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WEED CONTROL IN CLEAN AGRICULTURE: A REVIEW[1]

Métodos Alternativos de Controle não Químicos de Plantas Daninhas: Uma Revisão

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ABSTRACT - Weed control is consider 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.

Keywords: weeds, Safety methods, Mulch, Soil solarization, Natural herbicides, hot water, non-traditional methods.

RESUMO - O controle de plantas daninhas é considerado o maior obstáculo para os produtores de cultivos orgânicos. A baixa produtividade das plantas na agricultura orgânica está relacionada, principalmente, ao mau controle de plantas daninhas. Já se sabe que, na maioria dos casos, as perdas causadas por essas plantas ultrapassaram as perdas provenientes de qualquer categoria de pragas agrícolas. Em condições de estresse hídrico, as plantas daninhas podem reduzir o rendimento das culturas em mais de 50% apenas por meio da competição por umidade. Diante dos problemas ambientais e toxicológicos criados por herbicidas, tornou--se necessário desenvolver métodos de segurança para controle de plantas daninhas. Solarização do solo, cobertura morta, cobertura morta biodegradável, herbicidas naturais, água quente e práticas agronômicas foram adotados com êxito em muitos países como métodos seguros para controle de plantas daninhas na agricultura orgânica. Além disso, existem algumas medidas promissoras novas e não tradicionais, como lentes de Fresnel, controle elétrico de plantas daninhas, laser etc., que podem ser empregadas para controlar as plantas daninhas na agricultura orgânica. Além disso, práticas agronômicas, como a escolha de variedades competitivas e canteiros falsos, tiveram impacto significativo sobre as plantas daninhas. Os produtores de agricultura orgânica devem ter em mente estes três aspectos: 1) começar de modo limpo e manter limpo de forma bem-sucedida; 2) a prevenção é sempre melhor do que o tratamento; e 3) as sementes de um ano conduzirão à infestação por plantas daninhas durante sete anos. Os sistemas de manejo de plantas daninhas bem-sucedidos e sustentáveis são aqueles que empregam combinações de técnicas, em vez de depender de um único método. O objetivo deste artigo foi analisar alguns métodos seguros de controle de plantas daninhas em agricultura limpa.

Palavras-chave: sementes, métodos de segurança, cobertura morta, solarização do solo, herbicidas naturais, água quente, métodos não tradicionais.

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INTRODUCTION

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 & Baur, 2013).

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). While Rao (2000) 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.

Reduction in crop yield has a direct correlation with weed competition. Generally, an increase in one kilogram of weed growth corresponds to a reduction in one kilogram of crop growth (Rao, 2000). 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). In Australia and the USA, the cost of managing agricultural weeds exceeds 30 billion dollars per year (Lawes & Wallace, 2008).

In Egypt, Hussein (2001) has found that each 0.19 kg of weed dry matter has resulted in one kg loss in marketable onion bulb yield, allowing weeds to grow in association with crop plants up-to harvest has removed 36.9, 9.6 and 57.0 kg per acre of N, P and K elements from the soil, respectively. 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). 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). Riley et al. (2004) have found that beet yields were 135% and 123% after mulching, with and without hand-weeding, respectively, whilst cabbage yields were 124% and 118%, relatively to the weed control treatment.

Weeds were considered the most important pest group in a survey of organic vegetable growers (Gianessi & Reigner, 2007). 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).

Weed scientists are now facing new challenges, particularly in the light of the emergence of weeds resistant to herbicides and concerns and questions about herbicide residues in food, soil, groundwater-atmosphere.

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 (Li et al., 2003; Cox, 2006; Meksawat & Pornprom, 2010; Pot et al., 2011).

Soil solarization, mulching, hot water, Fresnel lens, biological control, natural herbicides and some cultural treatments have been successfully tried and were found to be effective and safe methods to control weeds (Riley et al., 2004; Khanh et al., 2005; Sahile et al., 2005; Benoit et al., 2006; Ramakrishna et al., 2006; Abouziena et al., 2008; Candidoa et al., 2011; Farooq et al., 2011; Abouziena et al., 2015).

IMPORTANT PROBLEMS OF WEED CONTROL IN ORGANIC FARMING

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).

Unavailable or limited herbicides candidate in clean 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).

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).

The costs of weed control in organic farming are more expensive

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). 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.

SAFETY METHODS OF WEED CONTROL IN CLEAN 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 & Reigner, 2007).

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 & Reigner, 2007).

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 & 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).

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).

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 & Sidahmed (2000) 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. Candidoa et al. (2011) have found that the average lettuce marketable yield was always found significantly higher in solarized soil than in untreated control in both greenhouse and in the field. Schreiner et al. (2001) 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.

Mechanisms of weed control 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 weaking or other mechanisms. Only clear (transparent) plastic reduced weed population for one year after solarization (Zimdahl, 2013). During solarization, the soil temperature is increased by 8 to 2 ^oC (Rao, 2000), In Egypt, soil temperature reached 69 ^oC, under solarization mulching (Fayed et al., 1997). 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. Patri et al. (2006) have mentioned that the concentrations of soil nutrients NH_4–N and DTPA-extractable-Mn sharply increased due to solarization.

Effect of soil solarization on weeds and yield

Soil solarization increased 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). Solarization for 6 weeks caused a significant reduction in fresh weight of total peanut weeds by 74% and increased pods and biological yields amounted to 62% and 78%, respectively, compared to unweeded checks (Fayed et al., 1997). Yields of onion, lettuce and carrot were significantly enhanced by solarization. Satour (1997) indicates that 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 1).

Parker & Riches (1993) 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%. They reported that solarization increased the yield of orange tree by 58% over noncovered treatment and the 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 2).

Table 1 - Soil solarization is an effective method for improving crop quantity and quality even in the absence of known pathogen(s)

Crop	Yield (t acre^{-1})		Increase (%)
	Non solar	Solar	
Onion	7.0	21.0	300
Strawberry	8.0	12.2	150
Broad-bean	0.9	1.4	155
Tomato	8.0	35.0	437
Potato	7.5	12.0	160
Cucumber*	12.0	35.0	292
Pepper*	16.0	24.0	150

* Under plastic houses. Source: Satour (1997).

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, and consequently increased marketable carrot yield compared to a nonsolarized one. Schreiner et al. (2001) have indicated that solarization had been just as effective as methyl bromide and vapam at the highest rate in controlling winter annual weeds measured 8 months after treatment. Stapleton et al. (2005) 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.

Economic feasibility of solarization

The cost of solarization was estimated as \$ 180-\$ 800 per acre (Satour, 1997). Economic feasibility of solarization depends on income increase, which is affected by yield increase and crop price. Additional factors to consider are the possibility of a long-term effect and benefits such as reduced usage of herbicides, prevention of outbreaks of new diseases, assurance for stable yield, and safety and reduced hazards to the environment. The use of old polyethylene (i.e., previously used) provides an extremely inexpensive method for solarization. Surprisingly, the use of old polyethylene was even more effectively than the new materials. This was attributed to changes in the photometric properties of the aged mulch.

Environmental, economic, and food safety concerns are among the many reasons why

Table 2 Yield increase of some crops due to soil solarization

Crop	Solarization period	Yield increase (%)	Reference
Tomato	Two months	195.5	Mauromicale et al. (2005).
	6 weeks	51.6	Sahile et al. (2005).
Potatoes	One month	86.3	Ngakou et al. (2006).
	One month	14.3	Megueni et al. (2011).
	One month	30.0	Mabong (2004).
Carrot	9 weeks	157.4	Marenco & Lustosa (2000).
Cabbage	2 weeks	130.2	Haidar & Sidahmed (2000).
Broccoli		64.0	Wang et al. (2008).
Strawberry	7 weeks	37.0	Stapleton et al. (2005).
Lettuce	Two months	23.9	Candido et al. (2011).
Soybean	Two months	80.0	Megueni et al. (2006).
Wheat	5 weeks	27.0	Singh et al. (2003).

some farmers choose organic production. Delate et al. (1999) have mentioned that certified organic soybeans in Iowa averaged a 250 percent premium price over conventional soybeans. On the environmental front, organic farmers hope to reduce the 240 million pounds of herbicides applied each year in the Midwest. Organic farmers also express concerns about weed resistance to herbicides and the transfer of herbicide-resistant genes to wild plants that may occur with increasing reliance on herbicide-resistant crops. Stapleton et al. (2005) have reported that the advantages of solarization include ease of use by the grower, relatively low treatment costs, and no hazards to the grower, workers or public, which is important as the urban agricultural interface. Solarization is acceptable for use in organic production, and no permits or pesticide reporting is required.

Limitations to using solarization in large scale agriculture

a) Solarization needs a large amount of plastic film for soil mulching. These materials tend to be bulky and difficult to apply. Besides, their disposal is a major problem. Environmental laws prohibit burning plastic waste, and when buried in the soil plastics are too slow in decomposing.

b) Solarization requires that land be rotated out of production for several weeks and months. This may interfere with normal cropping patterns. Fayed et al. (1997) have concluded that costs of solarization methods in Egypt are markedly higher than the economic return from the increases obtained in peanut yield. Moreover, controlling weeds with solarization mostly needs more than 5 weeks to achieve promising results and this will disturb crop rotation. Also, Zimdahl (2013) has indicated that solarization has potential to improve weed control management, but costs, compared to those of other methods, preclude widespread adoption in other than high value crops. In order to make soil solarization widely acceptable to farmers, improvements in the solarization process may need to be made. Mechanical application and new generation mulching materials such as photodegradable and biodegradable film may eliminate the disposal problem.

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, about LE 600 acre^{-1}, against LE 500 for herbicides and LE 300 for hoeing. It can be used for two seasons if carefully handled. Water saving is most important in the desert areas, especially in the vineyards using drip irrigation from deep wells, and water becomes the most expensive factor of production in such areas. Plastic mulching could be recommended in infected vineyards for its cost effectively control of weeds, to protect the environment from pollution and most importantly to save water and increase the grower's net income (Hegazi, 2000).

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 (Hussein & Radwan, 2004; Riley et al., 2004; Ramakrishna, 2006). 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 (Tolk et al., 1999).

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 (Monks et al., 1997, Silva et al., 2015). Synthetic mulches include polyethylene (plastic), polypropylene sheets or film (Rao, 2000). 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 & Radwan, 2004). Mulch has some effect on weeds such as *Cynodon dactylon*, *Sorghum halepense*, etc. (Rao, 2000). Riley et al. (2004) have mentioned that beet yields were 135% and 123% after mulching, whilst cabbage yields were 124% and 118%, with and without hand-weeding, respectively, relative to the unweeded treatment. Polythene and straw mulches had higher weed control efficacy than chemical control in groundnut fields (Ramakrishna et al. (2006).

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 (Hegazi, 2000; Awodoyin et al., 2007). 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 (Paul et al., 1997). 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).

Water hyacinth mulch produced the tallest plants with higher number of leaves and roots per plant, higher fresh and dry weight of bulb, length of bulb and highest yield per hectare. Bulb diameter and number of cloves per bulb were higher in black polyethylene mulch (Haque et al., 2003).

Mulch applications gave the higher early and total yield than control in melon and watermelon. In melon, early and total yields were increased with mulch applications about 5390% and 37-63% in organic and 59-100% and 35-59% in conventional areas. Early and total yields were found higher in mineral fertilizing and black mulch combinations by 2.63 and 5.39 kg m^{-2}, respectively. While in watermelon early and total yields were increased with mulch applications about 16-38% and 14-30% in organic, and 18-39% and 20-32% in conventional areas, respectively (Kurtar & CÝvelek, 2010).

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). 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). They have also noticed that in paddy fields weed biomass was reduced by 70-80% and rice yield was increased by an average of 20% relatively to unweeded.

Covering soil under mandarin trees with cattail or rice straw mulch (two layers) gave 85% to 98% weeds control (Abouziena et al., 2008). The most promising treatment producing the highest safety fruits production of mandarin was under black plastic mulch (Abouziena et al., 2014a). In onion field, clover weed mulch allowed onion to produce high marketable yield (Abouziena & Radwan, 2014).

According to Oliveira et al. (2014), 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 allelochemicals 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.

Effect of synthetic mulches

Traditionally, the introduction of synthetic mulches into agriculture, the mechanization of their application to meet the demands of large- and small-scale agriculture at reasonably low costs, and their favorable effects on yield and earliness and weed control favored the use of synthetic rather than organic mulched (Abdul-Baki & Teasdale, 1993). The use of 15 mm thick cellulose sheets (Kraft paper sandwiched between a biodegradable biopolymer layer of polylactic acid, one clear and the other pigmented with black carbon) for weed and insect control is the best envisioned for use in small orchards and provided adequate weed control (Benoit et al., 2006). A synthetic woven, black cloth is available for mulching. It is sold commercially in rolls about 6-feet wide and can be applied by machine when trees are planted. It is easy to spread and prevents the emergence of most annual weed seedlings (Zimdahl, 2013).

Effect of plastic sheet color

Soil temperatures are generally increased 1 to 3 °C for black and 3 to 5 °C for clear plastic sheets. This rise in temperature provides early season growth stimulation of crops which respond to elevated soil temperatures (cucumber, summer squash, watermelon, pepper, tomatoes, and sweet corn). Only opaque (brown or black) plastic sheets provide high weed control efficiency, primarily by restricting water and high penetration on the soil surface. Plastic mulches should not be used where creeping perennials are present (e.g., nutsedge), since these weeds can puncture the plastic, providing light to stimulate germination of additional weeds (Smeda & Weston, 1995). Himelrick et al. (1993) have mentioned that strawberry fields were mulched with six mulching color treatments, i.e., clear plastic, black, black on white, white on black and brown. They showed that the total yield with all treatments except white on black were significantly higher than for the control. They added that strawberry production was increased by covering the soil with plastic mulch and a non-clear effect was observed due to plastic mulch on vitamin C, Citric acid or total soluble solids. Hifny et al. (1994) have shown that the application of polyethylene either black or clear in five-year-old (Banaty) Thomson seedless grapevine for controlling weeds significant increased the yield components more than that of unmulched plots. The black polyethylene film was better than the clear one. Fayed et al. (1997) have stated that no treatment performed better than black polyethylene mulch for controlling peppermint weeds, and increased the total herb and oil yields per hectare, and black polyethylene mulch significantly exceeded those of hand hoeing or chemical treatments.

Rao (2000) has stated that when synthetic materials are used as mulch, white and black plastics are preferred. Silver plastic mulch significantly increased early and total yields of strawberry plants compared with bare soil (El-Shabasi et al., 2000). Saleh & El-Shabasi (2001) have found that black and clear plastic mulches treatments increased the total yield of strawberry with the superiority of clear plastic mulch. Abouziena et al. (2015) have found that black plastic mulch recorded the highest efficiency for controlling potatoes weeds than white, yellow and blue mulches and gave the highest tuber yield. Application of black plastic mulch caused a significant reduction in dry weight of broad-leaved, narrow-leaved and total weeds by 92, 100 and 93% at 75 days after planting, respectively. Rating of weed control percentage of less than 100% in soil mulch treatments was caused by weeds growing from the holes near the crop plant. They concluded that soil mulching by white or yellow plastics was ineffective, in most cases, to suppress weed growth. They also found that black plastic mulch increased tuber yield per hectare by 11.5% over hand-hoeing treatment.

Bond et al. (2003), in their review, have concluded that white and green coverings had little effect on the weeds, and brown, black, blue, and white on black (double colors) films prevented weeds from emerging. Sahile et al. (2005) have shown in three locations that *Orobanche* control was 97, 92 and 91% for white sheet cover, while black sheet cover gave 89, 88 and 86% control at the respective locations. Therefore they concluded that clear polyethylene sheets were slightly more effective than black ones.

Comparison between organic and synthetic mulches

Abdul-Baki & Teasdale (1993) have found that black polyethylene was superior to all other mulched (organic mulches) in enhancing earliness of tomato fruits, while the total tomato yield in the hairy vetch mulch was more than double the yield of the control (non-mulched) plants and significantly higher than the yield from the black polyethylene-mulched plots. Also, Hifny et al. (1994) have mentioned that growth parameters and yield of the seedless "Banaty" variety showed little response to straw mulch, relatively to white and black plastic mulches. Pederson (1999) has observed that organic mulches, and especially wood chip, were ineffective for perennial weeds control. The most efficient weed control was obtained by covering with plastic. Asphalt paper was prone to breaks, allowing weed growth. He has also found that fruit size increased following covering by straw and the content of potassium in the leaves of apple trees increased with organic materials. Meanwhile, Hussein & Radwan (2004) reported that black plastic mulch produced the highest pea yield, followed by rice straw mulch, and white polyethylene mulch came as third. Using plastic mulches (at 200 and 150 mm), two layers of cattail or rice straw mulch, and hand hoeing for controlling weeds resulted in the highest yield per tree without significant differences among these treatments (Abouziena et al., 2008).

Advantages of mulches

According to Müller-Sämann & Kotschi (1994); Farooq (2011); Abouziena et al. (2015) the advantages of soil mulching can be summarized as follows:

1) Weed control,
2) Reducing erosion,
3) Maintaining soil structure,
4) Water economy: results by McMillen (2013) have indicated that within the first 3 days a mulch layer of at least 5 cm reduced surface evaporation to 40% compared to water losses from bare soil, and all mulch types were equally effective. Doubling the mulch thickness from 5 cm to 10 cm maintained soil moisture 10% higher than the bare soil,
5) Improving root development,
6) Controlling soil erosion,
7) Enhancing soil chemical properties: mulch protects or even increases soil humus. It also brings about an increase in the cation exchange capacity, i.e., the soil capacity to store nutrients. Mulch stimulates the activity of soil organisms and organic matter is protected and enhanced. The availability of P, K and Mg was often significantly enhanced through mulching,
8) Soil life: there is no doubt that mulch has a positive effect on soil life, and
9) It increases the yield of crops.

Disadvantages of mulches

1) Established weeds are difficult to control with mulches.
2) The use of mulches is often limited by cost and availability.
3) Weeds such as field bindweed and nutsedge often have sufficient root reserves to enable them to penetrate thick mulches (>15 cm).
4) In warm climates, mulches quickly break down and require frequent replacement.
5) Plastic mulches should not be used where creeping perennials are present (e.g., nutsedge), since these weeds can puncture plastic, providing light to stimulate germination of additional weeds.
6) When crop residues are used as mulch, seeds from that crop may grow and create problems.

Hot water and steam treatment

Applications of hot water as a directed method of weed management between crop rows have been recommended. Water heated to 99 °C was applied over the top of weeds in a volume up to 4680 L ha^{-1}, with one application apparently effective on annual weeds and two applications exhibiting good control of perennial weeds such as Johnson grass (Smeda & Weston, 1995).

Pinel et al. (2000) have shown that using a self-propelled soil steaming machine raised temperatures to 100 °C in the top 10 cm of soil. Weed control reached 95-98% on bed surface and the majority of weeds recorded after treatment was wind-blown species. Five soil borne pathogens and native *Pythium* sp. were killed to a depth of 10 cm. On light soil, the effective kill depth increased to 15 cm. Hansson & Svensson (2004) have indicated, in preliminary results, that steam treatment can control *S. vulgaris* and *C. album.* It was not possible to show a significant weed control effect on *S. nigrum, S. physalifolium* and *Fallopia convolvulus* at the energy doses studied. One explanation for the insignificant effect may be that the soil temperature did not reach 70-80 °C in all parts of the treated soil volume, i.e., in the central part of the volume.

The energy dose required to achieve a 90% reduction in plant number (LD_{90}) was 850 L diesel ha^{-1}. The steam applicators used in the experiment were prototypes, i.e., there can be a great potential to decrease the energy use by technical development of the applicators. The steam treatment made it possible to reduce the working-hours for manual weed control (hoeing) from approximately 110 h ha^{-1} to 60 h ha^{-1}.

Deep steaming (6 minutes or more at 99-100) significantly reduced both the density (to about 5.3 % of untreated) and the percent cover (3.3%) of weeds, and the seed bank (to about 9%) in the soil compared with an untreated area (Sjursen & Netland, 2004). Yield increase was not consistent. At 10 cm soil depth, the temperature attained was minimum 70 °C in 6-9 minutes. At 20 cm soil depth the temperature was not always satisfactory. Shallow steaming in different salads and Chinese cabbage (about 2 minutes or more at 99-100 °C) significantly reduced the weed density and the seed bank (to about 1% of untreated). The yield was significantly increased. At 2 cm soil depth it achieved 70 °C or more in minimum 10 minutes. At 5 cm soil depth only a few times the temperature was not satisfactory. They added that according to the literature the lethal temperature of weed seeds is about 60-80 °C.

Stubble burning

Stubble burning is now banned because of the smoke and other hazards, but this traditional form of thermal weed control was used to reduce the number of viable weed seeds returned to the soil after cereal harvest (Bond et al., 2003). Soil surface temperatures under the burning straw reached in excess of 200 °C for 10-30 seconds and reduced the viability of freshly shed wild oat (*Avena fatua*) and black grass (*Alopecurus myosuroides*) seeds by up to 30% and 80% respectively. Current methods of thermal weed control use a variety of energy sources to generate the heat needed to kill weed seeds and seedlings.

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 & Keating, 1999).

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 & Johnson, 2009), 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). Cinmethylin, a natural herbicide produced by species of sage, controls many annual grasses and suppresses some broad-leaved weed species (Grossman et al., 2012). Different classes of compounds have been known for the potential use as natural herbicides.

Aqueous leachate of fresh leaves of *Eucalyptus globules* significantly suppressed the establishment of vegetative propagules and early seedling growth of the weeds (Chandra Bbu & Kandasamy, 1997). Good candidates for natural herbicides should have an activity between 10^{-5} and 10^{-7} M. Many phenolic compounds, alkoloids, and quinines, however, have an activity range of 10^{-2} -10^{-5} M and thus are poor candidates for natural herbicides (Inderjit & keating, 1999). Zimdahl (2013) has mentioned that one of the first phytotoxic compounds to be implicated in higher plants was 1,8-cineole. Cinmethylin was developed as a herbicide, but never used commercially for weed control in crops. It controls many annual grasses and suppresses some broad-leaved species. Bingaman & Christians (1995) have reported that Corn Gluten Meal (CGM) at rates of 100, 200, 300 and 400 g m^{-2} has reduced the percent of weed cover by 53, 76, 85, and 83%, respectively, compared to the control. They have added that CGM reduces germination of many broad-leaf and grass weeds. Xuan et al. (2004) have indicated that neem strongly inhibits germination and growth of several weeds. Abouziena et al. (2009) have examined the efficacy control of Alldown, Citric acid, Vineager, Acetic acid, CGM, Groundforce and Martan II as natural product herbicides and reported that Alldown applied to younger weeds had the maximum effect on broad-leaved weeds control, followed by Vinegar (30% acetic acid) > Citric acid > CGM > Household vinegar (5% acetic acid) > Groundforce and the lowest was Matran II treatments. There were nearly no detrimental effects of the herbicides on grass except the early postemergence of acetic acid at 30% and CGM.

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 & Pornprom, 2010).

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.

Selection of competitive varieties

Different varieties may vary in their canopy structure and growth characteristics and in turn influence the weed-suppressing ability (Mishra & Bhan, 1997). Cultivar competitive ability was associated with higher overall leaf area, resistance to loss of tiller under competitive pressure, greater height, canopy structure and development (Seavers & Wrigh 1999). Mirsha & Bhan (1997) have indicated that Pea 'JP 885' *cv.* showed a more significant reduction in weed population and weed dry matter than 'JMJ *cv.* and increase in grain yield. Hussein et al. (2001) have found that flax Giza 8 *cv.* was the most suppressive to weeds, followed by Ariane and then Belinka cultivars. Total dry weight of weed m^{-2} at 75 DAS in Giza 8 was lower than that of Ariane and Belinka cultivars by 42% and 53%, respectively. Moreover, Giza 8 *cv.* exhibited insignificant higher seed and oil yield per feddan than Belinka cv. by 9 and 10%, and greater than Ariane cv. by 12 and 11%, respectively. Fayed et al. (2002) have shown that faba bean *cv.* Giza 429 (*Orobanche* tolerant var.) had the lowest dry weight of *Orobanche* m^{-2} than other varieties. Faustini et al. (2004) have stated that earliness of flowering and an erect plant habit seemed to be the traits most related to crop competitive ability.

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). 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.

Stale seedbed has excessively delayed sowing time, thus inducing negative effects on crop seed yields of coriander, fennel, and psyllium crops (medicinal plants). Consequently, seed yield was 40-90% lower than in the untreated plots (Carrubba & Militello, 2013).

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.

Fresnel lens: an instrument that concentrates solar radiation to line or point.

Exposure of the dry soil surface for 1 to 10s at 290 °C has resulted in control of red root pigweed by 100%.

Fresnel lenses are used to concentrate solar radiation to a line or a point. A linear Fresnel lens (0.91 by 1.52 m, 0.74 m focal length, 0.01- by 1.52 m line focus) was investigated as a method for weed control. Field experiments were conducted to assess the effect of Fresnel lens concentrated solar radiation at various exposure times, stages of plant growth, and soil surface moisture conditions. On a dry soil surface, exposure times of 1 to 10s at 290 °C resulted in control of redroot pigweed from 100% for a 1s exposure at the cotyledon stage to 89% for a 10s exposure at the 10 leaf stage. Redroot pigweed control was similar at exposures of 3 to 10s, but less for kochia at 1 and 2s. Greenfoxtail control was less than that of kochia and redroot pigweed. Control was reduced on a moist compared to a dry soil surface. Concentrated solar radiation holds the greatest potential to control the small dicot weeds on a dry soil surface (Johnson et al., 1989). Johnson et al. (1990) have reported that the lens produced a line focus 1 by 150 cm with a mean temperature of 309 °C. A 20s exposure to seed on the soil surface was 100% lethal to greenfoxtail, kochia, lambsquarters, purslane, and wild buckwheat. In a separate study, emergence from kochia and yellow foxtail seed was reduced 100% at 10 mm soil depth after 15 min in soil of 35 and 93 g kg^{-1} moisture and 20 to 40% at 178 g kg^{-1} moisture content. Concentrated solar radiation from a Fresnel lens has the greatest potential for affecting weed seed on the soil surface. A series of Fresnel lenses and/or larger lenses may be required for many practical field applications.

Other safety weed control methods

Biological weed control and flame weeding are also used as alternative methods to synthetic herbicides for weed control in clean farming.

Finally, it could be concluded that successful and sustainable weed management systems are those that use an integration among techniques rather than depend on one method. Further research is needed for new technologies and methods for weed control in clean agriculture.

LITERATURE CITED

ABDUL-BAKI, A. A.; TEASDALE, J.M. A non-tillage tomato production system using hairyvetch and subterranean clover mulched. **Hortic. Sci.**, v. 28, n. 2, p. 106-108, 1993.

ABOUZIENA, H. F. et al. Comparison of weed suppression and mandarin fruit yield and quality obtained with organic mulches, synthetic mulches, cultivation, and glyphosate. **Hortsci.**, v. 43, n. 3, p. 795-799, 2008.

ABOUZIENA, H. F. et al. Comparison of some new natural product herbicides for weed control at two growth stages. **Weed Technol.**, v. 23,n. 3, p. 431-437, 2009.

ABOUZIENA, H. F.; EL-SAEID, H. M.; AMIN, A. A. E. Water loss by weeds: a review. **Intern. J. Chem. Technol. Res.**, v. 7, n. 1, p. 337-345, 2014.

ABOUZIENA, H. F.; ISMAIL, A. E.; RADWAN, S. M. Effect of bio-organic fertilizers, hoeing and polyethylene mulch on weeds, the citrus nematode (*Tylenchulus semipenetrans*) and yield of mandarin trees in Egypt. **Acta Adv. Agric. Sci.**, v. 2, n. 5, p. 10-26, 2014a.

ABOUZIENA, H. F.; RADWAN, S. M. Allelopathic effects of sawdust, rice straw, bur-clover weed and cogongrass on weed control and development of onion. **Intern. J. Chem. Technol. Res.**, v. 7, n. 1, p. 323-336, 2014b.

ABOUZIENA, H. F.; RADWAN, S. M.; ELDABAA, M. A. T. Comparison of potato yield, quality and weed control obtained with different plastic mulch colours. **Middle East J. Appl. Sci.**, v. 5, n. 2, p. 374-382, 2015.

AWODOYIN, R. O.; OGBEIDE, F. I.; 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.**, v. 10, n. 1, p. 53-60, 2007.

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.

BENOIT, L. D.; VINCENT, C.; CHOUINARD, G. Management of weeds, apple sawfly (*Hoplocampa testudinea* Klug) and plum curculio (*Conotrachelus nenuphar* Herbst) with cellulose sheeting. **Crop Protec.**, v. 25, n. 4, p. 331-337, 2006.

BINGAMAN, B. R.; CHRISTIANS, N. E. Greenhouse screening of corn gluten meal as a natural control product for broadleaf and grass weeds. **HortScience**, v. 30, n. 6, p. 1256-1259, 1995.

BOND, W.; TURNER, R. J.; GRUNDY, A. C. **A review of non-chemical weed management**. 2003. Disponible: <http://www.organicweeds.org.uk>. Accessed: 15, January 2016.

CANDIDOA, V. et al. Weed control and yield response of soil solarization with different plastic films in lettuce. **Sci. Hortic.**, v. 130, n. 3, p. 491-497, 2011.

CARRUBBA, A.; MILITELLO, M. Nonchemical weeding of medicinal and aromatic plants. **Agron. Sustain. Dev.**, v. 33, n. 3, p. 551-561, 2013.

CHANDRA, B.; KANDASAMY, O. S. Allelopathic effect of *Eucalyptus globules* Labill, on *Cyperus rotundus* L. and *Cynodon dactylon* L. Pers. **J. Agron. Crop Sci.**, v. 179, n. 1, p. 123-126, 1997.

CHICOUENE, D. Mechanical destruction of weeds. A review**. Agron. Sustain. Dev., v.** 27, n. 1, p. 19–27, 2007.

COX, C. Ten reasons not to use pesticides. **J. Pestic. Reform.**, v. 26, n. 2, p. 10-12, 2006.

DAVIES, D. H. K.; WELSH, J. P. 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. p. 77-114.

DELATE, K. et al. **Comparison of organic and conventional rotations at the Neely-Kinyon Long-Term Agroecological Res. (LTAR)** site: First year results. Leopold Center for Sustainable Agriculture Annual Report. Ames: Iowa State University, 1999.

EARTHBOUND ORGANIC. **Organic Farming** 101: Controlling weeds without chemical herbicides, 2006. Disponible: <http://www.ebfarm.com/WhyOrganic/Organic101.aspx>. Accessed: 15, January 2016.

EL-SHABASI, M. S. S.; SALEH, M. M.; GAAFER, S. A. A study on strawberry production under shaded tunnels, plastic mulch and different transplanting dates. **J. Agric. Sci. Mansoura Univ.**, v. 26, n. 6, p. 3883-3897, 2001.

FAROOQ, M. et al. The role of allelopathy in agricultural pest management. **Pestic Manage Sci.**, v. 67, n. 5, p. 493-506, 2011.

FAUSTINI, F. et al. First results on the competitive ability of lentil (*Lens culinaris*) genotypes. In: EWRS WORKSHOP ON PHYSICAL AND CULTURAL WEED CONTROL, 6., Lillehammer, 2004.

FAYED, M.T. et al. Efficiency of mechanical, physical and chemical weed control treatments under different plant spacings on weeds and yield of peppermint (*Mentha piperita* L.) plants. **Agric. Sci. Mansoura Univ.**, v. 22, n. 2, p. 495-509, 1997.

FAYED, M. T.; EL-NAGAR, S. M.; S. M.; FAWZY, H. F. 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, 1992. **Proceedings…** Zagazig: 1992. v. 2. p. 1072-1083.

FAYED, T. B. et al. Environmental impacts of integrated control for *Orobanche* in faba bean crop. **Egypt. J. Appl. Sci.**, v. 17, n. 1, p. 182-196, 2002.

GIANESSI, L. P.; REIGNER, N. P. Review: the value of herbicides in U.S. Crop Production. **Weed Technol.**, v. 21, n. 2, p. 559-566, 2007.

GROSSMAN, K. et al. On the mode of action of the herbicides cinmethylin and 5-benzyloxymethyl-1,2-isoxazolines: putative inhibitors of plant tyrosine aminotransferase. **Pest Manag. Sci.**, v. 68, n. 3, p. 482-491, 2012.

HAIDAR, M. A.; SIDAHMED, M. M. Soil solarization and chicken manure for the control of *Orobanche crenata* and other weeds in Lebanon. **Crop Protec.**, v. 19, n. 1, p. 169-173, 2000.

HANSSON, D.; SVENSSON, S. E. **Steaming soil in narrow strips for intra row weed control in sugar beet**. In: EWRS WORKSHOP ON PHYSICAL AND CULTURAL WEED CONTROL, 6., Lillehammer, 2004.

HAQUE, S. et al. Effects of natural and synthetic mulches on garlic (*Allium sativum* L.). **Asian J. Plant Sci.**, v. 2, n. 1, p. 83-89, 2003.

HEGAZI, A. Plastic mulching for weed control and water economy in vineyards. **Acta Hortic**. v. 536, n. 28, p. 245-250, 2000.

HIFNY, H. A.; BAGDADY, G. A.; ARAFA, M. S. Response of growth and yield of Banaty grapevine to soil mulch as a tool for weed control. **Egypt. J. Hortic.**, v. 21, n. 1, p. 81-92, 1994.

HIMELRICK, D. C.; DOZIER, J. R. W.; KRIDGE, J. R. A. Effect of mulch type in annual hill strawberry plastic culture systems. **Acta Hortic.**, v. 348, n. 1, p. 207-212, 1993.

HUSSEIN, H. F.; RADWAN, S. M. A. 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., 2004, Cairo. **Proceedings…** Cairo: 2004.

HUSSEIN, H. F. Estimation of critical period of crop-weed competition and nutrient removal by weeds in onion (*Allium cepa,* L.) in sandy soil. **Egypt. J. Agron.**, v. 24, n. 1, p. 43-62, 2001.

HUSSEIN, H. F.; EL-HARIRI, D. M.; HASSANEIN, M. S. Response of some flax (*Linum usitatissimum* L.) cultivars and associated weeds to weed control treatments. **Egypt. J. Agron.**, v. 24, n. 1, p. 23-42, 2001.

INDERJIT, KEATING, K. I. Allelopathy: principles, procedures, processes, and romises for biological control. **Adv. Agron.**, v. 67, p. 141-231, 1999.

ISMAIL, A. E. et al. Effect of soil heat management on growth and yield of Navel orange and control of citrus nematode, *Tylenchulus semipenetrans*. **B Faculdad. Agric. Univ. Cairo**, v. 48, n. 4, p. 683-706, 1997.

JOHNSON, D. W. et al. Response of monocot and dicot weed species to Fresnel lens concentrated solar radiation. **Weed Sci.**, v. 37, n. 6, p. 797-801, 1989.

JOHNSON, D. W. et al. Response of seed of 10 weed species to Fresnel-Lens-Concentrated solar radiation. **Weed Technol.**, v. 4, n. 1, p. 109-114, 1990.

KHANH, T. D. et al. Paddy weed control by medicinal and leguminous plants from Southeast Asia. **Crop Protec.**, v.24, n. 5, p.421-431, 2005.

KRAEHMER, H.; BAUR, P. **Weed anatomy**. London: Wiley-Blackwell, 2013. 504 p.

KURTAR, E. S.; CÝVELEK, C. Influences of organic and conventional fertilizing and mulching on yield and quality of melon and watermelon under protected cultivation. In: INTERNATIONAL CONFERENCE ON ORGANIC AGRICULTURE IN SCOPE OF ENVIRONMENT PROBLEMS, 2010, Famagusta. **Proceedings…** Famagusta: 2010. p. 51-54.

LAWES, R. A.; WALLACE, J. F. Monitoring an invasive perennial at the landscape scale with remote sensing. **Ecol. Manage Restor.**, v. 9, n. 1, p. 53-59, 2008.

LEINONEN, P.; NÄRKKI, V. Lay-down working chart improves efficacy of hand weeding. 6th EWRS Workshop on Physical and Cultural Weed Control 124, 2004.

LI, Y. et al. Research progress on microbial herbicides. (Review) **Crop Protec.**, v. 22, n. 2, p. 247-252, 2003.

MABONG, M. R. **Improvement of potato (*Solanum tuberosum* L.) production in Ngaoundere by the use of arbuscular mycorrhizal fungi**. (AMF). 34 f. 2004. Dissertacion (M.Sc.) – University of Ngaoundere, Ngaoundere, 2004.

MARENCO, R. A.; LUSTOSA, D. C. Soil solarization for weed control in carrot. **Pesq.Agropec. Bras.**, v. 35, n. 10, p. 2025-2032, 2000.

MAUROMICALE, G. et al. Soil solarization, a nonchemical method to control branched broomrape (*Orobanche ramosa*) and improve the yield of greenhouse tomato. **Weed Sci.**, v. 53, n. 6, p. 877-883, 2005.

McMILLEN, M. **The effect of mulch type and thickness on the soil surface evaporation rate**. San Luis Obispo: Horticulture and Crop Science Department/California Polytechnic State University, 2013. p. 1-14.

MEGYENI, C. et al. Responses of soybean (*Glycine max* L.) to soil solarization and rhizobial field inoculation at Dang Ngaoundere, Cameroon. **Asian J. Plant Sci.**, v. 5, n. 5, p. 832-837, 2006.

MEGUENI, C. et al. Weed control and yield improvement of *Solanum tuberosum* (L.) in Adamawa region (Cameroon) by soil solarization and chicken manure. **J. Appl. Biosci.**, v. 42, n. 6, p. 2867-2875, 2011.

MEKSAWAT, S.; PORNPROM, T. Allelopathic effect of itchgrass (*Rottboellia cochinchinensis*) on seed germination and plant growth. **Weed Biol. Manage.**, v. 10, n. 1, p. 16-24, 2010.

MISHRA, J. S.; BHAN, V. M. Effect of cultivar and weed control on weed growth and yield of pea (*Pisum sativum*). **Indian J. Agron.**, v. 42, n. 2, p. 316-319, 1997.

MONACO, T. J.; WELLER, S. C.; ASHTON, F. M. Weed science principles and practices. 4 ed. New York: John Wiley & Sons, 2002. p. 3-126.

MÜLLER-SÄMANN, K.M; KOTSCHI, J. **Sustaining growth:** soil fertility management in tropical small holdings. Weikersheim: Margraf Verlag, 1994. 486 p.

NGAKOU, A. et al. *Solanum tuberosum* (L.) responses to soil solarization and arbuscular mycorrhizal fungi inoculation under field conditions: growth, yield, health status of plants and tubers. **Middle East J. Sci. Res.**, v. 1, n. 1, p. 23-30, 2006.

NICE, G.; JOHNSON B. A comparison of "natural products" for organic production. West: Lafayette: Purdue Extension Weed Science, 2009. 6 p. Disponible: <www.btny.purdue.edu/weedscience/>. Accessed: 15, January 2016.

OERKE, E. C. Crop losses to pests. **J. Agric. Sci.**, v. 144, n. 1, p. 31-43, 2006.

OLIVEIRA, J. R. et al. Grass straw mulching to suppress emergence and early growth of weeds. **Planta Daninha**, v. 32, n. 1, p. 11-17, 2014.

OSSOM, E. M. et al. Effect of mulch on weed infestation, soil temperature, nutrient concentration, and tuber yield in *Ipomoea batatus* (L.) Lam. in Papua New Guinea. **Trop. Agric. Trinidad**, v. 78, v. 1, p. 144-151, 2001.

PARKER, C.; RICHES, C. R. "**Parasitic Weeds of the World**" biology and control. Wali Wallingford: CAB International, 1993. 332 p.

PARKER, R. "**Water Conservation, Weed Control Go Hand in Hand**". 2003. Disponible: <http://cru.cahe.wsu.edu/CEPublications/em4856/em4856.pdf>. Accessed: 15, January 2016.

PATRI, F. R. A. et al. Solarization and fungicides for the control of drop, bottom rot and weeds in lettuce. **Crop Protec.**, v. 25, n. 1, p. 31-38, 2006.

PAUL, P. et al. Tillage and crop residue management practices for sustainable dryland farming system. **Ann. Arid Zone**, v. 36, n. 3, p. 209-232, 1997.

PEDERSEN, H. L. Alternatives to herbicide use for controlling weeds in apple orchards. **R. Fruttic. Ortoflor.**, v. 61, n. 10, p. 81-83, 1999.

PINEL, M. P. C. et al. Control of soil-borne pathogens and weeds in leaf salad monoculture by use of a self-propelled soil-steaming machine. **Acta Hortic.**, n. 532, n. 14, p. 125-130, 2000.

POT, V. et al. Metribuzin transport in undisturbed soil cores under controlled water potential conditions: experiments and modeling to evaluate the risk of leaching in a sandy loam soil profile. **Pest Manage Sci.**, v. 67, n. 4, p. 397-407, 2011.

RAMAKRISHNA, A. et al. Effect of mulch on soil temperature, moisture, weed infestation and yield of groundnut in northern Vietnam. **Field Crop Res.**, v. 95, n. 2-3, p. 115-125, 2006.

RAO, S. **Principles of weed science**. 2 ed. New York: Science Publishers, 2000. 526 p.

RILEY, H.; BRANDSÆTER, L. O.; DANIELSBERG, G. Mulching compared to physical weed control measures in organically grown vegetables. In: EWRS Workshop on Physical and Cultural Weed Control, 6., 2004, Lillehammer. **Proceedings…** Lillehammer: 2004.

ROOD, M. A. Long-haul organic. **Rice J.**, v. 105, n. 1, p. 12-17, 2004.

SAHILE, G.; ABEBE, G.; AL-TAWAHA, A. M. Effect of soil solarization on *Orobanche* soil seed bank and tomato yield in Central Rift Valley of Ethiopia. **World J. Agric. Sci.**, v. 1, n. 1, p. 143-147, 2005.

SALEH, M. M.; EL-SHABASI, M. S. S. Effect of clear and black plastic mulch and clear polyethylene low tunnels on yield and fruit quality of strawberry plants. **J. Agric. Sci. Mansoura Univ.**, v. 26, n. 6, p. 3899-3906, 2001.

SATOUR, M. M. 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, January 2016.

SCHNEIDER, P. **The cotton brief**. New York Times: 1993. p.1.

SCHREINER, R. P.; KELLY, I.; PINKERTON, J. Soil solarization reduces arbuscular mycorrhizal fungi as a consequence of weed suppression. **Mycorrhiza**, v. 11, n. 6, p. 273-277, 2001.

SEAVERS, G. P.; WRIGHT, K. J. Crop canopy development and structure influence weed suppression. **Weed Res.**, v. 39, n. 4, p. 319-328, 1999.

SILVA, P. V. et al. Influence of sugarcane straw and sowing depth on the emergence of weed species. **Planta Daninha**, v. 33, n. 3, p. 405-412, 2015

SINGH, V. P. et al. Residual effect of different durations of soil solarization and weed control measures on weed growth and productivity of wheat (*Triticum aestivum* L.) in soybean-wheat system. **Indian J. Weed Sci.**, v. 35, n. 3&4, p. 221-224, 2003.

SJURSEN, H.; NETLAND, J. Thermal weed control by steaming in vegetable crops. In: 6th EWRS Workshop on Physical and Cultural Weed Control, 6., Lillehammer, 2004. **Proceedings…** Lillehammer: 2004. p. 179.

SMEDA, R. J.; WESTON, L. A. Weed management systems for horticultural crops. In: SMITH, A. E. (Ed.). **Handbook of weed management systems**. New York: Marcel Dekker, 1995. p. 553-570.

SOPEÑA, F. M. C.; MORILLO, E. Controlled release formulations of herbicides based on micro-encapsulation, Literature Review. **Cien. Invas. Agr.**, v. 35, n. 1, p. 27-42, 2009.

STAPLETON, J. J. et al. Methyl bromide alternatives: Soil solarization provides weed control for limited-resource and organic growers in warmer climates. **California Agric.**, v. 59, n. 2, p. 84-89, 2005.

TOLK, J. A.; HOWELL, T. A.; EVETT, S. R. Effect of mulch, irrigation, and soil type on water use and yield of maize. **Soil Tillage Res.**, v. 50, n. 1, p. 137-147, 1999.

UNGER, P. W.; KIRKHAM, M. B.; NIELSEN, D. C. **Water conservation for agriculture, soil and water conservation advances in the United States**. New York: Soil Science Society America, 2010. (Special Publication, 60)

VITO, M. D. et al. Effect of soil solarization and low doses fumigants control of the root-knot nematode *Meloidogyne incognita.* **Acta Hortic.**, v. 532, n. 1, p. 171-173, 2000.

WANG, G.; MCGIFFEN Jr., M. E.; OGBUCHIEKWE, E. J. Crop rotation effects on *Cyperus rotundus* and *C. esculentus* population dynamics in southern California vegetable production. **Weed Res.**, v. 48, n. 5, p. 420-428, 2008.

XU, H. et al. Integrated dryland weed control in nature farming systems. **J. Food Agric. & Environ.**, v. 7, n. 3&4, p. 744-749, 2009.

XUAN, T. D. et al. Evaluation on phytotoxicity of neem (*Azadirachta indica*. A. Juss) to crops and weeds. **Crop Protec.**, v. 23, n. 4, p. 335-345, 2004.

ZIMDAHL, R. L. **Fundamentals of weed science**. 4 ed. New York: Academic Press, 2013. 209 p.