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Weed management in greengram: A review

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ABSTRACT

Greengram [*Vigna radiata* (L.) Wilczek], also known as mungbean, is extensively cultivated in India and other Asian countries. Being rich in protein, its grains are an important daily dietary component. Weeds are a major limiting factor in production of greengram that lead to a drastic reduction in yield. The presence of hardy weeds and slow initial crop growth compound this problem. Different strategies incorporating non-chemical and chemical methods have been practiced for efficient weed control in greengram. Non-chemical control methods include straw mulch (12-63% reduction in weed biomass), narrow row spacing (60-92% reduction in weed biomass), method of sowing (1-20% reduction in weed biomass), tillage practices (58% reduction in weed biomass), the frequency and rate of irrigation and fertilizer application (13-23% reduction in weed biomass), timing of hand weeding and selection of cropping system. Chemical control methods include the many herbicides with different selectivity and efficiency available for use in greengram. For efficient weed control, herbicides should be applied at the recommended rate and time in order to avoid inhibiting growth, symbiotic properties (number of nodules, dry weight of nodules, leghaemoglobin content in nodules) and grain yield in greengram crop. In this review, different weed management strategies including non-chemical and chemical weed control methods have been reviewed for their ability to control weeds in greengram. Furthermore, their influence on growth, symbiosis, yield and nutrient uptake of greengram, soil microflora and residual effect on succeeding crops have also been reviewed.

INTRODUCTION

Greengram, also known as mungbean, is the fourth most widely produced pulse crop in India after chickpea, pigeonpea and blackgram. It can be grown during both rainy and summer seasons. Being a short duration crop, it fits well in traditional rice-wheat cropping systems and provides farmers with additional income. Being a leguminous crop, it can play a major role in nitrogen fixation from 20-80 kg/ha (Hayat *et al.* 2008), thus improving system sustainability. Greengram grains contain 22-28% protein, 60-65% carbohydrates, 1.0-1.5% fat, 3.5-4.5% fibre and 4.5-5.5% ash (USDA 2019). It is also a rich source of aromatic amino acids, *viz.* leucine, isoleucine and tryptophane (Bhatty 1982).

Weeds compete with crops for resources such as nutrients, water, light and space, thus reducing their yield. Naturally more hardy and competitive, they cause significant yield losses if not controlled properly. The highest losses of total annual agriculture production are caused by weeds (45%) followed by insects (30%), diseases (20%) and other causes (5%) (Rao 2000). In 10 major crops of India, total actual economic loss of about USD 11 billion has been estimated due to weeds alone (Gharde *et al.* 2018). Weeds can cause 31-58% yield loss in greengram under the irrigated conditions of Punjab (Buttar *et al.* 2006, Kaur *et al.* 2009, Singh *et al.* 2014a, Singh *et al.* 2015, Kaur *et al.* 2016). Similarly in other parts of India, weeds cause a 58% reduction in grain yield of greengram in Maharashtra (Khairnar *et al.* 2014), 34% and 51% in Gujarat (Chhodavadia *et al.* 2014, Patel *et al.* 2016, respectively), 39% and 52% in Uttar Pradesh (Kumar *et al.* 2016, Mirjha *et al.* 2013, respectively), 48% and75% in Rajasthan (Komal *et al.* 2015, Godara *et al.* 2014) and 53% in West Bengal (Tamang *et al.* 2015). The presence of weeds not only reduces grain yield, but it also influences the quality of seed.

Weed management is very important in successful cultivation of greengram. Due to its slow growth during early stages, weeds grow abundantly and interfere with the crop for uptake of water and nutrients. They also limit the availability of light and space for the crop. Weeds mature earlier than the crop and shed their seeds in soil, thereby, increasing weed seed bank in the soil. Weed seeds mixed in with the crop reduce the economic value of yields and serve as a source for further spread of weeds into new areas. Spiny weeds like *Tribulus terrestris* make field operations, such as inter-cultivation or harvesting, difficult and slow, causing additional economic losses to farmers.

Important weed flora in greengram

The crop is infested by very diverse weed flora. The major weed flora in greengram as reported by various researchers, are presented in **Table 1**.

Critical periods of weed competition

Weeds are present throughout the crop growth, yet there is a need to find out the exact time during which weeds cause the highest yield reductions. This is defined as the critical period of weed competition. The critical period of weed competition can also be defined as the shortest period during crop growth in which weed management results in almost similar yield as that in weed free conditions throughout crop growth.

The critical period of weed competition in greengram has been reported to be between 3 and 6 weeks after planting (Utomo *et al.* 1988). No reduction in biological yield of greengram was observed under uncontrolled weed competition upto 20 days after emergence (Naeem and Ahmad 1999). When weeds are allowed to grow upto 30 days after emergence, it leads to significant reduction in biological yield. Therefore, 20-30 days after emergence is the critical period for weed control. Similarly, Naeem *et al.* (2000) also observed that the presence of weeds upto 20 days after emergence did not influence crop yield.

In summer greengram, critical period of weed competition is 15-30 days after sowing (Singh *et al.* 1991, Singh *et al.* 1996). Sheoran *et al.* (2008) reported no significant reduction in weed biomass in weed free conditions for 20 days after sowing (DAS) as compared to unchecked weedy treatments, possibly due to late flushes of weeds. However, weed free conditions up to 40 DAS significantly reduced weed biomass, which may be attributed to the smothering effect of greengram owing to coverage of ground surface and low light penetration. There is a significant decrease in weed biomass when a weed free environment is maintained from 20-40 DAS in greengram.

Table 1. Major weed flora observed in greengram

Weed flora	Place	Author(s)
Trianthema portulacastrum, Amaranthus viridis, Phylanthus niruri, Cynodon dactylon, *Echinochloa colonum* and *Eleusine indica*	Jabalpur, Madhya Pradesh	Sachdeva *et al.* (1995)
Amaranthus viridis, Chenopodium album, Convolvulus arvensis, Cynodon dactylon, *Cyperus rotundus, Heliotropium europium, Melilotus indica* and *Rumex dentatus*	Failsalabad, Pakistan	Naeem *et al.* (1999)
In clayey loam soil *Trianthema portulacastrum, Amarannthus viridis, Phyllanthus niruri, Cynodon dactylon, Echinochloa colonum* and *Eleusine indica*	Annamalainagar, Tamil Nadu	Raman and Krishnamoorthy (2005)
In loamy sand soil *Digera arvensis*, *Eleusine indica, Poa annua, Tribulus terrestris* and *Cynodon dactylon*	Bathinda, Punjab	Buttar *et al.* (2006)
In sandy loam soil *Digera arvensis*¸ *Cyperus rotundus, Eleusine aegyptiacum* and *Commelina benghalensis*	Ballowal Saunkhri, Punjab	Sheoran *et al.* (2008)
In sandy loam textured soil *Eleusine indica*, *Echinochloa colona, Digitaria sanguinalis, Cleome viscosa*, *Alternanthera sessilis, Physalis minima*, *Euphorbia hirta* and *Cyperus rotundus*.	West Bengal	Kundu *et al.* (2009)
Dactyloctenium aegyptium, Echinochloa colona, Brachiaria sp., *Cyperus rotundus, Commelina diffusa, Amaranthus viridis, Digeria arvensis, Parthenium hysterophorus* and *Phyllanthus niruri*	Vidharbha, Maharashtra	Khairnar *et al.* (2014)
In loamy sand soil *Commelina benghalensis, Digitaria sanguinalis, Eleusine indica, Trianthema portulacastrum, Amaranthus viridis* and *Cyperus rotundus*	Ludhiana, Punjab	Kaur *et al.* (2016)
In sandy loam soil *Cynodon dactylon, Dactyloctenium aegyptium, Celotia argentea, Cyperus rotundus, Digera arvensis, Trianthema portulacastrum, Commelina benghalensis, Parthenium hysterophorus, Euphorbia hirta* and *Hemidesmus indica*	Hyderabad, Telangana	Nagender *et al.* (2017)

Non-chemical methods of weed control in greengram

Weed management methods vary with weed infestation, crop stage, availability of resources *etc*. In greengram, both non-chemical and chemical methods of weed control are prevalent. Several non-chemical methods include the use of straw mulch, altering or reducing row spacing, sowing method, tillage practices, rate and frequency of irrigation and fertilizers, timing of hand weeding, cropping system or crop rotation, *etc*. for weed management in greengram.

Effect of non-chemical methods on weeds

Effect of mulch: Straw mulch application helps in managing weeds. In Cambodia, application of rice mulch at 1 t/ha in Takeo Province significantly reduced weed biomass in greengram as compared to no mulch treatment (Bunna *et al.* 2011). Application of straw mulch at 5 t/ha resulted in significantly lower weed biomass as compared to weedy check, though it could be higher than hand weeding twice (Kundu *et al.* 2011). Mulching done at 25 DAS significantly reduced weed dry matter accumulation as compared to no mulch treatment (Ram *et al.* 2016). Straw mulch may reduce the red light intensity of solar radiation reaching the ground surface. As most weeds require red wavelength of solar radiation to germinate, straw mulch may lead to delayed emergence or reduced emergence. In addition to this, straw mulch may cause physical obstruction to the emergence of weeds. However, collection and storage of straw and its application as mulch involves a lot of labour and cost to farmers. That is why straw mulch has not been widely adopted as a method of weed control in greengram. However, sowing of greengram in the presence of wheat straw in combine harvested wheat using the Happy Seeder machine (PAU 2019) may help in using wheat straw as mulch, rather than its burning.

Effect of tillage: Tillage is the physical or mechanical manipulation of soil for obtaining ideal conditions for seed germination and seedling establishment. In Pakistan, tillage with mouldboard plough + rotavator significantly reduced weed dry mass as compared to a double pass with a tine cultivator and chisel plough + rotavator (Amin *et al.* 2014). Reduction in weeds with the mouldboard plough may be due to inversion of soil resulting in the burial of weed seeds. Amin *et al.* (2014) observed significantly higher weed dry matter using the broadcasting method (219 g/m^2) of sowing as compared to sowing with a seed drill (176 g/m^2). Sowing method, *viz.* conventional tillage method and furrow irrigated raised bed sowing did not significantly influence weed number and weed biomass (Malik *et al.* 2005). In an experiment conducted in Islamabad, Pakistan zero tillage increased the weed biomass as compared to conventional tillage in non-weeded treatment (Shafiq *et al.* 1994). However, the lowest weed biomass was recorded for the deep tillage method. Therefore, application of deep tillage and the sowing of greengram with a seed drill could help to reduce the problem of weeds by burying weed seeds into deeper soil layers and the uniform establishment of crop stand.

Effect of row spacing: Row spacings of 25 and 50 cm in Queensland, Australia have been reported to significantly reduce weed biomass as compared to 75 cm row spacing when weeds are not allowed to grow until 30 DAS (Chauhan *et al.* 2017). However, this difference becomes insignificant when weeds are allowed to grow throughout the crop growth period. Thus, narrow row spacing is only beneficial when integrated with some other weed management techniques to reduce initial weed growth. Increasing the seed rate of greengram from 20 kg/ha to 35 kg/ha significantly reduced weed dry matter (Zahan *et al.* 2016). Weed reduction in closer spacing and higher seed rate may be due to fast canopy closure, resulting in reduced light penetration, thus affecting weed seed germination as well as weed growth.

Effect of genotypes: Different genotypes of greengram may vary in their potential to suppress weed growth. For example, in Bangladesh, genotype '*BINA mung-5*' significantly reduced weed dry matter as compared to '*BINA mung-8*' and '*BARI mung-6*' (Zahan *et al.* 2016). This could be due to better early growth and establishment of '*BINA mung-5*'.

Effect of irrigation and fertilizer: The highest weed dry matter was observed when twice irrigated which was significantly higher than 3 and 4 irrigations to greengram during crop growth (Ram *et al.* 2016). As weeds show higher competitive ability to grow under moisture stress conditions, this could be the reason for higher weed dry matter under conditions of limited irrigation. Furthermore, higher weed biomass at reduced irrigation may be due to poor crop growth under these conditions. Weed index is not influenced by the fertility status of soil, however, weed control efficiency is significantly reduced by application of fertilizers at recommended rates (20 kg N, 50 kg P_2O_5 and 25 K_2O kg/ha) as compared to no fertilizer application (Goswami *et al.* 2015). Low weed suppression with application of fertilizers may be due to the fact that fertilizer application not only provides nourishment to the crop but also supplies nutrients to weeds, thus increasing their biomass and competitive ability

Effect of crop rotation: Crop rotation can influence weed dynamics in greengram. Certain crop rotations can be helpful in effective management of weeds while others may lead to higher rates of infestation. Greengram-mustard cropping system can result in 18% reduction of weed dry matter accumulation as compared to fallow-greengram (Singh 2006). Sorghum is known to have allelopathic effects on different crops and weeds. One study in Pakistan found that the application of three sprays of sorgaab (sorghum soaked in water for 24 hr and filtered to collect sorgaab) at 15, 30 and 45 DAS reduced the dry weight of *Cyperus rotundus, Convolvulus arvensis* and *Portulaca oleracea* by 50, 60 and 75% respectively, whereas *Trianthema portulacastrum* remained unaffected (Cheema *et al.* 2000).

Effect of integration of non-chemical methods: Application of straw mulch, sowing with a seed drill at narrow row spacing, correct irrigation and fertilizer application, crop rotation with mustard and deep tillage have been found efficient in managing weeds, however, their combined effect should be evaluated for future prospects of enhanced weed management.

Chemical weed control

Herbicides are chemicals used for the killing of weeds which provide improved and uniform control of weeds as compared to cultural practices alone. Use of herbicides significantly increases crop yield by reducing weed competition. Several herbicides have been found to be both effective and safe for controlling weeds in greengram.

Effect of herbicides on weeds

There are a number of herbicides available for controlling weeds in greengram, however, efficiency of weed control depends on the type of herbicide used, its concentration, type of weed flora present, soil type, methods of herbicide application *etc*.

Pre-emergence (PE) application of pendimethalin is widely used to control weeds in legumes. Application of pendimethalin at 1.0 kg/ha + HW at 20 DAS (Raman and Krishnamoorthy 2005, Raj *et al.* 2012), pendimethalin at 900 g/ha + HW at 30 DAS (Chhodavadia *et al.* 2014) and pendimethalin at 500 g/ha followed by (*fb*) intercultural 30 DAS (Patel *et al.* 2016) presents weed biomass statistically at par with two HW treatments at 20 and 40 DAS. Response of pendimethalin could vary according to soil texture. Weed biomass and plant number recorded after the application of marketable pendimethalin at 4, 3 and 2 l/ha were at par with that of hand weeding in clay soil texture (Khan *et al.* 2011). Therefore, increasing the rate of pendimethalin beyond 2 l/ha is uneconomical even under heavy texture soil. On the other hand, on light texture soil of loamy sand, the highest weed control was observed with pendimethalin at 0.75 kg/ha. Better weed control was observed with higher doses of pendimethalin (0.75 kg/ha) than lower dose (0.45 kg/ha) (Kaur *et al.* 2010). Pre-plant incorporation (PPI) of trifluralin at 1.0 kg/ha recorded the lowest weed dry matter followed by trifluralin at 0.75 and 0.5 kg/ha (Buttar *et al.* 2006).

Imazethapyr acts as a broad-spectrum herbicide and affects the establishment of weeds by retarding meristem cell division resulting in rapid weed suppression and highly efficient control of annual broad-leaf weeds and sedges (Khairnar *et al.* 2014). Application of imazethapyr 100 g/ha at 15-20 DAS (Ali *et al.* 2015, Khairnar *et al.* 2014), imazethapyr at 75 g/ha 20-25 DAS (Khairnar *et al.* 2014), imazethapyr at 40 and 60 g/ha 20 DAS (Godara *et al.* 2014) and imazethapyr at 100 g/ha pre-plant incorporation (Singh *et al.* 2014b) resulted in weed dry biomass at par with 2 interculture and HW treatment. Imazethapyr is both a soil and plant active herbicide, thus it can be taken up by weeds through both roots and leaves. Therefore, imazethapyr can also be applied as PE. However, post-emergence application of imazethapyr at 100 g/ha 15-20 DAS was found to be more efficient in weed control as compared to imazethapyr at 100 g/ha as pre-emergence (PE) (Ali *et al.* 2011, Ali *et al.* 2013). PE application of imazethapyr at 75 g/ha failed to control late flushes of weeds (Nagender *et al.* 2017). Similarly, response of weed flora to post-emergence (PoE) application of imazethapyr also varied with the growth stage of weed flora. For example, imazethapyr at 100 g/ha at 15 DAS resulted in similar levels of weed dry matter at harvest with imazethapyr 75 g/ha at 15 DAS and 100 g/ha at 25 DAS (Singh *et al.* 2014a). Hence, imazethapyr effectively controls weeds at 75 and 100 g/ha when applied at 15 DAS, however, at 25 DAS, 100 g/ha is only efficient, which may be due to increases in herbicide tolerance of weeds with age. Effectiveness of imazethapyr in controlling grasses and broad-leaf weeds increases up to 80 g/ha but for the control of *Cyperus* spp. application of imazethapyr 100 g/ha is required (Kumar *et al.* 2016).

Pendimethalin has been found to be ineffective against sedges and also loses its effectiveness against grasses and broad-leaf weeds after 20 days of application. However, application of pendimethalin + imazethapyr (pre-mix) at 800, 900 and 1000 g/ha resulted in an almost weed free condition till 40 DAS (Kaur *et al.* 2016). Conversely, pendimethalin + imazethapyr (pre-mix) at 0.75 kg/ha recorded lower weed control efficiency as compared to HW twice at 20 and 40 DAS (Khairnar *et al.*2014). Sequential application of pendimethalin as PE followed by imazethapyr as PoE can also be done for controlling weeds. PE application of pendimethalin at 0.75 g/ha + imazethapyr 40 g/ha at 20 DAS recorded weed dry matter at par with that of a weed free treatment (Komal *et al.* 2015). Later flushes of weeds are controlled by imidazolinole herbicide through their inhibition of the ALS enzyme. Weather conditions can play an important role in influencing the efficiency of PE herbicides. For example, pendimethalin + imazethapyr at 580 g/ha and imazethapyr at 75 g/ha failed to control late flushes of weeds due to heavy rainfall. Integration of herbicides with HW at 20 DAS is essential to control late flushes (Nagender *et al.* 2017).

Herbicides vary in their ability to control different monocot and dicot weeds. Herbicides such as fenoxaprop, pendimethalin and quizalofop control grassy weeds effectively whereas optimal control of sedges and broad-leaf weeds is observed with the application of fenoxaprop + chlorimuron (Mirjha *et al.* 2013). However, oxyfluorfen at 0.180 g/ha + HW at 30 DAS obtained results statistically at par with the number of monocots, dicots and sedges per m^2 with two HW at 20 and 40 DAS (Chhodavadia *et al.* 2014).

Application of chlorimuron-ethyl 15 g/ha has been found effective in weed management and obtained weed dry matter statistically similar with 2 HW at 25 and 40 DAS (Kaur *et al.* 2009). Dose of herbicide is one of the most important factors in controlling weeds. Sole application of quizalofop-ethyl at 37.5 g/ha at 7 days after emergence (DAE) and 50 g/ha at 14 or 21 DAE has not been found effective in controlling sedges and broad-leaf weeds (Kundu *et al.* 2009). On the other hand, quizalofop-ethyl at 100 g/ha at 15-20 DAS recorded statistically similar weed dry matter as that of 2 HW treatment (Ali *et al.* 2015). Patel *et al.* (2016) observed that PoE application of quizalofop-ethyl at 50 g/ha *fb* interculture 30 DAS and fenoxaprop-p-ethyl 100 g/ha *fb* interculture at 30 DAS proved to be inefficient in providing weed control. Imazethapyr + imazamox 0.10 kg/ha provided very efficient control of annual broad-leaf weeds and sedges (Khairnar *et al.* 2014).

It can be concluded that there are a number of herbicides which can be used for effective weed control in greengram. Pendimethalin at 0.75 to 2.0 kg/ha (PE), trifluralin 1.0 kg/ha (PPI), imazethapyr 40-100 g/ha at 15 to 20 DAS, pendimethalin + imazethapyr 0.8-1.0 kg/ha (PE), sequential application of pendimethalin at 0.75 kg/ha (PE) + imazethapyr at 40 g/ha (20 DAS), imazethapyr + imazamox at 0.100 kg/ha, chlorimuron-ethyl at 15 g/ha and quizalofop at 100 g/ha (15-20 DAS) can be effectively used for weed control in greengram. Integration of pendimethalin and quizalofop with HW at 4 WAS can also be used for successful weed management.

Effect of herbicides on symbiotic characteristics

The symbiotic relationship between greengram and *Rhizobium* is essential for proper growth and development of the crop. Any herbicide that adversely affects symbiosis will ultimately inhibit growth of greengram due to a short supply of nitrogen to plant. Thus the greengram-*Rhizobium* relationship is a unique component of herbicide selectivity.

Pendimethalin increases the nodule number and dry weight up to the recommended dose (Pahwa and Prakash 1997). Similarly, pendimethalin at 0.75 (Mishra *et al.* 2017) and 1.0 kg/ha (PE) (Singh *et al.* 2017) recorded nodulation statistically similar with that of weed-free treatment. On the other hand, application of pendimethalin has shown negative effects on nodule number, nodule dry weight (Singh *et al.* 2015) and leghaemoglobin content (Pahwa and Prakash 1997, Singh *et al.* 2015) as compared to two hand weeding treatment. Application of trifluralin at 0.96 kg/ha (pre-plant incorporation) significantly reduced nodule dry weight (Kaur *et al.* 2010) and fluchloralin at 2.0 µg/g significantly reduced the dry weight and number of root nodules (Zaidi *et al.* 2005), leghaemoglobin and nitrogen fixation efficiency (Pahwa and Prakash 1997).

Imazethapyr and other imidazolinone herbicides when used at proper time and rate show no/minimum inhibitory effects on symbiotic parameters. Nodule number and nodule dry weight of summer greengram with application of imazethapyr 50 and 60 g/ha at 20 DAS (Komal *et al.* 2015), 70 and 80 g/ha (as both PE and PoE at 15-20 DAS) (Mishra *et al.* 2017) and 80 and 100 g/ha at 25 DAS (Kumar *et al.* 2016) were statistically similar with weed-free check. PoE application of imazethapyr even at the higher dose of 100 g/ha in summer greengram showed no inhibition of symbiotic attributes. Similarly, combined application of imazethapyr + imazamox at 40 and 60 g/ha at 20 DAS (Komal *et al.* 2015) and at 70 and 80 g/ha (both PE or PoE at 15-20 DAS) (Mishra *et al.* 2017) also proved safe for greengram-*Rhizobium* symbiosis. Furthermore, the integration of the aforementioned herbicides with hand weeding at 40 DAS tended to improve dry weight of nodules as compared to their lone application (Komal *et al.* 2015).

In greengram, no significant reduction in nodule number was recorded with PE application of pendimethalin + imazethapyr (pre-mix) at 1000 g/ha (Mishra *et al.* 2017). Sequential application of pendimethalin at 1.0 kg (PE) + imazethapyr at 100 g/ ha (PoE) (Verma *et al.* 2017) and pendimethalin at 1.25 kg/ha (PE) + imazethapyr at 100 g/ha(PoE) (Kumar *et al.* 2017) recorded significantly higher nodule number/plant of greengram as compared to alone application of imazethapyr (PoE) owing to better weed control as pendimethalin prevents initial flushes while imazethapyr controls late flushes of weeds.

Application of quizalofop-p-ethyl at 37.5 g/ha (Singh *et al.* 2017) or 50 g/ha (at 15 DAS) (Kundu *et al.* 2011) negatively affected the nodule number and dry weight of nodules/plant as compared to weed free treatment. Similarly, in another study, the application of quizalafop-p-ethyl (40, 80 and 120 ppb) and clodinafop (400, 800 and 1200 ppb) resulted in a significant decrease in nodule number, nodule dry weight and leghaemoglobin content of greengram (Ahemad and Khan 2010).

Chlorimuron-ethyl belongs to sulfonyl urea group of herbicides and is effective for weed control even at very low doses. Post-emergence application of chlorimuron-ethyl 9 g/ha at 20 DAS was safe, however, 15 g/ha at 20 DAS negatively affected nodule dry weight (Kaur *et al.* 2010). Pre-plant incorporation of chlorimuron-ethyl at 4 g/ha significantly reduced the nodulation properties of greengram as compared to HW at 25 DAS (Goswami *et al.* 2017).

The inhibitory effects of herbicides on symbiotic parameters may possibly be due to the disruption of enzymes involved in growth and metabolism or the inhibition of host signal (leguminous plant) and *Rhizobium* which is essential for nodule formation and fixation of nitrogen (Zablotowicz and Reddy 2004, Fox *et al.* 2007).

From all the above studies, it can be concluded that application of pendimethalin (PE) at 0.75 to 1.0 kg/ha, imazethapyr (PoE at 20-25 DAS) at 50-100 g/ha, pendimethalin + imazethapyr (pre-mix) at 1.0 kg/ha, sequential application of pendimethalin (PE) + imazethapyr (PoE), chlorimuron-ethyl (PoE at 20 DAS) at 9 g/ha are safer to greengram-*Rhizobium* symbiosis.

Effect of herbicides on crop growth

The effect of herbicides on crop growth may vary with the type of herbicide used, dose of application, stage of crop growth, efficiency of herbicide in controlling weed flora, toxic effect of herbicide on crop, texture of the soil *etc*.

Pre-emergence application of dinitroaniline herbicides such as fluchloralin at 0.625 kg/ha (Kaur *et al.* 2010), trifluralin at 0.96 kg/ha (Kaur *et al.* 2010) or at 0.5, 0.75 and 1.0 kg/ha (Buttar *et al.* 2006) and pendimethalin at 0.45 and 0.75 kg/ha (Kaur *et al.* 2010) or at 1.0 kg/ha (Mirjha *et al.* 2013, Patil *et al.* 2014) do not have any adverse effect on plant growth.

Application of imazethapyr 50 and 70 g/ha at 20 DAS (Kaur *et al.* 2016) and at 50, 75 and 100 g/ha at 15 or 25 DAS (Singh *et al.* 2014a) significantly reduced plant height as compared to 2 HW at 20 and 40 DAS. However, Tamang *et al.* (2015) reported that leaf area index with imazethapyr at 40 g/ha was statistically similar with total weed-free treatment. Application of imazethapyr alone 40, 50 and 60 g/ha at 20 DAS or in combination *i.e.* imazethapyr + imazamox at 40 and 60 g/ha at 20 DAS, pendimethalin + imazethapyr + imazamox at 40 and 60 g/ha at 20 DAS have no adverse effect on plant height, branches per plant and dry matter accumulation as compared to weed-free treatment (Komal *et al.* 2015).

Sequential application of pendimethalin at 0.75 kg/ha (PE) + imazethapyr at 40 g/ha at 20 DAS had no adverse effect on plant height, branches per plant and dry matter accumulation as compared to weed-free treatment (Komal *et al.* 2015). Application of pendimethalin + imazethapyr (pre-mix) at 0.75 and 1.00 kg/ha (Tamang *et al.* 2015), pendimethalin + imazethapyr at 0.80, 0.90 and 1.0 kg/ha (Kaur *et al.* 2016) was also safe for greengram.

Application of quizalofop-ethyl at 35 and 50 g/ha and chlorimuron-ethyl at 9 and 15 g/ha at 20 DAS reduced the number of secondary branches as compared to 2 HW at 25 and 40 DAS, however, chlorimuron ethyl at both doses resulted in the highest number of primary braches, which might be due to the toxic effect of herbicides on greengram and re-growth later on (Kaur *et al.* 2009). In Canada, dry matter with application of fomesafen at 240 and 480 g/ha was at par with the untreated control, while bentazone at 1080 and 2160 g/ha and halosulfuron at 35 and 70 g/ha recorded lower dry matter due to higher injury to crop (Soltani *et al.* 2013). Generally, crop injury due to herbicides was higher at double dose as compared to the recommended dose.

Effect of herbicides on grain yield and yield attributes

Grain yield is the ultimate parameter which depends both on the availability of source and sink as well as translocation of the photosynthates from source to sink. Any adverse effect of herbicides on plant growth, symbiosis, sink formation and translocation of photosynthates will ultimately influence crop yield.

Application of pendimethalin at 0.50 kg/ha (Patel *et al.* 2016), 0.75 kg/ha (Buttar *et al.*2006) and 1.0 kg/ha (Ali *et al.* 2011, Mirjha *et al.* 2013, Khairnar *et al.* 2014, Ali *et al.* 2015) provided statistically similar grain yield of greengram as with that in 2 HW. However, PE application of pendimethalin at 0.90 kg/ha (Chhodavadia *et al.* 2014) and 1.0 kg/ha (Khaliq *et al.* 2002, Raj *et al.* 2012, Nagender *et al.* 2017) have been reported to provide significantly lower grain yield as compared to 2 HW treatment. Though pods per plant and test weight are varietal characteristics, high weed competition may result in adverse effect on these parameters due to severe competition for light, water and nutrients. Pre-plant incorporation of trifluralin at 0.96 kg/ha and fluchloralin at 0.625 kg/ha, PE application of pendimethalin at 0.45 and 0.75 kg/ha recorded seeds/ pod, pods/plant, 100-seed weight and grain yield at par with 2 HW treatment 25 and 40 DAS (Kaur *et al.* 2010). Pre-plant incorporation of trifluralin at 0.5, 0.75 and 1.0 kg/ha recorded grain yield at par with twice hoeing (Buttar *et al.* 2006).

Application of imazethapyr 100 g/ha at 15-20 DAS has been found to be the more effective as compared to inter cultivation (IC) and HW at 20 and 40 DAS (Ali *et al.* 2011, Ali *et al.* 2013, Ali *et al.* 2015). However, PE application of imazethapyr at 100 g/ha reduced grain and straw yield. Thus PoE application of imazethapyr is more efficient (Ali *et al.* 2015). Imazethapyr at 75 and 100 g/ha 20-25 DAS recorded statistically similar pods/plant, test weight, and grain yield as compared to HW twice at 20 and 40 DAS (Khairnar *et al.* 2014, Singh *et al.* 2014a, Kumar *et al.* 2016). Time of PoE application of imazethapyr may also affect crop yield due to changes in selectivity or its ability to control weeds. Imazethapyr at 100 g/ha 25 DAS reduced grain yield as compared to imazethapyr at 100 g/ha 15 DAS, which may be due to better weed control when herbicide was applied at 15 DAS, as weeds attain tolerance to herbicide application with age (Singh *et al.* 2014a). Grain yield and straw yield are not affected by application of imazethapyr at 40, 50 and 60 g/ha at 20 DAS, imazethapyr + imazamox at 40 and 60 g/ha 20 DAS and imazethapyr at 40 g/ha 20 DAS as compared to weed free treatment (Komal *et al.* 2015, Kaur *et al.* 2016).

Pre-emergence application of pendimethalin + imazethapyr (pre-mix) at 0.75 (Khairnar *et al.* 2014, Tamang *et al.* 2015) and 1.0 kg/ha (Tamang *et al.* 2015) recorded statistically similar pods/plant, test weight, and grain yield as compared to HW twice at 20 and 40 DAS. Similarly, Kaur *et al.* (2016) reported that application of pendimethalin + imazethapyr (pre-mix) at 800, 900 and 1000 g/ha recorded pods/plant and grain yield at par with 2 HW at 20 and 40 DAS. Grain yield and straw yield are also not significantly influenced by sequential application of pendimethalin at 0.75 kg/ha (PE) + imazethapyr at 40 g/ha 20 DAS as compared to weed free treatment (Komal *et al.* 2015).

Application of imazethapyr and quizalofop at 100 g/ha 15-20 DAS recorded similar grain yield with HW at 20 and 40 DAS (Ali *et al.* 2011, Ali *et al.* 2013, Ali *et al.* 2015). On the other hand, Chhodavadia *et al.* (2014) observed that application of quizalofop-ethyl 180 g/ha at 20 DAS reduced grain yield as compared to weed free treatment. Generally, integration of herbicide with HW effectively controls late flushes of weeds. Sole application of quizalofop-p-ethyl 50 g/ha at 7 DAE + HW 21 DAE significantly increased pods/ plant, seeds/pod and grain yield as compared to sole quizalofop-p-ethyl 50 g/ha at 21 DAE (Kundu *et al.* 2009). Similarly, in another study, grain yield with application of oxyfluorfen 180 g/ha + 1 HW at 30 DAS was statistically similar with weed free treatment (Chhodavadia *et al.* 2013).

Chhodavadia *et al.* (2014) observed that application of fenoxaprop-ethyl 75 g/ha at 20 DAS significantly reduced grain yield as compared to weed free treatment. PoE application of fenoxaprop 50 g/ha + chlorimuron 4 g/ha recorded statistically similar grain yield with two HW at 20 and 40 DAS. Since fenoxaprop does not control broad-leaf weeds, its combined application with chlorimuron (broad spectrum herbicide) may have resulted in better weed control thus providing better growth conditions for greengram.

In Bangladesh, glufosinate ammonia at 2 ml/l of water recorded significantly higher grain yield than oxadiargyl at 1 g/l, butachlor at 2.5 g/l and paraquat dichloride salt at 2 ml/l (Aktar *et al.* 2015). All these herbicides recorded higher yield than weedy control. In Pakistan, application of s-metolachlor at 2.3 kg/ha significantly reduced number of seeds/pod, pods/ plant, 1000-seed weight and grain yield as compared to 2 HW treatment at 15 and 30 DAS (Khaliq *et al.* 2002).

Herbicide applications generally provided higher grain yield of greengram. However, the herbicide may not always be effective due to reasons including toxicity caused to the crop, non-effective weed control *etc*. There is a need to find more safe and effective herbicides in greengram. Furthermore, some herbicides effective in controlling weeds and safe to the crop might incur label claim issues. These herbicides could not therefore be recommended for use in greengram. There is a need to sort out label claim issues of herbicides that could potentially benefit growers.

Effect of herbicides on nutrient uptake by crop

Nutrient uptake is the total uptake (grain + stover) of nutrients by the crop. Maximum nitrogen, phosphorus and potassium uptake in greengram is generally recorded with two HW. Application of pendimethalin at 0.75 kg/ha significantly increased the nutrient uptake as compared to weedy control (Komal *et al.* 2015). In another study, application of pendimethalin at 1.0 kg/ha has been reported to present nutrient uptake at par with 2 HW at 15 and 30 DAS (Kade *et al.* 2014). However, as compared to sole application of pendimethalin, the integration of pendimethalin with HW 30 DAS further enhanced uptake of nitrogen, phosphorus and potassium by greengram (Chhodavadia *et al.* 2013, Komal *et al.* 2015).

Application of imazethapyr 75 and 100 g/ha recorded nutrient uptake at par with that in two HW 15 and 30 DAS (Kade *et al.* 2014, Lal *et al.* 2017). On the other hand, application of imazethapyr at 40, 50 and 60 g/ha significantly reduced the nitrogen, phosphorus and potassium uptake by the crop as compared to weed free treatment (Kataria *et al.* 2016). Application of imazethapyr and imazethapyr + imazamox significantly increased the nutrient uptake as compared to weedy control (Komal *et al.* 2015).

Application of quizalofop-ethyl at 35 and 50 g/ha and chlorimuron-ethyl at 9 and 15 g/ha significantly reduced the nutrient uptake (Kaur *et al.* 2010). Similarly, Chhodavadia *et al.* (2013) reported that sole application of oxyfluorfen, fenoxaprop-p-ethyl and quizalofop-ethyl significantly reduced uptake of nitrogen, phosphorus and potassium, however, integration of oxyfluorfen with HW at 30 DAS recorded nutrient uptake at par with that in 2 HW at 20 and 40 DAS. Low nutrient uptake by the greengram crop with the application of some herbicides might be due to poor crop growth owing to phyto-toxicity or poor weed control, resulting in severe crop weed competition.

Effect of herbicides on soil microflora

Soil microflora play a major role in breakdown of organic matter, recycling of nutrients and maintaining soil fertility. Adverse effects of herbicides on soil microflora, if any, will ultimately influence availability of nutrients and fertility of soil. Studies have shown that the PE application of pendimethalin 1.0 kg/ha recorded statistically similar microbial biomass carbon at 25 DAS with that of weed free check (Jinger *et al.* 2016) though it recorded significantly lower dehydrogenase activity at 25 and 50 DAS as compared to weed free treatment. However, in another study, application of pendimethalin 1.0 kg/ha recorded significantly lower bacteria, fungi and actinomycetes colony forming units at 30 DAS as compared to weed free and weedy check (Khairnar *et al.* 2014). Similarly, PE application of pendimethalin reduces the soil microflora initially, however, these are recovered at later stages due to degradation of herbicide in the soil (Shruthi *et al.* 2015).

Imazethapyr 50 and 75 g/ha at 20 DAS significantly reduced microbial biomass carbon and dehydrogenase activity at 25 DAS as compared to weed free treatment (Jinger *et al.* 2016). Similarly, Lal *et al.* (2017) also reported that imazethapyr at 75 g/ha + adjuvant at 2 ml/ha at 23 DAS recorded low dehydrogenase activity (DHA) at 7 days after spraying which was significantly lower than HW treatment, however, no influence of herbicides on DHA was observed at 15 days after spraying. Application of imazethapyr recorded significantly lower bacteria, fungi and actinomycetes colony forming units at 30 DAS as compared to weed free treatment (Khairnar *et al.* 2014).

Quizalofop 50 and 75 g/ha at 20 DAS significantly reduced microbial biomass carbon and dehydrogenase activity at 25 DAS as compared to weed free treatment (Jinger *et al.* 2016). However, no influence of quizalofop on DHA has been observed at 15 days after spraying (Lal *et al.* 2017). Application of quizalofop-ethyl 75 g/ha at 20-25 DAS recorded significant reduction in bacteria, fungi and actinomycetes colony forming units at 30 DAS as compared to pendimethalin at 1.0 kg/ha as PE (Khairnar *et al.* 2014). Application of quizalofop-p-ethyl 50 g/ha and fenoxaprop-p-ethyl at 30 g/ha significantly reduced non-symbiotic nitrogen fixing bacteria, phosphate solubilizing bacteria, fungi, actinomycetes and total bacterial population at 30 DAS as compared to weedy check and hand weeding at 20 DAS (Nongmaithem and Pal 2013, Nongmaithem and Pal 2016). Similarly, PE application of oxyfluorfen and alachlor reduced the soil microflora initially after application, however, these are recovered at later stages due to degradation of herbicide in the soil (Shruthi *et al.* 2015). The highest reduction in soil microflora has been noted with the application of oxyfluorfen.

Generally, the highest toxicity of herbicides on microbial population appears immediately after application of herbicides, when their concentration is highest. Subsequent decomposition of herbicides and decreases in their concentration allow for the recovery of microbial populations after initial set back.

Residual effect of herbicides on succeeding crops

Residue activity of herbicide applied to the crop may result in inhibition of growth of the succeeding crop. Generally longer persistence of herbicides is desirable to control later flushes of weeds. However, it should not persist long enough to inhibit growth of the next crop. Persistence of herbicides depends on their properties such as vapor pressure, solubility, degradation rate *etc.*, crop factors such as type of succeeding crop sown and growth of previous crop, prevailing climatic conditions, and soil factors such as physical, chemical and biological properties of soil (Janaki *et al.* 2015). Bioassay studies conducted on succeeding crop indicated no harmful effect of pendimethalin at 500 g/ha (PE), imazethapyr at 75 g/ha (PE), quizalofop-ethyl at 50 g/ha (PoE) and fenoxaprop-p-ethyl at 100 g/ha (PoE), when applied alone or integrated with HW, on mustard, wheat and chickpea (Patel *et al.* 2016).

Conclusion

Non-chemical methods show variable response in weed management and could not alone provide efficient weed control. Among the non-chemical methods straw mulch (1-5 t/ha) and competitive genotypes lead to reduction in weed dry matter. However, the variable response of straw mulch has been observed on growth and yield of greengram. The effect of straw mulch on herbicide requirement and efficacy need further research. Herbicides, however, remain the most efficient method of weed management in greengram and a large number of effective herbicides are currently available. Label claim issues with some herbicides remain unresolved, thus preventing grower application. The effect of herbicides on weed control and crop growth varies with dosage, time of application as well as type of weed flora present. While herbicide application initially inhibits soil microflora, populations rebound with the passage of time due to degradation of herbicides. Integration of herbicides with HW generally provides efficient weed control without any negative influence on symbiosis, growth, yield and nutrient uptake of greengram.

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