International Journal of Chemistry Studies
ISSN: 2581-348X
Impact Factor: RJIF 5.44
www.chemistryjournal.in
Volume 2; Issue 6; November 2018; Page No. 24-38

Weed management in conventional and organic potato production

SP Singh[1], S Rawal[2], VK Dua[3], S Roy[4], MJ Sadaworthy[5], SK Charkrabarti[6]
[1, 4, 5] ICAR, Central Potato Research Station, Gwalior, Madhya Pradesh, India
[2] ICAR, Central Potato Research Institute Campus, Modipuram, Meerut, Uttar Pradesh, India
[3, 6] ICAR, Central Potato Research Institute, Shimla, Himachal Pradesh, India

Abstract
It is widely known that losses caused by weeds have exceeded the losses from any category of agricultural pests such as insects, nematodes, diseases, rodents, etc. The potential crop yield loss without weed control was estimated by 43%, on a global scale. Despite the annual investment of US$ 40 billion for the application of 3 million metric tonnes of pesticides, plus the use of various biological and other non-chemical controls worldwide, global crop losses remain a matter of concern. Concerted efforts were made to implement integrated pest management programmes in principal food and cash crops. As a result of these developments, losses due to insect pests in several agricultural crops have shown a declining trend. Even then during 2007-08, insect pests inflicted a loss of about US$ 21.5 billion in major agricultural crops. Most critical period of crop-weed competition for potato is 25-30 days from planting. Metribuzin, an s-triazine or triazinone, is one of the oldest potato herbicides and is still widely used in potato production. Metribuzin controls a range of broadleaf weed species and suppresses many additional grasses. Resistance to triazine herbicides has developed in 69 species worldwide, limiting activity and requiring a combination of control practices for these weeds. Herbicide Bentazone (Basagran) was found very effective when applied @ 1 litre/ha at 4-6 leaf stage of weeds in potato crop. This herbicide did not show any toxic effect on potato plants. Weeds are considered the biggest problem facing organic farming, where weed control is more expensive compared to synthetic herbicides whose use is prohibited in organic (clean) agriculture. Weed management is the most difficult part of organic crop production and it is the major reason for organic crop yields being 50% lower than conventional yields. Lower yields and higher costs for weed control labor are two of the major reasons that organic produce must be sold with high price premiums. The growers in organic farming should keep these three points in mind: 1) start clean stay clean successful, 2) Prevention is always better than treatment and, 3) One year's seeds will lead to seven year's weed infestation. Successful and sustainable weed management systems are those that employ combinations of techniques rather than relying on one method. The objectives of this paper are to review some safe weed control methods for potato production.

Keywords: weed management, potato production, insects, nematodes, diseases, rodents

Introduction

The potato is a tuber grown underground on a specialized plant part (subterranean stem) known as stolon. Therefore, it is a modified stem in a strict botanical sense. A potato tuber is usually oval to round in shape, although intermediate shapes are also frequently encountered. It consists of an inner flesh and an outer protective cover known as a skin. There is a great variation in flesh colour and skin finish. And these two characteristics broadly, if not completely, determine the consumer preference vis-à-vis acceptability. The eye-shaped depressions on a potato tuber is known as its eyes, and actually these are the dormant buds, which give rise to new shoots under suitable conditions. These white to creamy white or pigmented new shoots are known as sprouts. And that is why the process is known as sprouting. This is a very important process in potato, because a sprouted potato is not acceptable for consumption. But optimum sprouting is a desired attribute when the tubers are used for propagation. The initiation and development of potato in the plant is known as tuberization. A potato plant tuberizes only when two specific environmental conditions are met with. These are short-day photoperiod (daylight) and cool night temperature. As these conditions are only available during winter in sub-tropical Indo-Gangetic plains, the potatoes are grown in this season. And that is why the potato growing conditions in India are entirely different from those in temperate countries of Europe and North America. Nevertheless, temperate potato growing conditions are also available in Indian hills, and there it is cultivated during summer. But this temperate potato production constitutes only about 8-10 % of the total production. In India, therefore, the potato is regarded as a short-duration crop with an average cropping stand of 90-100 days. In contrast to most of the major food crops (cereals) which are propagated through seeds (products of sexual hybridization), a potato plant is propagated through tubers. The tubers meant for propagation are known as seed tubers or seed potatoes. For this mode of propagation does not involve sexual hybridization or process, it is known as asexual or vegetative propagation. This type of propagation has advantages and disadvantages as well. The main advantage is that a good potato clone can be maintained with a high degree of genetic purity. It is often colloquial to call a potato plant as a clone, because it is advanced through the generations by clonal propagation, another term of asexual or vegetative propagation. The disadvantage is that many deadly viruses and seed-borne pathogens are progressively accumulated in the tubers and carried over repeated multiplications resulting in the gradual degeneration of a clone. For this reason, successful potato cultivation and production depend upon the availability of disease-free high-quality seed tubers. This is mostly important in tropical and sub-tropical warm climates as in India where there is an abundance of various vectors, e. g. aphids, mites, thrips, white flies, etc. for virus transmission. As a consequence, the cost of good quality seed potatoes alone accounts for about 40-60 % of the total production cost. In addition to tubers, a potato plant can also be propagated through botanical seeds, which are known as True Potato Seeds (TPS). In areas where seed potato production is not feasible or economic, TPS is an alternative means of propagation. Potato production through TPS can not only reduce the production cost, but also increase the net profit of the farmers. However, TPS technology is presently not full-proof for a large-scale commercial exploitation due to one or other agro-technical as well as techno-economical problems. Since potato is a bulky perishable commodity and its harvest in sub-tropical conditions as in India is followed by high temperatures, it requires to be stored at low temperatures. Therefore, the cost of refrigerated storage also adds up to the total cost of potato production before the produce is available either for consumption or for seed propagation. In addition, the potatoes are cultivated in the vast Indo-Gangetic plains under fully irrigated conditions requiring optimum cultural practices for maximum productivity. These all make the potato crop highly input-intensive for cultivation.

In India potato is cultivated in about 2 million hectares with a total production of a 44.30 million tonnes with productivity of 21.97 t/ha. It is cultivated on a large scale in Uttar Pradesh, West Bengal, Bihar and Punjab. Uttar Pradesh is the largest producer of potato in India. Uttar Pradesh alone produces nearly 43 per cent of India’s total production of potato. Distribution of area and production of potato is different states during 2013-14 are given table.

Table 1: All India Area, production and productivity of potato

Year	Area (In 000 ha)	% of total Veg. Area	Production (in 000 MT)	% of total Veg. Production	Productivity (In MT/ha)
1991-92	1135.1	20.3	18195.0	31.1	16.0
2001-02	1259.5	20.5	24456.1	26.1	19.4
2002-03	1337.2	22.0	23161.4	27.3	17.3
2003-04	1484.7	23.5	27925.8	30.0	`18.8
2004-05	1523.9	22.6	2878.7	28.4	18.9
2005-06	1569.2	21.9	29174.6	26.4	18.6
2006-07	1743.0	23.0	28600.0	24.9	18.4
2007-08	1795.0	22.9	34858.0	27.0	19.3
2008-09	1828.0	22.9	34391.0	26.6	18.8
2009-10	1835.3	23.0	36577.3	27.3	19.9
2010-11	1863.0	21.9	42339.0	28.9	22.7
2011-12	1907.0	21.2	41482.8	26.5	21.8
2012-13	1992.2	21.6	45343.6	28.0	22.8
2013-14	1973.2	21.0	41555.4	25.5	21.1

Indian potato varieties

Concerted breeding efforts of potato varietal improvement programmes at Central Potato Research Institute has led to development of 51 improved potato varieties for cultivation under diverse agro-climatic zones of the country. Presently 23 varieties are under cultivation and occupy nearly 95% of the total potato area in India. Prominent among them are KufriJyoti in the hills and state of West Bengal, Kufri Badshah in Gujarat, Kufri Bahar in Uttar Pradesh and Kufri Pukhraj in plains of India. Varieties for specific problem areas are Kufri Kanchan for Darjeeling hills where wart is a serious problem and Kufri Swarna for Nilgiri hills where cyst nematodes are serious pests. Varieties specifically suitable for processing are Kufri Chipsona-1, Kufri Chipsona-3, Kufri Chipsona-4 for making chips and Kufri Frysona for French Fries. The salient features of some important varieties along with their distinguishing morphological features helpful in their identification are described below. Fast growing varieties which have more canopy are helpful in weed management. Red skin variety Kufri Sindhuri is among one of them.

Crop loss due to pests

Global Scenario: It is estimated that food plants of the world are damaged by more than 10,000 species of insects, 30,000 species of weeds, 100,000 diseases (caused by fungi, viruses, bacteria and other microorganisms) and 1000 species of nematodes (Dhaliwal *et al*., 2007) [13]. However, less than 10% of the total identified pest species are generally considered major pests. Herbivorous insects are said to be responsible for destroying one-fifth of the world’s total crop production annually. Despite the annual investment of US$ 40 billion for the application of 3 million metric tonnes of pesticides, plus the use of various biological and other non-chemical controls worldwide, global crop losses remain a matter of concern (Pimentel and Peshin, 2014) [66].

The first attempt to estimate crop losses due to various pests on global scale was made by Cramer (1967) [8] who put the global losses due to insect pests at 10.8%. Subsequently, Oerke *et al*. (1994) [40] made extensive study to estimate losses in principal food and cash crops, and total losses due to all categories of pests (animals, weeds and pathogens) were estimated at 42.1%. In spite of the wide spread use of synthetic pesticides and other control measures, the losses due to insect and mite pests increased in post-green revolution era than in pre-green revolution era (Table 1). Worldwide total crop losses for post-green revolution era (1988 through 1990) period value at US$ 90 billion for eight principal food and cash crops (barley, coffee, cotton, maize, potato, rice, soybean and wheat) (Benedict, 2003) [5].

Since mid-nineties, the production systems have undergone a tremendous change, particularly in crops like maize, soybean and cotton in which the advent of transgenic technology has modified the strategies for pest management in some major production regions. Therefore, Oerke (2006) [39] updated the loss data for major food and cash crops for the period 2001-03 according to which the total losses due to all categories of pests were calculated as 32.1%. The actual losses due to various pests have been estimated as 26-29% for soybean, wheat, cotton, and 31, 37 and 40% for maize, rice and potatoes, respectively (Table 2). Thus, there is a decline in global crop losses due to various pests from 42.1% during 1988-90 to 32.1% during 2001 to 2003. The corresponding decline in loss due to animal pests, weeds and pathogens was from 15.6 to 10.8, 13.2 to 8.8 and 13.3 to 12.5%, respectively.

Table 2: Worldwide crop losses due to insect and mite pests during pre- and post-green revolution era

Crop	Losses (%)		
	Pre-green revolution (1965) (1)	Post-green revolution (1988-90) (2)	Changes in loss
Barley	3.9	8.8	+ 4.9
Cotton	16.0	15.4	- 0.6
Maize	13.0	14.5	+1.5
Potatoes	5.9	16.1	+10.2
Rice	27.5	20.7	-6.8
Soybean	4.4	10.4	+6.0
Wheat	5.1	9.3	+4.2
Average	10.8	13.6	2.8

***Source*:** Benedict 2003

Table 3: Global losses due to various categories of pests in major crops, 2001-03

Crop	Losses (%)				
	Animal pests	Weeds	Pathogens	Viruses	Total
Cotton	12.3	8.6	7.2	0.7	28.8
Maize	9.6	10.5	8.5	2.7	31.3
Potatoes	10.9	8.3	14.5	6.6	40.3
Rice	15.1	10.2	10.8	1.4	37.5
Soybean	8.8	7.5	8.9	1.2	26.4
Wheat	7.9	7.7	10.2	2.4	28.2
Average	10.8	8.8	10.0	2.5	32.1

***Source*:** Oerke (2006) [39]

Indian Scenario: Losses due to insect pests in Indian agriculture have been estimated from time to time (Singh *et al*., 2014; Dhaliwal and Arora, 2015) [66, 11]. Extensive surveys carried out during early 1960s revealed that fruits, cotton, rice and sugarcane suffered 25, 18, 10, and 10% yield losses, respectively (Pradhan, 1964). However, during the early 2000s, the losses increased considerably due to increased intensification of agriculture. The highest losses were reported in cotton (50%), followed by sorghum and millets (30%), and rice, maize and oilseeds (each 25%) (Dhaliwal *et al*., 2004) [12]. In general the losses in post green revolution era have shown an increasing trend than in pre-green revolution era. Overall, there was increase in from 7.2% in early 1960s to 23.3% in early 2000s (Table 3). The maximum increase in loss was reported in cotton (18.0 to 50.0%), followed by other crops like sorghum and millets (3.5 to 30.0), maize (5.0 to 25.0) and oilseeds (other than groundnut) (5.0 to 25.0)

There has been a paradigm shift in the crop management scenario of Indian agriculture since the beginning of this century. Concerted efforts were made to implement integrated pest management programmes in principal food and cash crops. As a result of these developments, losses due to insect pests in several agricultural crops have shown a declining trend. Even then during 2007-08, insect pests inflicted a loss of about US$ 21.5 billion in major agricultural crops (Dhaliwal *et al*., 2010) [14].

Weeds of Potato Crop

Weeds prevalent in potato crop vary from region to region and have been grouped mainly into two sub-groups *i.e.* weed species found in plains and in hills. The knowledge of dominant and invasive flora is of paramount importance for controlling weeds efficiently in different potato growing zones. The dominant weeds of potato crop in Indo-gangetic plains are *Cynodon dactylon* L.(Pers.), *Cyperus rotundus* L., *Trianthema monogyna* L., *Chenopodium album* L. *Poa annua* L. *Anagallis arvensis* L., *Meliotus spp*., *Sonchus oleraceus* L. and *Vicia sativa* L. Major weeds of hills are *Amaranthus viridis* L., *Chenopodium* spp., *Oxalis* spp., *Digitaria sanguinalis* (L.) Scop. *Setaria glauca* (L). Beauv., *Spergula arvensis* L. and *Meliotus spp*. (Lal 1993) [26]. The occurrence and intensity of weeds vary under various agro climatic regions, cropping systems and management conditions. In Assam, a total of 33 weed species belonging to different families have been reported in potato crop, where *Chenopodium album* L., *Axonopus compressus* and *Cynodon dactylon* L. (Pers) were the dominant weeds (Baruah and Sarma, 1994). In Meghalaya forty-two weed species in potato fields have been registered with dicot/monocot ratio of 2.4:1 (Laloo, 2004) [28]. In Nilgiris hills (Tamil Nadu), the most dominant weeds in potato fields were *Polygonum nepalense*, *Coronpus didymus* and *Spergula arvensis* (Manorama, 2004) [30]. Punia *et al*., (2007) [51] conducted a survey of weed flora of potato fields in Haryana and observed a total of 23.

Table 4: Weeds and period of their infestation by *Myzus persicae*

S.No.	Plant species	Period		Host/Collateral host
		Group-1 (Plains)		
1.	Anagallis arvensis L.	January	March	-
2.	Chenopodium album L.	January	March	-
3.	C.murale L.	February	March	-
4.	Convolvulus arvensis L.	December	March	PVY, PLRV
5.	Datura metal L.	February	March	-
6.	D.alba	February	March	-
7.	D.nees	February	March	-
8.	Fumaria purviflora Lam.	January	March	-
9.	Medicago sativa L.	February	March	-
10.	Melilotus indica Larn.	January	March	-
11.	Solanum nigrum L.	January	February	-
12.	Sonchus oleraceus L.	February	March-	-
13.	Spergula arvensis L.	February	March	-
14.	Trifolium alexadrium L.	February	March	-
		Group-II (Hills)		
15.	Datura metal/L.	July	September	PVY,PLRV
16.	D.stramonium L.	July	September	PLRV
17.	Medicago sativa L.	July		-
18.	Nicandra physaloides Gaeten	June	August	PVY,PLRV

species, out of which three were grassy, sixteen broad leaf and one sedge weeds. *Cyperus rotundus, Chenopodium album, Anagallis arvensis, Phalaris minor, Poa annua, Melilotus indica, Polypogon monspliensis, Coronopus didymus* and *Medicago denticulata* were the major weeds of potato crop. Major weed species infesting potato crop in central Uttar Pradesh were *Chenopodium album, Anagallis arvensis, Melilotus indica, Vicia sativa* and *Cyperus rotundus* (Tripathi and Tripathi, 2008) [72]. Biology of important weeds of potato crop in the country has been described separately in chapter of Biology and control of weeds of potato crop.

Table 5: Weed hosts of viruses and virus like diseases of potato

Potato diseases	Weed hosts	References
Potato virus X	*Amaranthus caudatus* *Amaranthus blitum* *Chednopdium album L.* *Chenopodium murale L.* *Ipomea purpurea Lam*.	Garg *et al* (1990) Upreti and Nagaich (1963)
Potato virus S	*Amaranthus caudatus* *Chenopodium murale L.* *Chenopodium ficifolium* L.	Garg *et al*.(1990) Upreti *et al*.(1969)
Potato virus Y	*Ageratum conzoides* L. *Chenopodium murale* L. *Convolvulus arvensis* L. *Datura metal L.* *Nicandra physaloides Gaeten* *Solanum nigrum* L.	Joshi and Prakash (1977) Nagaich and Upreti(1965) Rizvi *et al*(1976)
Potato leaf roll virus	*Convolvulus arvensis* L. *Datura metal* L. *Nicandra physaloides Gaearten* *Solanum nigrum* L.	Rizvi *et al*.(1976)
Potato top roll Potato phyllody	Convolvulus arvensis L. Datura metal L.	Singh *et al* (1981) Singh *et al* (1981) and Singh *et al* (1985) Singh *et al* (1985)
Purple top roll And Marginal Flavescence	*Datura metal* L. *Datura stramonium* *Solanum nigrum* L.	Singh *et al* (1985)

Critical period of crop: weed competition in potato

Potato crop is usually raised in wider geometry with liberal use of manures and fertilizers. Further, irrigations are frequent in plains and generally rains are heavy in hills during crop growth season. All these practices are advantageous for early and faster growth of weeds even before the crop emerge out. It provides ample opportunity for weeds to flourish and dominate the crop if not managed timely. This would culminate into reduction in tuber productivity particularly due to initial takeover of weeds rather than late in the season. Gupta *et al.* (1977) [19] found that irrigated crop responded well to initial weed management. Early coverage of crop canopy by weeds or their allelopathic effect was speculated as major factor in crop-weed competition. Thakral *et al*., (1985) [70] reported that the most critical period of crop-weed competition is 25-30 days from planting. At Kufri, tuber yield reduced indicating the criticality of this period (Lal and Jaiswal, 1989-90).

Table 6: Major weeds of potato crop

Scientific name	Common name	Local name
	Weed flora of the plains	
Amaranthis viridis L.	Pigweed	Jangali Chaulai
Anagallis arevensis L.	Pimpernel	Krishnaneel
Asphodelus tenuifolius Cavan	Wild onion	Piazi
Avena fatua L.	Wild oat	Jangali Jai
Chenopodium album L.	Lambs quarters	Bathua
Chenopodium murale L.	Goose foot	Kharthua
Cirsium arevnse L.Scop.	Canada thistle	Kantaila
Convolvulus arvensis L.	Field binweed	Hirankhuri
Coronopus didymus (L.) Sm.	Swinecress	Jangali halon
Cynodon dactylon (L.) Pers.	Bermuda grass	Dub
Cyperus iria L.	Yellow nutsedge	Motha
Cyperus rotundus L.	Purple nutsedge	Motha
Melilotus alba Desr.	White sweet clover	Safed senji
Melilotus indica L.,All	Yellow sweet clover	Pilli senji
Oxalis corniculata L.	Indian sorrel	Khati-buti
Oxalis latifolia HBK	Wood sorrel	Khati-mithi ghas
Phalaris minor Retz.	Canary grass	Gulli-danda
Poa annua L.	Blue grass	Buin
Solanum nigrum L.	Blacknight shade	Makho
Sonchus aleraeus L.	Sowthistle	Sow thistle
Sataria gaua L.Beauv.	Foxtails	Banra, Banari
Trianthema monogyna L.	Carpet weed	Patharhatta/Its chit
Vicia sativa L.	Common vetch	Ruari, Ankari
	Wewed flora of the hills	
Amaranthus viridis L.	Pig weed	Jangali Chaulai
Bindens pilosa L.	Begger's sticks	Dipmal
Chenopodium Album L.	Common Lamb's quarters	Bathua
Chenopodium murale L.	Common Lamb's quarters	Kharthua
Commelina benghalensis L.	Tropical spider wort	Kanchara/Kanakaua
Cynodon dactylon L.,Pers.	Bermuda grass	Dub
Digitaria sanguinalis L.Scop.	Crab grass	-
Echinochloa crugalli (L.) Beauv	Bamyardgrass/Water grass	Savank
Melilotus indica L.All.,	Annual yellow sweet Clover	Pili senji
Oxalis corniculata L.	Wood sorrel	Khati-buti
Pennistum clandestium	Kikuya grass	Kikuya grass
Polygonum species	Black bird weed	-
Rumex species	-	Jangali palak
Setaria glauca (L.) Beauv.	Foxtails	-
Spergula arvensis L.	Com spurry	Bundhania/Matkan

Lal (1990 and 1993) [26, 27] concluded that the initial period of 20-40 days after planting of potato crop was the most critical period for competition in western Uttar Pradesh. Singh (1982) [62] suggested that weeding should not be delayed beyond four weeks of planting as delay in weeding would adversely affect potato productivity. In Nilgiris (Tamil Nadu) the most critical period for crop-weed competition was 4-6 weeks after planting in the plains and 5-7 weeks after planting in the hills (Manorama, 2004) [30]. The potato crop should remain weed free up to 40-50 days depending upon farming situation. However, towards maturity, potato plants tend to drop between ridges after 65-70 days of planting and at this stage second flush of weeds come up. These weeds do not cause significant damage to tuber productivity but play a major role in increasing weed seed bank and cause hindrance in crop harvesting and its quality by mechanical damage. Weeds emerging at this stage are main source of seed working as seed bank in the field. Hence, control of weeds at this stage not only reduces weed problem of current season but of subsequent years also. Therefore, weeds in potato crop have to be managed in such a way that these do not dominate at any stage of growth.

Crop loss due to weeds in organic farming

Weeds affect everyone in the world by reducing crop yield and crop quality, delaying or interfering with harvesting, interfering with animal feeding (including poisoning), reducing animal health, preventing water flow, as plant parasites, etc. Weeds are common everywhere and cause many $ billions worth of crop losses annually, with the global cost of controlling weeds running into $ billions (Kraehmer and Baur, 2013) [25]. There is no reliable study of worldwide damage due to weeds. However, it is widely known that losses caused by weeds have exceeded the losses from any category of agricultural pests such as insects, nematodes, diseases, rodents, etc. The potential crop yield loss without weed control was estimated by 43%, on a global scale (Oerke, 2006) [39].

Weed competition can reduce yield (VanGessel and Renner. 1990) [74] and potato quality, affecting tuber size, weight, and quantity (Wall and Friesen. 1990a) [76]. Weeds interfere with harvest, causing more potatoes to be left in the field and increasing mechanical injury. If a mixed population of annual weeds is allowed to compete with potatoes all season, each 10% increase in dry weed biomass causes a 12% decrease in tuber yield (Nelson and. Thoreson. 1981.) [37]. While (Rao 2000) [53] has reported that of the total annual loss of agricultural produce from various pests, weeds account for 45%, insects 30%, diseases 20% and other pests 5%. Annual worldwide losses to weeds were estimated to comprise approximately 10-15% of attainable production among the principal food sources. Weeds are the most acute pest in agriculture with an estimated annual global damage of around 40 billion dollars per year (Monaco *et al*., 2002) [33].

One redroot pigweed (*Amaranthus retroflexus* L.) or barnyardgrass [*Echinochloa crusgalli* (L.) Beauv.] per meter of row reduced marketable tuber yield 19 to 33% (VanGessel and Renner. 1990) [74]. The critical period for weed removal in potatoes is about 4 to 6 weeks after planting (Thakral *et al*. 1989) [71]. Weeds emerging 4 weeks after planting are suppressed by crop growth (Thakral *et al*. 1989) [71]. These weeds may not reduce tuber yield through competition, but can interfere with harvest operations. Mechanical cultivation does not remove weeds within the row and may damage potato plants and reduce yields (Nelson and Giles. 1989.) [36]. Herbicides can reduce the number of cultivations required and enhance weed control (Nelson and Giles. 1989.) [36], particularly during the early season before hilling. Some common annual weeds growing with cultivated crops use up to three times as much water to produce a pound of dry matter as do the crops (Parker, 2003) [46]. Therefore, controlling weeds in fields is necessary to rise up yield quantity and quality, as well as minimize great losses in crop production resulting from weed-crop competition. That is an assumption that if all the weeds in food crops were controlled, the current world's food production would be higher by 10% to 25% (Rao, 2000) [53]. Worldwide consumption of herbicides represents 47.5% of the 2 million tons of pesticide consumed each year. However, the heavy use of herbicides has given rise to serious environmental and public health problems (Sopeña *et al*., 2009) [67]. Weeds were considered the most important pest group in a survey of organic vegetable growers (Gianessi and Reigner, 2007) [17]. The potential problems associated with herbicides use are (1) injury to non-target vegetation, (2) crop injury, (3) residues in soil and water, i.e., reduction of soil and water quality, (4) toxicity to other non-target organisms, (5) concerns for human health and safety and (6) herbicide-resistant weed populations (Meksawat and Pornprom, 2010) [31].

Weed management in potato crop

Prime objective of weed management is to keep the intensity of these undesirable plants well below a level where the desirable tuber yields are achieved and the farm profits are not hampered. The decision of choosing a suitable method of weed control would depend upon severity of specific weeds, stage of weed growth, weather conditions and socio-economic conditions of farm enterprise. An attempt has been made to describe various weed management practices feasible for the potato crop. These are mainly cultural, mechanical and chemical methods, and an integrated approach towards weed management.

Cultural weed control

Weeds are suppressed out specifically in initial phases of crop growth by way of crop competition through adoption of best crop production practices and making major components of crop growth in favour of potato crop. It includes vigorous and faster growth of potato plants and having crop environments such that it always smothers weeds. The weeds emerging out under better crop canopy are generally frail and will not be much harmful to tuber productivity. Further, these can be managed without much difficulty by adopting inter-cultivation or chemical methods. The potato cultivars having vigorous and rapid growing habits may prove better competitors for weeds as they cover fields quickly and overwhelm these undesirable plants. Studies of crop weed competition versus chemical weed control in potato crop suggested that comparable yield could be achieved by achieving optimum plant density and inter-cultivation (Channappagoudar *et al*., 2007) [6]. Adoption of suitable agronomic practices can reduce dependence on chemicals.

Crop rotations

Rotate, rotate, rotate. Growing the same crop year after year will favor the same weeds. Rotate crops to prevent weeds from becoming adapted to your farm.Well-planned cropping systems can be quite useful in controlling weed density in long run. This may be done following at least two-year crop rotation in a particular field or having green manure crops like dhaincha, cowpea etc. for smothering weeds. Two-year crop rotation will assist in reducing weed seed bank in field, while in green manuring even for a shorter period (45-50 days), weeds get buried along with the green manure crops and are decomposed, which also add to the soil organic carbon. Thus, this operation also facilities better potato growth for posing tough competition to these detrimental plants.

Hot weather cultivation and soil solarisation

Advantage of hot and dry summer season should be harnessed in a cropping system for desiccating the weeds. Two-three deep field cultivations in this period are very useful for the control of annuals and also for perennials like *Cynodon* *dactylon* L. Similarly, soil solarisation may be quite useful in specific situations or for premium potato crop like seed *etc*. Soil solarisation done using transparent polyethylene (TPE) film of 0.05 and 0.10 mm thickness for 30 and 40 days with and without conventional weeding or chemical weed control in potato crop after groundnut recorded lowest mean total weed count and weed dry weight (Soumya *et al.*, 2004) [68].

Proper seed bed preparation

Seed bed should be prepared thoroughly depending upon soil type of a region. Pre-plant tillage operations for making a proper soil tilth not only accelerate faster emergence of potato plant, but also destroy the weeds and give an edge to the crop.

Proper planting

A competitive edge is given to potato crop by way of optimized planting time. First of all, a variety should be planted at an optimum date, where soil bed is prepared properly and contains sufficient moisture. Well-sprouted seed tubers should be planted at optimum crop geometry at a proper depth. This will help in faster emergence and growth of potato plant. At Jabalpur, ridge planting significantly reduced the population of *Phalaris minor, Medicago hispida, Cichorium intybus* and *Vicia sativa* at 40 days over other methods like flat planting (Mishra *et al*., 2002) [32].

Placement of manures and fertilizers

At planting, manures and fertilizers should be precisely placed in bands 5-6 cm below seed tubers, so that these inputs remain in root zone of the crop. Thus, the plants will be able to harness nutrition efficiently in comparison to weeds, which will accelerate the vegetative growth. Faster coverage of fields of potato canopy would deprive weeds from uptake of nutrients and thus assist potato crop in reducing their intensity more specifically in initial phase of plant growth.

Mechanical weed management

Hand pulling, chopping, and hoeing weeds are simple forms of weed control used on smaller farms where weed control options are limited, particularly in less developed regions or those growing potatoes organically specially by small and marginal farmers. Most commercial farms, however, use tractor tillage for mechanical weed control. Tillage is an important component of weed control in potatoes, regardless of region or production system. Some of these methods are as old as human beings started the farming. Mechanical weed management is very significant in modern era due to concerns for the environments and emphasis on avoidance of chemicals.

Manual weeding

Removal of weed plants simply by hand or by manual implements like Khurpi, hand hoe, spades *etc* is an old practice and still followed in many parts of India in potato crop. This may be a feasible and efficient method for controlling the undesirable vegetation provided manual labour is available and cheap. Further, it is quite effective against annuals and biennials, as they do not re-generate from the pieces of vegetative parts left in soil after such operation. This method is particularly better as it destroys weeds within the rows, which are generally not controlled by the cultivation. Hand weeding produced higher tuber yields and net returns than the herbicide in potatoes (Sharma, 1994) [59]. Prasad and Singh (1995) [49] concluded that weeding at 30 days + earthing up was comparable with pre-emergence applications of atrazine and fluchloralin for reducing weed dry weight, increasing weed control efficiency and also better tuber yield. Pandey (2001) [43] recorded comparable tuber productivity in treatments of hand weeding + earthing up, isoproturon, metribuzin and pendimethalin. Integration of hand weeding with earthing up had lowest weed population and biomass with 65.8-94.3% weed control efficiency. Maximum tuber yield was also observed with hand weeding + earting up followed by Prometryn @ 1.00 and 0.75 kg ha^{-1} (Mukhopadhyay, 2002 and Nandekar, 2005) [34, 35].

Mechanical Methods

These methods mainly include two options i.e. animal drawn or tractor drawn implements for the potato growers depending upon their farm size. Animal-drawn three-tine cultivators are quite efficient and cost effective implements for inter-cultivation in potato crop (Shyam and Singh, 1979) [60]. Narrow shovels are better for weeding operation as it will not damage roots and stolons of potato plants growing over ridges. One pair of bullocks per day can cover approximately one hectare of land. After inter-cultivation, animal-drawn single bottom ridger is better for earthing up of the crop. Tractor operated machines are very efficient and can cover larger fields in a day. Spring tine cultivars consisting of spring tines with narrow reversible shovels fitted to a tractor tool bar may cultivate three or more potato rows at a time. As each tine is hinged at its base so the lateral position on shovels can be changed easily with a mild foot below, to reduce root and stolon damage if crop is cultivated at different stages of growth. Later on ridgers consisting of three or more bottoms do the earthing up operation in potato crop. Tractor based mechanization can cover 3-5 hectrare of crop field per day.

Potato crop has critical period of crop-weed competition, so timely inter-cultivation and weeding are very pertinent for maintaining better crop growth and high tuber productivity. First four to six weeks after crop emergence are very crucial for canopy development and covering the fields to give potato crop an edge over undesirable vegetation in fields. Inter-cultivation is better 20-25 days after planting when the plants are about 10-12 cm in height. Earthing up should immediately be done after inter-cultivation and weed removal otherwise soil moisture will deplete and proper ridges will not form. In Punjab, blind hoeing proved advantageous in early potato crop where *Trianthema monogyna* L. germinated much earlier and covered the entire field before the emergence of potato plants (Singh and Saini, 1980). Mechanical weed control proved comparable to chemicals in terms of crop growth, yields and economics of weed management in potato crop in a field trial conducted on red sandy loam soil at Chintamani (Reddy *et al*., 1993) [54]. Panghal *et al* (2004) [44] also reported similar results from Haryana.

Mulching

Though it is very old practice but it is a very efficient way for smothering the weed growth during crop season and more specifically for annuals. Main objective of mulching is to deprive weeds of solar radiation and thus inhibition of weed growth. Germination of weeds is also hampered and this practice helps in conserving soil moisture, which facilitate quick emergence of potato plants. Crop residue, dry straw, dry grasses, pine needles and other vegetative material may be utilized in this operation. Recently plastic mulching has also come up as a promising technique for weed control. However, mulching cost has increased due to increase in cost of residues and labour. Lal (1990d) observed effective weed management in potatoes with the mulching of paddy straw in Uttar Pradesh and pine needles in Meghalaya. Tuber productivity of mulching treatments was comparable with conventional weed control. It was also concluded that mulch should be thick enough (5-10 cm) to prevent light interception so that weeds photosynthesis is hindered. At Bengaluru, mulching with straw and polyethylene films reduced weed dry weight from 12.7 g m^{-2} (no mulch) to 5g and 3 g m^{-2}, respectively. Mulching with straw and polyethylene also increased tuber yields from 14.3 t ha^{-1} (no mulch) to 16.7 t and 18.2 t ha^{-1}, respectively thereby enhancing cost: benefit ratios (Khalak and Kumaraswamy, 1993) [23]. In West Bengal, potatoes Cv. Kufri Jyoti recorded better tuber productivity with *L. leucocephala* mulching followed by FYM, rice husk ash and mustard oil cake incorporation (Datta and Chakraborty, 1995) [9].

Efficient use of herbicides

Selection of proper herbicide by judging the crop stage, presence of various weed species and their intensity, soil type and weather conditions is very important, which determines the effectiveness of the chemical applied. Considerable skill in application of these chemicals is essential for getting better results with optimal quantity and without causing any ill effect to crop and the environment. Following facts should be included in weed management strategy while selecting and applying the herbicides for their safe and efficient use:

Herbicides recommended for spraying at different crop growth stages should only be chosen and applied in proper doses at an appropriate time.

Selection of the herbicides should be based upon weed problem of a field and its past history. Composition of weed species, their intensity and stage is important in choice of chemicals.

Sprayer suitable for a given farming situation should be opted for application of herbicides. Various conventional knapsack and power sprayers are available in the market. Similarly, selection of proper nozzle is also pertinent for efficient use of herbicides. Optimum pressure in sprayer tank has to be maintained for uniform application of the chemical.

Calculation of optimal chemical dose of commercial formulations is very important for desired efficacy of the herbicides. It is mandatory to provide chemical details and composition of any product by an organization in the market, so active ingredient (ai) is used in computing the quantity of chemical for a given farm area by adopting following formula:

Dose of commercial product

$$\frac{\text{Weight of chemical required per ha}}{\text{Active ingredient in a product (\%)}} \times 100$$

The chemical especially wettable powder should be dissolved properly in water and stirred at a regular interval for maintaining uniformity of application. Likewise, air drift should be avoided and if strong wind (more than 10 km hr-1) is there then the spray may be stopped for some time. Volatile herbicides should be applied before making ridges and mixed thoroughly in soil to reduce volatilization or photo-decomposition losses. This is quite relevant in case of pre-plant incorporation of herbicides.

Soil should be well prepared and brought to proper tilth before spraying the pre-emergence chemicals. Do not disturb the field after their application as the residual effect would be reduced. The contact herbicides should only be applied when weeds start appearing to avoid wastage.

Pre-emergence herbicides are critical for providing an optimal growing environment for potatoes early in the season. Pre-emergence herbicides labeled for use in potato include EPTC, linuron, metribuzin, S-metolachlor, pendimethalin, rimsulfuron etc. Metribuzin is currently the most widely used pesticide in potato production. Metribuzin, an s-triazine or triazinone, is one of the oldest potato herbicides and is still widely used in potato production. Pre emergence application of metribuzin @ 0.5 kg *a.i.*/ ha in potato controls a range of broadleaf weed species and suppresses many additional grasses. Resistance to triazine herbicides has developed in 69 species worldwide, limiting activity and requiring a combination of control practices for these weeds.

Now a day due to mechanized planting of potato crop and in the interest of inch by inch utilization of land for cultivation hoeing operation in potato is vanished. Hence, under current situation there is demand for post emergence herbicide. Most widely used herbicide metribuzin is also used as pre emergence as well as post emergence up to 5% emergence of plants. After full emergence of crop there is no herbicide which can be used in potato crop. At ICAR-CPRS, Gwalior three post emergence herbicides viz Propaquizafop, Sulfofuron and Bentazone (Basagran) were evaluated in potato crop. Propaquizafop used in different levels was found to in-effective in controlling potato weeds (Singh *et al*. 2015) [63] specially weeds of *Chenopodium sp.* Herbicide Sulfosulfuron was very effective in controlling potato weeds but it caused phytotoxic effect at its all tried doses (Singh *et al* 2016) [65] ultimately causing reduction in yield, hence it was not suitable for potato crop. Sulfosulfuron caused phytotoxic effect in all the four varieties Kufri Chandramukhi, Kufri Jyoti, Kufri Sindhuri and Kufri Lauvkar. Herbicide Bentazone (Basagran) was found very effective when applied @ 1 litre/ha at 4-6 leaf stage of weeds. This herbicide did not show any toxic effect on potato plants (Singh *et al.* 2015) [63]. Un-recoverable phytotoxic effect of Metribuzin was also observed in potato varieties Kufri Lauvkar and Kufri Surya hence application of Metribuzin should be avoided in these varieties.

Biological weed control

Biological weed control is divided into two groups where first is crop competition and second one is use of parasites, predators and pathogens. Second option is in focus now to bring the weeds of a given crop or cropping system below economic threshold level by utilizing natural enemies of specific weed species.

Williams *et al*. (2004) [77] attempted to use combined effect of herbicide induced stress and arthropod herbivory to reduce the weed intensity. Fluroxypyr dose-response bioassays using volunteer potato Cv. Russel Burbank were conducted in the presence and absence of Colorado potato beetle (*Leptinotarsa decemlineata*) herbivory in USA. Parameters like leaf area, shoot biomass, tuber number and weight were lower with herbivory compared with no herbivory. Season-long bioassays revealed that addition of herbivory reduced herbicide use by 65-85%. Prashanthi and Kulkarni (2005) [50] isolated organisms from the diseased parts of Eupatorium (*Chromolaena odorata*) an alien aggressive weed and eighteen isolates belonging to nine genera were obtained. Among them fungus *Aureobasidium pullulans* was found potent for probable use on various target weed plants. Similarly, an attempt was made by *Paijwar et al*. (2005) to collect and identify fungi associated with the infected parts of *Lantana camara* for further exploitation as biological control agents. They were able to isolate two fungi in pure culture (*Alternaria* sp. and *Fusarium sp*) for potential use in biological control strategies.

Intercultural operations and weed control

The objective of intercultural operation in potato are weed control, earthing up for firming up the ridges to prevent exposure of growing tubers and application of split dose of N and thimet insecticide. However, operations involving human, animal and implement movement in standing seed crop should be minimal to prevent transmission of plant viruses through physical contact. It would be better if these operations are completed by 20-25 days after planting when plants attain the height of about 10-15 cm, when foliage cover is still small. The split dose of nitrogen and thimet should be applied at hoeing and earthing up about 5 cm away from the plant. The hoeing must not be delayed beyond 30 days after planting to avoid damage to the plant roots, foliage and stolons, which may adversely affect the number of tubers resulting in reduction in yield. Broadleaf annuals, with the exception of nightshade (*Solanum spp*.), are usually the easiest to control. The most widely distributed broadleaf weeds of concern in potato fields are: hairy nightshade (*Solanum sarrachoides* Sendtner or *Solanum physalifolium* Rusby), bathua or common lambsquarters (*Chenopodium album* L.), kharbathua (*Chenopodium murale*), redroot pigweed (*Amaranthus retroflexus* L.), kochia (*Kochia scoparia* L.) Schrad.), ragweed (*Ambrosia artemisiifolia* L.), and Pennsylvania smartweed (*Polygonum pensylvanicum* L.). Annual grasses such as barnyardgrass (*Echinochloa crusgalli* L), foxtail (*Setaria spp*.), wild oat (*Avena fatua* L.), and fall panicum (*Panicum dichotomiflorum Michx*.) may germinate later than most broadleaf annuals. Because of the later germination, a pre-emergence herbicide with residual activity or an effective herbicide that can be applied after potato emergence is needed for control of these weeds. The most difficult weeds to control are the perennial weed species. The major perennial problem weeds include nutsedges (*Cyperus spp*.), quackgrass (*Elytrigia repens* L.), and Canada thistle (*Cirsium arvense* L.)). In addition to causing yield reduction and decreasing harvest efficiency, rooting structures of perennial grasses and nut sedges can penetrate potato tubers causing severe reduction in quality. When perennial weeds are the primary problem, more than the standard number of tillage operations may be needed for effective weed control even though herbicides are used. Perennial weed control may be more effective and economical in crops rotated with potatoes, such as winter wheat. Potato cultivars that develop and maintain a dense canopy with early row closure can be competitive with many weeds. Weed control practices in potatoes include cultivation and herbicides, and a combination of the two is often more effective than either alone. Heavy weed infestations can require multiple cultivations. However, strict tuber quality requirements may limit the use of mechanical cultivation for weed control. Multiple cultivations can cause soil compaction, which reduces aeration and potato growth, and can produce clods that bruise potatoes at harvesting. Cultivation also may directly damage potato foliage and roots, reducing yield and tuber quality. In seed - growing areas, cultivation after potato emergence may spread diseases. Wet soil interferes with cultivation timeliness, and in - row weed control is usually not effective. A combination of a timely pre - emergence herbicide application and cultivation as the weeds are germinating and emerging provides effective early season control. Many pre - emergence herbicides do not control emerged weeds. These herbicides work most effectively when applied shortly after a hilling operation that is performed just before potato emergence. Weeds emerged after planting are killed off by the hilling operation and herbicides are applied to a “clean bed.” Pre-emergence herbicides usually have to be incorporated into the soil 2 to 5 cm where the weed seeds are germinating. This can be done by irrigation and sometimes by tillage if adequate rainfall has not occurred after application. A few non - selective herbicides also are labelled for use before potato emergence. These herbicides control emerged weeds and have no residual activity for later - emerging weeds. Some herbicides may be applied post - emergence to the potato crop. Other crops in a potato cropping system may not be tolerant to the herbicides used for potatoes, so crop rotation should be considered when making herbicide choices. Repeated use of herbicide(s) with the same mode of action for killing a weed can cause selection pressure for weed biotypes naturally resistant to that mode of action. These biotypes are usually present in a given weed population in very small numbers. If susceptible weed biotypes are killed off and the resistant biotypes survive, then the weed population can become dominated by the resistant biotypes. Herbicides with the same action that has been used repeatedly may no longer be effective. Rotating herbicides with different modes of action from year – to - year and/or tank - mixing herbicides with different modes of action and overlapping weed control spectrums can help prevent or delay the development of herbicide - resistant weed populations. Pre - emergence herbicides like Metribuzin @ 0.75 kg/ha, Oxyfluorfen @ 0.15 kg/ha, Linuron @ 0.5 kg/ha, Alachlor @ 1.5 kg/ha and isoproturon @ 0.75 kg/ha applied 2 - 3 days after planting are effective. Pre - emergence herbicides are most effective when applied in moist soil. Therefore, if soil is dry apply herbicides after first irrigation as soon as it is possible to enter the field. Herbicide Metribuzin @ 0.75 kg/ha mixed with 1000 litre of water can be applied just after planting under dry soil which should be followed by irrigation also control weeds effectively. Chemical weed control eliminates manual hoeing. Thus, full earthing up at planting combined with chemical weed control effectively minimizes undesirable physical intervention in standing seed crop.

Fig 6: Chemical weed control using metribuzin as pre - emergence followed by hoeing

Weed control in organic agriculture

Weed control is considered the major obstacle for the growers in the organic farming. Lower plant productivity in organic farming mainly related to the poor weed control. It is widely known, in most cases, that losses caused by weeds exceeded the losses from any category of agricultural pests. Under water-stress condition, weeds can reduce crop yields more than 50% through moisture competition alone. In the light of the environmental and toxicological problems created by herbicides, it has become necessary to develop the safety methods for controlling weeds. Soil solarization, mulching, biodegradable mulch, natural herbicides, Hot water, and agronomic practices have been successfully adopted in many countries as safe methods for controlling weeds in the organic farming. In addition, there are some promising new and non-traditional measures such as Fresnel Lens, Electrical Weed Control, Lasers, etc which could be employed for controlling the weeds in organic farming. Also the agronomic practices such as choice of competitive varieties, stale seedbeds had a significant impact on weeds. The growers in organic farming should keep these three points in mind: 1) start clean stay clean successful, 2) Prevention is always better than treatment and, 3) One year's seeds will lead to seven year's weed infestation. Successful and sustainable weed management systems are those that employ combinations of techniques rather than relying on one method. The objectives of this paper are to review some safe weed control methods in the clean agricultural. Weeds are considered the biggest problem facing organic farming, where weed control is more expensive compared to synthetic herbicides whose use is prohibited in clean agriculture. Rood (2002) has reported that weed management is the most difficult part of organic rice production and it is the major reason for organic rice yields being 50% lower than conventional yields. Lower yields and higher costs for weed control labor are two of the major reasons that organic cotton must be sold with high price premiums (Schneider, 1993) [57].

Unavailability or limited herbicides availability in organic farming

Controlling weeds without herbicides takes a lot of time and is very costly for us. All weeding is done by tractors or hand, which is very labor-intensive. Conventional farmers spend only about $50 per one acre on herbicides that knock out every weed in sight. Organic farmers may have to spend up to $1,000 an acre to keep weeds under control (Earthbound Organic, 2006) [15].

Various least toxic, natural herbicides have limited efficacy, particularly against noxious perennial weeds. Also, mycoherbicides have some promise, but also pose risks to non-target plants (Baker & Brown-Rosen, 2007) [4].

Weed control cost in organic farming

Where synthetic herbicides have their use prohibited compared to herbicides allowed in conventional farming. Growers of organic crops cite weed control as their greatest difficulty in crop production because they are not permitted to use chemical herbicides (Gianessi & Reigner, 2007) [17]. They substitute hand weeding and cultivation for herbicides at a greatly increased cost and with reduced effectiveness. Aggregate studies that estimate the value of herbicides assume that growers would substitute a certain amount of hand weeding and tillage if chemicals were not used, which would not be sufficient to prevent yield losses totaling about 20% of the U.S. crop production.

Methods of weed control in organic agriculture

Mechanical weeding

Most organic crop growers rely on hoeing (mechanical in large farms or hand hoeing in small farms) as a safe and available method for controlling weeds. However, hand hoeing for a long time would inadvertently damage or remove some of the vegetable plants, while missing some of the weeds. In addition, organic crop growers were unwilling to accept hoeing damage to their vegetable crops and to increase plants spacing because of yields losses. Also, the method is highly expensive if enough labor is used to remove weeds: corn required 150 h ha^{-1}, cotton 165 h ha^{-1}, and spinach 516 h ha^{-1} (Gianessi and Reigner, 2007) [17].

Chicouene, 2007 have summarized the reviews about mechanical weeding and reported that mechanical weeding is certainly the most immediately applicable method for weed management when using chemicals is undesirable. Sometimes, mechanical weeding needs to be supported by the adoption of special techniques, such as sowing in a double instead of single rows, as successfully tried for oregano. In fact, one of the greatest difficulties in mechanical weed control is planning crop arrangement in space, which is, considering from the outset, the kind of equipment that will be used for weeding and then setting appropriate inter-row distances. Many failures of mechanical weeding are linked to neglect of this aspect of management. Cultivation had been shown to reduce the yields of several crops, including potato (*Solanum tuberosum*) and asparagus (*Asparagus officinalis*) because of root pruning and crop damage (Gianessi and Reigner, 2007) [17].

In recent years, weed control programs have often focused on nonchemical weed control, i.e., safety methods, or are generally "environmental or eco-friendly". Hand weeding or hoeing is safe and very effective against annual and biennial weeds. However, with rapid industrialization and urbanization in developing countries, human labor is rapidly becoming scarce and expensive. In this concern, Leinonen and Närkki (2004) have stated that hand work on (organically managed) horticultural fields is often unavoidable. Hand planting, hand weeding, and harvesting of strawberries and cucumbers are examples of tasks which are hard to mechanize. They have concluded that manual weed control is often the major limiting factor for organic vegetable production on a farm level. Furthermore, some closely planted (seeded) or broadcast crops are difficult for hand weed without damage to crops (Rao, 2000) [53].

Mechanical weed control may also have the added benefit of stimulating the mineralization of soil-bound nitrogen, which, if timed with the crops peak demand for nitrogen, could help to improve crop yield and quality (Davies & Welsh, 2002) [10].

Soil solarization

Soil solarization is a nonchemical method successfully used in many countries to control or reduce soil borne plant pathogens, weeds and mites. Solarization involves the use of transparent polyethylene sheeting to trap the heat from solar radiation to raise soil temperature to levels that are lethal to weed seeds and seedlings. In this regard, Haidar and Sidahmed (2000) [20] have found that solarization for 2, 4 and 6 weeks with chicken manure has increased the average weight of cabbage plants by 55, 70 and 75%, respectively compared to the control with chicken manure. Schreiner *et al*. (2001) [58] have reported that soil solarization is a promising method to reduce the populations of soilborne pests and weeds without using pesticides. Weed control effectiveness is dependent on moist soil, sufficiently high air temperatures and solar radiation, and an adequate length of exposure. Moist soil is essential to heat conductivity and for keeping seeds in a more susceptible imbibed state. The effects of solarization on weed emergence were apparent for a short time after plastic was removed. During the first two months after removal, the number of emerging annuals was less than 15% of an untreated check.

How weeds managed by solarization

The possible mechanisms of weed control by solarization are (1) thermal killing of seeds, (2) thermal killing of seeds induced to germinate, (3) breaking seed dormancy and consequently killing the germinating seed, and (4) biological control through weakening or other mechanisms. Only clear (transparent) plastic reduced weed population for one year after solarization (Zimdahl, 2013) [78]. During solarization, the soil temperature is increased by 8 to 2 ºC (Rao, 2000) [53]. The effect of solarization is greater at top 5- to 10-cm layer than at lower layers. This explains the efficacy of solarization on weed seed germination and seedling growth. Patricio *et al*. (2006) [47] have mentioned that the concentrations of soil nutrients NH_4-N and DTPA-extractable-Mn sharply increased due to solarization.

Soil solarization effect of on weeds and yield

Soil solarization increases temperature by up to 10 to 21 ºC in the upper soil layer, and increased levels of N, P, K, Na and EC in soil, but a slight effect was detected on O.M (%) and pH of solarized soil comparing with an unsolarized one (Fayed *et al.* 1992). There is a decrease in disease incidence, an increase in growth of various crops, and an improvement in crop yield (up to 437%) and crop quality as shown in (Table 7).

Table 7: Soil solarization is an effective method for improving crop quantity and quality even in the absence of known pathogen(s)

Crop	Yield (t/acre)		% increase
	Non solar	Solar	
Onoin	7	21	300
Tomat	8	35	437
Potato	7.5	12	160

Source: Satour 1997 [56]

Parker & Riches (1993) [45] have mentioned in their book that solarization provides an excellent control of *Orobanche aegyptica*, *O. ramose* and *O. crenata*. They have demonstrated that an incidental benefit of solarization is a 30-50% reduction in salinity. Ismail *et al*. (1997) have found that soil solarization reduced soil and root population of nematodes by 9 to 96%. Best result was obtained with 160-µm thick transparent sheets. The increments in yield of some crops due to solarization period are presented in (Table 8).

Table 8: Yield increase in some crops including potato due to soil solarization

Crop	Solarization period	Yield increase (%)	Reference
Tomato	2 month	195.5	Mauromicale *et al* 2005
Potato	1 month	14.3	Megueni *et al* 2011
Carrot	9 weeks	157.4	Marenca and Lustosa 2000
Cabbage	2 weeks	130.2	Haidar and Sidahmed 2000 [20]
Soybean	2 month	80.0	Megueni *et al*2006
Wheat	5 weeks	27.0	Singh *et al* 2003

Raw (2000) has pointed out that total weed emergence was reduced by 97% one week after removal of plastic sheets and up to 77% for the season. Solarization for a period of 5 weeks may be adequate for controlling most summer and winter annual weeds, while a period of at least 5 months is required for such perennial weeds. Vito *et al.* (2000) have reported that soil solarization for a 6-week period effectively controlled both nematodes and weeds. Stapleton *et al.* (2005) [69] have showed that all of the solarization treatments were equally effective in providing weed management, where weed numbers were reduced by 86% to 94%, and weed biomass reduced by 94% to 99%, as compared with the untreated controls. They have found that all of the plots receiving solarization treatments provided an economic yield of parsley foliage, ranging from 6.7-fold to more than 20 fold increases over the untreated control.

Mulching

Mulching is widely used in production of vegetables, crops, fruits, medicinal & aromatic plants as well as nursery and ornamental plants. Mulches can be natural such as straw, sawdust, weeds, paper and plant residues or synthetic (plastic). However, the cost of weed control with plastic mulching is apparently high which is twice of hoeing and one and half times of herbicides. It can be used for two seasons if carefully handled. Water saving is most important in the desert areas.

Soil mulch (covering the soil with organic or synthetic materials) has been recorded as a safe method to control weeds in comparison to herbicides application (Ramakrishna, 2006) [59]. The use of vertical mulching has substantially increased soil water storage (up to 41%) under some conditions.

Soil mulching increased grain yield by 17%, soil water storage (up to 41%) increased grain water use efficiency by 14% and reduced water loss from 0 to 30 cm soil depth (Unger *et al*., 2010). Mulch increased aboveground biomass by 19%, and grain water use efficiency (WUE) by 14% compared with bare soil treatments. Water saving under plastic mulching was more than 50% compared to herbicides or hoeing treatments and the benefits of mulching to crop performance are increased under water stress.

Organic mulches include straw, weeds (especially perennial grass), water-hyacinth, residues from perennial crops like banana, sugarcane straw or sugar cane bagasse and sawdust, newspaper and shredded paper (Silva *et al*., 2015) [61]. Synthetic mulches include polyethylene (plastic), polypropylene sheets or film (Rao, 2000) [53]. Mulching increases growth yield of potato, cabbage, tomato, okra, onion, etc. Mulch system suppresses weeds through their physical presence with soil surface (by shading, lowering soil temperature, allelopathic activity and blocking the light required for germination of many small-seeded weed species) (Hussein and Radwan, 2004) [21]. Mulch has some effect on weeds such as *Cynodon dactylon*, *Sorghum halepense*, etc. (Rao, 2000) [53].

Effect of organic mulches

Soil mulching with plant wastes or synthetic mulches is one of the management practices for reducing soil evaporation; it increases water retention, increasing WUE and weed control in crop fields (Awodoyin *et al*., 2007) [3]. This also ensures a more even moisture distribution throughout the soil profile, which further improves water use. Organic mulches also improve WUE indirectly. As mulch decomposes, humus is added to the soil, which increases its water holding capacity. A mulch layer prevents weed seedling growth by inhibiting light penetration to the soil surface. Lower weed prevalence significantly improves WUE (Ossom *et al*., 2001). Straw mulching (wheat straw after harvesting the ears) significantly depressed weeds, increased soil microbial quantity and activity, avoided powdery mildew and increased pumpkin fruit yield (Xu *et al*., 2009) [29].

Rice straw, sawdust, clover weed and cogon grass mulch treatments significantly reduced the total dry weight of onion weeds at 45 days after transplanting. Broad-leaved weeds were more susceptible than grassy weeds to mulching treatments (Abouziena *et al.*, 2014b) [1]. They added that the application of sawdust mulch, rice straw, clover weed and cogon grass mulches produced a higher bulb yield over unweeded by 127, 118, 152% and 123%, respectively. All mulch plant species examined at 1.5 t ha^{-1} markedly reduced growth and dry weight of weeds by 60-100% and 70-100%, respectively (Khanh *et al.*, 2005) [24].

According to Oliveira *et al.* (2014) [41], the inhibitory effect of organic mulch on weeds may be due to both the physical (the reduced passage of solar radiation and temperature range on soil superficial layer) effect of emergence suppression and the possible chemical effects arising from all elochemicals released by straw that may have contributed to emergence reduction. Besides, allelopathic interaction and chemical/biological effects of mulching include changes in pH and nutrients dynamics in the soil.

Natural herbicides

Extensive use of synthetic herbicides poses serious threats to both the environment and public health. From both public health and environmental perspectives, there is a great incentive for biologically active natural products from higher plants that are as good as or better than synthetic herbicides and that are likely to be much safer. Furthermore, in comparison to long-persistence, non-target toxicity, polluting, carcinogenic and mutagenic activities of synthetic herbicides, natural plant products are biodegradable, somewhat specific, and likely to be recycled through nature (Inderjit and Keating, 1999) [22].

Natural herbicides: The term 'natural-product' might be defined as "ingredients extracted directly from plants or animal products as opposed to being produced synthetically (Nice and Johnson, 2009) [38], and that are as good as or better than synthetic herbicides and that are likely to be much safer." Corn gluten meal, Alldown, Matran II, Groundforce, Vinegar (Acetic acid) and Citric acid have promises as non-synthetic herbicides for controlling weeds (Abouziena *et al.*, 2009) [2]. Cinmethylin, a natural herbicide produced by species of sage, controls many annual grasses and suppresses some broad-leaved weed species (Grossman *et al*., 2012) [18]. Different classes of compounds have been known for the potential use as natural herbicides.

Allelopathy

Some plants can be used as natural herbicides. *Jasonia montana* plants had a herbicidal activity as preemergence or postemergence, where a concentration of 10 g DW 100 mL^{-1} completely inhibited germination of *C. arvensis*and *C. inflate* (bindweed weeds). Different classes of compounds have been known to have a potential use as natural herbicides. Water-soluble extracts from all parts of itchgrass had inhibitory effects on the growth of *Bidenspilosa*, *Mimosa pudica*, *Ageratum conyzoides*, *Echinochloa crus-galli*, *Oryza sativa* and *Lactuca sativa* plants (Meksawat & Porn prom, 2010) [31].

Cultural control methods

Cultural control methods include any husbandry or management practice that enhances a crop ability to compete with weeds. Cultural weed control such as the critical period of weed competition, companion cropping, plant density, fertilizer manipulation, stale seedbed, cover crops, cultivation in darkness, intercropping, crop rotation and other agronomic practices play an important role and are successfully used for weed control in organic farming.

Stale seedbed technique

This technique involves preparing the seedbed several weeks before sowing in order to stimulate a flush of weeds, therefore reducing the weed seedbank likely to affect the crop. Moist conditions are essential to encourage weed emergence. Small weeds can then be removed with a very shallow harrow, or with a flame-weeder or an infra-red burner (Davies & Welsh, 2002) [10]. They have added that, in winter, delayed crop sowing is preferred because major weed problems can be greatly reduced, and this also gives an opportunity for stale seedbed approaches. The small loss in yield that is possible from delayed sowing is balanced by the reduced losses due to weeds.

New and nontraditional methods

There are some promising new and nontraditional measures that could be used for controlling weeds in organic farming. New and nontraditional weed control methods such as Infrared Radiation (IR), Electrical Weed Control (Slaughter *et al*., 2008), Lasers (Mathiassen *et al*., 2006), Microwave radiation (Brodie *et al*., 2007), Ultra Sonic weed Control Systems, Real-time intelligent robotic weed control system (Pérez-Ruiz *et al*., 2012) could be used for weed control under field conditions. However, they are still under development and are used in small areas, not on large scale.

References

1. Abouziena HF, El-Saeid HM, Amin AAE. Water loss by weeds: a review. Intern. J. of Chem Tech Res. 2014; 7(1):323-336
2. Abouziena HFH, Ahmad AMO, Sharma SD, Singh M. Comparison of some new natural product herbicides for weed control at two growth stages. Weed Technol. 2009; 23(3):431-437.
3. Awodoyin RO, Ogbeide FI, Oluwole, O. Effects of three mulch types on the growth and yield of tomato (*Lycopersicon esculentum* Mill.) and weed suppression in Ibadan, Rainforest-savanna Transition Zone of Nigeria. Trop Agric. Res. Exten. 2007; 10(1):53-60.
4. Baker B, Brown-Rosen E. Crop protection product formulation for the organic market. In: FELSOT, A. S.; RACKE, K. D. (Ed.). Crop protection products for organic agriculture: environmental, health, and efficacy assessment. Oxford: Oxford University Press, 2007.
5. Benedict JH. Strategies for controlling insect, mite and nematode pests In: Chrispeels, M.J. and D.E. Sadava (eds.). Plants, Genes, and Crop Biotechnology. Jones and Bartlett Publishers, Sudbery, MA, USA, 2003, 414-442.
6. Channappagoudar BB, Biradar NR, Bharmagoudar TD, Koti RV. Crop weed competition and chemical control of weeds in potato. Karnataka J Agric Sci. 2007; 20(4):715-718.
7. Chicouene D. Mechanical destruction of weeds. A review. Agron. Sustain. Dev. 2007; 27(1):19-27.
8. Cramer HH. Plant protection and world crop production. Bayer Pflanzenschutz-Nachr. 1967; 20:1-24.
9. Datta JK, Chakraborty T. Effect of organic manures and subabul (*Leucaena leucocephala*) leaf mulching under varying levels of fertility on growth and yield of potato (*Solanum tuberosum*) and weed biomass. Indian J Agron. 1995; 40(1):140-142.
10. Davies DHK, Welsh JP. Weed control in organic cereals and pulses. In: YOUNIE, *et al*. (Ed.). Organic cereals and pulses. Papers presented at conferences held at the Heriot-Watt University, Edinburgh; Cranfield University Silsoe Campus, Bedfordshire, 6 and 9 Nov. 2001. Bedfordshire: Chalcombe Publications, 2002, 77-114.
11. Dhaliwal GS, Arora R. Integrated Pest Management: Concepts and Approaches, Kalyani Publishers, New Delhi, 2015.
12. Dhaliwal GS, Arora R, Dhawan AK. Crop losses due to insect pests in Indian Agriculture: An update. Indian J Ecol. 2004; 31(1):1-7.
13. Dhaliwal GS, Dhawan AK, Singh R. Biodiversity and ecological agriculture: Issues and perspectives. Indian J. Ecol. 2007; 34(2):100-108.
14. Dhaliwal GS, Jindal V, Dhawan AK. Insect pest problems and crop losses: Changing trends. Indian J Ecol. 2010; 37(1):1-7.
15. Earthbound Organic. Organic Farming 101: Controlling weeds without chemical herbicides, 2006-2016. Disponible: http://www.ebfarm.com /Why Organic/ Organic 101. aspx. Accessed
16. Fayed MT, EL-Nagar, Fawzy HF. Performance of several weed control programs in peanut (*Arachis hypogaea* L.). lll yield components and chemical composition of peanut plants. In: conference Agronomy 5, Zagazig. Proceedings... Zagazig. 1992; 2:1072-1083.
17. Gianessi LP, Reigner NP. Review: the value of herbicides in U.S. Crop Production. Weed Technol. 2007; 21(2):559-566.
18. Grossman K. On the mode of action of the herbicides cinmethylin and 5-benzyloxymethyl-1, 2- isoxazolines: putative inhibitors of plant tyrosine aminotransferase. Pest Manag. Sci. 2012; 68(3):482-491.
19. Gupta OP, Chaudhary GR, Bansal RG, Didwania GD. Evaluation` of early period weed control in potato through herbicides. In, Abstracts. Weed Science conference and workshop in India, 1977.
20. Haidar MA, Sidahmed MM. Soil solarization and chicken manure for the control of *Orobanche crenata* and other weeds in Lebanon. Crop Protec. 2000; 19(1):169-173.
21. Hussein HF, Radwan SMA. Associative action between bio-organic farming & safety weed control methods on pea productivity. In: Symposium on scientific research and technological development outlook in the arab world, 3 Cairo. Proceedings... Cairo, 2004.
22. Inderjit Keating KI. Allelopathy: principles, procedures, processes, and promises for biological control. Adv. Agron. 67: 141-231.

23. Khalak A, Kumaraswamy AS. Weed biomass in relation to irrigation and mulching and economics of mulching potato crop under condition of acute water scarcity J Indian Potato Assoc. 1993; 20(3-4):185-189.
24. Khanh, TD, Hong NH, Xuan TD, Chung M. Paddy weed control by medicinal and leguminous plants from Southeast Asia. Crop Protec. 24(5):421-431
25. Kraehmer H, Baur P. Weed anatomy. London: Wiley-Blackwell, 2013, 504.
26. Lal SS. Weed management in potato .In Adv. in Hort.: Potato 7.Chadha KL and Grewal JS (eds): Central Potato Research Institute, Shimla India, 1993, 179-207.
27. Lal SS, Jaiswal VP. Investigation on the biology and management of weeds in potato. Annual Scientific Report CPRI, Shimla, India, 1990, 60-63.
28. Laloo. (Ecological studies of weed flora of different crop fields in high altitude and heavy rainfall area of Meghalaya. Flora and Fauna. 2004; 10(2):93-97.
29. Leinonen P, Närkki V. Lay-down working chart improves efficacy of hand weeding. 6th EWRS Workshop on Physical and Cultural Weed Control, 2004, 124.
30. Manorama K. Weed management in potato in nilgiris. J Indian Potato Assoc. 2004; 31(1/2):91-93.
31. Meksawat S, Pornprom T. Allelopathic effect of itch grass (*Rottboellia cochinchinensis*) on seed germination and plant growth. Weed Biol. Manage. 2010; 10(1):16-24.
32. Mishra JS, Singh VP, Yaduraju NT. Effect of methods of planting and metribuzin on weed growth and yield of potato (Solanum tuberosum) under vertisols. Indian J Agric Sci. 2002; 72(5):292-294.
33. Monaco TJ, Weller SC, Ashton FM. Weed science principles and practices. 4 ed. New York: John Wiley & Sons, 2002, 3-126.
34. Mukhopadhyay SK, Dhiman R, Chettri M, Ray D, Chettri M. Evaluation of Prometryn 50WP as a herbicide in potato (*Solanum tuberosum*) Oryssa J Hort. 2002; 30(1):64-67.
35. Nandekar DN. Efficacy of prometryn herbicide for weed management in potato under Satpura zone of Madhya Pradesh. Potato J. 2005; 32(1/2):91-92.
36. Nelson DC, Giles JF. Weed management in two potato (*Solanum tuberosum*) cultivars using tillage and pendimethalin. Weed Sci. 1989; 37:228-232.
37. Nelson DC, Thoreson MC. Competition between potatoes (*Solanum tuberosum*) and weeds. Weed Sci. 1981; 29:672-677.
38. Nice G, Johnson BA. comparison of "natural products" for organic production. West: Lafayette: Purdue Extension Weed Science,. 6 p. Disponible, 2009, <www.btny.purdue. edu/weedscience/. Accessed: 15, January 2016
39. Oerke EC. Crop losses due to pests. The J Agric Sci. 2006; 144:31-43.
40. Oerke, EC, Dekne HW, Schonbeck F, Weber A. Crop Production and Crop Protection-Estimated Losses in Major Food and Cash Crops, Elsevier Science, Amsterdam. Pimentel, D. and Peshin, R. (eds) 2014. Integrated Pest Management: Pesticide Problems, Vol. 3. Springer ScienceBusiness Media, Dordrecht, 1994.
41. Oliveira JR, Rios RS, Constantin FA, Ishii- Iwamoto J, Gemelli EL and Martini PE. Grass straw mulching to suppress emergence and early growth of weeds. *Planta Daninha*. 2014; 32(1):11-17.
42. Paizwar MS, Saxena P, Rizvi G, Saxena A. Isolation of fungi associated with Lantana camara. Flora and Fauna. 2005; 11(1):63-65.
43. Pandey J, Singh R, Verma AK. Influence of herbicides on weed management in true potato. *Act Agronomica Hungarica*. 2001; 49(2):183-187.
44. Panghal VS, Nehra VK, Khurana SC, Singh N. Effect of different doses of herbicides alone and their combination on weed flora and tuber yield of potato. Haryana Agric. University J Res. 2004; 38(2):163-165.
45. Parker C, Riches CR. Parasitic Weeds of the World biology and control. CAB International, 1993, 1-332.
46. Parker R. Water Conservation, Weed Control Go Hand in Hand. 2003-2016. Disponible: http://cru.cahe.wsu. edu/ CEPublications/em4856/em4856.pdf>. Accessed: 15, January
47. Patricio FRA, Sinigaglia C, Berros BC, Freitas SS Tessarioli Neto J, Cantarella H, *et al*. Solarization and fungicides for the control of drop, bottom rot and weeds in lettuce. Crop Protec. 2006; 25(1):31-38
48. Pradhan S. Assessment of losses caused by insect pests of crops and estimation of insect population In: N.C. Pant (ed.) Entomology in India, Entomological Society of India, New Delhi, 1964, 17-58.
49. Prasad K, Singh RS. Influence of weed control measures on weed growth, nutrient uptake and tuber yield of potato (*Solanum tuberosum*) Indian J Agric Sci. 1995; 65(1):46-48.
50. Prashanthi SK, Kulkarni S. *Aureobasidium pullulans*, a potential mycoherbicide for biocontrol of eupatorium (*Chromolaena odorata*)weed, *Current Sci* 88(1):18-21
51. Punia SS, Yadav D, Garg R, Lathwal OP. Weeed flora of potato in north eastern Haryana. Indian J weed Sci. 2007; 39(1/2)78-80.
52. Ramakrishna A, Hoang MT, Suhas, PW, Tranh. Effect of mulch on soil temperature, moisture, weed infestation and yield of groundnut in northern Vietnam. Field Crop Res. 2006; 95(2-3):115-125.
53. Rao S. Principles of weed science 2ed. New York: Science Publishers, 2000, 526.
54. Reddy RVS, Nanjappa HV, Krishnappa KS, Thirumalaraju, GT, Gowda TNV, Shankaranarayana V. Economics of chemical and cultural weed control methods in potato. J Indian Potato Assoc. 1993; 20(3-4):252-254.
55. Rood M. Ann. Long-haul organic. Rice J. 2004; 105(1):12-17.
56. Satour MM. Soil solarization: a non-chemical approach for control of soil borne pathogens & pests in Egypt, 1997. Disponible: http://www.mevic.org/papers/ solarization.html>. Accessed: 15, January2016
57. Schneider P. The cotton brief. New York Times, 1993, 1.
58. Schreiner RP, Kelly I, Pinkerton J. Soil solarization reduces arbuscular mycorrhizal fungi as a consequence of weed suppression. Mycorrhiza. 2001; 11(6):273-277.
59. Sharma. Production potential and economics of potato

under different schedules of irrigation, levels of potassium and methods of weed control. J Potassium Research. 1994; 10(3):278-281.
60. Shyam M, Singh R. Animal drawn implements for potato. Indian Farming. 1979; 29(5):21-24.
61. Silva PV, Monquero PA, Silva FB, Bevilaqua NC, Malardo MR. Influence of sugarcane straw and sowing depth on the emergence of weed species. *Planta Daninha*. 2015; 33(3):405-412.
62. Singh BN. Effect of periodic manual weeding on potato. Indian J Agron. 1982; 27:291-293.
63. Singh, Rawal SP, Sharma S, Dua SK, Sadaworty VK, Roy MJ, Singh BP. Evaluation of Propaquizafop – a new molecule as post emergence weedicide in potato. In, Abstracts. National seminar on climate change and smart agriculture technologies Gwalior, MP, India, 2015, 107-108.
64. Singh SP, Rawal S, Sharma SK, Dua VK, Sadaworty MJ, Roy S. Evaluation of herbicide Bentazone in potato (*Solanum tuberosum*). In, Abstracts. National conference on Dynamics of smart horticulture for Livelihood and Rural Development, Chitrakoot, Satna, MP:T5.2.3, 2015, 70-71.
65. Singh SP, Rawal S, Sharma SK, Dua VK, Sadaworty MJ, Roy S. evaluation of post emergence herbicide sulfosulfuron in potato (*Solanum tuberosum* L). In, Abstracts. Global conference on perspective of future challenges and options in agriculture, JISL, Dist. Jalgaon, Maharashtra, India, 2016, 60.
66. Singh TVK, Satyanarayanan J, Peshin, R. Crop loss assessment in India-Past experiences and future strategies. In: Pimentel, D. and R. Peshin (eds.) Integrated Pest Management: Pesticide Problems, Springer Science-Business Media, Dordrecht. 2014; 3:227-243.
67. Sopeña FMC, Morillo E. Controlled release formulations of herbicides based on micro-encapsulation, Literature Review. Cien. Invas. Agr. 2009; 35(1):27-42.
68. Soumya TM, Nanjappa HV, Ramchandrappa BK. Growth and yield of potato as influenced by residual effect of soil solarization. Mysore J Agric Sci. 2004; 38(4):509-513.
69. Stapleton JJ, Molinar RH, Lynn-Patterson K, Feeters SK, Shrestha A. Methyl bromide alternatives. Soil solarization provides weed control for limited-resource and organic growers in warmer climates. California Agriculture. 2005; 59(2):84-89.
70. Thakral KK, Pandita ML, Khurana SC. Effect of time of weed removal on growth and yield of potato. In Abstracts: Annual conference of Indian Society of Weed Science (undated), 1985, 16.
71. Thakral KK, Pandita ML, Khurana SC, Kallu G. Efficacy of cultural and chemical weed control methods in potato. J Indian Potato Assoc. 1989; 29:33-38.
72. Tripathi JS, Tripathi D. Structure of weeds in rab and kharif vegetable crops. International J Plant Sci. 2008; 3(2):636-638.
73. Unger PW, Kirkham MB, Nielsen DC. Water conservation for agriculture, soil and water conservation advances in the United States. New York: Soil Sci Society America, 2010, (Special Publication, 60)
74. Van Gessel MJ, Renner KA. Redroot pigweed (*Amaranthus retroflexus*) and barnyardgrass (Echinochloa crusgalli) interference in potatoes (*Solanum tuberosum*). Weed Sci. 1990; 38:338-343.
75. Vito MD. Effect of soil solarization and low doses fumigants control of the root-knot nematode Meloidogyne incognita. Acta Hortic. 2000; 532(1):171-173.
76. Wall DA, Friesen GH. Effect of duration of green foxtail (Setaria viridis) competition on potato (*Solanum tuberosum*) yield. Weed Technol. 1990a; 4:539-542.
77. Williams MM-II, Walsh DB, Boydston RA. Integrating Arthropod herbivory and reduced herbicide use for weed management. Weed Sci. 2004; 52(6):1018-1025.
78. Zimdahl RL. Fundamentals of weed science. 4ed. New York: Academic Press, 2013, 209.