Journal of Research in Weed Science

Journal homepage: www.jrweedsci.com

Orginal Research Article

Bio-economic assessment of non-chemical weed management strategies in minor crops: A review on Weed research issues, challenges, and opportunities in Pakistan

Muhammad Asad [a,*], Zahid Mahmood[b], Muhammad Mudassar[c], Adnan Arshad[d], Muhammad Umair Raza[e], Wajiha Anum[f]

a Department of Agronomy, PMAS Arid Agriculture University Rawalpindi.

b Wheat Wide Crosses Programme, National Agriculture Research Center (NARC) Islamabad, Pakistan.

c Department of Environmental Economics, Pakistan Institute of Developmental Economics, Pakistan.

d Stockholm international water institute (siwi), Sweden

e Lok sanjh foundation, Islamabad

f Department of Agronomy, Regional Agricultural Research Institute Bahawalpur, Pakistan

ARTICLE INFORMATION

Received: 7 January 2019

Revised: 8 February 2019

Accepted: 9 February 2019

Available online: 9 February 2019

DOI: 10.26655/JRWEEDSCI.2019.3.4

KEYWORDS

Assessment

Bio-economic

Minor crops

Non-chemical

Weed research

ABSTRACT

Availability of herbicides inflicts to adopt an integrated use of weed control methods (other than chemical methods) in minor crops. In Pakistan more than 70% farmers have land less than 5 ha, so it is improvident to employ very costly chemical and mechanical weed control methods. At present, the resource conservation technology is widely adopted, so it is a major challenge to develop a sustainable, reliable and integrated weed management system. As in minor crops, sustainable production contributes in agricultural production as well as food security and food supply; therefore, it is important for national economies and human health. Excessive use of herbicides over a long time make leads herbicide resistant weeds. There are some factors including shifting ability of weed population, increase in environmental concerns and increase in cost of management, all these factors made farmers difficult to control resistant weeds within their limited resources. It is proved from previous research that selection of viable seed and the use of different cultural practices maybe conceivable strategy to decrease weed competition. Our focus in this review article is on the utilization of these practices to reduce the competitive ability of weeds, for their proper management in minor crops. Our basic aim of this article is to assist researchers in the design of eco-friendly and economically viable weed management strategies, which will help in reducing the herbicides liability and mechanical cultivation from farmer's production costs.

Corresponding author, email: asadarid786@gmail.com (Muhammad Asad).

Introduction

In Pakistan, Agriculture is considered as the lifeline of its economy accounting for 42.3% employing for the labor force, 19.5% of the gross domestic product and make available raw material for numerous value-added productions (Asad et al., 2017). Pakistan is considered by inclusive climatic diversity, which deals with great prospects for growing a variety of vegetable crops during the year (Tahir and Altaf, 2013). Therefore, production of vegetable is properly varied in terms of a range of grown species (Ahmad et al., 2005). In Pakistan more than thirty-seven different types of fruits and vegetables are grown in various ecosystems, rainfed to irrigated land, from low to high elevation areas and different input systems (greenhouses). Potato, tomato, brinjal, chilli, cucumber, gourds and okra are profusely obtainable through summer, whereas gourds, okra, cucumber and beans are commonly grown throughout the rainy season. As all the provinces of the country have varied agro-climatic conditions, it contributes to the production of different types of vegetable crops with diverse production restraints (Damalas and Khan, 2017).

Augmented use of chemicals imperils soil, air and water contamination, as lot of environmental health threats associated with these chemicals (Mehdizade et al. 2017). Approximately 60% of the vegetable farmers had an adequate knowledge about the use of pesticide, while only 6.4% of the vegetable farmers revealed high levels of knowledge and just 12.9% are able to get information. Obviously, less information about the pesticide use made farmers to misuse of pesticides, aggregate the possibility of adverse health effects on themselves, the environment and the customers, also menacing the pest control sustainability (Damalas and Khan, 2017). In developing countries, for pest and weed management a wide range of pesticides is used in agricultural areas however lots of farmers are not sufficiently educated about the hazards related to the chemicals (Ngowi et al., 2007; Obopile et al., 2008; Sibanda et al., 2000).

By the virtue of faster growth and high adaptability of weeds, they dominate the habitat of crop and reduce the potential of yield in crop (Dnyaneshwar et al., 2018). By analyzing 200 different vegetables, collected from diverse marketplaces of Hyderabad in Pakistan, it is indicated that certain pesticide residues are present in all investigated pesticides (Latif et al., 2011). Evidently, farmers were not following safety measures with respect to pesticides use and the essential pre-harvest interims, i.e., the time among the last pesticide application and the harvest of treated crops (Latif et al., 2011). Therefore, monitoring of pesticides in commodities by the country's authorities and imposing procedures established on permitted confines is important (Syed et al., 2014). Farmers are routinely exposed to high levels of pesticides, usually much greater than consumers (Damalas and Khan, 2016). However, precautions are required in pesticides selection as residues left on the plants may cause health dangers to animals and people. Since there is an overuse of

harmful chemicals, research on integrated weed management with minimum use of pesticides has to be undertaken as significance (Damalas, 2016). Previous research has revealed misuse of pesticides for cotton crop in Pakistan with poor levels of knowledge on its application among farmers (Khan and Damalas, 2015; Khan et al. 2015).In this perception, there is a necessity that researchers, policy makers and shareholders are together dedicated to decrease the herbicides use and develop eco-friendly and healthy tools for non-chemical IWM. The objective of this article is to call for inflated research efforts in the field of non-chemical IWM in minor crops, offering some ideas on weed management strategies without using chemicals that could be convenient to develop useful and viable results for Pakistani weed scientists and farmers.

Challenges in weed management in Pakistan

In Pakistan a number of weed management methods, such as biological, mechanical, chemical and manual control approaches, have been working for weeds control in different crops (Kandhro et al., 2014). The excessive use of chemical herbicides throughout the past few years has consumed severe environmental concerns, such as dominance of minor weeds, weed population shifts and weed resistance (Chauhan et al. 2012). One of the main problems related with the use of chemical for weed control is an extreme drain of soil residuals; a solemn ecological distress (Khaliq et al. 2011). There is no entrance to farm technology and mortgages for the farmers with small landholdings to obtain essential farming inputs for the weeds management in main crops. The high price of inputs ruins a main interruption for farmers around the world, including Pakistan (Ali et al. 2013). Shortage of labor, increased incomes, augmented distresses of human health, and ecological deprivation are creating weed control gradually difficult (Khaliq et al. 2011).

Conceivable Weed Management Technologies and Their Adoption

Increase in yield of wheat could occur by 50-70% by the usage of amended different weed control techniques (Ashrafi et al. 2009). Amongst agronomic rehearses, row orientation, seeding density and row spacing are of enormous position, impelling the weed dynamics and crop-weed intrusion (Matloob et al. 2015).

Prevention Method

The primary target is to keep weeds from spreading and to evade the growth of new weed species. This point can be refined by following these fundamental principles: make use of the seeds with high rate of purity and cleanness; always clean mechanical tools if they have worked in a weed

infested field; sieve the irrigation water to avoid water from sluggishness use an effective hydraulic system, binge of some persistent weeds (e.g. *Cirsium arvense* L.) Scop., *Equisetum spp*.) and less crop yield; take out weeds that are arduous to be precise, before their spread (Graziani et al., 2008). In extremely infested fields, it is prescribed to evade species cultivation with deprived competitiveness, for example, garlic, onion, carrot, and leek. It is also discreet to evade asparagus and medicinal plants cultivation in existence of perennial weeds (Lichtenhahn et al., 2005). In the glasshouse, the protective methods are depend on sanitation and incorporate the subsequent actions: evade to present weed propagules (rhizomes, seed, tubers, and so on.) in the glasshouse by utilizing sterilized substrates; acquaint with only "clean" plant constituents; control of weeds outer of the glasshouse; screen vents and different openings to confine the windblown seed introduction; use a physical obstruction, for example, block fabric of weed to limit the establishment of weed on glasshouse bases; frequently hand pull any absconded weeds afore their distribution (Neal, 2015).

Row Orientation

As solar energy is ample in Pakistan, change in row orientation and its impact on weed density in agronomic crops has not been examined yet. Availability of light effects on plant and is essential in regulating the crop-weed competition (Ballaré and Casal, 2000). Thus, management of crop row layout and coordination is a consistent way to increase the interception of light by reducing the light interception and by the crop canopy (Chauhan, 2012; Chauhan and Johnson, 2010). Direction of rows vertical to the sun light increases water and light use efficiency in crop; and subsequently, as a result an increase in crop yield occurs. Several scientists have described condensed in density and biomass of weed when crops were angled at a right angle to daylight, with no additional costs of implementation and a small number of negative effects on farming systems (Borger et al. 2010). Similarly, it is reported that by suppressing in growth of weeds by sowing crop in rows right angle to the light increased crop yield (Hozayn et al. 2012). It is alleged that crops angled east-west as an alternate of south-north could blind weeds in inter-row spaces and would overturn the population of weed to a longer range.

Crop Establishment

High vigor seeds of crop and a sufficient depth of seed sowing are essential in order to have a consistent plant emergence and a deep-rooted crop that result in a high affordability of crop in contrast to weeds (Pannacci et al. 2017). As transplanted crops have their early competitive capability alongside weeds so preferred to sown crops. Moreover, a transplanted crop has a smaller

critical period of rivalry and chemical or mechanical control of weed is easy to carry out. Increased in plant population is used successfully to reduce row spacing and therefore it helps crop effectiveness (Norris et al. 2001; Uludag et al. 2003). In many crops (tomato, pepper and cabbage) paired rows are also used to stimulate competitiveness of crop. However sometimes transplant is limited (in an IWM system) due to: a) high price of transplanted crop plants (e.g. pepper, tomato); b) adverse influence of high crop density on vendible yield (e.g. lettuce and cabbage); c) requirement of sufficient inter-row space to permit mechanical weed control (e.g., carrot, coriander, onion and fennel) (Bastiaans et al. 2008). In winter cereal crops (where only flex-tine harrow can be used) a greater space for inter-row could be assumed to permit the usage of other mechanical tools for example precision hoe or traditional hoe (Pannacci et al. 2016).

Brush-weeder

The operational tool of revolving brush weeder is a brush on polypropylene attached on a horizontal or vertical axis and driven by tractor; weeding feat is due to gashing and deracinating. Vertical brush weeder eradicates weeds on intra-row space while horizontal brush weeder controls weeds on inter-row space. In horizontal weeder, brushes can be attuned on horizontal alliance to adequate with inter-row space and crop plants are secure by armors. Soil is cultured shallowly to evade the new weeds emergence. It is mostly used in different crops (i.e. lettuce, tomato, carrot, spinach, chicory etc.) with 0.20-0.25 m to 0.40 m inter-row space (Tei et al. 2002; Turner et al. 2007).

Finger-weeder

Finger-weeder works both in intra-row and inter-row crop line to control weeds, especially in greenhouse and horticultural crops with inter-row space from 0.30 m to 0.50 m (i.e., radish, common bean, tomato, celery, spinach, onion, lettuce, French's bean, chicory, leak, fennel, carrot, etc.) (Table 1). Intra-row weeding is attained by rubber finger weeders containing two pairs of wheels furnished with rubber fingers thrilling the surface of soil. Two attached wheels come across in the crop row, during the procedure small weeds pull out (Figure 3). Depth differs from 10-30 mm (Table 1). Very precise routing is essential for finger weeder to work nearby the crop rows and its usage is acclaimed when crop plants are well-rooted; thus, at the same time finger-weeder can cultivate maximum six crop rows and its speed differs from 4-5 km h^{-1} (Table 1). Research on horticultural crops have revealed a short efficiency beside weeds over the 2-4 true leaves stage, in clay soils and a small discernment of crop plants (Ascard and Bellinder, 1996; Kurstjens and

Bleeker, 2000). Finger weeding on onion crop (preserved when crop was at the stage cotyledonal) had 50% efficiency (with a density 182 plants m^{-2} in *Portulaca oleracea* L. and 27 plants m^{-2} in *A. retroflexus*) beside weeds and produced 25% decrease in crop density (Pannacci et al. 2008). Similar field situations were used in a study on spinach: inter-row space for this crop was 0.25 m and at 4-6 true-leaves stage finger weeder was used; due to the use of finger-weeder weed density decreased by 68% (Tei et al., 2002). In transplanted tomato, with 1m inter-row space, it can be used from the crop growth stage i.e. 2-3 leaves on main shoot outspread to 8-9 leaves, attaining a good value in weed controlling and a good discrimination toward crop plants. In contradiction of a high invasion rate of E. *crus-galli*, A. *retroflexus*, P. *oleracea* and C. *album*, finger weeder revealed a weeding action lesser than 65% because in clay soil at 2-4 true leaves stage it was impotent to control weeds. Finger weeder joined with a split-hoe can be used successfully to increase weeding action in low weed density and in poor soil situations (Table 1) (Pannacci and Tei, 2014).

Table 1. Intra-row mechanical weed tools features.

Mechanical weed control tools	Torsion-weeder	Flex-tines harrow	Finger-weeder
Soil texture	better in loose and not condensed soils	better in loose and uncompact soils	better in loose and uncompact soils
Weed action	burying and uprooting	burying and uprooting	burying and uprooting
Inter-row distance	from 20-25 cm to 75 cm	-	from 25-30 cm to 40-50 cm
Working depth	1-3 cm	1-3 cm	1-3 cm
Optimum crop growth stage	well-rooted (from 4 true-leaves) stage	well-rooted (from 4 true-leaves) stage	well-rooted (from 4 true- leaves) stage
Optimum weed growth stage	cotyledon to 2 true-leaves stage	cotyledon to 2-4 true-leaves stage	cotyledon to 2-4 true-leaves stage
Work capacity (ha h^{1}) having fixed working width	0.5 (150 cm)	2.5 (600 cm)	0.5 (150 cm)
Suitable crops	Tomato, common bean, leak, fennel, celery, lettuce, cabbage	chickpea, common bean, onion, carrot, pea, minor cereal, lentil,	Tomato, cabbage, common bean, leak, lettuce, fennel, spinach, carrot

Torsion Weeder

By connecting spring tines pairs having 45 mm radius with a rigid frame is known as torsion weeder. There are two parts of spring tine i.e. the first one is a horizontal, angled part jagged to crop plant and the second one is a vertical axis of 0.3 to 0.4 m barbed to the surface of soil.

Generally, torsion weeder is attached as precision hoe on more sophisticated machine (Table 1). By using different tools (e.g. sweep, hoe and blade) precision hoe is made to improve tilling of soil and commonly, it complete torsion weeder's action by working on inter-row space (Peruzzi et al. 2005). Efficiency of torsion weeder has been proved mostly in greenhouse crops and horticultural crops (i.e. cabbage, fennel, tomato, celery, leak, lettuce and common bean). According to (Ascard and Bellinder, 1996), the production yield of onion was same either we use chemical weed control or we use torsion weeder. Torsion weeder had 80–per cent weeding action in leek (Kurstjens and Bleeker, 2000). For the experiments on sugar beet and maize crops, torsion weeder revealed good consequences, specifically against small weeds; the optimal stage for the growth of weed is from cotyledon to two leaves stage (Table 1). Selectivity of crop is a good tool setting as well as persuaded at the stage of crop growth (Kurstjens and Bleeker, 2000; Peruzzi et al. 2006; Raffaelli et al. 2005). Predominantly, torsion weeder should be used to minimize damage in crop when plants are at the growth stage of 2-4-true-leaves.

Case Studies

In minor crops to consider the diversity and complexity of weed management, it is convenient to recapitulate four "case studies" drawn by (Lichtenhahn et al. 2005). In all these four case studies it can be noted that when infestation level increase, the number of treatments will also be increased. Flaming and flex-tine harrow would be applied in pre-transplant or pre-sowing after preparing a proper seedbed. Both these two methods of non-chemical weed control may also be applied for deep sowing or slow sowing crops (e.g. carrot, onion, beans and fennel) in pre-emergence condition. For better weed control in transplanted crops having large inter-row distance, brush-weeder (traditional hoe with rigid shanks) combined with finger-weeder are used for inter-row and intra-row weed control respectively. It seems the best strategy for weed control specifically for those crops having high competition ability i.e. cabbages. At advanced crop growth (before inter-row closure) stage to control intra-row weeds ridging can also be applied (Fig. 1). In order to control weeds more efficiently, manual weeding and split hoeing combined with the above mentioned strategy can also be used in transplanted crops (i.e. lettuce, onion) having less or no competitiveness (Figure 1).

For proper weed control in crops having longer critical period, less inter-row distance, small seedlings and lower competitiveness in their growth cycle, manual weeder and finger-weeder for intra-row weed control, combined with split-hoeing or brush-weeder for inter-row weed control should be used (Figure 2). Base on the crop growth stage, inter-row width and level of infestation all these treatments would be frequent during all the critical period. To obtain a higher weed

control in leafy crops (leaf beet, lettuce, chicory, spinach), it is essential to use manual weeding; it may also be helpful in weed absence in the harvested product (Figure 2).

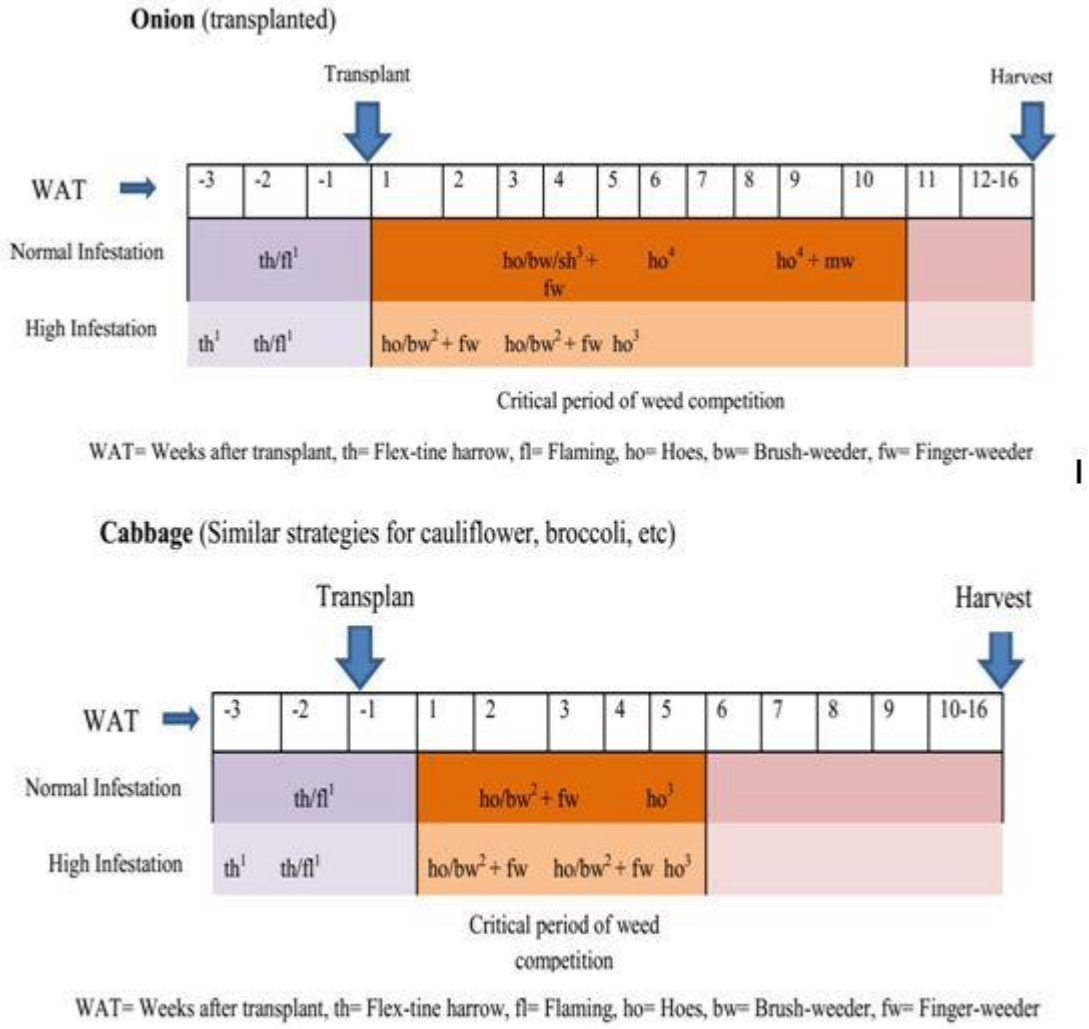

Figure 1. Non-chemical weed control strategies for two "case studies" in transplanted crops (from Lichtenhahn et al. 2005; modified).

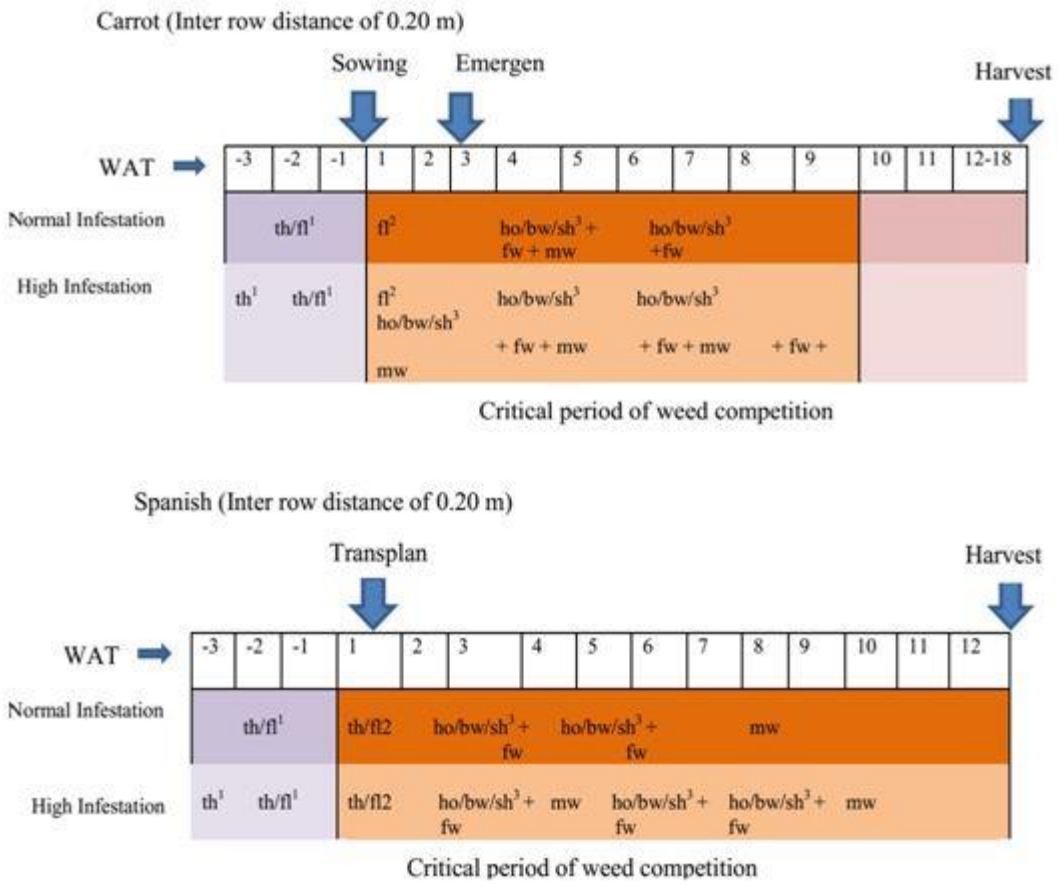

Figure 2. Non-chemical weed control strategies for two "case studies" in sown crops (from Lichtenhahn et al. 2005; modified).

Figure 3. Finger weeder in action on soybean (a); finger weeder: special-flat share type "Holland" and discs equipped with rubber fingers (b) (photos by Pannacci Euro).

Conclusion

One of the most serious reasons for environmental degradation in Pakistan is that the farmers are unaware regarding the excessive use of chemicals, with high risk of herbicide resistance. For such situations, the only possible options for the farmers are sustainable and economically viable approaches, with the aim to alleviate the negative effect of weeds. Reliable options for farmers to reduce their input costs with same level of net benefits are incorporation of cultural practices, and their manipulation. However, more research will be needed to regulate perceptions of farmers about different approaches of cultural weed management, as well as more extension work is required to teach them how they can increase their capacity to adopt these cultural practices at farm level. By providing regular funding (regional, international or European), modern research can make available sustainable and effective strategies against the problems related to non-chemical weed management in minor crops. Moreover, if the weed problem is for long term we need to use all accessible solutions combined with non-chemical integrated weed control strategies. For nonchemical weed management in minor crops our modern research technology should emphasis on the existing gaps. Generally where chemical herbicides are insufficient or unavailable, mechanical and physical methods for weed control play an important role in minor crops. In last few decades, mechanical weed control method was impressive, but it needs further improvement in order to implement the precision technologies for farming system. Advanced methods (i.e., freezing, infrared, lasers, microwave, ultraviolet radiation, lasers and electrocution) are not however used for weed science, then it might be a fascinating field of study to grow the profitable apparatuses for weed control, particularly for greenhouse crops. At the end, in present time the breeding programmes for minor crops is not a priority by our scientist, but it seems to be a research area which needs to be more investigated just because of its potential as a cultural method.

Acknowledgments

The authors are appreciative to Dr. Muhammad Rasheed for his kind help in linguistic editing of this review article. Authors also outspread thanks to three reviewers for their appreciated remarks on the former manuscript drafts.

Conflict of Interest

Authors declare no conflict of interest.

References

Ahmad M, Akhtar M, Anwar M. 2005. Basmati rice: progress, issues and prospects for rice crop in Pakistan. Soil Environ. 30: 50-57.

Ali H, Abid S, Ahmad S, Sarwar N, Arooj M, Mahmood A, Shahzad A. 2013. Impact of integrated weed management on flat-sown cotton (*Gossypium hirsutum* L.). J. Anim. Plant Sci. 23: 1185-1192.

Asad M, Mahmood Z, Rasheed M, Ramzan A, Mudassar M. 2017. Efficacy of Some Selective Herbicides against Broad Leaved Weeds of Wheat Crop Grown Under Moisture Deficit Conditions of Pakistan. Turkish J. of Weed Sci. 20: 38-45.

Ascard J, Bellinder R. 1996. Mechanical in-row cultivation in row crops. *In* "2. International Weed Control Congress, Copenhagen (Denmark), 25-28 Jun 1996". SP.

Ashrafi Z.Y, Sadeghi S, Mashhadi H.R. 2009. Study of integrate methods chemical and cultural control of weeds to wheat (*Triticum aestivum* L.). J. Agri. Sci. 1: 113.

Ballaré C.L, Casal J.J 2000. Light signals perceived by crop and weed plants. Field Crops Res. 67: 149-160.

Bastiaans L, Paolini R, Baumann D. 2008. Focus on ecological weed management: what is hindering adoption? Weed Res. 48: 481-491.

Borger C.P, Hashem A, Pathan S. 2010. Manipulating crop row orientation to suppress weeds and increase crop yield. Weed Sci. 58: 174-178.

Chauhan B.S. 2012. Weed ecology and weed management strategies for dry-seeded rice in Asia. Weed Technol. 26: 1-13.

Chauhan B.S, Johnson D.E. 2010. Implications of narrow crop row spacing and delayed Echinochloa colona and Echinochloa crus-galli emergence for weed growth and crop yield loss in aerobic rice. Field Crops Res. 117: 177-182.

Chauhan B.S, Mahajan G, Sardana V, Timsina J, Jat M.L. 2012. Productivity and sustainability of the rice–wheat cropping system in the Indo-Gangetic Plains of the Indian subcontinent: problems, opportunities, and strategies. *In* "Advances in Agronomy", Vol. 117, pp. 315-369. Elsevier.

Damalas, C. A. 2016. Safe food production with minimum and judicious use of pesticides. *In* "Food Safety", pp. 43-55. Springer.

Damalas C.A, Khan M. 2016. Farmers' attitudes towards pesticide labels: implications for personal and environmental safety. Int. j. of pest manag. 62: 319-325.

Damalas C.A, Khan M. 2017. Pesticide use in vegetable crops in Pakistan: Insights through an ordered probit model. Crop prot. 99: 59-64.

Dnyaneshwar J, Pawar P, Sutar M, Jadhav M, Pinjari S, Meshram N. 2018. Effect of weed management practices on Kharif rice-A review. J. Res. Weed Sci. 1: 99-109.

Graziani I, Eliasz S, De Marco M.A, Chen Y, Pass H.I, Richard M, Strack P.R, Miele L, Bocchetta M. 2008. Opposite effects of Notch-1 and Notch-2 on mesothelioma cell survival under hypoxia are exerted through the Akt pathway. Cancer res. 68: 9678-9685.

Hozayn M, El-Shahawy T, Sharara F. 2012. Implication of crop row orientation and row spacing for controlling weeds and increasing yield in wheat. Aust. J. Basic Appl. Sci. 6: 422-427.

Kandhro M.N, Tunio S, Rajpar I, Chachar Q. 2014. Allelopathic impact of sorghum and sunflower intercropping on weed management and yield enhancement in cotton. Sarhad J. Agri. 30.

Khaliq A, Riaz M.Y, Matloob A. 2011. Bio-economic assessment of chemical and non-chemical weed management strategies in dry seeded fine rice (*Oryza sativa* L.). J. Plant Breed. Crop Sci. 3: 302-310.

Khan M, Damalas C.A. 2015. Farmers' knowledge about common pests and pesticide safety in conventional cotton production in Pakistan. Crop Prot. 77: 45-51.

Khan M, Mahmood H.Z, Damalas C.A. 2015. Pesticide use and risk perceptions among farmers in the cotton belt of Punjab, Pakistan. Crop Prot. 67: 184-190.

Kurstjens D, Bleeker P. 2000. Optimising torsion weeders and finger weeders. *In* "Workshop EWRS Physical Weed Control, Elspeet, 2000".

Latif, Y, Sherazi S, Bhanger M. 2011. Assessment of pesticide residues in commonly used vegetables in Hyderabad, Pakistan. Ecotoxicol Environ. Saf. 74: 2299-2303.

Lichtenhahn M, Koller M, Dierauer H, Baumann D. 2005. Weed control in organic vegetable cultivation. Research Institute of Organic Agriculture (FiBL).

Matloob A, Khaliq A, Tanveer A, Wahid A. 2015. Dry matter accumulation and growth response of zero tilled direct seeded fine rice to different weed competition durations and sowing times. Int. J. Agri. Biol. 17.

Mehdizadeh M, Alebrahim M.T, Roushani M. 2017. Determination of Two Sulfonylurea Herbicides Residues in Soil Environment Using HPLC and Phytotoxicity of These Herbicides by Lentil Bioassay. Bull Environ. Contam. Toxicol. 99: 93-99.

Neal J. 2015. Greenhouse Weed Control-Horticulture Information Leaflet. NC Cooperative Extension Resources. Available on line at: NC State University.

Ngowi A, Mbise T, Ijani A, London L, Ajayi O. 2007. Smallholder vegetable farmers in Northern Tanzania: Pesticides use practices, perceptions, cost and health effects. Crop Prot. 26: 1617-1624.

Norris R.F, Elmore C.L, Rejmánek M, Akey W.C. 2001. Spatial arrangement, density, and competition between barnyardgrass and tomato: I. Crop growth and yield. Weed Sci. 49: 61-68.

Obopile M, Munthali D, Matilo B. 2008. Farmers' knowledge, perceptions and management of vegetable pests and diseases in Botswana. Crop Prot. 27: 1220-1224.

Pannacci E, Lattanzi B, Tei F. 2017. Non-chemical weed management strategies in minor crops: A review. Crop prot. 96: 44-58.

Pannacci E, Tei F. 2014. Effects of mechanical and chemical methods on weed control, weed seed rain and crop yield in maize, sunflower and soyabean. Crop prot. 64: 51-59.

Pannacci E, Graziani F, Guiducci M, Tei F. 2008. Controllo meccanico delle malerbe in colture da seme di cipolla. In: Proceedings of Research Project "Azioni di innovazione e ricerca a supporto del piano sementiero. PRIS2 Progetto di ricerca interregionale, Programma "Sviluppo Rurale" e Sottoprogramma "Innovazione e Ricerca, pp. 265-275.

Pannacci E, Tei F, Guiducci M. 2016. Mechanical weed control in organic winter wheat. In: Proceedings XLV Congress of Italian Society for Agronomy, Sassari, Italy, 20-22 September 2016, pp. 115-116.

Peruzzi A, Ginanni M, Mazzoncini M, Raffaelli M, Fontanelli M, Ciolo S.D, Fantoni E, Costa I, DI COLO M, Boschetti I. 2006. Il controllo fisico delle infestanti su spinacio in coltivazione biologica ed integrata nella Bassa Valle del Serchio.

Peruzzi A, Ginanni M, Mazzoncini M, Raffaelli M, Fontanelli M, Di Ciolo S, Verna P, Casaccia D, Recinelli E. 2005. La gestione fisica delle infestanti su carota biologica e su altre colture tipiche dell'altopiano del Fucino.

Raffaelli M, Barberi P, Peruzzi A, Ginanni M. 2005. Mechanical weed control in maize: evaluation of weed harrowing and hoeing systems. Agricoltura Mediter. 135: 33-43.

Sibanda T, Dobson H, Cooper J, Manyangarirwa W, Chiimba W. 2000. Pest management challenges for smallholder vegetable farmers in Zimbabwe. Crop prot. 19: 807-815.

Syed J.H, Alamdar A, Mohammad A, Ahad K, Shabir Z, Ahmed H, Ali S.M, Sani S.G.A.S, Bokhari H, Gallagher K.D. 2014. Pesticide residues in fruits and vegetables from Pakistan: a review of the occurrence and associated human health risks. Envir. Sci. Pollu. Res. 21: 13367-13393.

Tahir A, Altaf Z. 2013. Determinants of income from vegetables production: A comparative study of normal and off-season vegetables in Abbottabad. Pak. J. Agric. Res. 26.

Tei F, Stagnari F, and Granier A. 2002. Preliminary results on physical weed control in processing spinach. *In* "Proceedings 5 th EWRS Workshop on Physical and Cultural Weed Control", pp. 164-171. Citeseer.

Turner R, Davies G, Moore H, Grundy A, Mead A. 2007. Organic weed management: a review of the current UK farmer perspective. Crop Prot. 26: 377-382.

Uludag A, Bohren C, Bulcke R, Demirci M, Dobrzanski A, Froud-Williams R.J, Hoek H, Rocha F, Stagnari F, Tei F. 2003. A review of weed control management in green peas. Vegetable Crops Res. Bulle. 59: 5-16.

Cite this article as: Muhammad Asad, Zahid Mahmood, Muhammad Mudassar, Adnan Arshad, Muhammad Umair Raza, Wajiha Anum. Bio-economic assessment of non-chemical weed management strategies in minor crops: A review on Weed research issues, challenges, and opportunities in Pakistan. *Journal of Research in Weed Science*, 2019, 2(2), 127-140. DOI: 10.26655/JRWEEDSCI.2019.3.4