampur. There was also a little infestation of *Stellaria media*, *Poa annua*, *Anagallis arvensis and Coronopus didymus. Phalaris minor*, *Vicia* sp. and *Polygonum alatum* were the major weeds found growing in association with peas (Tehria *et al*. 2014 and 2015) [67, 66]. In the Indian Himalayas Gopinath *et al.* (2008) revealed *Polygonum plebejum* L. (34%*)*, *Melilotus indica* L. (31%) and *Avena ludoviciana Dur*. (17%) the predominant weeds which together constituted 82% of total weed population in garden pea. *Stellaria media* L., *Lolium temulentum* L., *Anagallis arvensis L*., *Salvia anthemifolia* (Juss) Rs. By., *Polypogon fugax Nees*., *Fumaria parviflora Lam.*, *Cynodon dactylon* (Linn) Pers. and *Cyperus rotundus* L. were also observed in low densities.

Das (2016) at Murshidabad, West Bengal found that the experimental field was dominated by natural infestation of broad leaf weed (BLW) like *Anagallis arvensis*, *Chenopodiuln album, Convolvulus arvensis, Fumaria parviflora*, *Melilotus alba, Lathyrus aphaca, Euphorbia hirta, Parthenium hysterophorus, Gnaphalium leuteoalbum, Commelina banghalensis* and grasses like *Echinochloa colona, Cynodon dactylon, Digitaria sanguinalis* and sedges like *Cyperus rotundus*. Kumar *et al.* (2019) at Varanasi found that field pea was dominated by narrow leaved weeds which constituted 37.6 percent weeds such as *Cyperus rotundus L.*(14.1%) and *Parthenium hysterophorus* L.(23.5%). Whereas, broad leaved weed species *Melilotus alba* (7.0%), *Solanum nigrum L*. (11.8%), *Chenopodium album L*.(35.3%), *Anagallis arvensis L*.(5.9%) and *Vicia sativa L*.(2.4%) accounted for 72.4 percent of weed of total weed species.

Thus, from the above cited literature, it can be concluded that the weed flora in pea were diverse with *Stellaria media*, *Vicia sativa, Phalaris minor, Anagallis arvensis, Trianthema portulacastrum and Digera arvensis* being predominant in peas throughout the world.

2.1.2 Critical period

It is important to have understanding about the critical period of weed competition (CPWC) so that weed control measures can be targeted during this window to avoid weed competition as part of overall weed management strategy. The weed emergence timing and duration of weed competition has significant effect on crop yield. A few days of early growth by crop relative to weeds give competitive advantage in favour of crop over weeds (Mohler 2001) [39, 40]. Therefore, it is important to identify the critical period of weed control. The CPWC is defined as the critical window during which weed competition with crop is maximum and thus they must be kept under check to avoid yield losses.

In field pea, it was found that the presence of weeds during the initial 20 days did not affect pea seed yield (Singh *et al*. 2016) [58]. A similar study by Harker *et al.* (2001) [17] found that the beginning of the CPWC in field pea in Western Canada started 1 or 2 weeks after field pea emergence. Thus, early weed control is critical to avoid yield losses due to weeds. Tripathi *et al*. (2001) [68] reported critical period of weed competition from 15-60 days in tendril pea under tarai of Uttaranchal. This showed that majority of weeds emerged up to 60 DAS. Peas are poor competitors, particularly at the seedling stage, avoiding early season weed interference is critical. Kumar *et al*. (2009) [26] reported the critical period of crop-weed competition between 30-60 days after sowing in field pea under rainfed subtropical conditions of Kandi belt of Jammu. Tripathi *et al.* (2001) [68] found the increase in the density of weeds up to 60 DAS in tendril pea. This showed that the window for CPWC was 20-63 days and 20-70 days after field pea sowing in year 1 and 2, respectively at 5% level of acceptable yield loss (AYL). Singh *et al*. (2010) reported that the predominant weeds such as *Melilotus indica*, *Fumaria parviflora*, *Coronopus didymus*, *Cyperus rotundus*, *Avena ludoviciana*, *Anagallis arvensis*, *Convolvulus arvensis* and *Chenopodium album* increased up to 60 DAS and then, a decreasing trend was observed in season-long weedy treatment. Based on 2 year's study at Hisar, Singh *et al*. (2016) [58] found that the window for critical period of weed competition (CPWC) in field peas was 20-70 DAS at 5% acceptable yield loss (AYL) and 30-53 DAS based on 10% AYL. Therefore, weed control measures should be deployed in such a way that there is minimum crop-weed competition during the window of CPWC. Dry weight of weeds was influenced significantly due to crop-weed competition. In season long weedy check treatment, dry weight of weeds increased upto crop harvest. Dry weight of weeds decreased with the increase in weed-free duration and increased with increase in weedy duration in the crop (Singh *et al.* 2016) [58].

The first flush of weeds emergence is of much significance for crop-weed competition but in the later stages, crop gets the hold on land and emergence pattern greatly affected by irrigation and hoeing. Therefore, in case of pea, the critical period of crop-weed competition was found to be between 30 – 60 DAS.

2.1.3 Economic threshold levels of weeds

An economic threshold (ET), or the "break-even point" is the level of weed infestation at which the cost of weed control is equal to the increase in crop value obtained as a result of controlling the weeds. The ET is a criterion for determining whether or not a treatment against a weed is necessary and economical. It is the density at which the cost of control measures equals the benefits obtained (Hazra *et al*. 2011) [19]. Weed can reduce crop yield provided their densities reach a biological threshold.

Research evaluating potential yield losses in field pea resulting from weed competition has been limited. In Minnesota, 33 wild mustard plants/m^2 reduced pea stand density by 25% and seed yields up to 64% (Nelson and Nylund 1962) [43]. When wild mustard emerged 3 days before peas, vine fresh weight was reduced by 54%, but when the weed emerged 4 days after peas, vine weight was reduced by only 17%. In a similar experiment, comparable stand and yield reductions resulted from 300 foxtail *Setaria viridis* (L.) *Beauv* plants/m^2 (Nelson and Nylund 1962) [43]. These authors concluded that competition between peas and weeds was primarily for light and moisture. Quackgrass *Elytrigia repens* (L.) *Nevski*l also affected the growth and yield of peas, but only at high weed densities (954 kg of rhizomes/ha) (Proctor 1972) [45]. Quackgrass interference reduced seed and vine yieids and accelerated crop maturity (Proctor 1972) [45]. Rana *et al*. (2019) [19] opined that the economic threshold levels i.e. number/m^2 and g/m^2 with the weed management practices studied varied between 2.4 – 19.4 m^{-2} and 5.2-41.2 g/m^2 when determined after Stone and Pedigo (1972) [62] and 1.6 to 9.4 after Uygur and Mennan (1995) [69]. It was indicated that any increase in cost of weed control would lead to higher values of economic threshold, whereas an increase in price of pea crop produce would result in lowering the economic threshold.

While working on ET of nutsedge (*Cyperus rotundus*) in soybean, Das *et al*. (2014) [14] revealed that the natural weed infestation both including and excluding nutsedge and the treatment of 200 nutsedge plants per m^2 caused greater reductions in soybean yields and were the most competitive. The ET of nutsedge in soybean was 19-22 plants/m^2. This nutsedge density caused 9.1-11.5 per cent yield losses. ET of Downy Brome (*Bromus tectorum* L.) in wheat determined by prediction model was 2.6 plants/m^2 (Muhammad *et al*. 2018) [41].

2.2 Effect of weed control methods on weed diversity

2.2.1 Effect of cultural practices

Due to low cost and accessibility, cultural weed management practices, are worldwide widely practiced among organic producers (Mohler 2001) [39, 40]. Cultural methods provide competitive advantage to crop against weeds by reducing weed establishment (Singh 2014) and through selective stimulation, facilitating faster crop growth to smother weeds (Das *et al.* 2012) [10]. Precise knowledge of when and where weeds occur in a field will also facilitate increased efficiencies of cultural techniques. Crop seed rate could be increased or planting pattern altered in dense weed patches to reduce weed competition. Timing or application method of fertilizers could possibly be manipulated according to weed spatial data to reduce weed establishment and competitive ability with the crop. Individual cultural practices for weed suppression are variable due to complex interactions between crops and weeds that are often strongly influenced by environment. Consistency of weed management can be greatly improved by combining several cultural practices. Cultural practices related to rotation design, crop sequencing, no-till, crop residue management, and competitive crop canopies are integrated to reduce weed densities over years. This population management approach has reduced weed community density such that weeds can be controlled with lower herbicide doses (Anderson, 2003) [2].

2.2.1.1 Effect of hoeing/earthing up

It is the conventional method of controlling weeds. It is still a practical and efficient method of eliminating weeds in cropped and non-cropped lands. But it is labour intensive and very costly method. It is very effective against annual and biennial weeds (Sharma *et al.* 2000) [51]. Marshall (1992) [35] reported that hand weeding and use of hand hoes can lower the weed numbers considerably, but the timing and frequency is critical in case of organically managed peas at Berkshire. Bhalerao *et al*. (2011) [6] reported that the maximum value of yield attributes (*viz*., total number of developed pods, hundred pod and hundred kernel, test weight, shelling percentage and volume weight) were observed in weed free treatment followed by two hand weeding and hoeing at 15 and 30 DAS being comparable to pre-emergence pendimethalin followed by one hand weeding at 30 DAS.

From the above literature it can be interpreted that hoeing/hand weeding twice or thrice resulted in better weed control.

2.2.1.2 Effect of mulching

Mulch prevents penetration of light and/or excludes certain wavelengths of light that are needed for the weed seedlings to grow and reducing photosynthesis (Kamara *et al*. 2000) [23]. Mulching also affects the weed emergence by imposing physical hindrance. At Peshawar in Pakistan, Bhakt *et al* (2009) [3] found that hand weeding and newspapers mulch produced better results as compared to the other treatments in edible pea. Maximum number of pods plant^{-1} (50.87, 48.40), number of seed pod^{-1} (5.83, 5.80) and pod yield (2707, 2613 and 2512 kg ha^{-1}) was recorded in hand weeding, newspaper and polyethylene black treatments, respectively, whereas minimum values in these parameters were recorded in weedy check. Anil Kumar (2001) reported that pine (*Pinus roxburghi Sargent*) needles can be effectively utilized for soil moisture conservation and weed control in garden pea in the Garhwal Himalayas of India. Gupta *et al.* (2013) [57] revealed that soil temperature could be increased by 1-2 °C after the application of mulch. The moisture retention for mulch treatments varied from 4.0 to 4.5 cm which was 0.4-0.6 cm higher as compared to no mulch. The dry weight of weeds could be reduced in the range of 50-60 per cent over no mulch treatment.

It can be concluded from above cited literature that due to mulching water holding/moisture retention capacity of soil was improved. Further mulches have a suppressing effect on the weeds with beneficial effects on growth and yield of crop (Baten *et al.* 1995) [5].

2.2.1.3 Effect of Stale Seed Bed/Raised Stale Seed Bed

In stale seedbed technique, after seedbed preparation, the field is irrigated and left unsown to allow weeds to germinate which are killed by carrying out tillage or thermal weed control prior to the sowing. This technique reduces weeds emergence (Singh *et al*. 2012) [59], delaying early crop-weed competition and also reduces weed seeds bank (Sindhu *et al.* 2010) [53].

Stale seed bed and raised stale seed bed was equal to pendimethalin fb hand weeding in controlling *Phalaris minor*, green pea yield (Tehria *et al.* 2014) [67] and stale seedbed and raised stale seedbed were significantly superior to weedy check in reducing total weed dry weight, weed growth rate, NPK depletion by weeds and increasing crop dry matter, crop growth rate (CGR), relative growth rate (RGR), NPK uptake by crop and subsequent radish yield (Tehria *et al*. 2015) [66]. Kumar *et al*. (2003) [29] found that stale seed bed was at par with normal seed bed followed by triallate 1.0 kg/ha (pre-plant incorporation) in decreasing LAI and growth rate of *P. minor* in wheat. NPK depletion by *P. minor* and *Lolium temulentum* was significantly lower in stale seed bed and normal seed bed + triallate 1.0 kg/ha (Kumar *et al*. 2005). However, NPK depletion by *Avena fatua* in normal seed bed + triallate was significantly lower as compared to stale seed bed.

2.2.1.4 Effect of Intercropping

Intercropping refers to growing two or more crops simultaneously (Vandermeer, 1989) [70]. It may involve mixtures of annual crops with other annuals, annuals with perennials, or perennials with perennials. Increasing crop productivity (while simultaneously reducing the risk of total crop failure) and managing weeds are the major objectives of intercropping systems (Liebman and Dyck, 1993) [33]. Indeed, the second crop in some intercropping systems is grown for the sole purpose of weed management. Intercrops may inhibit weeds by limiting resource capture by weeds or through allelopathic interactions (Liebman and Dyck, 1993). Intercropping results in spatial diversification of crops that may aid in competitive interactions with weeds. Studies have reported that intercrops often shade weeds to a greater extent compared with sole crops (Liebman and Dyck, 1993) [33]. Crop competitive ability for nutrients and water can also be greater in intercrop than in monoculture systems (Hauggaard-Nielsen *et al*., 2001) [18]. Liebman and Dyck (1993) [33] reviewed the literature and found that weed biomass was reduced in 90% of the cases when a main crop was intercropped with a ‘smother’ crop. When two or more main crops were intercropped, weed biomass was lower than in all component individual crops in 50% of the cases, intermediate between component individual crops in 42% of the cases, and higher than all individual crops in 8% of the cases.

There is increasing interest in intercropping of field crops in North America. Wheat–lentil, wheat–canola, wheat– canola–pea and barley–medic (Medicago spp.) intercrops have shown potential to reduce herbicide use while maintaining adequate levels of weed management (Carr *et al*., 1995; Szumigalski and Van Acker, 2006) [64]. Weed management in non-competitive vegetable crops may be improved with intercropping. Wheat–lentil, wheat–canola, wheat– canola–pea and barley–medic (Medicago sp.) intercrops have shown potential to reduce herbicide use while maintaining adequate levels of weed management (Carr *et al*., 1995; Szumigalski and Van Acker, 2006) [64].

Several researchers have reported that more crop cover and high plant density of intercropping caused severe competition with weeds and reduced the weed biomass (Guleria and Singh 1979). A study by Singh *et al*. (2016) [58] on companion cropping of field pea, wheat, gram, mustard and berseem for green fodder in the inter-spaces of cane ratoon at the village Niyamatpur Thakuran, Farrukhabad, under Uttar Pradesh revealed that vegetable pea planted for green pods proved to be more remunerative by a margin of 14.25%. They reported that the inter-crops played a complementary role and were helpful for the maximum yield of the main crop. Intercropping especially with the inclusion of legume/cover crops has an important role in weed control. Intercropping within the organic agricultural production has an important role in weed control.

From the above literature it is evident that weed population and weed dry matter were significantly reduced when combined with legumes. It is further improved when combined with hand weeding.

2.2.1.5 Effect of crop rotation

Crop rotation introduces condition and practices that are not favourable for a specific weed species and thus growth and reproduction of that species is hampered. Systems with diverse crops require application of different measures that influence weed community composition. Change in crop production practices like field preparation, sowing method, interculture operations and weed management practices with change in cropping systems affect weed diversity of the system and the individual crops. Inclusion of crops like sorghum, rice, wheat, with strong allelopathic potential, in the existing cropping systems may help in weed management. The chemicals released from the allelopathic crops may suppress the associated weeds. 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) [10], mainly by smothering and allopathic effect (Dwivedi *et al*., 2012) [12]. According to Teasdale *et al*. (2004) [65], growing of wheat, maize and soybeans in rotation tends to decrease the weed seed bank and abundance of broadleaf weeds.

Diverse crop rotations can aid in reducing the weed seed bank. Seeds in soil can germinate, die of natural causes, or be consumed by fauna or microorganisms; consequently, the number of live seeds in soil declines with time (Anderson, 2003) [2].

2.2.1.6 Effect of intensive cropping

There is a growing need to meet the food grain requirements of the ever-increasing human population and to sustain a reasonably higher productivity level. Hence, there is an urgency to intensify and/or diversify the existing cropping system into new areas like pulses, legumes, oilseeds, fruits and vegetables. In this context, crop diversification and/or intensification shows lot of opportunities in alleviating these problems besides fulfilling the basic needs, regulating farm income, withstanding weather aberrations, conserving natural resources, environmental safety and creating employment opportunities (Hegde *et al.* 2003; Gill and Ahlawat 2006; Singh 2010) [20, 15].

Incorporation of pulse/oilseeds/green manure as a second or third crop in a cropping system maintains the soil fertility and generates additional income to the farmers. Among sixteen different maize based cropping systems, maize - pigeon pea - wheat - green gram recorded higher net return of INR 12573 ha^{-1} and this was due to higher market price of pulses included in the system (Kaore, 2002) [24]. Alireza *et al*. (2008) [1] showed that weed seed densities in organic and integrated cropping systems, of about 5000-6000 seeds/m^2 were higher than conventional and high-input cropping systems showing about 2000 seeds/m^2. They found that different rotations that include crops with different life cycles such as winter wheat-maize and winter wheat-sugar beet could lead to additional benefits of reducing the weed seed bank. Gangwar and Ram (2005) [14] reported that inclusion of legumes and other crops using intensification and interruptive approaches, depending on availability of resources led to significant improvement in productivity and profitability on one hand and soil fertility on the other hand.

2.2.1.7 Effect of soil solarization

Soil solarization involves covering the soil with transparent polyethylene films for 2 6 weeks during hot summer months. It has potential to raise the soil temperature by 60 degree Celcius. Solarization works when the heat created under the plastic film becomes intense enough to kill weed seeds. In Northern India, high soil temperature can develop in soil covered with transparent polyethylene sheets in May-June (Kumar *et al.* 1993) [28]. 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*). In a long-term trial conducted at New Delhi, solarization gave 33 and 52% more yield of soybean over hand weeding and herbicide treatment, respectively. The corresponding increase in the succeeding wheat crop was 10 and 25% (Yaduraju and Ahuja 1996) [71]. Although very efficient, the solarization has not found wider adoption due to high cost involved. However, with repeated use of the same films, the cost can be reduced substantially.

2.2.2 Effect of manual weeding

Mechanical or physical methods of weed control are those in which either some tool or machine is used to reduce the competition by weeds or the weed plants are removed simply by hand pulling. Mechanical methods are intensively used to provide effective control of weeds in areas where labour is cheap and easily available whenever required. The concept of MWC is to ease crop competition with weeds by physical removal of weeds from the cropping system. Among weed control, it may loosen the soil and improve tilth, which occasionally is more important to crop yield than weed control itself (Brandsaetter *et al.* 2012) [8].

Hand weeding twice 30 and 60 days after sowing (DAS) in garden pea is sufficient to achieve pod yield similar to that of plots kept weed-free during entire season (Singh and Angiras 2004) [56]. In field pea, however, one hand weeding at 30 DAS gives comparable yields with that of herbicide application (Mishra and Bhan 1997; Rana 2002) [38, 48]. Rana *et al*. (2004) [46] found hand weeding twice comparable to herbicides and herbicide combinations *viz.* alachlor + pendimathalin and alachlor + isoproturon under Lahaul valley conditions of Himachal Pradesh. Hand weeding twice 30 and 60 DAS was found almost similar to imazethapyr at 80 g/ha early post and at 100 g/ha (40 DAS in influencing green pod yield at Palampur (Rana *et al*. 2019) [47].

From the above literature reviewed it is inferred that two hand weedings/hoeing/mechanical weedings are sufficient for weed control in peas. Although it is labour intensive, still manual eradication of weeds has proved its superiority over all the measures in managing weeds and is quite effective.

2.2.3 Effect of herbicides

Herbicides contribute effectively and profitably to weed control, environmental protection, and at the same time, saving labour necessary for weed control practices, reducing soil erosion, saving energy, increasing maize production and reducing the cost of cereal farming. Therefore, herbicides benefit society as a whole. The importance of herbicides in modern weed management is underscored by the estimates that losses in the agricultural sector would increase to about 500% without the use of herbicides (Bridges 1992) [9].

Johnson and Holm (2010) [21] at Scott, SK found that none of the weed management systems had a significant effect on field pea density. The herbicides were amongst the treatments those had a significant effect on weed density as the application timing was more synchronous with weed emergence than were the tillage treatments. The pre-emergence tillage treatments reduced weed biomass when seeding was delayed until mid-May following weed emergence. Delayed seeding until late May, resulted in 30 to 35% reduction in field pea yield compared with early or mid-May seeding. A strategy for field pea producers who choose not to use herbicides would be to delay seeding until some weeds emerge and seed at a 7.5-cm depth followed by two sequential rod-weeding passes prior to crop emergence. Effective weed control and higher yields of peas with the application of pendimethalin 1-1.5 kg/ha have been reported by various researchers (Sharma and Vats 1988; Chauhan *el al*. 1992; Sekhon *et al*. 1993; Tripathi *et al*. 1993; Singh *et al* 1994). Rana (2002) [48] concluded that pendimethalin at 1.0-1.50 kg/ha significantly increased pods/plant, seeds/pods and yield of pea under Sangla valley conditions of Himachal Pradesh. Use of selective herbicides such as alachlor, pendimethalin and fluchloralin has been reported quite effective against pea weeds (Kumar and Singh, 1994; Banga *et al*., 1998; Negi *et al*., 2001) [4].

Kumar *et al*. (2019) [31] conducted an experiment at Varanasi and observed that sequential application of pendimethalin 1 kg/ha (PE) + imazethapyr 50g/ha (PoE) resulted in significantly highest number of pods, number of grains/pod and seed index over imazethapyr 50g/ha, chlorimuron – ethyl 4g/ha and pendimethalin 1 kg/ha and were at par with the application of pendimethalin 1 kg/ha + imazethayr 75 g/ha, quizalofop ethyl 60 g/ha and imazethapyr 75 g/ha.

2.2.4 Integrated weed, management (IWM)

Weed management differs from weed control or weed eradication wherein weeds are kept under check at a level that they do not cause economic loss from the crop. Instead of depending on one method, say herbicide, cultural or mechanical methods, integration of different methods like mechanical, cultural and use of herbicide at lower level keeps the weeds under check at an economic cost. In Gujarat, Mathukia *et al* (2015) [36] found that depending upon the availability of labour, profitability of *rabi* field pea could be achieved through 2 hand weeding and intercultural operation at 20 and 40 days after sowing. The study also revealed that application of pendimethalin 0.75 kg ha^{-1} or oxyfluoron 0.18 kg ha^{-1} was also suitable. Mawalia *et al*. (2015) [37] at Palampur found that weed free, pendimethalin fb hand weeding, pendimethalin fb imazethapayr + imazanox, imazethapyr + pendimethalin fb imazethapyr and imazethapyr + imazamox 60 g/ha gave more than 85 per cent weed control efficiency upto 60 DAS. Mawalia *et al*. (2016) concluded that pendimethalin 1000 g/ha supplemented with one hand weeding at 45 DAS being statistically at par to the application of pendimethalin fb imazethapyr + imazamox 60 g/ha (post) significantly reduced the density of major weeds in peas.

Khan *et al*.(2003) [25] stated that pod length (9.6 cm), No. of seeds pod^{-1} (6.14) and pod yield (4673 kg ha^{-1}) were the maximum in hand weeding followed by postemergence of application metribuzin treated plots. Jukka *et al*. (2005) [22] and Salonen *et al*. (2005) [50] showed that herbicides decreased number of weed species per field (*Chenopodium album*, *Stellaria media* and *Viola arvensis* and *Elymus repens*).

2.4 Economics of weed control

Weeds should be controlled by least expensive available technology that does not interference with other phases of crop production or other human activities. Any weed control measure should be used only when its results are expected to be more economically beneficial than the results if not using any control measure. Growers compare the cost of the different options of weed control. Therefore, choice of weed control inputs depends not only on their efficacy but also on their cost. Marginal benefits cost ratio and net returns are the best means to assess the economic viability of a particular weed control treatment.

Singh *et al*. (2015) [57] at Lahaul valley recorded highest gross returns (Rs.1,13,320/ha), net returns (Rs.76,294/ha), B:C ratio (3.06) and profitability (Rs.1105.11/ha/day) with pre-emergence pendimethalin 1200 g/ha and the highest cost of cultivation (Rs.63155/ha) was recorded in hand weeding. A study was conducted in the district Shaheed Bhagat Singh Nagar by Mahala *et al.* (2018) [34] revealed advantages in total system productivity and monetary income of crop intensification with the inclusion of a pea crop between successive rice crops instead of a fallow period. Reckling *et al.* (2016) [49] also reported that a cropping system with legumes had higher or equivalent gross margins. Moreover, by including a legume crop soil fertility can be maintained for a longer time. Net return per rupee invested was significantly more (1.48) with pre-emergence pendimethalin @ 1.0 kg a.i. ha^{-1} than hand weeding and no weeding due to lower cost involved under herbicidal treatment (Sinha *et al*. 1999) [61].

The B/C ratio was highest under chemical treatments as compared to manual methods. Hence, chemical treatment is the most economical method of weed control. However, herbicides are not allowed in organic, so the growers need to be compensated by virtue of higher price of the organic produce and providing incentives on purchased inputs if any.

2.5 Energetics of weed control

Energy is the valuable input and in agriculture it is invested in various forms *viz.* mechanical (farm machines, human labour, animal draft), chemical (fertilizer, pesticides, herbicides) and electrical. Ample availability of the right energy and its effective use are prerequisites for improved agricultural production. Crop yields and food supplies are directly linked to energy (Stout 1990) [63]. Increase in the crop yields were mainly due to increase in the commercial energy inputs in addition to improved crop varieties (Faidley 1992) [13].

Prakash *et al.*, (2007) [44] reported that maize (green cobs) + tomato + garden pea + french bean relay intercropping sequence had significantly highest maize equivalent yield (71.3 t/ha) due to fairly good yield of tomato and it got good market price and highest sustainability index (0.91), production efficiency (195.4 kg/day/ha) and economic efficiency (Rs 656/ha/day). Highest system energy output (10,83,760 MJ/ha), system net energy return (10,40,856 MJ/ha) and system energy use efficiency (2,852 MJ/ha/day) was recorded in the same sequence due to inclusion of more number of vegetables in the system and higher system productivity. The lowest maize grain equivalent yield (18.8 t/ha), net returns (Rs 48,020/ha), production efficiency (51.5 kg/day/ha) and economic efficiency (Rs 132/ha/day) were recorded under maize (green cobs) - garden pea sequential cropping.

Shilpha *et al.* (2018) [52] analysed that among six cropping systems, rice-vegetable pea-wheat-greengram was found to be more energy consuming system in all operations followed by rice-wheat, rice-mustard-green gram, maize-vegetable pea-wheat. The higher energy use in rice-veg. pea-wheat greengram was due to high intensity of cropping sequence. However, in two green manuring systems, rice-mustard-greengram and rice-vegetable pea-wheat-greengram, the total input energy use was 43614 MJ/ha and 65052 MJ/ha in which 5546 MJ/ha and 5311 MJ/ha energy was consumed for green manuring crop in greengram as input (grain + crop residue use), respectively.

These foregoing energy research results showed that cropping systems involving more number of crops require more energy and the output energy was also high.

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