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

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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 imprudent 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 to 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 makes 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.

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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 \textit{Portulaca oleracea} L. and 27 plants m\(^{-2}\) in \textit{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 \textit{E. crus-galli}, \textit{A. retroflexus}, \textit{P. oleracea} and \textit{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).

\textbf{Table 1.} Intra-row mechanical weed tools features.

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

\textit{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).

<table>
<thead>
<tr>
<th>Normal Infestation</th>
<th>High Infestation</th>
</tr>
</thead>
<tbody>
<tr>
<td>th/th1'</td>
<td>th1/II'</td>
</tr>
<tr>
<td>th1'</td>
<td>th1'/II'</td>
</tr>
<tr>
<td>th1'</td>
<td>th1'</td>
</tr>
</tbody>
</table>

Critical period of weed competition

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.

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Conflict of Interest

Authors declare no conflict of interest.
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