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Review Article

WEED MANAGEMENT STRATEGIES IN SOYBEAN [*Glycine max* (L.) Merrill)] UNDER CHANGING CLIMATE SCENARIO

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Abstract: Soybean [*Glycine max* (L.) Merrill] contains 18-22 % oil and 38-42 % protein and is a potential source of oil as well as protein. Soybean has attracted the Indian farmers due to its wider adaptability and high yield potential and better prices like cash crop as compared to another oilseed crop. There is no parallel to the phenomenal increase in area of soybean in India and particularly in Rajasthan. Soybean is a rainy season crop and it faces severe weed-crop competition and yield reduction which may vary from 12-85 per cent. Weeds rob the soybean crop for valuable inputs like nutrients, moisture, energy which cause severe reduction in growth and yield of soybean due to their better establishment and faster growth. Weeds control is the most challenging task in the soybean and the type, nature and their threats are changing due to change in the climate mainly rise in the temperature and CO_2 in the atmosphere entailing to the untimely, undistributed, and intense rains. Keeping these points in view, integration of various weed managements techniques, their new dimensions including precision, robotics, drone, and new potentials etc. have been contemplated to achieve maximum degree of weed control with minimum losses in yield for sustainable production of soybean.

Keywords: *Weed, Integrated Weed Management, Soybean, Climate*

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Introduction

Weeds are one of the main threats to the agriculture but under climate change, management of this threat will be an increasing challenge in two ways. A major adaptation response to climate change is increased but this presents a major opportunity for increased weed invasion. Adaptation responses include quarantine and filtering methods to monitor species displacement [1]. Climate change will require revisiting what we deem appropriate for weed control to keep current and future management strategies efficient and effective [2]. Weeds are relatively constant and pose severe problems in crop production [3]. Yield losses due to weeds vary according to crops, weed species, and farming practices. Weeds also interfere with harvest operations, produce harmful chemicals (allelopathy), and serve as hosts for insect pests and diseases [4,5]. Hence, weed control is a major component of successful production of *kharif* pulses and soybean. Both extreme weather events and rapid climatic changes interrupt the stability of cultivated ecosystems and increase the level of disturbance [6]. Climatic variations have increased both spatially and temporally over the past 50 years in India [7]. Temperature and rainfall are the climate variables most critical to measure with regards to weeds management. Weeds are the major competitors for the crop plants as they take up the resources available for them. Because of more response and endurance of weeds towards altered climate, majority of the weeds belong to C4 pathway [8]. Soybean are amongst the largest monoculture registered and is main potential protein as well as oilseed crop in India as well as Rajasthan state. Due to several merits, its cultivation has gained momentum in several states of the nation due to special pulse and oilseed programmes in the country. The availability of edible oils has shrinked to 12 g/capita/day against minimum requirement of 35 g/capita/day. There is no parallel to the phenomenal increase in area of soybean in India and particularly in Rajasthan state. In this approach, the potential of soybean crop to augment productivity utmost important for *kharif* soybean as has been become an important and integral component of cropping system.

Soybean area, production, and productivity scenario

The world is seeking a greater demand of agriculture output especially pulses and soybean, are potential protein and oil source worldwide and their cultivation has gained momentum in India especially in S.E. Rajasthan. In India *kharif* soybean, occupies about 411, 2549, 15.5, 92.5 thousand ha in 2021 [9] respectively with hovering productivity. *Kharif* soybean is mostly grown in rainy season and faces severe weed competition which is a major constraint of low productivity. Weeds exploit the habitat very efficiently for natural resources and don't allow the crop plants to make any headway growth in early growth period causing severe reduction in yield. Apartfrom other factors, weed management in *kharif* season had really bean a challenging factor due to unpredictability of rains, entailing to non-workable conditions of soil and non-availability of timely labour. The next alternative in such situations is chemical weed control is in its infancy. Herbicidal approaches can provide a better choice to the growers to control specific or mixed weed flora and have more flexibility in their efficacy &applicability especially post-emergence herbicides. India is one of the most outstanding soybean producing country in the world having 6h position in area and production globally. The total area under soybean is 119.98 lac ha with a production of 118.89 lac tons. with a hovering productivity of 865-1002 kg/ha. Major soybean producing states are Madhya Pradesh, Maharashtra, Rajasthan [9].

Common weed spectrum in soybean fields

Major weed species appeared during the crop seasons are most prominent monocots (53.1%) Echinochloa *colonum, E. crusgalli, Cyanodon dactylon, Cyperus rotundus*, whereas among dicots (46.9%) Celosia argentea, Digera arvensis, *Commelina benghalensis* and *T. portulacastrum* were dominant species [10]. Soybean was infested with major weeds *Echinochloa colona* (35.37%) and *Mollugo pentaphyla* (25.00%) and some other weeds less in number like *Cyperus iria, Cichorium intybus, Phyllanthus urinaria, Eclipta alba*[11]. Higher weed population in unweeded control plots adversely affected the growth of crop and thus resulted in minimum yield attributes, seed, and stover yield of soybean.

Soybean infested severely with weeds *Echinochloa colona* (35.37%) and *Mollugo pentaphylla* (25.00%) whereas other weeds like *Cyperus iria, Cichorium intybus*, *Phyllanthus niruri* and *Eclipta alba* were also present in less numbers [12,13]. The lowest yield in soybean (6.82 q/ha) in no weed control [14].

Crop-Weed Interference: losses due to weeds in soybean

Weeds have been a problem for man ever since they took domestication of plants and therefore, weed management seems to be as old as agriculture itself. In India, the estimates have been made about the annual losses of agricultural production nearly Rs. 6000 crores annually out of which weeds accounts for the maximum loss (33-37%). Soybean is grown in rainy season and it faces severe weed-crop competition. On account of which, they exploit the habitat very effectively and do not allow the crop plants to make any headway growth. Yield reduction in soybean due to weeds may varies from 12-85 or 33-100 per cent [15-17] depending on the level of management. Although weeds pose problems during the entire crop period but the first month of the crop is especially critical. Failure usually results from delay in the operations occasioned by wet soil or excessive weed recovery. Among the *kharif* oilseed crops, soybean is worstly affected, where depletion was estimated around 54.0, 5.6, 0.4 kg/ha NPK [18]. Poor control of weeds is one of reason for the lowered fertilizer use efficiency also.[19]in soybean found that application of pendimethalin 1.0 kg a.i//ha as pre-emergence herbicide integrated with one hand weeding at 35 DAS is the most effective weed management method and profitable cultivation of soybean resulting in 19.73 % oil & 40.68 % crude protein content. Oil content in soybean influenced significantly but protein content was not affected by weed control treatments [20,21] preemergence application of pendimethalin + imazethapyr at 750 g/ha recorded significantly higher seed oil (20.34 %) and seed protein (40.06%) in soybean.[22] inferred that application of fomesafen 250 g/ha at 30 DAS in soybean recorded higher protein (29.22%) and oil content (18.12 %).

Climate Change Scenarios in India

- Temperature increased 0.68°C in the last century, to increase 1.4-5.8°C by 2100
- Rainfall may increase/decrease 10 % by 2050 with increased variability causing timeless frequent, high intensity in short span, leads to water logging and variable Geo-droughts
- *Kharif* season may lengthen & *rabi* season may be Shortened
- More vulnerability of weeds & incidences of diseases and pests will occur
- At Kota more variation in rainfall (496-1503 mm) and rainy days (30-46) occurs and maximum temp. rises to 2.6°C during last 5 years.

Impact of Climate Change on weed intensity and diversity

Increased temperatures-leads to vigrous fast growth of weeds. Changed rainfall - survival of weeds. Water stress affects the degree of competition between soybean / pulses and weeds. Altered frequency and intensity of extreme weather events- droughts and Increased temperatures can cause great changes in weed abundance, competition and weed distributions at a local level. Increasing CO_2 concentrations: due to eCO_2- *Parthenium hysterophorus* and *Vulpia myuros* (amphi intermediate C3- C4) and other C4 type weeds found to be more competitive & venerable. [23] reported that glyphosate tolerance in *Chenopodium album* (C3 weedy specie). Due to Such changes efficacy of chemical herbicides may be reduced in the future and enhancement of herbicide tolerance cases will occurs. [1] also reported increase in biomass production capacity of C3 and C4 weeds may be doubled due to eCO_2. Due to climate changes Intensity, biomass & diversity of following Weeds (C3& C4 pathway) will be increased & influenced due to changes in the their various physiological metabolism as reported by [24-26].

Critical period of Weed Competition

For efficient management of weeds in soybean, it is very essential to know about the critical period of weed competition. The soybean crop requires initial 3-5 weeks of weed free period for realizing the maximums yield. The actual duration, however is dependent on the weed intensity, type of weed flora and time of sowing *etc*. soybean crop can withstand weeds for initial 2-3 weeks after sowing depending upon the type of weed species and the intensity of weeds in given area. Ziska (2020) [4] found that weeding during the initial 20 to 40 DAS was most critical requirement is soybean. Various factors controlling the degree of competition *i.e*., weed density, distribution, during, crop density, crop distribution and duration. On silty clay loam at Ranichauri the most problematic weed was *Oxalis latifolia*. Keeping a weed-free period up to 40 DAS resulted in the greatest soybean grain and straw yields of 2.7 and 5.4 t ha^{-1}, respectively [27]. In rainy season weed free environment between 28 to 40 days after sowing were found imperative to produce yields equivalent to season long weed free situation and indicated that if the chemicals are to be adopted, should have residual effects only up to the end of this critical period. According to Chhokar, *et al.,* (1995) [28] critical period of weed control in soybean was 27 to 40 days after sowing. Most of the weeds started to emerge from 20 DAS until 40 DAS and higher seed yield was obtained by eliminating weeds until 40 DAS. The most critical period of weed competition in soybean was 4-5 weeks after sowing [29]. At Mashhad (Iran), 23 days after emergence (DAE) was determined as the critical time for weed control in soybean and maintaining a weed free period until 23 DAE reduced weed dry weight by 85 per cent and the weed count by 70 per cent, compared to the weedy control [30] At Hisar, *Echinochloa colonum* was competitive throughout the growing season, whereas Celosia argentea was more competitive during later stages. The critical period of crop-weed competition was found to be 30 to 45 DAS [31].

Management Strategies and methods

Various major approaches for managing the weeds in soybean cultivation including -

Mechanical Weed Control

In India, several hand tools and implements are used for mechanical removal of weeds before and after sowing of the crop. Mechanical methods are costly and required more time.

Deep summer ploughing/Soil Turning

Soil turning/deep summer ploughing by disc plough is largely used to bury the seeds and the annual weeds into deeper layer of soil and bring-up rhizomes and tubers of the perennial weeds to the surface of the soil for desiccation and death by the hot and dry winds that prevails during the summer season. Deep summer ploughing reduces growth of perennial weeds like Burmuda grass, Yellow nut sedges, Cut the plant roots and dried up *i.e*., *Pluchea lanceolata*, and delay the regeneration time *i.e., Alhagae camelorum*.

Manual Hand Weeding

It is probably the oldest method of controlling weeds and is still a very popular and effective method of eliminating weeds in soybean field if cheap labour available. It is a costly method and time consuming, no weed control in intra rows and climatic dependent on workable conditions of soil due to unpredictable conditions of rains during rainy season. Crop damage may take place, if done at later stage and re-growth of weeds may be due to cutting. Patra (1987) [32] reported that significantly higher grain yield of soybean was recorded with two hand weeding at 30 and 45 DAS over weedy checks, one hand weeding Soybean yield as influenced by time of Hand weeding. Habimana, *et al.,* (2013) [33] and Akter, *et al.,* (2016) [34] researched that inter cultivation fb hand weedings at 20 & 40 DAS in soybean recorded significantly lower weed density and their dry weight of weeds and were effectively controlled by two hand weedings at 20 & 40 DAS. Similarly, twice hand weeding at 20 and 40 DAS results in the maximum seed yield of soybean than other treatments [35,36], while Sharma, *et al.,* (2016) [37] reported that during *kharif* season soybean two hand weedings at 15 & 30 DAS resulted in significantly higher weed control efficiency.

Hoeing (Use of Implements)

Hoe has been the most appropriate and widely used weeding tool for centuries.

However, is still a very useful implement to obtain results effectively and cheaply. Hoeing is particularly more effective on annuals and biennials as weed growth can be destroyed. Wheel hoe is very popular for controlling weeds in soybean.

Dora Operation (Inter row Cultivator)

Dora is the blade harrow, may be Bullock or tractor drawn. It is operated in between the rows of soybean and cuts the weeds 7.5-10 cm below the ground and leaves them on the soil surface as much, without causing any inversion of the soil. In dora, operation, crop damage may take place due to uncontrolled running. No weed control in intra-rows Dora operation also dependent on the climatic and soil conditions. Kushwah and Vyas (2006) [38] reported that two dora operations at 20 and 30 DAS was better than one dora operation in controlling weeds and was cost effective.

Cultural Practices/Agronomic Manipulations

Crop rotation

Continuous growing of soybean could result in an increase in the population of weeds that characteristically associate with it. Proper rotation and sequence of crops result in reduced weed growth in soybean. Furthermore, repeated growing of the same crop could increase an occurrence of plant diseases and insects resulting in patchy crop stands which are invaded by weeds. Mostly soybean - wheat crop rotation is followed and other alternative rotation may be soybean-coriander, soybean - linseed for Rajasthan conditions, recommenced by Singh and Kumar (2008) [39].

Competitive Genotypes

Different varieties may differ in their canopy structure. Early growth characteristics play a pivotal role in smoothering weeds. Singh, *et al.,* (2000) [40] found that various soybean varieties differ in their weed smoothering effects and variety JS-335 was superior in reducing weed density, weed dry matter and poses higher weed control efficiency and crop growth rate and finally gave higher yield compared to other cultivars.

Intercropping system as a tool for weed management

Complete crop cover and high plant density available in intercropping causes severe competition with weeds and reduces weed growth. Early maturing inters crop of soybean crop cover the vacant inter row spaces rapidly and keeps weeds under check. However, the weeds suppressing ability of the system depends on the genotype, planting pattern and fertility and moisture status of soil. In general, intercropping is better than sole cropping in weed suppression wherein total population should be more than sole crop population. Soybean intercropped with other wide row crops smoother weeds effectively. Soybean when intercropped with other crops, the ratio of sowing was more important factor in suppressing weeds. Nimje (1996) [41] reported that when soybean intercropped with pigeonpea 3:1 and 2:1 ratio, the weed smoothering effect was more compared to 1:1 and sole soybean.

***In situ* mulching of weeds**

After hand weeding, weeds are thrown outside the fields. They should be placed in between the rows, in such a stairs manner so that their roots should not touch the soils and after some time they dried up and add organic matter in the next season crop and acts like Live Mulch & reduces evaporation and reduce next weed flush also.

Herbicidal Weed Management

Herbicides are convenient to use where other methods are not effective, manual, and mechanical weeding are not possible. Herbicide use are safe on erodable and sloppy lands. Herbicides kill weeds that survive by mimicry. Timely availability of labour for weed control can be overcome and provide benefits of timely weed control at the critical time facilitated by herbicidal weed control. Herbicide use are safe on erodable and sloppy lands. Herbicides as applied either to the soil or to the foliage (foliar application). Environmental factors, convenience and cost are other factors that influence the choice of correct methods of application.

In soybean herbicides are applied as preplant incorporation (PPI) Pre-Emergence (PE) and Post-Emergence (POE) for controlling weeds.

Pre-plant incorporation (PPI) Herbicides

Some of the herbicides used in soybean belonging to aniline group are volatile *e.g*., *fluchloralin, trifluralin* (1kg a.i./ha). When they are applied to the soil surface, are lost by volatilization. Thus, these are incorporated into the soil to reduce losses. Generally, these are applied before planting as it is difficult to incorporate the herbicide after sowing. Tuteja, *et al.,* (1995) [42] found that fluchloralin PPI significantly increased the pods/plant, grain and protein compared with diuron and unweeded due to phytotoxic effect of diuron PE application.

Pre-emergence (PE)

Herbicides are sprayed on the soil surface to form a uniform herbicide layer and due to their low solubility may penetrate only few centimeters into the soil. Germinating weeds in the top layer are killed due to incidental absorption of herbicide. The herbicides for surface soil application must be soil active less soluble and less volatile *e.g*., alachlor, pendimethalin, clomozone, metalachlor (1.0 kg a.i./ha). After application, the surface soil should not be disturbed. Preemergence application of pendimethalin at 1000 g a.i./ha proved effective in reduction of weed density and consequently weed dry matter during initial crop growth stages and resulted in maximum weed control efficiency (63.71%) at 30 DAS and (58.05%) at 60 DAS over control as reported by Moguloju and Ramana (2014) [43], Devi, *et al.,* (2016) [44], Choudhary, *et al.,* (2018) [45]. Jain, *et al.,* (2000) [46] revealed that the alachlor 2.0 kg/ha PE and pendimethalin 1.5 kg/ha PE registered lower weed density, weed dry matter, and weed index and higher weed control efficiency comparable with two hand weedings. Both these were effective in controlling all weeds but none of the herbicide was much effective to control *Cyperus iria*. Highest soybean yield 12.81 q/ha was obtained with the highest net return and benefit cost ratio and was at par with two hand weeding with respect to yield. Kewat and Pandey (2001) [47] reported that pre-emergence application of metribuzin 0.5 kg/ha recorded the highest yield 2342 kg/ha due to effective control of almost all weeds except *Cyprerus rotundus*.

Post-emergence herbicides (POE)

A foliage active herbicide is applied to weeds after their emergence from the soil and are absorbed by the plant foliage and in many cases, these are translocated to the other plant parts. At normal rates the foliage active herbicides are most effective against young (15-25 Days) weeds in their seedling stages. Post-emergence herbicides are highly selective and small higher amount may cause phytotoxicity to the crop *i.e*., quizalofop-ethyl, propaquizalofop, chlorimuron-ethyl, imazethapyr. Singh and Chandel (1995) [48] at Pantnagar concluded that the highest seed yield was with the post-emergence application of haloxyfop methyl 0.5 kg/ha. Rana and Angris (1996) [49] at palampur revealed that post-emergence application of Imazethapyr gave the effective control of weeds and more seed yield 2274-3540 kg/ha was at par with two hand weedings (3501 kg/ha). Binjha, *et al.,* (2022) [50] at Kota found that application of quizalofop-ethyl at 50 g/ha as post-emergence (15-25 DAS) was found very effective and selective in controlling grassy weeds in soybean without any phytotoxic effect on the soybean crop. Higher soybean yield (1778 kg/ha) was obtained with quizalofop ethyl 50 g/ha application as compared to alachlor, farmers practice and weedy check. In soybean application of propaquizafop 100 g/ha at 15 DAS as post emergence resulted higher nutrient uptake by soybean [51,52]. Singh, *et al.,* (2006) [53] reported that Tank Mixture CE + FPE (6+50 g) have broad spectrum weed control and gave higher soybean yield, net return and IBCR compared to sole herbicide. Application of imazethapyr at 75 g/ha in soybean at 21 DAS caused significant reduction in weed biomass (52.9%) and thus, significantly increased seed and straw yields by 86.0 and 40.5 per cent, respectively over weedy check registered by Tiwari, *et al.,* (2006) [54], Tiwari, *et al.,* (2007) [55]. At Kota (Rajasthan) found that application of imazethapyr at 75 g/ha as post-emergence significantly reduced weed dry matter at 30 and 60 DAS (85.7 and 71.0 per cent) and reported 103.2 per cent increase in soybean yield compared to weedy check 9.50 q /ha. Meena, *et al.,* (2011) [56] soybean crop at Kota was infested with 51.6 % grassy weeds, 34.1% broad leaved weeds and 13.2% sedges and application of imazethapyr 10 % SL at 100 g a.i. /ha as post emergence controlled grassy, broad leaved weeds and sedges effectively. Sangeetha, *et al.,* (2012) [57], Jha, *et al.,* (2014) [58] showed better control of *Parthenium hysterophorus, Phyllanthus niruri* and *Cyperus rotundus* than quizalofop-p-ethyl at 30, 45 and 75 DAS in soybean crop. Emmiganur and Hosmath (2020) [59] stated that imazethapyr 10 % SL at 100 g a.i. /hawas significantly good in controlling weeds in soybean with less phytotoxicity effect on the crop. Application of fluazifop-p-butyl @ 0.25 and 0.5 kg/ha post-emergence at 20 DAS effectively controlled the grassy weeds *viz*., *Echinochloacrusgalli, Cynodon dactylon, Digitaria adscendens* and broadleaf weeds and sedges were found resistant to it. Tiwari, *et al.,* (1997) [60], Andhale and Kathmale (2019) [61], Jose, *et al.,* (2021) [62] indicated a higher sensitivity of velvetleaf to fluthiacet methyl. Meena, *et al.,* (2012) [63] reported clodinafop-propargyl (60-100 g /ha) as post-emergence significantly reduced the weed density and its dry weight and enhanced the growth, yield attributes and yields of soybean over the weedy check. The highest weed control efficiency recorded under clodinafop propargyl 100 g/ha against the grassy weeds of soybean at 60 DAS. [58] observed that tank mixtures application of 0.25-0.50 kg/ha of fomesafen + fluazifop-p-butyl at early post emergence gave better broad-spectrum weed control than did alachlor + metalachlor applied pre-emergence in soybean. Mixture of fluazifop-p-butil + fomesafen, as postemergence application at rates (0,4; 0,3; and 0,2 kg. a.i./ha) together, it was possible to reduce the herbicide rates up to 50% to control this weed community without significant yield reduction [64]. Oliveira, *et al*., (2017) [65] observed that post emergence application of fomesafen 0.269 kg/ha and fomesafen + imazethapyr 0.347 kg/ha provided maximum control of broadleaved weeds mainly ivyleaf morning-glory, common lambsquarters, common waterhemp and redroot pigweed (≥ 85%) in soybean field at Nebraska-Lincoln, Concord (USA). Patidar, *et al.,* (2020) [66] reported that application of fomesafen as post emergence is better option for reducing the broadleaved weeds as well as producing higher yield in *kharif* season. Fluazifop-p-butyl at 125 g/ha PoE registered lower density of monocots and their dry weight at 30 & 60 DAS as compared to weedy check & resulted 72.3 and 64.1 per cent of weed control in soybean. Jadhav and Gadade (2012) [67], Vaghasia and Nadiyadhara (2014) [68] recorded significantly least number of grassy weeds and total dry weed matter with weed control efficiency (79.6 %) and weed index (20.2%) while graded doses of fluazifop-p-butyl 13.4 EC (100, 134, 167 & 335 g a.i./ha) was not found effective against broadleaf weeds. Similarly, efficacy of propaquizafop at lower dose (62.5 g/ha) as well as at higher dose (75 g/ha) as post emergence was not well marked against most of the broadleaved weeds but application of imazethapyr at 75, 100 g/ha controlled both broad leaved and grassy weeds reported by Sandil, *et al.,*(2015) [69] and Kumar, *et al.,(*2018) [70] but in soybean found propaquizafop 100 g/ha at 15 DAS as post emergence better in lowering weed density and weed dry matter and getting higher yields. The lack of controlling broad-spectrum weed flora is mostly found in herbicides. The best alternative to have the wide spectrum weed control through herbicide mixtures. Besides, controlling complex weed flora, herbicide mixtures may provide an opportunity for increasing herbicide efficiency and arresting weed flora shift. Compatible herbicide in the herbicide mixtures at low rate do offer either additive or synergistic and enhancement effects in weed control *i.e*., pendimethalin + imazethapyr(PE)and PoE- chlorimuron-ethyl + quizalofop-ethyl, chlorimuron-ethyl + fenoxaprop ethyl, propaquizafop + iImazethapyr, sodium acifluorfen + clodinafop - propargyl) and fomesafen + fluazifop-p-butyl *etc*. Likewise, Jadon, *et al.,(*2019) [71] also reported application of ready mix of imazethapyr + imazamox 75 g/ha at 15 DAS produced highest protein yield (815.7 kg/ha) and oil yield of soybean (385.7kg/ha) which was significantly superior weedy check.

Integrated Weed Management (IWM)

Weeds can be controlled in soybean by several methods. However, each weed control method has advantages and disadvantages. Integrated weed control is a weed population management system that uses all suitable techniques in a compatible manner to reduce weed population and then at levels below those causing economic injury. For integrated approach for weed management, we can use one chemical method with physical or cultural and chemical methods with other feasible approaches includes cultural practices (CD) + Mechanical methods (MM); Cultural practices + Chemical control (CC); and Cultural practices + Biological tools (BT). At pantnagar highest seed of soybean yield was under combined approach of sowing at 22.5 cm + alachlor 2.0 kg/ha PE and was at par with two hand weedings at 30 and 45 DAS [72].

New Options of Weed Management Strategies

Soil Solarization

soil solarization treatments invariably gave significantly higher yield of soybean as well as wheat compared to non-solarized and herbicides and have the monetary benefit over hand weeding. Novel and new method of weed management involves covering of the soil with transparent polythyne sheet films for 2-6 weeks during summer months. This will enhance the surface soil temperature to levels lethal to soil pathogen and weed seeds [73].

Herbicidal Mixtures

Now, to control grasses, sedges and broad leaf weeds, the integration of methods *i.e.,* PE fb one hand weedings or PE fb post-emergence. The next best alternative to solve the wide spectrum weed control may be herbicide mixtures. Besides, controlling complex weed flora, herbicide mixtures provide an opportunity for increasing herbicide efficiency and arresting weed flora shift. But, the compatibility is a great problem and sometimes phytotoxicity to the main crop and residual toxicity to the succeeding crop may occur. Compatible herbicides in the herbicide mixture do offer a low rate of each in achieving their some activities through additive, synergistic and enhancement effect which could be seen through an eco-friendly angle towards sustainable production. Post-emergence application of propaquizafop + Imazethapyr at 53+74 g/ha was most effective for controlling weeds and improving seed yield of soybean [74]. Post emergence application of pre mixture of propaquizafop + imazethapyr at 53 + 80 g a.i./ha checked the growth of weed s more efficiently and recorded lower weed index of 7.9 %. Similar to this, Panda*, et al.,* (2015) [75], Panda, *et al*., (2017) [76], Lal, *et al*.,(2017) [77] found that combined application of propaquizafop + imazethapyr as post-emergence 55+80 g/ha was most effective. Mangaraj, *et al.,(*2021) [78] on soybean find superiority of tank mix application of propaquizafop + imazethapyr at 50 + 80 g/ha at 15-20 DAS in soybean, but Harisha, *et al., (*2021) [79] in urdbean recommends tank mix propaquizafop + imazethapyr at 50+75g/ha Kutariye*, et al*., (2021) [80] found that propquizafop 50g + imazethapyr 100 g/ha significantly reduces the density and dry weight of growing weeds and was statistically at per with hand weedings at 20 and 40 DAS. Similarly, Patel, *et al.,* (2019) [81], Patel, *et al.,* (2019) [82] stated that post-emergence application of propaquizafop + imazethapyr (ready mixture) at 55 + 80 g/ha arrested weed density and weed biomass production remarkably and proved superior to its lower doses (50 + 75 and 45 + 70 g/ha), alone application of imazethapyr (150 g/ha) and pendimethalin (1,000 g/ha) as pre-emergence. Likewise, Elankavi, *et al.,* (2019) [83] conducted an experiment on irrigated urdbean reported that application of sodium acifluorfen 16.5% + clodinafop - propargyl 8 % EC at 1250 ml /ha at 20 DAS recorded significantly lower weed population, weed dry matter, higher weed control efficiency and weed control index. find that clodinafop-propargyl 8% EC + sodium acifluorfen 16.5 % SL at different rates 100+206.2, 160+330 was found superior in weed control efficiency in soybean. Meena, *et al.,* (2022) [84] reported that pre-mix post emergence application of sodium acifluorfen + clodinafop propargyl at 165+80 g/ha at 30 DAS recorded significantly broad-spectrum activity on grassed and broadleaved weeds. Balyan and Malik (2003) [85] reported that tank mixture of fomesafen and haloxyfop at 200 +150 g produced higher grain yield of soybean which is also like season long weed free yields. Kadam, *et al*., (2018) [86] at Parbhani (MH) post emergence application of fomesafen + fluazifop-p-butyl at 250 g a.i./ha recorded lower weed density of monocot and dicot weeds. An early post-emergence application of fomesafen + fluazifop-p-butyl mixture (90+90 g/ha) effectively reduced monocot and dicot weeds density and dry weight with higher weed control efficiency of monocot (86.74%) and dicot (90.94%), respectively and proved significantly superior over fomesafen + fluazifop-p-butyl mixture at 110+110 g/ha (94.71 and 95.36% WCE), Jitendra, *et al.,* (2022) [87] revealed that the lowest weed density, dry weight and the highest weed control efficiency were recorded with hand weeding at 20 and 40 DAS, which was at par with alachlor @ 1.5 kg a.i ha^{-1} as PE fb hand weeding at 30 DAS and fomesafen @ 110g + fluazifop-p-butyl @ 110 g a.i ha^{-1} as PoE at 20 DAS. Fomesafen + fluazifop-butyl (ready-mix) at 222 g/ha gave effective control of weeds which resulted in lower density and biomass of weeds and gave effective control of diverse weed flora by registering 97.02 % and 94.68 % weed control efficiency of monocot and dicot weeds and was more remunerative without any phytotoxicity on soybean crop [88].

Biological Weed Management

The *Collectotrichum gloeosporiodes* sp. a commercial mycoherbicide formulation collego is used for control of weed *Aeschynomerie* sp. in soybean fields. Also, *Alternaria cassiae* has been reported to control sickle pod in soybean [89]. Recently, it is reported that some soybean genotypes have allelopathic properties that allow them to compete well with weeds such as velvet leaf and sickle pod.

Bio-technological tools

- GM/ Herbicides Resistant crops [90]
- Roundup Ready Soybean-Aromatic Amino Acid; Synthesis inhibitor
- Liberty Link Soybean -Glutamine Synthase; Inhibitor (Glyphosinate Resistant Soybean)
- Sulfonyl Tolerant Soybean Synchrony, Classic

Developing precision technology (DPT)

A more form central, regional level to village, farm, field and within field also scale of management will be a gradual process with many transitional forms and differential among crop management practices. Site & situation specific weed management probably focus on over long term or on short term, including cost effective methods and other requires quantitative insight into both crop-weed interactions and variable weed control techniques. While developing the precision technology various parameters should also involve like weed persistence index, crop resistance index, weed management index and integrated weed management index *etc*. Sometime due to aberrant weather situations, we must think about our ancient technology *i.e*., mixed cropping and new ways of intercropping. Thus, we must have also evaluated the bio-efficacy of herbicides involving the intercropping of *kharif* pulses and soybean with maize, sorghum, pigeonpea, sesamum, sunflower or any other crop. Thus, we must step up forward into the new millennium with the SSSWM as a part of IWM to enhance growth rate in productivity and sustainability, SSOCM practice must be developed [91] with more precision keeping in view of our eco-system. It should involve

- Weed economic thresholds levels (WETL)- (for POE)
- Weed Economic injury level (WETLs) - (for POE)
- Competitive Index -Relationship of weed population to yield reduction in different for each species. Most prevalent weed is not necessarily the most competitive one. The ETLS for weed depends on limiting resources - light, moisture or nutrients.
- Selection of methodology/ herbicide in accordance with weed flora and their application flexibility
- Auto herbicide rotation (AHR)

Year	I	II	III	IV	V	VI	VII
Herbicide	NLWH	BLWH	N+BLWH	HW	NLWH	BLWH	N+BLWH

- Herbicidal - crop phytotoxicity
- Crop grown recovery period

Weed Sensing Systems (WSS),Ground-based sensing system(GBSS), Aerial-based remote sensing system (ARSS), Weed Modelling, Weed Economic Threshold Levels (WETL),Economic injury levels (EILS) , Weed persistence Index (WPI), Crop resistance index(CRI), Weed management index (WMI), Herbigation research needs : with surface water / drip or sprinkler irrigation ,After phytotoxicity setback, Crop growth recovery period and measures to recoup growth fast - still are not available, so it is area of concern.

Robotic Weed Control Technology (RWCT)

Application of modeling and robotics in a highly scientific and practical manner will help to achieve site-specific and economical weed management in the future [92,93]. Software program of robotics are Robocrop, IC-Cultivator, Robovator Hoeing Robot, Thermalhoeing Robot, Ecorobot, Ladybird, Bonirob, Agbot, Swarmbots, Rippa.

Use of drone (UAV) for Weed Control

For POE herbicides in standing crop specially during rainy season and vertosols may be a super tool for weed management. Researchable Issues for UAV are : carrying capacity, flying height and speed, droplet size, auto control for area basis, wind speed.

Conclusion

No single approach can be successful for long against weeds control as they are very quickly adopting to the changed environment. An integrated approach involving weed biology, modified agronomic practices and reorient herbicidal approach under an umbrella of integrated weed management is essential for higher soybean production. Thus, we must step up forward with new weed management strategies in soybean for controlling weeds and to enhance growth in the productivity. Thus, we must evaluate and recommend advance weed management strategies in soybean for controlling weeds and to enhance the productivity. Climate changing factors have serious implications for not only crop growth and productivity but also weeds and herbicide effectiveness. We must step up forward with new weed management strategies in soybean to enhance the productivity. Weed scientists need to look ahead to explore and develop a combination of the methods for the benefit of farming community.

Application of research

Climate change factors has serious implications for not only crop growth and productivity but also weeds and herbicide effectiveness, thus weed management should be based on these. Weeds tend to show better survival mechanisms under changing climate because of their greater interspecific genetic variation and physiological plasticity. Current weed management strategies that rely heavily on herbicide usage may have altered effects on these aggressively growing weeds in future climatic conditions and effective & feasible weed management programmes should be evaluated with more precision and demonstrated to the farmers. Weed management strategies in changing climate conditions will give a pathway to control weeds in soybean and weed management programmes may be planned with more feasible, practical and more precision using modern tolls as well.

Research Category: Weed management

Abbreviations: NLWH- Narrow leaf weed herbicides
BLWH-Broad leaf weed herbicides
HW-Hand weeding, ST-Summer tillage
UAV-Unmanned Aerial vehicle

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University: Agriculture University, Kota, 324001, Rajasthan, India
Research project name or number: Review study

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Study area / Sample Collection: College of Agriculture, Agriculture University, Kota, 324001, Rajasthan, India

Cultivar / Variety / Breed name: Soybean [*Glycine max* (L.)

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