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Review and outlook of weed management in Pearl millet

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Abstract
Pearl millet is an important staple food in arid and semi-arid tropics of Asia and Africa. Low productivity and susceptibility to biotic and abiotic factors are the major causes for declining area and productivity of millets in India. As the pearl millet is grown predominantly in the hot and humid rainy season, weeds deprive these crops of vital nutrients and moisture and bring down the yield considerably. Because of wider row spacing and slow initial growth in pearl millet, weeds are more problematic during initial crop growth period, and therefore, early control is required to optimize the yield. The aim of this report is to critique the research that has been conducted pertaining to diverse aspects of weed management in pearl millet while also identifying key knowledge gaps that should be addressed in future research. Literature indicates that satisfactory weed control can be achieved by integration of pre-emergence herbicides with one manual/mechanical weeding. Additionally, future research is needed to evaluate the post-emergence herbicides that are the best suited for pearl millet and pearl millet based intercropping systems to improve weed control and reduce environmental impacts, including herbicide residues.

Keywords: crop-weed competition, herbicides, losses, pearl millet, *striga*, weeds

Introduction
Among the cereals, pearl millet [*Pennisetum glaucum* (L.) R. Br. emend. And Stuntz] is one of the most important and extensively cultivated crops. Pearl millet is a warm weather coarse cereal grown in a semi-arid and arid climate of tropical and sub-tropical regions of the country and has the potential to contribute substantially to food, fodder and nutritional security. Because of their drought tolerance, pearl millet can be cultivated in areas that are often too hot and dry for other crops to be grown. It is grown during rainy and summer season. As Pearl millet is grown predominantly in warm rainy season, weeds of different kinds deprive the crop. Weed management is an important factor for enhancing the productivity of pearl millet, as weeds compete for nutrient, water, light, and space; reduce crop yield and quality with crop plant during the early growth period. Weeds cause the lower grain and straw yields of *kharif* pearl millet. Pearl millet grows slowly at first and is a relatively poor competitor with weeds during the first few weeks of development. Planting in wider rows to help inter-row cultivation and/or ditch furrow irrigation worsens the problems. Because the crop canopy forms slowly and provide little shading of weeds between the rows until midseason; by then, most weeds are well established. When improved agricultural technologies are adopted, efficient weed management becomes even more important, otherwise, the weeds rather than the crops benefit from the costly inputs.

Losses due to weeds
Weeds compete with crops for nutrients, soil moisture, sunlight and space when they are limiting, resulting in reduced yields, lower grain quality and increased production costs. The magnitude of losses depends on crop cultivars, the nature, and strength of weeds, spacing, duration of weed infestation, environmental conditions and management exercises. Yield loss due to weeds is given (Table 1). The nutrient depletion by weeds in Pearl millet is up to 61.8 kg N, 5.6 kg P and 57.6 kg K/ha, this was reported by (Ram *et al*. 2004).

Table 1: Losses due to weeds in pearl millet

Reduction in grain yield (%)	Reference
40	Sharma and Jain, 2003 [22]
55	Banga *et al*, 2000 [2]
16-94	Balyan *et al.* 1993 [1]
31-46	Gautam and Kaushik, 1984 [10]
35-90	Umarani *et al.* 1980 [25]

The critical period of crop-weed competition

In the rainy season, weeds emerge in succession almost throughout the crop season. Getting rid of weed competition any time during the growing season is not desired. Time of weed removal is as important as removing *per se*. 'Critical period' defines the maximum period weeds can be endured without affecting final crop yields (Zimdahl, 1988) [27]. This provides data on the active duration when the presence of weeds makes their deleterious effect on crops (Table 2). Pearl millet is very susceptible to competition from weeds early in the lifespan of the crop. Therefore, efficient weed control at the pre- and early post-emergence stages is all important. At one time the crop reaches approximately 0.5 m in height, weed control no longer affects yield. Pearl millet-weed competition is mostly determined by moisture availability. Singh and Singh (2010) [24] obtained low weed density in narrow rows without cultivation than in wide rows.

Critical periods (DAS)	Reference
28-42	Singh *et al.* 1986

Weed flora of Pearl millet in India

A mixed population of broad-leaved, grasses and cyperaceous weeds grows with pearl millet crop in India (Table 3).

Table 3: Major weeds of Pearl millet in India

Broad-leaved	Grasses	Sedges
Ageratum conyzoides, Alhagi camelorum, Ageratum conyzoides, Amaranthus viridis, A. spinosus, Borreria articularis, Commelina benghalensis, Celosia argentea, Corchorus olitorius, Corchorus aestuans, Canabis sativa, Chrozophora rottleri, Cleome viscose, Convolvulus arvensis, Croton bonplandianum, Digera arvensis, Euphorbia geniculata, E. hirta, Eclipta alba, Fumaria parviflora, Ipomoea purpurea, Leucas aspera, Oxalis latiifolia, Phyllanthus niruri, Striga asiatica, Sonchus arvensis, Trianthema portulacastrum, Tridax procumbens	*Brachiaria ramose, Brachiaria eruciformis, Brachiaria ramose, Cynodon dactylon, Dactyloctenium aegyptium, Digitaria sanguinalis, Digitaria marginata, Digitaria ciliaris, Echinochloa colona E. crus-galli, Eleusine aegypticum, Ischene despaire, Paspalum paspaloides, Panicum dichotomiflorum, Panicum repens, Saccharum spontaneum, Sorghum halepense*	*Cyperus rotundus, C. esculentus, C. iria, Eragrostis major, Fimbristylis diphylla*

Control strategies

1. **Mechanical weeding:** Manual and mechanical weeding is by far the most widely adopted method of weed control in millets. Hand weeding or inter-row cultivation provides reasonable weed control. But during the rainy time of year, there are not many open days and as a result, inter-culture operations have to be delayed and this helps weed to overtake the crops and cause a severe reduction in output. Also with rising labor wages and non-availability of adequate labor at times required, it is becoming a serious problem to control weeds manually on a larger area at the proper time. Patel *et al.* (2013) [4] concluded that lowest weed density and highest weed control efficiency is obtained by doing inter-culturing *fb* HW at 20 and 40 DAS.
2. **Cultural operations:** Growing of mungbean, groundnut, cowpea, soybean etc. as intercrops in sorghum/pearl millet could exert suppressing effect on weeds. Similarly, narrow row spacing, use of higher seed rate, early application of nitrogen and its positioning near to plants can assist in increasing the dynamism of the crop and exert smothering effect on weeds. Kaur and Singh (2006) [9] obtained that mulching @ 21 DAS effectively control the weed infestation and increase the production of the harvest. Growing of intercrops in a widely spaced row not only reduces the intensity of weeds but also gives an additional yield. Although intercropping may reduce weed infestation and growth, there is, however, a need for some level of weed management in most shells. Choudhary *et al.* (2012) concluded that intercropping of pearl millet with green gram at 2:2 pair row ratio was clearly superior over sole pearl millet and found most profitable by making the highest net return and LER. While second weeding may be needed in sole crop, this is frequently not required in intercropping since the canopy coverage is nearly complete and weeds growth after the first weeding is minimal. Manual or mechanical weed control is the main method in intercropping systems. Most of the herbicides are crop specific and thus, can't be used in intercropping systems. Use of pendimethalin (0.75-1.0 kg/ha), metolachlor (1.0 kg/ha), Butachlor (0.75-1.0 kg/ha) has been found safe and effective in intercropping systems. Metolachlor was, nevertheless, not effective against *Celosia argentea*.
3. **Chemical control:** he delay in manual weeding and inter-cultivation could be due to uncertain weather conditions. Thus, chemical weed control has a place in pearl millet weed control strategy. Chemical control or herbicide application is advantageous in case of non-availability of labor and/or very high monetary value of labor for manual weeding. Use of correct herbicides will provide a completely weed-free situation to the crop whereas manual or mechanical weeding can be done only after the emergence of weeds. Use of chemicals (herbicides) to control weeds should be grounded on their relative advantage over the manual and mechanical control of weeds. Herbicide application requires some knowledge about the use of such chemicals. Improper use of herbicides may lead to the complete loss of the crop. Depending upon the chemicals they may be used either before planting of the crop (pre-planting e. g. fluchloralin), after planting but before the emergence of the crop (pre-emergence e.g., atrazine, metolachlor, pendimethalin) or after the emergence of the crop (post-emergence e. g. 2, 4-D). Lower doses of saflufenacil (50 g/ha) may be safely applied as near as 7 days before planting pearl millet. If the situation demands, saflufenacil at 36 g/ha can also be applied as a pre-emergence to either crop with the risk of any crop injury (Reddy *et al.* 2014) [21]. Several herbicides have been

evaluated for weed control efficacy and crop safety in pearl millet (Table 4). At present atrazine is the only herbicide most commonly used as pre-emergence for weed control in millets at various doses?

Table 4: Herbicides recommended for Pearl millet

Herbicide	Time of application	Dose (kg/ha)	Type of weeds controlled	Notes	References
Atrazine	Pre-emergence/ early post-emergence	0.50	Broad spectrum weeds control. Some grasses are tolerant	For sole crop only	Munde *et al*. 2015
Pendimethalin	Pre-emergence	0.75-1	Effective control of grasses	Suitable for intercropping	Ram *et al*. 2005 [18]
Oxadiazon	Pre-emergence	1	Annual grasses and broad-leaved weeds	For sole crop only	Ram *et al*. 2005 [18]
2,4-D (ethyl ester)	Post-emergence	0.50-0.75	Effective against broad-leaved weeds	For sole crop only. Apply at 4-6 weeks after planting. Good as sequential application to pre emergence herbicides	Singh and Singh, 2010 [24]
Saflufenacil	Pre-emergence	0.05	Broad spectrum weed control	For sole crop only	Reddy *et al.* 2014 [21]

4. IWM with herbicides as a component: Research on IWM was carried out to use herbicide as a component of weed management rather than using herbicides alone.

Like crop rotations, Cropping Systems and herbicides, tillage and herbicides as components of IWM, integration of crop competitiveness with herbicides, integration of herbicides with mulching and integration of hand weeding with herbicides. In cropping system legumes provide nutritious food and feed, increase soil fertility through biological nitrogen fixation, reduce disease/insect pest incidence, add organic matter and help conserve farming resources, and provide for more flexible weed control. As pearl millet showed allelopathic ability, allelopathy holds promise as a possible component of IWM to reduce weed population. Researchers' analyses indicated a different type of IWM approaches and most common is an integration of hand weeding with herbicides.

Economics of IWM

Economic analyses are needed for arriving at management decisions by farmers, policy-making by administrators and setting research priorities by researchers. The fundamental economic principle for weed management is simple: act only if the benefits exceed the cost (King *et al.* 1998) [11]. Every researcher may not agree, but farmers' decision-making mostly depends on the economic benefits of the available weed management options. Researchers' economic analysis of IWM options (Table. 5) indicated that herbicide application followed by hand weeding was most economical.

Table 5: Most economical IWM methods for managing weeds

IWM	Reference
Intercropping of pearl millet with green gram at 2:2 pair row ratio	Choudhary *et al.* 2012 [3]
Pendimethalin at 1.50 kg/ha + HW 40 DAS	Shinde *et al*. 2003 [23]
Atrazine 1000 g/ha PE *fb* HW at 30 DAS	Patel *et al.* 2013 [4]
Atrazine 750 g/ha PE *fb* HW at 30 DAS	Mishra *et al.* 2017 [14, 15]
Interculturing *fb* HW at 20 and 40 DAS	Patel *et al.* 2013 [4]
Hand weeding + interculturing at 35DAS	Munde *et al.* 2012 [16]
Oxadiazon each at 1.0 kg/ha supplemented with hand-weeding once at 45 DAS	Baldev *et al.* 2003
Closer line sowing at 30 cm.	Singh and Singh, 2010 [24]
Pendimethalin 0.75 kg/ha PE supplemented with one HW at 6 WAS	Mathukia *et al.* 2015 [12]
Fluchloralin at 1.0 kg a. i./ha + HW at 40 DAS	Virkar *et al.* 2007 [26]
Oxyfluorfen fb hand weeding at 25 DAS	Deshveer and Deshveer, 2005 [5]
Mulch application at4 t/ha	Kaur and Singh, 2006 [9]

Striga in Pearl millet

Striga is a major biotic constraint in the subsistence agriculture and causes considerable crop damage in millets in the semi-arid tropics. Depending upon the extent of the infestation, 30-60% of the reduction in grain yield can occur. Striga infestation is most severe in low moisture and low fertility soils. An adaptation of *Striga* to parasitism includes not only depends upon a host plant for metabolic inputs such as water, minerals, and energy, but also for developmental signals. In this way, parasite and host development are highly integrated. The early host-derived chemical signals *Striga* requires, for seed germination and for initiation of the haustorium by which it bonds to the host roots, are exuded from host roots into the soil. After *Striga* penetrates the host root, subsequent developmental signals are apparently exchanged directly, through vascular tissue. Germination stimulants for most *Striga* hosts have been identified as strigol-type compounds (strigolacetates).

Control measures: Physical control: Hand pulling at too early stage may break the shoot and reduce the rapid growth. Sparse infestation should be hand pulled shortly before flowering to prevent a build-up of seed. Such hand pulling should continue through to harvest and beyond so long as flowering is occurring.

1. **Cultural control:** It has been noted that pearl millet plant shading can restrict Striga growth when generous soil fertilizer is used. In areas of high rainfall, factors such as high plant populations recommended fertility levels, and good weed control encourages lush crop growth and shading in spite of Striga parasitism. This is not feasible in moisture-stressed rain-fed areas. Crop rotation should be practiced with trap crops which stimulate Striga seeds to germinate without themselves being parasitized. Crops

claimed to be effective include: cotton, sunflower, groundnut, castor, Dolichos bean, and linseed. Unfortunately, once a severe infestation has developed, it may require many years to reduce Striga population in the field of the non-damaging level.

2. **Chemical control:** As Striga is a broadleaf plant, pre-plant herbicides such as Atrazine, Goal, and Flex show some effect though not efficient enough to be excused. Post-emergence use of 2, 4-D is effective when sprayed on the Striga leaves. Though down in price, pearl millet is vulnerable to stalk twisting and lodging if 2, 4-D is sprayed into the leaf whorl. Spraying should only be performed by trained labor and cautioned to the hazards.

In summary, control of Striga infestation is difficult and calls for an integrated approach. Non-host crops must be rotated (for two years in heavily infested fields) with pearl millet varieties.

Adopting safe practices will help to reduce Striga effect in pearl millet crop:

- plant populations and fertility adjusted for soil moisture available to maximize shading,
- weeding and Striga control by hand pulling and perhaps limited 2,4-D spraying, and lastly
- Careful not to spread seeds of Striga, though fodder, manure or contaminated soil with tillage tools.

Future research needs

Pearl millet has now been emphasized as nutricereal and will take on a major role in crop diversification, and food and nutritional security under changing climate scenario. As this crop is developed as subsistence crop mainly during the rainy season by resource-poor farmers on marginal lands with low inputs, efficient weed management is a major challenge. In general, weeds in pearl millet are removed manually using hand tools and implements at the stagecoach when they attain a good amount of biomass and used as a source of animal fodder. Only the crop yield reduces drastically due to severe competition for nutrients and moisture. Thus, the critical period of crop-weed competition, particularly for the pearl millet needs to be identified and weeds should be managed during that period. There is a need to acquire energy efficient small weeding tools for different agro-ecological regions. Herbicides very effective for weed control in pearl millet. As this crop is also employed as major fodder source for animals, farmers fear that use of herbicides may deteriorate the fodder quality and animal health. Hence, they should be developed and trained the usage of herbicides in pearl millet. As the pearl millet is grown in moisture stress conditions, the efficacy of pre-emergence herbicides like atrazine is reduced. Hence, there is a need for exploring potential post-emergence herbicides for safe and efficient weed control. Pearl millet is mainly grown as an intercrop with pulses and oilseeds. Under such conditions, safe and effective broad-spectrum herbicides need to be developed and evaluated. Herbicide residues in soil and plant (grain and stover) need to be studied in different situations. More investigations are needed on integrated weed management.

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