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Weed management approaches in direct-seeded rice in eastern Indian ecologies – A critical and updated review

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ABSTRACT

Direct-seeded rice (DSR) is significant in modern day agriculture because it requires less water input (20%) and labour (65-80 person-days/ha). Moreover, it enables farmers to establish rice early, which allows the crop stand more power to resist flush flood happening more frequently in the beginning of the monsoon. Direct-seeded rice produces at par or higher yield compared to manual transplanted rice but significantly higher yield (1.07 t/ha) compared to traditional manual broadcasted rice followed by *beushening* practice. It helps to increase system productivity by 0.25 t/ha, increase income by US$ 150/ha, reduce greenhouse gas emission (20% GWP) besides instrumental in reducing straw burning and environmental footprints. Despite all these advantages, the DSR has not been adopted at large scale at farmers' field in eastern India particularly in Bihar, Odisha and Uttar Pradesh. One of the most important reasons for this is heavy and diversified weed infestation in DSR which consequently reduces rice yields significantly. In the present review article, the authors have tried to compile relevant information on the weed management approaches in DSR with special reference to eastern Indian states. Detailed discussions on weed species based on their occurrence and infestation, critical period of weed competition and different methods of weed management in DSR in eastern Indian ecologies have been enlightened in this paper. It also includes that weed management options in DSR depend on many factors like land situation, soil condition, water status, planting geometry and resources availability; and therefore, one single method of weed management practices may not be sufficient to control all the flushes of diversified weeds. Integrated approach combining cultural, physical and chemical methods can provide a more robust control of weeds in DSR. Relevant data generated in Odisha representing eastern Indian ecologies have also been included herein to further enrich knowledge and skills regarding DSR productivity, in general and possible weed management options, in particular.

INTRODUCTION

Rice is the staple food for more than half of the world population and is presently grown in more than hundred countries in the world, with a total harvested area of approximately 158 million hectares, producing 756.7 million tons annually (502.2 million tons of milled rice). In Asia, nearly 680 million tons of rice is grown, representing 90% of global production (FAO 2017). India is the second largest producer of rice next to China, where it is grown in an area of 43.2 mha annually with a production of 110 mt and accounts for about 40% of food grain production in the country (GOI 2017-18). Around 23% of rice is direct-seeded in the world (Rao *et al.* 2007). In India, out of total 42.5 mha rice area in last decade, estimated direct-seeded rice (DSR) area was 11.9 mha, which is 28% of the total rice area (Pandey and Velasco 2002). Direct seeding of rice is an alternative method that could reduce the labor and irrigation water requirements for crop establishment (Kumar and Ladha 2011). In eastern India, DSR enable farmers to establish rice early, consequently harvesting rice early and allowing farmers to start sowing a subsequent crop like wheat, leading to higher yield of the crop (Singh *et al.* 2008). Shortage of labour in present day agriculture has driven the shift of interest on DSR from puddled transplanted rice in India as well as in many other countries in south-east Asia. Moreover, huge water inputs, labour costs and labour requirements for puddled transplanted rice have reduced profit margins (Pandey and Velasco 1999). DSR helps increase system productivity by 0.25 t/ha, increase income by US$ 150/ha and reduce greenhouse gas emission (20% GWP) besides instrumental in reducing straw burning and environmental footprints. It requires less water input (20%) and labour (65-80 person-days/ha) compared to traditional broadcasted rice (CSISA 2016).

There are three types of establishment methods in DSR, i) sowing dry seeds into the dry soil (dry-seeding), ii) sowing pre-germinated seeds in puddled soil (wet-seeding), and iii) sowing seeds into standing water (water-seeding). Among these, dry-seeding is the most common practice in India. Dry seeding has been the principal method of rice establishment since the 1950s in developing countries (Pandey and Velasco 2005). The dry-seeding can be done by two ways-a) sowing by manual broadcasting and b) sowing by seed-cum-fertilizer drill. Direct-seeded rice sowing by seed-cum-fertilizer drill, which is commonly referred as DSR is practiced in eastern India by two methods-(a) In *vattar* condition, where in a well prepared field after pre-sowing irrigation or after rainfall, the field is ploughed followed by planking. Sowing of pre-soaked treated seeds is done when the field reaches to *vattar* condition (field capacity), (b) In dry soil condition, where sowing of dry seeds is done using a seed drill in a well prepared dry field, after that light irrigation is applied or wait for receiving rainfall for crop emergence. In Asia, dry seeding is extensively practiced in rainfed lowlands, uplands, and flood-prone areas, while wet seeding remains a common practice in irrigated areas (Azmi *et al.* 2005, de Dios *et al.* 2005, Kim *et al.* 2001, Luat 2000). DSR can be grown in almost all types of soils suitable for rice, but medium textured soils are more suited (Kamboj *et al.* 2012). DSR is established earlier than puddled transplanted rice (PTR) without growth delays from transplant injury. Rana *et al.* (2014) reported that DSR matures 7 to 10 days earlier than transplanted rice due to absence of transplanting shock; which hastens physiological maturity and reduces vulnerability to late-season drought (Tuong *et al.* 2000). Awan *et al.* (2006) reported that DSR was almost at par in yield with transplanted crop. Similarly, research study in Odisha in Cereal Systems Initiative in South Asia (CSISA) domain areas (20

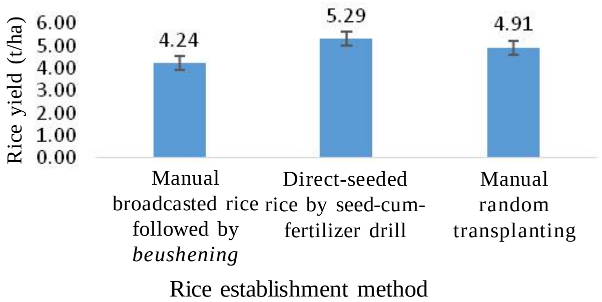

Figure 1. Performance of different rice establishment method in Odisha (2017-2018)

locations in Bhadrak and Mayurbhanj districts in 2017-2018, unpublished) revealed that DSR by seed-cum-fertilizer drill produced the highest rice yield (5.29 t/ha) which was at par with manual random transplanting (4.91 t/ha) but significantly higher than manual broadcasted rice followed by *beushening* (4.24 t/ha) (**Figure 1**). Despite these advantages in DSR, poor germination, uneven crop stand and heavy infestation of weeds become critical factors/ constraints for DSR to upscale compared to traditional transplanted rice (Farooq *et al.* 2010).

Major weed species in direct-seeded rice

More than 50 weed species infest DSR, causing major losses to rice production worldwide (Rao *et al.* 2007). Singh *et al.* (2016) reported that research evidences at different places has shown around 20-100% losses due to weeds such as *Echinochloa* spp., *Leptochloa* spp., *Cyanotis* spp., *Commelina* spp., *Digitaria* spp. and *Alternanthera* spp., in DSR. Among these *Echinochloa colona* and *Echinochloa crusgalli* are the most serious weeds affecting DSR. The density of these weeds in DSR depends upon moisture condition in the field. *Echinochloa colona* requires less water which may be the reason that it is more abundant in DSR. *Cyperus rotundus* and *Cynodon dactylon* may be major problems in poorly managed fields or where un-decomposed farm yard manure has been applied. Singh (2008) also found that *C. rotundus* may pose a severe threat to Direct-seeded rice system where regular flooding is absent. Grasses and broad-leaf weeds are major problem in DSR system and these further led to shift in weed flora towards difficult-to control weeds (Choudhary and Dixit 2018). On an average, yield loss due to weed competition ranges from 15 to 20 per cent, but in severe cases, it may exceed 50 per cent (Hasanuzzaman *et al.* 2009).

Weedy rice

Weedy rices are broadly defined as plants from the genus *Oryza* that mimic, infest and compete with rice (Delouche *et al.* 2007a). Weedy rice increases production costs and reduces growers' profit through yield reduction. The major traits of weedy rice are early shattering of the grain and variable seed dormancy (Azmi and Karim 2008, Delouche *et al.* 2007b). Weedy rice's origin in India is as old as the cultivation of rice since it occupies a special position in the Vedas from ancient times. Many weedy rice species are present in India as the country is the centre of origin of cultivated rice. Weedy rice spreads rapidly from infested fields to new non-infested areas. Knowledge of the sources responsible for the dispersal of weedy rice can help in preventing its spread to non-infested areas. The use of weedy rice contaminated seed is the most important source of its spread to new areas. Contaminated agricultural machineries also play a vital role in spreading of weedy rice. Otherwise, it can also be dispersed through irrigation water, heavy wind/storm and flooding (Chauhan *et al.* 2013). Weedy rice is very difficult to control with a single method and an integrated weed management (IWM) strategy is needed for its effective control in DSR systems (Chauhan 2013). Farooq *et al.* (2009) found that weedy rice (*Oryza sativa f. spontanea*), which is also known as red rice, is highly competitive and causes severe rice yield losses ranging from 15 to 100%. In eastern India, traditionally farmers control weedy rice by occasional manual rouging of panicles only. Use of weedy rice–free seeds and clean agricultural implements can be the best preventive measures to control weedy rice (Chauhan *et al.* 2013).

Volunteer rice

Seeds of previous rice crop usually shatters in the field at maturity and after receiving rains/irrigation germinate with following season rice crop. These volunteer rice plants behave like weeds, compete with main rice crop in place and also contaminate the produce. Chauhan (2012) reported that stale seed bed technique which proved to very effective in direct-seeded rice could be a good option to control volunteer rice. Crop rotation with other crops like pulses or oilseeds in double rice cropping systems could be another option to control volunteer rice in direct-seeded rice.

Critical period of weed competition in DSR

Weeds are a major yield limiting factor in DSR and the literature reporting yield losses are numerous. Weeds adversely affect the yield, quality and cost of production due to competition for various growth factors (Singh 2008). Because of wide adaptability and faster growth, weeds dominate the crops habitat and reduce the yield potential (Rao 2011). Raj *et al.* (2013) reported that season long weed competition in wet seeded rice caused 69.71 and 67.40 per cent reduction in grain yield during *Kharif* and *Rabi* season, respectively. In DSR, competition of weeds is more compared to PTR as weeds and rice seedlings emerge simultaneously, and also due to absence of standing water in DSR. The critical period of weed competition is 14- 41 days after sowing in DSR (Chauhan and Johnson 2011). Azmi *et al.* (2007) reported that critical period for weed control under mixed weed infestation in DSR was from 12 to 60 DAS. The effective control of weeds at initial stages of rice growth (0 to 40 DAS) could help in improving the productivity of DSR (Maity and Mukherjee 2008). Singh (2008) opined that a weed free situation for first 60 or 70 DAS produced yield comparable with weed free situation until harvesting. The competition in DSR beyond 15 days after seeding may cause significant reduction in grain yield. Weeds compete with crop for growth factors such as nutrients, soil moisture, light, space *etc.* and cause losses to the crop (Walia 2016). Estimated losses from weeds in rice are around 10% of total production grain yield; however, such losses can be much higher (Rao *et al.* 2007). In wet-seeded and dry-seeded rice, weed growth reduced grain yield by up to 53 and 74%, respectively (Ramzan 2003), and up to 68–100% for direct-seeded *Aus* rice (cropping season in Bangladesh) (Mamun 1990) and in extreme cases, complete failure of aerobic rice (Jayadeva *et al.* 2011).

WEED MANAGEMENT

Cultural method of weed control

Cultural method plays a significant role in reducing crop-weed competition (Dass *et al.* 2016) in many ways.

Seed rate: Many researchers confirmed that seed rate plays an important role in controlling weeds in direct-seeded rice. In the Indo-Gangetic Plain, a seed rate of 20 to 25 kg/ha has been recommended for DSR (Kumar and Ladha 2011) under optimum weed control. However, results of Chauhan *et al.* (2011) suggest that a seeding rate of 95 to 125 kg/ha for inbred varieties and 83 to 92 kg/ha for hybrid varieties is needed to achieve maximum yields in competition with weeds. One study showed that there was no effect of seeding rates, ranging from 15 to 125 kg/ha, on the grain yield of direct-seeded rice grown in weed-free conditions (Chauhan *et al.* 2011). Research study in Odisha in CSISA domain areas (29 locations in Puri, Bhadrak and Mayurbhanj districts in

2016-2018, unpublished) on optimization of seed rate and weed management option in manual broadcasted rice revealed that use of lower seed rate (60 kg/ha) with weed control by pre-emergence herbicide pretilachlor + safener followed by post-emergence herbicide bispyribac sodium + 1 hand weeding at 2 weeks after post-emergence herbicide spray recorded highest rice yield (4.80 t/ha), which was significantly higher than that of manual broadcasted DSR using high seed rate (100 kg/ha) and weed control (**Figure 2**) by *beushening* practice (3.68 t/ha). The cost benefit study indicates that net benefit per unit investment was also significantly higher in use of lower seed rate and weed control by chemical method (B:C 1.94) compared to use of higher seed rate and weed control by traditional *beushening* practice (B:C 0.90).

Stale seed bed: Stale seed bed technique is an important method of cultural practice to control weeds in direct-seeded rice. In this technique, weeds are allowed/provoked to germinate after application of irrigation water or rainfall and then the weeds are killed either by shallow tillage or by application of non-selective herbicide prior to rice sowing. In general, weed species sensitive to the stale seed bed practice are those that are present in the top-soil layer, have low initial dormancy, and require light to germinate. But weeds which have high initial dormancy cannot be controlled by this method (Chauhan 2012). Singh *et al.* (2016) reported that stale seed bed combined with herbicide (paraquat/ glyphosate) and zero till results in better weed control. This may be due to low seed dormancy of weeds and their inability to emerge from a depth >1 cm (Chauhan and Johnson 2010). About 53% lower weed density was recorded due to stale seed bed. On the basis of farmer's field trials, Singh *et al.* (2009) also observed a 53% lower weed population after stale seed bed practices in DSR. Singh (2013) reported that in dry direct-seeded condition, stale seed bed using glyphosate application 1.0 kg/ha was more effective in reducing the weed density and it recorded higher grain yield and B-C ratio than stale seed bed using shallow tillage. Jose *et al.* (2013) reported that stale seed bed technique effectively controls weedy rice in DSR. Stale seed bed technique was also realized most effective tool against volunteer rice which often causes serious problem in DSR (Yadav and Yadav 2010).

Brown manuring with *Sesbania*: *Sesbania* sown on the day of sowing in DSR suppresses the weeds maximum (Singh *et al.* 2007). *Sesbania* is sown 25 kg/ha and after 25-30 days of sowing, it is knocked down by application of 2,4-D ester 0.5 kg/ha. Anita and Mathew (2010) reported that the best time for incorporating *Sesbania* for maximum weed suppression and grain yield was at 30 DAS for semi-dry rice and the best method for knocking down *Sesbania* was 2,4-D spraying 1.0 kg/ha. Kumar and Ladha (2011) found that *Sesbania* was less effective on grasses compared to sedges or broad-leaf weeds. Hence, pretilachlor + safener can be applied as pre-emergence during *Sesbania* sowing to control grasses effectively in DSR. *Sesbania* also helps in fixing atmospheric nitrogen into the soil and facilitate in crop emergence in areas where soil crust exist (Gopal *et al.* 2010). But contrary to this, there are many reports and observations about *Sesbabia* to causing heavy yield penalties when co-cultured with DSR and this could be an important reason for which *Sesbania* is not co-cultured at scale in DSR.

Land levelling: It is well known that good land preparation helps to reduce weed problem. Precise land levelling like laser land levelling (LLL) is not yet widely adopted in eastern India. Activities in CSISA domain areas in Bihar, eastern Uttar Pradesh and Odisha confirmed that LLL helps to get uniform crop stand and subsequently help to reduce weed population. Studies in north and western India

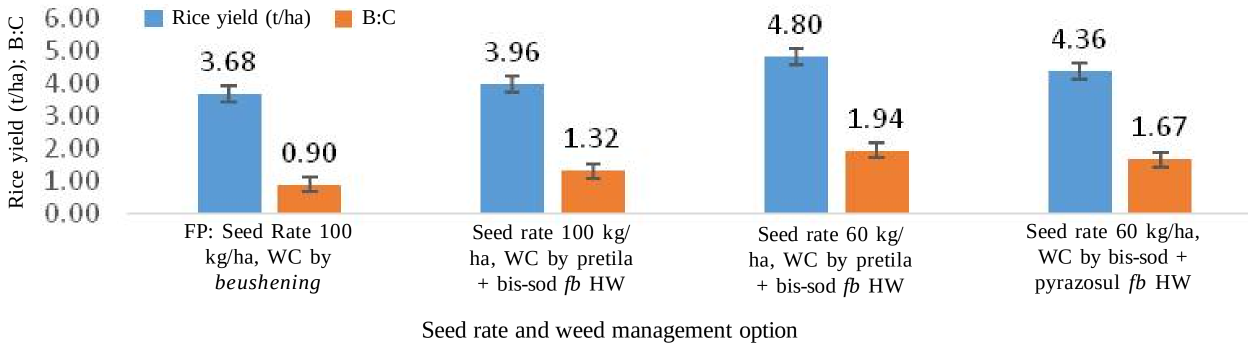

Figure 2. Optimization of seed rate and weed management in manual broadcasted rice in Odisha (2016-2018)

revealed that laser land levelling ensures better crop establishment (Jat *et al.* 2009), precise water control, energy savings, improved weed control, increased nutrient use efficiency and increased herbicide use efficiency (Chauhan 2012). Rickman (2002) reported that laser land levelling reduces the weed population by up to 40% and the labour requirement for weeding by 75% (16 person-days/ha).

Crop rotation: Crop rotation sometimes could be adopted to control obnoxious weeds. Singh *et al.* (2013) reported that rice crop rotation with other crops like mung bean, soybean, cotton and maize effectively controls weedy rice. In coastal Odisha, in double crop areas, some farmers practice rice in rotation with mung bean to control weedy rice and volunteer rice seedlings. Watanabe *et al.* (1998) reported similarly in Malaysia, Suriname and Vietnam. DSR can be rotated with transplanted rice after 2-3 years, if need be, to check build-up of problematic weeds such as *Leptochloa chinensis*, *Eragrostis* spp., weedy/volunteer rice *etc*. (Bharti *et al.* 2016). In eastern Indian states like Bihar, Odisha and Uttar Pradesh, direct-seeded rice is mainly grown in only one season (mostly in *Kharif*) particularly in double rice crop areas to avoid emergence of voluntary rice (the rice seed from previous season germinate in the field in next season) in the DSR field.

Cultivars: Seed germination in anaerobic condition and tolerance of early submergence of rice cultivar are crucial in weed management in direct-seeded rice. In rainfed situation, risk of uncertainty of rainfall and possibilities of flooding after seeding can be controlled by development of suitable variety. In many places in eastern India, germination and crop establishment in DSR fail because of poor germination of rice seeds in anaerobic condition. Rice cultivars with Sub-1 gene though can tolerate complete submergence at seedlings stage but they are susceptible to anaerobic germination (Iftekharuddaula *et al.* 2011). Development of cultivar which can germinate under anaerobic condition will help to control early flush of weeds by initial flooding. The cultivars should have characteristics like high seedling vigour and rapid leaf area development in the early vegetative growth stage to suppress weed growth. Besides cultivars with having allelopathic effect and herbicide resistance will add value to this to control weeds. With the use of cultivars having anaerobic germination, the cost of herbicides may decline as weeds can be controlled by early flooding (Yamauchi 1996). QTLs for this trait have been identified (Septiningsih *et al.* 2009) at the International Rice Research Institute (IRRI). Evaluation trials are also undergoing at many Indian Institutes in close collaboration with IRRI and initial outcomes are encouraging (personal communication).

Physical method of weed control

Manual hand weeding: In eastern India, traditional farmers practice to control weeds in rice is by hand weeding. Though, in present day agriculture, it is not economically viable option to go for manual hand weeding in direct-seeded rice because of shortage of labour and rising price of labour besides being less effective. Hand weeding is environment friendly however, practice is tedious/cumbersome, labour intensive and costly. Roder (2001) reported that 150-200 labour-day/ha are required to keep rice crop free of weeds. In some parts of eastern India, farmers sometimes prefer to go for spot hand weeding particularly after application of post-emergence herbicide to remove escaped weeds, which are not controlled by herbicides. Chopping of panicles or cutting of whole weedy rice by manually are practiced in rice field in many parts of India to control weedy rice. Singh *et al.* (2013) reported that weedy rice panicles are cut with the help of a machete or a special knife attached to a stick in India as well as in many other countries.

Mechanical weeding: In direct-seeded rice, mechanical method can effectively control weeds due to the fact that desired spacing in between rows can be obtained by adjusting tynes in the seed drill machines while sowing in DSR. Mechanical weeders are used to control weeds in between rows; though by this method, weeds which are within rows cannot be removed. Sufficient soil moisture during weeding operation plays a vital role to increase efficiency of mechanical weeder. Though, mechanical weeding by hand pushed cono-weeder is tedious and time consuming, it is still in practice in many parts of eastern India. Recently farmers now showing interest in mechanical weeding by petrol/diesel operated rice power weeder in eastern India. Two-row rice power weeder has the capacity of weeding one acre within 2-3 hours depending on density of weeds in DSR fields. The rice power weeder operates well in standing water in the field and there should be at least 25 cm row-row spacing to avoid cutting of rice seedlings during weeding operation. An early operation at younger stage of weeds (15-25 DAS) and also in combination of effective pre-emergence herbicides will help make the power weeder operation more easy and effective. We have also observed in CSISA Project Domain in Odisha during 2016 and 2017 that herbicide use can be totally displaced by mechanical weeding through use of power weeder twice (15 and 30 DAS) in the field of DSR supplemented with manual hand weeding to remove left over weeds in general and within the rows, in particular. It requires adequate training of the operator and custom hiring could be more practical and feasible way to scale it up. Actually, concerted efforts need to be invested to promote this eco-friendly technique in DSR and mechanical transplanted rice (unpuddled) as well.

Chemical method of weed control

Chemical method of weed control proved to be the best alternative compared to manual or mechanical method of weed control in rice (Chauhan *et al*. 2014). In cases where weeds are morphologically similar to rice crop, chemical method of weed control is the viable option (Chauhan 2012). Jacob *et al*. (2014) opined that the major advantage in herbicide based weed control in DSR is the reduction in the cost of cultivation. Hill *et al*. (2001) reported that the success of herbicidal method of weed control is closely linked to water management to provide suitable condition for achieving specificity in weed control and minimizing the risk of phytotoxicity to rice seedlings. Chauhan and Yadav (2013) reported that combination of two or more herbicides may become an effective and integrated approach to control complex weed flora in DSR. Singh *et al*. (2005) reported to successfully control weeds in DSR by using the stale seed bed technique combined with a pre-emergence herbicide, pendimethalin, applied within 2 days after seeding. Several pre-emergence herbicides including butachlor, thiobencarb, pendimethalin, oxadiazon, oxyfluorfen and nitrofen, alone or supplemented with hand weeding, resulted in good weed control as expressed by reduced weed density and improved yields (Moorthy and Manna 1993, Pellerin and Webster 2004). Paraquat (0.5% by volume) is recommended for burndown application. If fields are infested with perennial weeds, glyphosate should be applied instead of paraquat (Kamboj *et al*. 2012). CSISA on-station and on-farm studies revealed that pendimethalin/oxadiargyl as pre-emergence followed by post-emergence application of bispyribac or azimsulfuron or bispyribac + azimsulfuron 15-20 DAS yielded similar to weed-free conditions. In DSR, time of application of pre-emergence herbicide (particularly pendimethalin) is very important under rainfed condition as pendimethalin can create toxicity to rice seed and damage rice seedling emergence if it comes in direct contact of seeds. Pretilachlor with safener 30.7 EC 500 g/ha or oxadiargyl 80 WP 90 g/ha using 375-500 litre/ha water volume control grasses, broad-leaf and sedges when applied on the same day of sowing under *vattar* condition and within 1-3 days after seeding in case sown in dry and irrigated condition (Kumar *et al*. 2017). Application of post-emergence herbicide in DSR in situations where application of pre-emergence herbicide is missed due to unfavourable weather or other reasons or weeds are not controlled effectively can be one of the suitable options to control weeds which are in 4-5 leaf stage. To cover broad spectrum of weeds, herbicide mixtures increase chances of getting better results for weed control in rice. Post-emergence herbicide bispyribac-sodium 10 SL 20 g/ha controls grasses and broad-leaf and particularly very effective on *Echinochloa* sp. and *Ischaemum rugosum*, but poor on *Leptochloa chinensis, Eragrostis* spp. and *Dactyloctenium aegyptium* when sprayed at 15-25 days after sowing using 300 litre water/ha. Fenoxaprop-p-ethyl with safener 6.9 EC 90 g/ha + ethoxysulfuron 15 WG 18.75 g/ha controls complex weed flora including *Leptochloa* and *Dactyloctenium*. Bispyribac sodium + pyrazosulfuron-ethyl 20 + 20 g/ha controls complex weed flora including grasses, broad-leaf and sedges. It is particularly effective on complex weed flora dominated by *Cyperus rotundus* (Kumar *et al*. 2017). Singh *et al*. (2004) reported that a ready mix formulation of metsulfuron-methyl 10 WP + chlorimuron-ethyl 10 WP 4 g/ha was very effective against diverse weed flora. Selection of herbicide(s) or their combinations should be done very carefully depending upon weed infestation in DSR. For post-emergence herbicides, the field should be moist but without stagnating water before spray and the field should not be irrigated at least up to the next day also.

Integration of weed management practices

Many researchers have emphasized that integration of different weed management practices depending on land situation, soil condition, water status, planting geometry and resources available, can provide great control of weeds as well as cost of production can be minimized. Integration of different weed management practices (cultural, physical and chemical) effectively control weeds in DSR than depending on a single method of weed management practice. Chauhan and Yadav (2013) reported that the combination of two or more herbicides may become a part of an effective and integrated approach to achieve more satisfactory control of complex weed flora in DSR. The sequential applications of a pre-emergence herbicide (*e.g.*, pendimethalin or oxadiargyl) followed by post-emergence herbicide (*e.g.*, bispyribac-sodium) can provide effective weed control in DSR, if supplemented with some other weed management strategies like hand weeding, mechanical weeding and/or other need based herbicides (ethoxysulfuron, pyrazosulfuron, 2,4-D, Almix etc.) (Yadav and Yadav 2010). There is a need to watch weed infestation scenario in the crop to select suitable herbicide(s) accordingly. It is imperative to educate not only the farmers but all other stakeholders including dealers to emphasize more on integrated management of weeds in DSR rather than only chemicals. One has to move in a step-wise manner according to recommended package of practices to harness full benefits of this resource conserving technology not only in the eastern ecologies but also in other parts of the country and South Asia as well.

Conclusions

Direct-seeded rice is catching interest of researchers, planners and farmers in eastern Indo-Gangetic Plain. However, weeds are still perceived as the major limiting factor in wider adoption of DSR. An integrated approach is required to attain effective control of complex weed flora including weedy rice and volunteer rice. Chemical control is the smartest and most economic option for weed management in present day agriculture. Pretilachlor with safener 30.7 EC 500 g/ha as pre-emergence followed by post-emergence herbicide bispyribac sodium 10 SL 20 g/ha at 15-25 DAS takes care of most of the weeds in DSR. One manual/mechanical weeding may also be employed after one week of post-emergence herbicide application to control escaped weeds. Pyrazosulfuron-ethyl, ethoxysulfuron and metsulfuron-methyl + chlorimuron-ethyl may be used as tank mixture with post-emergence herbicide depending upon weed flora and particularly in situations where manual weeding is not feasible. Knowledge and skills of different stakeholders needs to be strengthened on improved herbicide spraying techniques, weed identification and new herbicide molecules along with cultural method of weed management including stale seed bed, competitive varieties and crop rotation.

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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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Temperature, pH and light effect on germination and growth behavior of grassy weeds of direct-seeded rice

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ABSTRACT

Environmental factors have significant implications on the biology of weeds, hence the study of biology of major weeds in a crop, could prove an ecological and economical viable tool for their management. *Echinochloa glabrescens*, *Leptochloa chinensis*, *Eragrostis japonica* and *Dactyloctenium aegyptium* are the major weeds of direct-seeded rice (DSR) and many other *Kharif* crops. The effect of temperature, pH and light was studied on the biology of these four weed species under laboratory conditions during the *Kharif* seasons of 2012 and 2013. Temperature regimes of 15, 20, 25, 30, 35, 40 and 45°C; pH 5.0, 7.0, 9.0 and 11.0 and light period of 0, 3, 6, 12, 24 and 48 hours were evaluated for their effects on germination, shoot and root growth. Conducive temperature for germination of all four-weed species was 35°C except *Dactyloctenium aegyptium*, which has maximum germination at 30°C. Similar to germination, maximum shoot and root length was recorded at 35°C in all the weed species except *E. japonica*, for which 30°C was the optimum. Seed germination was observed over a broad range of pH of all weed species; however, it was highest at pH 7.0. *Echinochloa glabrescens* was most sensitive to a given pH range among all the weed species. Light periods didn't alter the process of germination, shoot and root growth. Manipulation of these factors at field level could be helpful in reducing the weed pressure in DSR by preventing their germination.

INTRODUCTION

Weed biology is an important, but neglected tool of integrated weed management compared to chemical weed management. Studying weed biology will help to develop a robust and sustainable weed management program (Kumari *et al.* 2010). But, there are concerns about laboratory experimental results that can be translated into field weed management programme (Acker 2009). Many factors like seeding depth, temperature, soil moisture, soil pH have influence on germination of weed species and their subsequent growth behavior that will affect crop-weed competition (Singh and Punia 2008, Chauhan and Johnson 2010, Kumari *et al.* 2010). Alteration of above factors by agronomic management could reduce the weed crop competition. Direct-seeded rice (DSR) has more weed competition compared to transplanted rice, because of the absence of a size differential between the crop and weeds and the suppressive effect of standing water on weed growth at crop establishment (Chauhan and Johnson 2010). Weed control is major limitation for the success of DSR (Rao *et al.* 2007).When optimum weed control was achieved in DSR, there was non-significant yield difference compared to transplanted crop (Sipaseuth *et al.* 2000, Chauhan *et al.* 2015). Reducing the weed-crop competition by integration of weed biology could reduce the dependency on chemicals for weed management, hence harnessing high yields in DSR.

Popular tool fascinating the farmers, chemical weed management is also facing problems of resistance, residue for next crop, leaching into ground water, *etc*. Singh and Punia (2008) argued that understanding the biology and ecology of weeds could be helpful for effective weed management in herbicide era where there is a rapid rate of evolution of resistant weed biotypes. According to Zimdhal (1991), unlike entomology and pathology, weed science evolved as 'how to control' weeds and focuses on mainly chemical weed control, whereas, weed biology stress on 'cause.'Advance information on weed biology and ecology is a key to improve weed management programme and determining the biology of the species determines the strengths and weakness in its growth cycle and allow for the development of better weed control strategies. So, integration of multifaceted characterization of weed biology of DSR weeds can results in designing an efficient weed management system for this crop.

MATERIALS AND METHODS

Experiments were conducted at CCS Haryana Agricultural University during 2012 and 2013 under laboratory conditions. Effect of temperature, pH and light at different levels on germination and growth were studied. In all studies, each treatment included four replications (four Petri dishes) and data of two experiments was used for analysis. Seed of four weed species (*Echinochloa glabrescens* (Tall Barnyard grass), *Leptochloa chinensis* (Chinese sprangletop), *Eragrostis japonica* (Love grass) and *Dactyloctenium aegyptium* (Crowfoot grass) were used in the study. Seed of these weeds were collected in 2011 and 2012 from the plants growing in DSR fields. Harvested seeds were bulked, cleaned and sieved to remove any extraneous plant or floral material and then stored in weed science laboratory of department of Agronomy at 15°C temperature. These seeds were kept for approximately 6-7 months. The seeds collected in 2011 were used for sowing in June of 2012 and those collected in 2012 were used for 2013 studies. Seeds were treated with 0.1% sodium hypochlorite immediately before each experiment for 30 minutes and washed 3-4 times with distilled water so as to ensure disease free seeds. Before starting the experiment, seeds of each weed species were tested for viability with 1% tetrazolium chloride solution. A germination test was carried out for each species, at room temperature using Whatman filter paper No. 1 in Petri dishes in both the seasons.

Effect of temperature

To determine the effect of temperature on germination of the above mentioned weed species, twenty seed of each weed were placed uniformly between two layers of filter papers (Whatman No. 1) of 90 mm in Petri dishes of 100 mm diameter (Borosil glass). They were moistened with distilled water and then incubated at 15, 20, 25, 30, 35, 40 and 45^{O}C ± 1.5^{o}C in seed germinator. The filter paper was kept moist throughout the period by regular application of deionized water. Constant temperatures were maintained in the incubator without any diurnal fluctuations. Germination, shoot and root length were recorded at 1, 2 and 3 weeks after sowing (WAS).

Effect of pH

Buffered solutions of pH 5.0 was prepared by using citric acid and pH of 7.0, 9.0 and 11.0 by using potassium hydroxide pellets. Twenty seeds of each weed species were placed on filter paper in Petri dishes. A 10 ml pH solution was added to each Petri dish and theses were watered as and when required with freshly prepared pH solutions. Germination, shoot and root length was recorded at 1, 2 and 3 WAS.

Effect of light

To evaluate the effect of light on germination, twenty seeds were placed in Petri dishes with 10 ml deionized water applied/Petri dish and kept under six regimes of light periods (0, 3, 6, 12, 24 and 48 hour). After a given light hour, the Petri dishes were immediately wrapped with double layer aluminum foil to ensure no light penetration. In case of 0 h light, Petri dishes were covered with aluminum foil immediately after moisture application. Wrapped Petri dishes were kept undisturbed for seven days and then were unwrapped to observe germination and then maintained under natural day and light conditions. Germination, shoot and root length was recorded at 1, 2 and 3 WAS.

Statistical analysis

All the experiments were conducted in completely randomized block design. Treatments of each experiment were replicated four times, and each experiment was conducted twice and experimental data were analyzed using software SPSS version 7.5. Arcsine transformation was used wherever needed. Formula used for arcsine transformation in SPSS was= ARSIN[SQRT(germination/100)]x90/1.571

RESULTS AND DISCUSSION

Effect of temperature

Optimum temperature recorded for germination of *Eragrostis japonica* was 30 to 35°C and it was the lowest at 15°C (**Figure 1**), whereas shoot and root length were recorded highest at 30°C (**Table 1**). Some of the weed species may germinate at a higher temperature, but may not grow at that high temperature, as the optimum temperature for the germination of small flower morning glory (*Jacquemontia tamnifolia*) was 35 to 40^{O}C, but optimum growth was between 25 to 35°C (Shaw *et al*. 1987**)**. This can be attributed to high photosynthesis rate at these temperature regimes as Kebede *et al.* (1989) recorded carbon exchange rate of *Eragrostis tenella* was the highest between 36 and 42°C. Singh and Singh (2009) reported that Germination of *Sida spinosa* (prickly sida) and *Desmodium tortuosum* (Florida beggar weed) was highest between 25 to 40^{O}C and *Senna obtusifolia* (sicklepod) from 20 to 40^{O}C, but maximum germination of Feather Lovegrass [*Eragrostis tenella* (L.)] occurred at 30/20°C alternating temperature (Chauhan 2013). Seed germination,

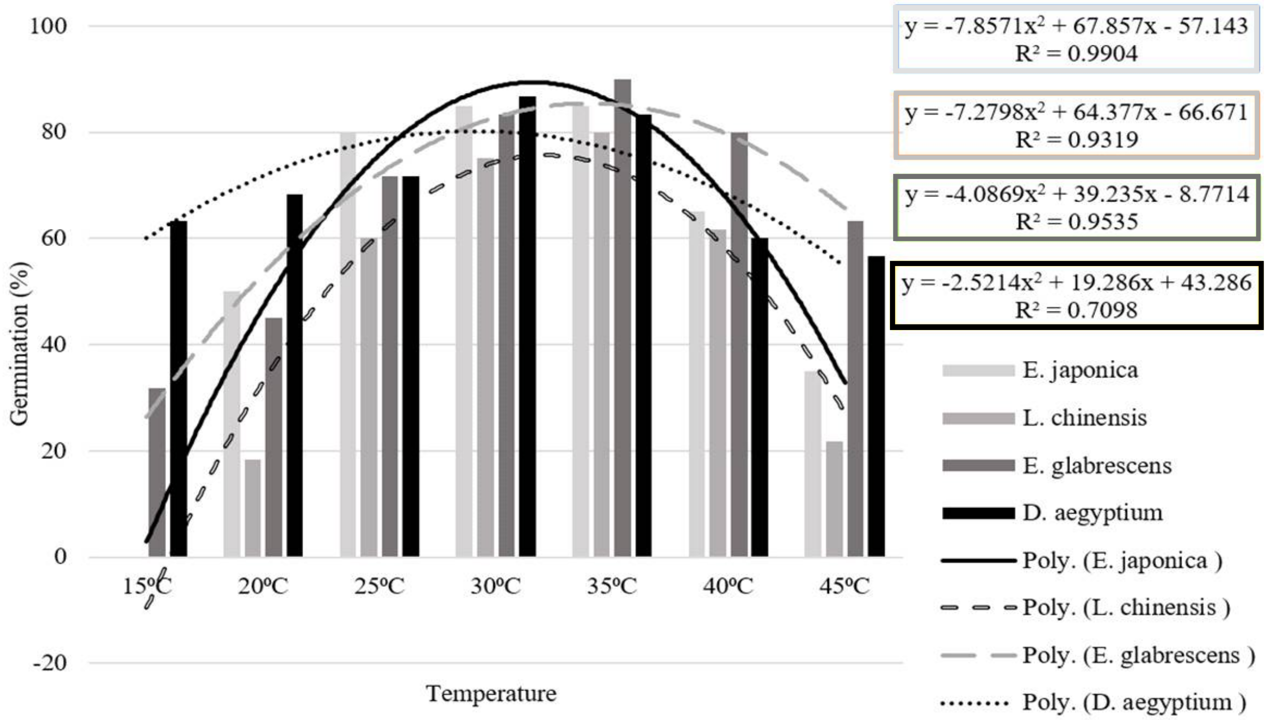

Figure1. Effect of temperature regimes on germination (%) of different weed species (3 WAS)

Table 1. Effect of temperature regimes on shoot length and root length (cm) of different weed species (3 WAS)

Temperature	Shoot length (cm)				Root length (cm)			
	E. japonica	*L. chinensis*	*E. glabrescens*	*D. aegyptium*	*E. japonica*	*L. chinensis*	*E. glabrescens*	*D. aegyptium*
15^{O}C	0.00 (0.10)	0.00 (0.10)	3.90 (1.98)	1.40 (1.18)	0.00 (0.10)	0.00 (0.10)	1.17 (1.08)	2.43 (1.56)
20^{O}C	0.97 (0.98)	0.60 (0.78)	4.27 (2.06)	1.87 (1.37)	0.47 (0.68)	0.53 (0.71)	1.57 (1.25)	2.57 (1.60)
25^{O}C	1.23 (1.11)	1.47 (1.21)	5.60 (2.37)	2.17 (1.47)	0.67 (0.79)	0.63 (0.82)	2.30 (1.52)	4.40 (2.10)
30^{O}C	2.17 (1.47)	1.77 (1.33)	7.37 (2.71)	2.40 (1.55)	1.04 (1.02)	0.97 (0.98)	4.40 (2.10)	5.20 (2.28)
35^{O}C	1.73 (1.32)	2.10 (1.45)	7.77 (2.78)	2.57 (1.60)	1.03 (1.02)	0.97 (0.98)	4.67 (2.16)	5.37 (2.32)
40^{O}C	0.90 (0.94)	1.37 (1.17)	6.10 (2.47)	1.97 (1.40)	0.47 (0.68)	0.90 (0.95)	4.23 (2.06)	3.73 (1.93)
45^{O}C	0.37 (0.60)	1.17 (1.08)	6.23 (2.50)	1.53 (1.24)	0.27 (0.51)	0.73 (0.86)	3.17 (1.78)	2.27 (1.50)
LSD (p=0.05)	0.18	0.12	0.10	0.12	0.19	0.14	0.13	0.17

shoot and root length in case of *Leptochloa chinensis* was the highest at 35^{O}C, which was similar at 25°C, 30°C and 40°C at all observation stages. However, Aulakh *et al.* (2006) reported differences in germination of *L. chinensis* were non-significant due to temperature variations. At initial stage of experiment, *L. chinensis* did not germinate at 15 and 20°C, but at later stages emergence took place. Temperature and time (*i.e.* degree days) is a more comprehensive parameter for the study of temperate effect on germination (Ritchie and NeSmith 1991). Different weed species has different degree days requirement for germination, therefore, variation was recorded in germination of different weed species. Degree days requirement of *L. chinensis* could be more compared to other weed species, resulting into delay germination at lower temperature.

The maximum germination, shoot and root growth of *E. glabrescens* was observed at 35°C. The germination of *E. glabrescens* at 15°C in first week was very less, but it increased at 3 WAS. Germination, shoot and root growth of *E. glabrescens* at all temperature regimes suggest that this species could emerge throughout the year at low altitudes in tropical countries. Similar results were reported for *E. prostrata*, in which seeds germinated at all test temperatures (*i.e.*, 25/15, 30/20, and 35/25°C). The germination of *E. glabrescens* and *D. aegyptium* was faster and showed the earliest germination among all the four-weed species tested. So, it could establish itself very quickly under field conditions and found major species in rice fields. Maximum seed germination was reported at 30°C in *D. aegyptium* and minimum at 45°C, shoot and root length was also high at 30°C. Similar to this study, Burke *et al.* (2003) found that *D. aegyptium* germinated over a range of 15-40°C with the optimum germination occurring at 30°C. So, *D. aegyptium* has a wide range of temperature for germination, this may be due to its wider adaptability from temperate to tropical climate. Whereas, Singh and Singh (2009) found that when data averaged over different weed species and temperatures, highest weed seed germination was recorded in the temperature regime of 25 to 35 °C and maximum being at 30°C. Higher germination in the present study was observed in *E. glabrescens* among the four test species and minimum in *E. japonica*. There was no germination recorded in *E. japonica* and *L. chinensis* at 15°C.

Temperature changes may affect a number of processes during seed germination and growth including the membrane permeability, activity of membrane-bound protein and cytosol enzymes reported by Bewley and Black (1994).Seed germination includes two stages: water absorption and radicle emergence; may be the first stage is not related to temperature, but the second stage is temperature dependent. However, Horowitz and Taylorson (1983) found effect of temperature on imbibition of velvet leaf (*Abutilon theophrasti* Medic.). Exposure of seed to lower or higher temperature than optimum at the second stage cause inhibition of germination while few seed could germinate. Optimum temperature regime is important for embryo development before germination (Harris *et al.* 1998). Some researchers have pointed out that high humidity and temperature environments may readily cause seeds to age and to lose some vigor (Walters 2000).

Effect of pH

The present experimental results indicated that *E. japonica* showed germination at all pH ranges, with highest germination at pH 7.0 (**Figure 2**). Solution of pH 9.0 and 11.0 had similar effect on the germination of *E. japonica*. Similar to *E. japonica,* pH had an effect on the germination of *L. chinensis* and showed tolerance to change in pH. At 1 WAS, pH 5.0 and 7.0 had similar effect on germination. This trend was followed at all observation time. Also, increase in pH from 9.0 to 11.0 had non-significant effect on the germination at each observation stage. Moderate effect of pH was recorded by Altop *et al.* (2015) on germination of bearded spangled (*Leptochloa fusca)* as maximum germination (92%) occurred at a pH of 7 and the lowest germination (54%) at a pH of 10. Similar to this, spotted spurge (*Euphorbia maculate* L.) germination was not affected by the tested levels of pH as germination was 95% over a broad pH range from 4 to 10 (Agropur *et al.* 2015). In a study of 12 Florida weed species, Singh and Singh (2009) found no weed seed germination at pH 3, except *Cyperus esculentus* (yellow nutsedge). A pH range of 5 to 11 had no adverse effect on the germination, when data were averaged over 12 weed species. Germination of prickly sida was the highest at pH 9 and any increase or decrease in pH resulted in reduced germination. Yellow nutsedge tubers germinated 14% at pH 3 compared to 47% at pH 7.

Among all the weed species, *E. glabrescens* showed more pH sensitivity as there was no germination recorded at pH 11.0 during the whole experiment. Maximum germination took place at pH 7.0. There was asteep reduction in the germination at all three observation stages when pH was increased from 7.0 to 9.0. Similar to *E. glabrescens* in this study, *E. crus-galli* was also sensitive to pH change as reported by Sadeghloo *et al.* (2013) and recorded very less germination at pH 9. Although, there was highly variable difference in *D. aegyptium* germination at different pH levels initially, this variability was narrowed down with advancement of the experiment. It showed that higher and lower pH had slowed down the process of germination. Maximum germination occurred at pH 7.0 and this could be explained to favorable ion concentration at this pH. Similarly, germination of sheep sorrel (*Rumex acetosella* L.) seed was occurred in a wide range of buffered pH solutions but the highest germination occurred over a pH range of 6 to 7 (Yazid *et al.* 2013).

Maximum shoot and root length of all weed species was recorded at pH 7.0 (**Table 2**), as this pH may not have affected different enzymic activities and also absorption of nutrients could be more at this pH, compared to other levels. *E. japonica* was less sensitive to pH change as considerable shoot and root length was recorded at all pH levels, maximum being at 7.0. Effect of pH was lowered as the experiment advanced. Similar effect of pH 7.0 was observed in *L. chinensis* on shoot and root growth. However, pH 5.0 affected shoot and root length in similar way at all observation times. Similar to germination, *E. glabrescens* had no shoot and root growth at pH 11.0 during the whole experiment and proved most sensitive to higher pH. Like other weed species, favorable pH for shoot and root growth of *E. glabrescens* was 7.0. As the pH was lowered from 7.0 to 5.0 there was only 9% reduction in shoot length but when it was increased from 7.0 to 9.0, 31% reduction was recorded. In contrast to other species, *D. aegyptium* had less reduction in shoot and root length as pH was increased from 9.0 to 11.0. Hydrogen ion concentration produced its effect on

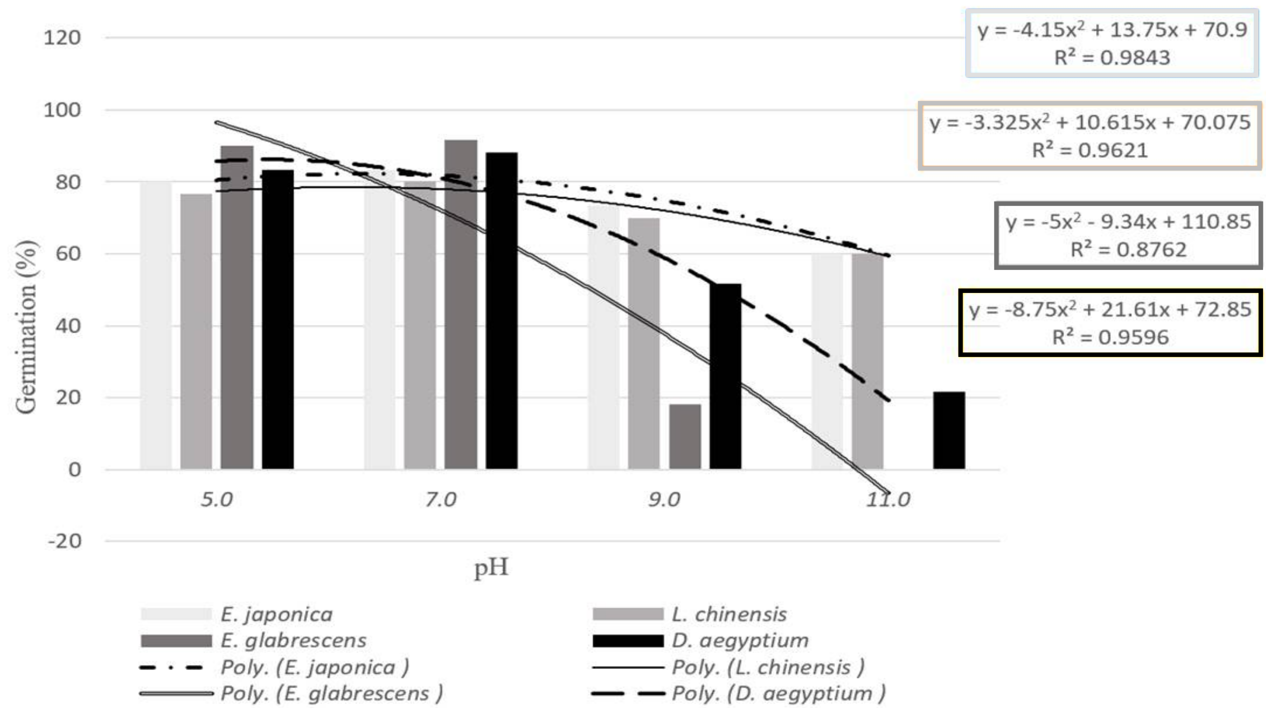

Figure 2. Effect of pH on germination (%) of different weed species (3 WAS)

Table 2. Effect of pH on shoot length and root length of different weed species (3 WAS)

pH	Shoot length (cm)				Root length (cm)			
	E. japonica	*L. chinensis*	*E. glabrescens*	*D. aegyptium*	*E. japonica*	*L. chinensis*	*E. glabrescens*	*D. aegyptium*
5.0	2.10	2.10	6.10 (2.47)	2.07 (1.44)	1.27	0.90	2.03 (1.43)	2.90 (1.70)
7.0	2.37	2.37	6.67 (2.58)	2.37 (1.54)	1.43	1.27	2.23 (1.50)	3.33 (1.83)
9.0	1.43	1.67	4.57 (2.14)	1.27 (1.13)	1.03	1.03	1.33 (1.15)	2.43 (1.56)
11.0	1.07	1.00	0.00 (0.10)	1.07 (1.04)	0.93	0.67	0.00 (0.10)	2.03 (1.42)
LSD (p=0.05)	0.13	0.17	0.12	0.12	0.18	0.19	0.17	0.20

root length of *D. aegyptium*, as there was 40% change in maximum and minimum at 3 WAS. But, Burke *et al.* (2003) recorded highest *D. aegyptium* growth at pH 4.0 compared to other higher pH. Similar to present experiment results, Buchanan *et al.*, (1975) recorded higher growth of *D. aegyptium* at pH 6.3 than 5.4.

Effect of light periods

Results indicated that light was not a prerequisite for germination of these weed species (Data not presented). These results are similar to sicklepod (*Senna obtusifolia*) germination, which was not responsive to light (Norsworthy and Oliveira 2006), while dissimilar to the germination of four weeds under study, *Celosia argentea* was stimulated by light for higher germination (Chauhan and Johnson 2007). Seed germination response to light varies from species to species. Seed of some species require light to germinate (Chauhan and Johnson 2008b, Chauhan and Johnson 2008c) and others can germinate equally in light and dark (Chauhan and Johnson 2008a). Higher germination under both conditions *i.e.* light and dark shows that these weeds can germinate from deeper depths. So, weed species under the present study could germinate from deeper depths if other factors are favorable.

Singh and Singh (2009) found no germination inhibition for any of the 12 test species in dark, except *Richardia brasiliensis* (Brazil pusley). After 168 h, germination of Brazil pusley ranged from 2 to 10% with light exposure of 0 and 16 h, respectively, before placing them in dark. Under alternate light and darkness cycle of 12 h, germination of Brazil pusley increased to 59%. Other than Brazil pusley no other species exhibited the photoblastic effect.

For shoot growth, light is the prime requirement mainly for photosynthesis, even though in the beginning darkness for seven days had non-significant effect on shoot growth. It was observed that in absence of light, achlorophyllous growth occurred during first week. After 7 days when Petri dish were kept in normal day and night conditions, seedlings resumed normal growth. Maximum shoot length (7.43 cm) was recorded in *E. glabrescens* at 3

WAS. Therefore, exposing to light or dark for 7 days did not affect the growth of weeds significantly. These results are in conformity with that of Wang *et al*. (2009) on *Urena lobata* which was not light dependent and emerged from depths up to 9 cm. There was no effect of light/dark period on the root length when seed placed in dark or in light for initial one week, in all weed species. Therefore, it can be concluded that these weeds can emerge from deeper depths where light cannot reach.

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Novel wiper device for the management of weedy rice

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ABSTRACT

The research programme undertaken at Rice Research Station, Moncompu, Kerala Agricultural University, for the post-emergence management of weedy rice by direct contact application (DCA) of broad-spectrum non-selective herbicides using specially designed novel hand held weed wiper device could selectively dry the panicles of weedy rice at 60-65 DAS, taking advantage of the height difference of 15-20 cm between weedy rice and cultivated rice. The study revealed that DCA can be effectively done in weedy rice infested cropped field using non-selective herbicides, *viz*. glufosinate ammonium, paraquat dichloride or glyphosate at 10-15% concentration. Weed control efficiency by this method in terms of drying of the weedy rice panicles was as high as 83 to 88%. The device has been filed for Indian Patent at Patent Office, Chennai (Application No. 1763/CHE/2014 dated 01.04.2014). The technology can reduce the seed rain and buildup of soil seed bank of weedy rice. It is highly energy efficient, less labour intensive, and eco-friendly compared to hand weeding, cutting of weedy rice ear heads or application of large quantity of herbicides using sprayers. The device has become popular among the farming community of Kerala and transfer of technology of the device was done during 2015. The product is now marketed as '*KAU Weed Wiper*' by M/s Raidco Ltd, for large scale manufacturing and sale to farmers

INTRODUCTION

Weedy rice (*Oryza sativa* f. *spontanea*) infestation has become a serious threat to global rice production. India has the earliest history of rice cultivation and introgression between perennial wild rice and cultivated rice, which has given rise to highly variable population of weedy/wild rice forms, including annuals and perennials (Chang *et al.* 1982 and Espinoza *et al.* 2005). Angiras and Singh (1985) observed that grains of weedy rice ripe earlier and less regularly than those of cultivated rice, and were extremely prone to shattering. This situation has forced many farmers to abandon the rice crop without harvesting and subsequently leave the field fallow. Heavy infestation of weedy rice and subsequent reduction in crop yield (50-70%) in rice fields of the country have become a threat to profitable rice production (Abraham *et al.* 2012). Management of weedy rice infestation is complex mainly because of its morphological similarities to cultivated rice making hand weeding ineffective. Lack of herbicides for selective control of weedy rice in cropped fields, seed shattering and variable seed dormancy lead to staggered germination of weedy rice (Abraham and Jose 2015). Direct contact application (DCA) of non-selective broad-spectrum post-emergent herbicides is a management strategy for the control of tall growing weeds in standing crop only with the help of specially designed applicators (Stroud and Kempen 1989).

Under the circumstances, a research programme was undertaken during 2013-15 for the post-emergence management of weedy rice by DCA of broad-spectrum herbicides taking advantage of the earliness in flowering and 15-20 cm height difference of weedy rice to cultivated rice. With this objective, a novel 'Weed Wiper Device' (WWD) was fabricated for doing DCA, for selective drying of weedy rice panicles and thus preventing the build-up of soil seed bank in weedy rice infested areas, its further spread and invasion.

MATERIALS AND METHODS

The research programme was undertaken during 2013-15 at Rice Research Station, Moncompu of Kerala Agricultural University. Design and fabrication of the equipment was done locally and the experiment on identifying the most efficient herbicide for DCA was conducted in farmers' fields in Kuttanad region during *Rabi* 2013-14 and *Kharif* 2014. For optimum development of the equipment, experiments were laid out. Variants of weedy rice and the cultivated species *Uma* were collected from different polders and observations were recorded.

To prevent the shattering of grains and build-up of soil seed bank, management of weedy rice by DCA was attempted. A new hand held WWD (**Figure 1**) was fabricated and the experimental trials on the post-emergence management of weedy rice using the device were done at KAU during 2013-15. The device consisted of a herbicide holding tank of five litre capacity, sprayer pump, 'U' shaped frame fitted with handle, 'U' shapped hose with 8 holes of 3 mm diametre, control valve, end cap, nozzle and cloth towel to smear the herbicide.

The prototype of the hand held WWD fabricated was tested for DCA at 60-65 DAS in infested cropped fields of Kuttanad region. The possibility of using weed wiper for DCA was assessed by counting the density of weedy rice plants, the height difference between the rice and weedy rice plants and days to 50 per cent flowering of weedy rice and rice plants. The efficiency of herbicides in selective drying of weedy rice panicles by DCA using the WWD was experimented using three broad-spectrum herbicides, glufosinate ammonium 15 SL, paraquat dichloride 24 SC or glyphosate 41 SL at 5-15 per cent concentration of the final formulated product. Rice variety '*Uma'* (MO 16) was used for field experimental studies. It is a medium duration, red, medium bold, non-lodging, high yielding rice with average yield of 7-8 t/ha.

RESULTS AND DISCUSSION

Design and fabrication of the WWD

Most of the herbicides currently available in the market do not function selectively against weedy rice without affecting cultivated rice in cropped field (Chen *et al*., 2004). Seed longevity was identified as a major characteristic of weedy rice population and management to reduce the size of the buried weed seed bank was suggested to be equally important (California Department of Food and Agriculture, 2001). The new prototype of the hand held WWD (**Figure 1**) has a five litre herbicide containing tank which can be hung on the shoulder of the operator. A sprayer pump is attached to the herbicide tank to develop pressure. The pressurized herbicide from the tank flows through a hose, placed on a 'U' shaped frame fitted with a handle. Nozzle present at the proximal end of the hose is used to dispense the herbicide. Chances for dripping of the herbicide can be avoided by an easy to operate control valve with button switch or by tilting the device to spread the chemical on to the cloth towel, fastened on the herbicide carrying 'U' shaped frame of the device. The 'U' shaped hose mounting frame is connected to the front end cap of the handle, which in turn is connected to the rear end

Figure 1. Weed wiper device

cap. The hose dummy is present at the distal end of the hose to seal the end of the hose.

The 'U' shaped hose has eight pores, four pores on each parallel limb (**Figure 2**). The hose and the pores are covered with cloth towel which gets saturated by the herbicide coming out from the pores. The 'U' shaped frame increased the working efficiency and area coverage by the device. Herbicide can be smeared on both the sides of the panicle along the entire length by the horizontal swinging movement of the WWD. Patent application has been filed for the fabricated hand held WWD at the Patent Office, Chennai (Application No. 1763/CHE/2014 dated 1.04.2014) and has been published in the Patent Journal (Jose *et al*. 2015b) and is awaiting examination.

Traits of weedy rice favourable for DCA

The morphotypes of weedy rice seen in different polders of Kuttanad were compared with the cultivated rice variety of the polder, *Uma* (**Table 1**). It was observed that the height of weedy rice morphotypes ranged from 65-87 cm, while that of cultivated rice was 53 - 66 cm at 60 DAS. The plant height at 80 DAS was 92-191 cm and 99-109 cm for weedy rice and cultivated rice, respectively. This clearly reveals that as weedy rice approaches 60 DAS, it maintains height difference of more than 15 cm with rice plant and favours DCA for the selective drying of tall weedy rice plants in standing crop. At the time of ear head emergence of weedy rice, it was seen that the second internode from the top elongates, pushing the ear head above the crop canopy to a height of 15-20 cm. As the crop approaches 80 DAS, the height difference between weedy rice and

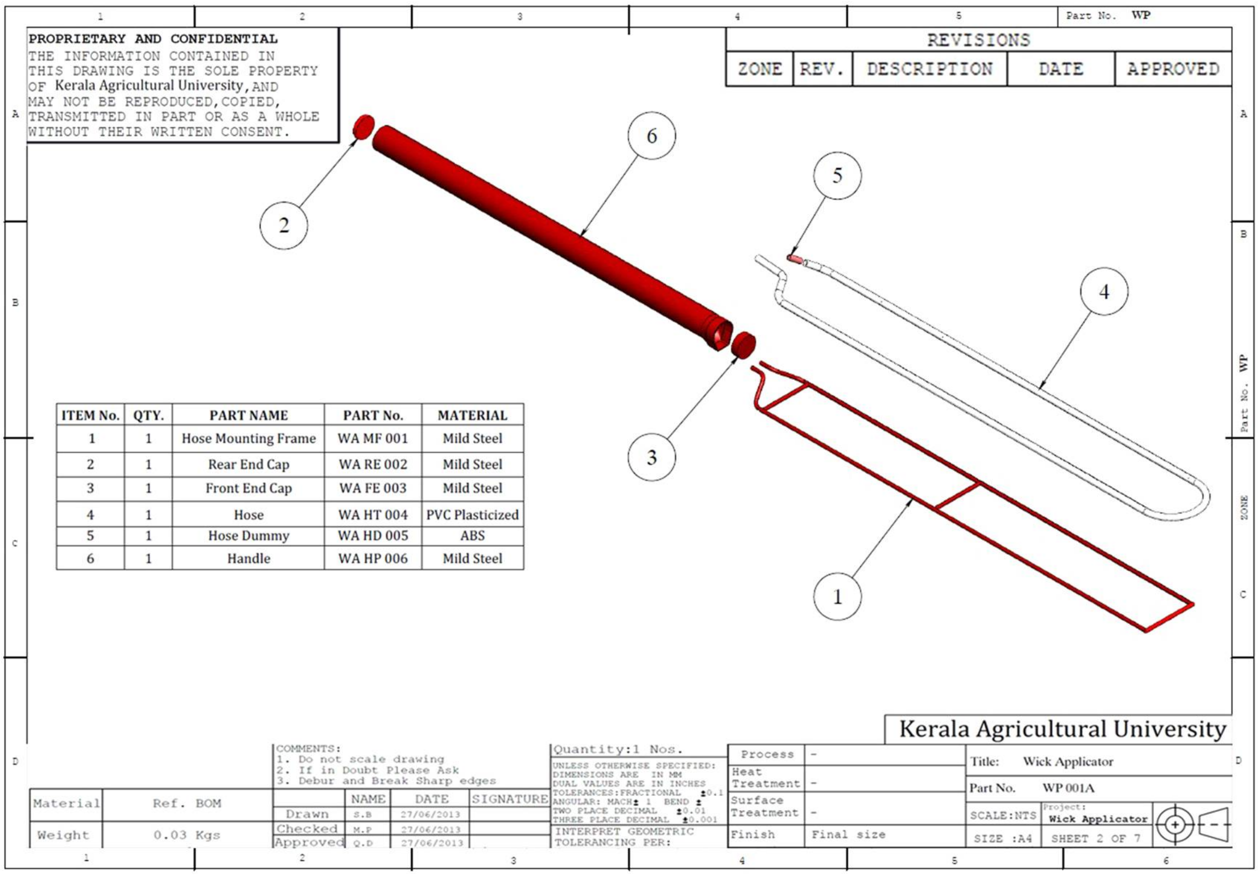

Figure 2. Illustration of the weed wiper device

cultivated rice decreases. Hence, control of weedy rice by DCA is possible only within 60 -75 DAS in cropped field.

The study also observed that flowering in weedy rice was between 55-70 DAS, while that in rice was between 82-88 DAS (**Table 1)**. As weedy rice has staggered germination and panicle emergence under field conditions, use of DCA should be initiated at a stage when more than 50-70% of the weedy rice panicles have emerged. Under certain situations, second application of herbicides by DCA may become necessary if there is late emergence of weedy rice panicles. As crop approaches 80-85 DAS, rice plants would have initiated flowering. Exertion of panicle in rice increases the plant height, reducing the height difference between weedy rice and rice. Hence, control of weedy rice by DCA is possible only within 60-75 DAS in cropped field. The uniformity among the rice plants and that among weedy rice population in a crop stand decides the effectiveness of the device in selective drying of the ear heads of weedy rice without affecting the crop stand beneath. As weedy rice has staggered germination in cropped field, repeated DCA can be resorted at around 60-65 and/or 70-75 DAS, when the weedy rice panicles are at a height of 15 cm above the crop canopy (Jose *et al.* 2015a).

Table 1. Variation in the height and time of flowering in cultivated rice and weedy rice

Morphotype	No. of tillers/weedy rice plant/m^2	No. of weedy rice panicles/m^2	Height of weedy rice (cm)		Height of rice (cm)		Days to 50% flowering	
	60 DAS	65 DAS	60 DAS	80 DAS	60 DAS	80 DAS	Weedy rice	Rice
Kainakari	5.6	20	87.7	119.1	60	105	55	88
Champakulam	4.5	35	69.9	101.4	53	105.5	58	82
Nedumudy	6.2	30	65.8	98.3	58.7	102.6	68	85
Ambalapuzha North	4	19	68	107	55.2	99.8	70	86
Ramankary	5.1	24	87.5	140.5	68.5	100.7	57	85
Ambalapuzha South	5.5	17	85	119.5	65.9	102.4	60	86
Punnapra	2.5	18	80	113	66.7	109.2	59	88
Alapuzha	4.7	40	69	92.5	62.5	105	65	85
LSD (p=0.05)	3.2	15	NS	23	NS	NS	10.3	NS

Chauhan (2013) reported that earliness in flowering of weedy rice plants compared to cultivated rice varieties also favoured DCA. Olguin *et al*. (2007) and Rathore *et al*. (2016) reported that early flowering in weedy rice is an additional advantage for survival in rice fields. It was observed that the weedy rice plants had very early flowering which resulted in early grain maturation and seed shattering. In the population studied, all most 70 per cent of grains in a panicle shattered within 15 days after flowering and there was no sequence in the nature of shattering. Both fully matured (black or brown coloured) and partially matured grains (light straw coloured) shattered randomly along the entire length of the panicle (Jose 2015). Ferrero (2010) reported that this behaviour could most likely be explained by the incomplete development of the early shattered grains, which broke off mainly because of the environmental causes like wind. Shattered seeds added to the soil seed bank would intensify the problem in future (Perreto *et al.* 1993). Early seed shattering was identified as a specific characteristic of weedy rice, controlled by the gene Sh which shows the shattering character in dominant homozygosys (Sh Sh) or heterozygosys (sh Sh) conditions (Sastry and Seetharaman 1973).

Effect of herbicides on selective drying of weedy rice panicles

Post-planting chemical control of weedy rice in cropped field should be considered only as a salvage operation and it mainly relies on difference in size or growth stage between weedy rice and commercial rice. The experiment on identifying the most efficient herbicide was conducted in farmers' fields in Kuttanad region during *Rabi* 2013-14 with severe infestation of weedy rice. Among the chemicals used in the experiment, the efficacy of glufosinate ammonium at 5% concentration was inferior to all other treatments (**Table 2**). At 15% concentration, it was at par with glyphosate at 10 and 15% and paraquat dichloride at 15% concentration in drying the panicle. The number of ear heads that were not dried by herbicidal action varied significantly among treatments. Number of ear heads that escaped the DCA was significantly higher in glufosinate ammonium at 5% concentration while, it was significantly lower and at par in the treatments with glyphosate at 10 and 15%, and paraquat dichloride and glufosinate ammonium at 15% concentration. The treatments which were at par in the control of weedy rice ear heads exhibited 83 to 88% control efficiency.

Similar experiment was also conducted in severely weedy rice infested direct-seeded rice fields of Kuttanad during *Kharif,* 2014. Different concentrations of glyphosate (10 and 15%) did not vary significantly in the control of weedy rice ear heads (**Table 2**). Glufosinate ammonium at 5% was inferior in controlling weedy rice compared to its higher concentrations at 10 and 15%, which were at par. Among the different herbicides tried, glufosinate ammonium 15% had the highest per cent control followed by glyphosate and paraquat dichloride at 15% and glufosinate ammonium at 10% concentration. The number of ear heads that escaped from the herbicidal contact varied significantly among treatments. No. of ear heads that remained unaffected was significantly higher for the contact herbicides, glufosinate ammonium (5%) followed by glufosinate ammonium (10%) and paraquat dichloride at 10% concentration. Number of weedy rice panicles that were skipped in DCA was significantly low and at par at higher concentration of glufosinate ammonium (15%), paraquat dichloride (15%) and glyphosate (at concentrations, 10% and 15%).

The dried ear heads were collected for checking the viability using Tetrazolium test and it was found that majority of the spikelets were either in the dough stage or sterile. The ear heads which dried within 2-5 days after application of the herbicide subsequently fell off from the plant within 10-15 days of

Table 2. Effectiveness of DCA on selective drying of weedy rice panicles

Herbicide formulation	Dose of application (%)	Panicles (no./m^2) Before sweeping		Panicles (no./m^2) Not dried		Panicles dried (%)	
		2013 *Rabi*	2014 *Kharif*	2013 *Rabi*	2014 *Kharif*	2013 *Rabi*	2014 *Kharif*
Paraquat dichloride 24 SC	10	42	41	*4 (11)^{cd}	*4 (15)^{bc}	74^{bc}	63^{bc}
Paraquat dichloride 24 SC	15	41	44	3 (7)^{de}	3 (7)^{c}	83^{ab}	78^{ab}
Glyphosate 41 SL	10	43	44	3 (6)^{de}	4 (13)^{bc}	85^{ab}	71^{ab}
Glyphosate 41 SL	15	41	45	2 (5)^{e}	4 (12)^{bc}	88^{a}	73^{ab}
Glufosinate ammonium 15 SL	5	40	39	5 (22)^{b}	4 (19)^{b}	45^{d}	52^{c}
Glufosinate ammonium 15 SL	10	43	43	4 (13)^{c}	4 (15)^{bc}	69^{c}	67^{bc}
Glufosinate ammonium 15 SL	15	43	44	3 (7)^{de}	3 (9)^{c}	85^{ab}	80^{a}
Control	-	44	42	7 (44)^{a}	7 (42)^{a}	0^{e}	0^{d}
LSD (p=0.05)		NS	NS	1.7 (5)	1.3 (8.4)	12.7	16

*Square root transformed value. Figures in the parentheses are original values and those followed by the same alphabets in a column do not vary significantly in DMRT application. Ferrero and Vidotto (1999) have observed 90% reduction in germination of dried seeds collected after sweeping weedy rice panicles with wick applicator using glyphosate (10-15%) at 65 DAS in infested cropped fields. The possibility of using weed wiper for DCA depends on the density of weedy rice plants, the height difference between the rice and weedy rice plants and days to 50% flowering of weedy rice and rice plants.

Precautions while using WWD

While sweeping the herbicide over the crop stand, utmost care should be taken to prevent dripping of the herbicide from the applicator lance and touching the crop canopy which is at minimum permissible height difference with weedy rice ear heads. The efficiency of the wick applicator depends primarily on the mode of action of the chemical and its concentration. The skill of the person using the equipment and his perceptions on the mode of action of the chemical, either contact or systemic also affects the efficacy of DCA. The efficiency of selective drying depends on the herbicide used, its concentration, stage of the crop and weed, and skill of the personal engaged for DCA. While selecting herbicides for swabbing, it is always better to use those with contact broad-spectrum action (glufosinate ammonium and paraquat dichloride) than systemic action (glyphosate) to prevent accidental drying of the rice plants. However, if skilled personnel are engaged, even systemic herbicides can be used to dry the entire weedy plants. The quantity of herbicide required for swabbing an area of one hectare with moderate weedy rice infestation (6-10 weedy rice ear heads per square metre) was recorded as 1.5 to 2.0 litre, at 10 per cent concentration of the herbicide. Using the novel WWD, one hectare of moderately infested fields was covered in 3-4 hours.

It can be concluded that early flowering in weedy rice 20 to 25 days earlier than cultivated rice and height difference of 15 to 20 cm between weedy rice and cultivated rice at the time of flowering make post-emergence management by selective drying of weedy rice panicles by DCA with specially designed WWD very effective. This can be done with non-selective broad-spectrum herbicides, glufosinate ammonium 15 SL at 15%, paraquat dichloride 24 SC at 15% or glyphosate 41 SL at 10-15% concentration. The novel method is effective in reducing the weedy rice infestation by preventing seed rain and subsequent build-up of soil seed bank. The device developed in the project was filed for the Indian Patent at Patent Office, Chennai (Application No. 1763/CHE/2014 dated 01.04.2014) and the technology of the device has been transferred to M/s Raidco Ltd, for large scale manufacturing and sale to farmers.

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Herbicide options for weed management in sugarcane + wheat intercropping system in Indo-Gangetic Plains

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ABSTRACT

Field and farmer participatory trials were conducted from 2006-07 to 2012-13 to evaluate the efficacy of herbicides alone and in combination on complex weed flora in sugarcane + wheat intercropping system. Sulfosulfuron 25 g/ha, sulfosulfuron + metsulfuron (ready-mix) 32 g/ha, mesosulfuron + iodosulfuron (ready-mix) 14.4 g/ha, pinoxaden 50 g/ha, pinoxaden + metsulfuron 50 + 4 g/ha, pinoxaden + 2,4-D 50 + 500 g/ha, pinoxaden *fb* carfentrazone 50 *fb* 20 g/ha gave satisfactory control of *Phalaris minor*. However, pinoxaden treatments were superior to other herbicides in respect of grassy weed management. For control of broad-leaf weeds, tank-mix of metsulfuron or 2,4-D with pinoxaden were found effective. Ready-mix herbicides sulfosulfuron+ metsulfuron and mesosulfuron+ iodosulfuron were also found promising against complex weed flora in sugarcane + wheat intercropping system. Clodinafop 60 g/ha, fenoxaprop 100 g/ha and carfentrazone 20 g/ha were phyto-toxic to the sugarcane. Grain yields of wheat under sulfosulfuron, sulfosulfuron + metsulfuron (ready-mix), mesosulfuron + iodosulfuron (ready-mix), pinoxaden alone and in combination with metsulfuron, 2,4-D or carfentrazone were as good as weed free check. Similarly the cane yields under these treatments except pinoxaden *fb* carfentrazone and sulfosulfuron + metsulfuron (ready-mix) were at par with each other and also with weed free check. Sulfosulfuron 25 g/ha, sulfosulfuron+ metsulfuron (ready-mix) 32 g/ha, mesosulfuron+ iodosulfuron (ready-mix) 14.4 g/ha or pinoxaden 50 g/ha provided effective control (83-97%) of weeds including *Phalaris minor* over the years. These treatments provided higher grain yield of wheat (4.65-4.93 t/ha) and cane yield (85.5-91.1 t/ha) of sugarcane.

INTRODUCTION

Sugarcane is planted in autumn (September-October), spring (February-March) and summer (April-May) seasons in Indo-Gangetic Plains. Autumn planting provides longer time for germination as well as tillering as compared to spring and summer plantings. When sugarcane planting is delayed from February to April/May, it gets lesser time for tillering and reduces productivity (Pandey and Shukla 2001). Hence, the autumn sugarcane yields 25-30% more than spring cane and 40-50% more than the summer planted crop (Rana *et al*. 2006 and Singh *et al*. 1990). Autumn sugarcane is considered more congenial for intercropping of winter season crops as low temperature regime causes slow growth of sugarcane (Singh *et al*. 1999). But the area under autumn planted sugarcane is limited as the profitability from sole sugarcane is less than the two crops (*Rabi* crop *fb* summer season sugarcane). Moreover, many farmers, who do not want to sacrifice *Rabi* crop at the cost of autumn cane; this could be compensated by raising intercrops in between the rows of sugarcane during early 4-5 months leading to efficient utilization of resources. Intercropping systems of sugarcane with wheat, raya, peas, rapeseed, barley and gram were more profitable than sole sugarcane (Singh *et al*. 2007). Wheat is an important crop of this zone, which is staple food crop with assured market and plays a major role in food security of the country. Sugarcane can be successfully grown in intercropping system with wheat under furrow irrigated raised beds (FIRB) (Kamboj *et al*. 2008, IISR 2017). Wheat can be sown on beds and sugarcane in the furrows during the last week of October. The performance of this system is quite good and has been recommended by the state University in Haryana.

Autumn sugarcane remains in the field for a year or more and the space between sugarcane rows (90 cm) provide ample chance for profuse weed growth which draws huge amount of nutrients and moisture from the soil and thus reduce the cane yields. Yield losses due to the presence of weeds (in sole sugarcane/ intercropping system) were estimated to the tune of 26-75% (Patil *et al.* 1991; Srivastav *et al.* 2005). Conventional method of hand hoeing or inter culture is not feasible in intercropping systems. This discourages the farmers to adopt intercropping in sugarcane. These concerns necessitated the use of herbicides for timely and effective control of weeds as well as an economic alternative to the costly labour (Bhullar *et al.* 2006). In inter-cropping system, there is a need for evaluation of herbicides alone or in combination for control of the complex weed flora for making system based recommendations. Hence, the present investigation was undertaken to identify the effective herbicidal options (particularly post-emergence) for weed control in sugarcane+ wheat intercropping system.

MATERIALS AND METHODS

Experiment 1

The phyto-toxicity evaluation trial was conducted at CCS HAU Regional Research Station, Karnal, Haryana during 2006-07 using herbicides used in wheat clodinafop 60 g/ha, sulfosulfuron 25 g/ha and fenoxaprop 100 g/ha. The treatments were randomly arranged in three replications. The field was slightly alkaline in reaction (pH=8.3), low in organic carbon (0.34%), medium in phosphorus (12 kg P_2O_5/ha) and potash (227 kg K_2O/ha). Sowing of sugarcane and wheat intercrop was done on 25 October, 2006. During 2007-08, phyto-toxicity evaluation of sulfosulfuron 25 g/ha, sulfosulfuron+ metsulfuron (ready-mix) 32 g/ha, pinoxaden 50 g/ha, mesosulfuron+ iodosulfuron 14.4 g/ha was done at village Khanpur, Yamuna Nagar. The plot size was 10.0 x 3.6 m and the treatments were randomly arranged in three replications. Sowing of sugarcane and wheat crops was done on 22 October, 2007. The field was slightly alkaline in reaction (pH=8.0), low in organic carbon (0.38%), medium in phosphorus (16 kg P_2O_5/ha) and potash (245 kg K_2O/ha). The observations on crop phytotoxicity (chlorosis, necrosis, stunting, epinasty, hyponasty and wilting) on a 0-10 scale (0-no phyto-toxicity and 10-complete phyto-toxicity) were recorded at 30, 60 and 90 days after treatment application during both the years.

Experiment 2

Based on findings of Experiment 1, a field experiment was laid out at CCS Haryana Agricultural University, Regional Research Station, Karnal to evaluate the herbicides for control of weeds in sugarcane+ wheat intercropping system. The soil of the experimental plots was clay loam in texture, low in organic carbon (0.32-0.34%), medium in phosphorus (12-14 kg P_2O_5/ha) and potash (224-232 kg K_2O/ha) with slightly alkaline pH (pH=8.2-8.4). The treatments included pendimethalin 1000 g/ha, isoproturon 1000 g/ha, sulfosulfuron 25 g/ha, sulfosulfuron+ metsulfuron (ready-mix) 32 g/ha, mesosulfuron+ iodosulfuron (ready-mix) 14.4 g/ha, pinoxaden 50 g/ha, pinoxaden+ 2,4-D 50 + 500 g/ha, pinoxaden + metsulfuron 50 + 4 g/ha, pinoxaden 50 g/ha *fb* carfentrazone 20 g/ha, along with weed free and weedy checks. The treatments were laid out in randomized block design with three replicates during 2008-09 and 2009-10. Sowing was done on 25th October 2008 by adopting furrow irrigated raised bed method (90 cm = 55 cm top, 35 cm furrow) during 2008-09 and on 30th October by wide bed and furrow method (135 cm = 90 cm top, 45 cm furrow) during 2009-10 with wheat cultivar '*DBW 17*' sown on beds and sugarcane cultivar '*CoH-136*' planted in the furrows. Seed rate used was 112.5 kg/ha for wheat and 8.75 t/ha for sugarcane. Three rows (18 cm spacing) and four rows (22 cm) of wheat were sown per bed, making a 54:18:18 cm and 69:22:22:22 cm crop geometry during 2008-09 and 2009-10, respectively. During 2008-09, the row to row spacing for sugarcane was 90 cm, while during 2009-10, two rows of sugarcane were planted (35 cm spacing) in each furrow (furrow spacing of 135 cm), in a 100:35 cm crop geometry for sugarcane. Crops were raised according to package of practices of the state University. Observations on weeds were recorded at 90 days after sowing (DAS). Crop yield and yield parameters were recorded at maturity of respective crops. Harvesting of wheat was done on 5th April, 2009 and 20th April, 2010 and sugarcane on 26th October, 2009 and 2nd November, 2010 during 2008-09 and 2009-10 seasons, respectively.

Experiment 3

Some of the herbicidal options found suitable in the experiments at research farm for weed control in sugarcane + wheat intercropping system, were also evaluated at farmers' field situations in farmer-participatory trials as well during 2010-11, 2011-12 and 2012-13, with nine, eight and seven locations, respectively. The treatments included sulfosulfuron 25 g/ha, sulfosulfuron + metsulfuron (ready-mix) 32 g/ha, mesosulfuron + iodosulfuron (ready-mix) 14.4 g/ha and pinoxaden 50 g/ha along with weed free and weedy checks. The experiment was laid out in randomized block design with number of locations serving as number of replications.

Sowing of crops was done on 25-31 October 2010, 26-31 October 2011 and 26-30 October 2012 during 2010-11, 2011-12 and 2012-13 crop seasons, respectively, using a seed rate of 100 kg/ha for wheat and 7.0-8.5 t/ha for sugarcane. Sugarcane was sown at a spacing of 90 cm and three rows of wheat were sown in between with a row spacing of 18 cm. The plot size was 600 m^2. The herbicides were applied as spray in a spray volume of 500 liter water per hectare, with knapsack sprayer using flat-fan nozzle. Data on percent weed control was recorded at 75 DAS. Wheat crop was harvested on 14-21 April during different years. For recording grain yield of the crop, two samples from an area of 5.0 x 5.0 m in each plot were harvested. The data on cane yield were recorded at harvest of the crop. Harvesting of sugarcane was done on 10-31 December. For recording cane yield, two samples from an area 9 x 10 m in each plot were harvested.

RESULTS AND DISCUSSION

Experiment 1

The phyto-toxicity studies during 2006-07 and 2007-08 indicated that among wheat herbicides, clodinafop 60 g/ha and fenoxaprop 120 g/ha resulted in phyto-toxicity on the sugarcane crop (4.0 and 4.8 on 10 point scale at 30 days after treatment (DAT), which progressed further with time (6.3 and 7.0 at 60 DAT, respectively) leading to almost complete toxicity (8.8 and 9.3 at 90 DAT, respectively). Other herbicides (sulfosulfuron, sulfosulfuron + metsulfuron, pinoxaden and metsulfuron + iodosulfuron) were found to be safe to sugarcane (data not given).

Experiment 2

The field was infested mainly with *Phalaris minor* among grassy weeds, *Coronopus didymus, Anagallis arvensis, Vicia sativa* and *Rumex dentatus* among broad-leaf weeds and *Cyperus rotundus* among sedges.

Sulfosulfuron 25 g/ha, sulfosulfuron + metsulfuron (ready-mix) 32 g/ha, mesosulfuron + iodosulfuron 14.4 g/ha, pinoxaden 50 g/ha, pinoxaden + metsulfuron 50 + 4 g/ha, pinoxaden + 2,4-D 50 + 500 g/ha provided effective control of weed grassy weed *Phalaris minor,* as evidenced by reduction in grassy weeds density and biomass by these herbicides during both the years (**Table 1**). These treatments resulted in *P. minor* biomass reduction (0.0-8.4 g/m^2 in 2008-09 and 2.2-12.9 g/m^2 in 2009-10) as low as weed free check during both the years; however, pinoxaden treatments were superior to other herbicidal treatments in respect of density (0.0-2.7/m^2) and were at par with weed free checks during 2008-09. All these treatments were superior to pendimethalin or isoproturon in respect of density and biomass of grassy weeds; however, pendimethalin was superior to isoproturon against *P. minor.* Efficacy of sulfosulfuron, sulfosulfuron + metsulfuron, mesosulfuron + iodosulfuron, pinoxaden, metsulfuron-methyl and 2,4-D at a dose already recommended to wheat crop as post-emergence herbicides for weed control in sugarcane+ wheat system was reported by other workers as well (Kamboj *et al.* 2008, Kumar *et al.* 2017). Other workers have reported that pendimethalin (IISR, 2017) and isoproturon (Fahad *et al.* 2013) could be used for control of weeds in sugarcane + wheat intercropping system.

Sulfosulfuron + metsulfuron (ready-mix), mesosulfuron + iodosulfuron (ready-mix), and tank-mix of metsulfuron or 2,4-D with pinoxaden provided excellent control of broad-leaf weeds also as evidenced from weed density (38.0-76.0/m^2 in 2008-09 and 1.3-12.7/m^2 in 2009-10) and biomass (12.9-23.6 g/m^2 in 2008-09 and 0.5-4.0 g/m^2 in 2009-10), which were superior to pinoxaden or sulfosulfuron alone. Isoproturon or pendimethalin were also effective against broad-leaf weeds and pendimethalin (4.3-30.0 g/m^2) had an edge over isoproturon (10.6-33.5 g/m^2). Sulfosulfuron+ metsulfuron (ready-mix) or pinoxaden + 2,4-D also significantly suppressed the sedges, while other herbicides were not effective against sedges (*Cyperus rotundus*) except little suppression by sulfosulfuron. 2,4-D was the best option against sedges. Carfentrazone 20 g/ha in sequence with pinoxaden 50 g/ha provided good control of grass and broad-leaf weeds (**Table 1**) but was phyto-toxic to the sugarcane crop with necrotic red spots appearing on the leaves (**Table 3**). All the other herbicide treatments were safe to both the crops. However, slight phyto-toxicity (1.2 on 0-10 scale) of sulfosulfuron+ metsulfuron (ready-mix) was observed on sugarcane at later stages during 2009-10, but it did not have any adverse effect on sugarcane yield. There was little phyto-toxicity of mesosulfuron + iodosulfuron and carfentrazone on wheat (0.1-0.2 on 0-10 scale) during 2008-09 but it recovered very shortly (**Table 2**).

Plant height and ear head length of wheat were not influenced by different treatments, except during 2008-09 when lowest plant height was recorded under pendimethalin, isoproturon and weedy check (**Table 2**). Similarly cane height and cane girth were not influenced by different treatments (**Table 3**). Number of effective tillers (104.3-109.5/mrl in 2008-09 and 105.9-113.7/mrl in 2009-10) and grain yield (5.64-6.05 t/ha in 2008-09 and 3.52-3.82 t/ha in 2009-10) of wheat under sulfosulfuron 25 g/ha, sulfosulfuron + metsulfuron (ready-mix) 32 g/ha, mesosulfuron + iodosulfuron (ready-mix) 14.4 g/ha, pinoxaden 50 g/ha, pinoxaden + metsulfuron 50 + 4 g/ha, pinoxaden + 2,4-D 50 + 500 g/ha, pinoxaden 50 g/ha *fb* carfentrazone 20 g/ha were at par with weed free check (112.7/mrl and 6.08 t/ha in 2008-09; 115.7/mrl and 3.86 t/ha in 2009-10, respectively) during both the years (**Table 2**). Similarly, number of millable canes and cane yield (81.6-88.5 t/ha in 2008-09 and 85.0-96.7 t/ha) under these treatments except pinoxaden *fb* carfentrazone were at par with weed free check (89.9 and 100.7 t/ha, respectively) except sulfosulfuron + metsulfuron (ready-mix) being inferior during 2009-10 (**Table 3**). Pinoxaden *fb* carfentrazone gave the lowest yield (62.0 t/ha) of sugarcane among all the herbicidal treatments during 2008-09 and was even lower than pendimethalin or isoproturon (71.1-76.1 t/ha); however, these three treatments were at par with each other during 2009-10 (72.1-84.3 t/ha). Pendimethalin 1000 g/ha was superior to isoproturon 1000 g/ha in controlling weeds (**Table 1**), however, the differences in respect of crop yields were not always significant (**Table 2** and **3**).

Experiment 3

The farmer-participatory trials during 2010-11 to 2012-13 indicated that sulfosulfuron 25 g/ha, sulfosulfuron + metsulfuron (ready-mix) 32 g/ha, mesosulfuron + iodosulfuron (ready-mix) 14.4 g/ha or pinoxaden 50 g/ha provided effective control (83-97% control of weeds including *P. minor* over the years) in sugarcane + wheat intercropping system (**Table 4**). These treatments provided grain yields of wheat (4.52-4.93 t/ha) and cane yield (82.7-91.1 t/ha) of sugarcane at par with each other and also the weed free check (4.90-5.04 t/ha of wheat and 87.7-91.7 t/ha of sugarcane) during all the seasons, except sulfosulfuron 25 g/ha during 2011-12 being inferior to pinoxaden 50 g/ha in respect of grain yield of wheat. Earlier reports have also established suitability of sulfosulfuron, sulfosulfuron + metsulfuron, mesosulfuron + iodosulfuron, and pinoxaden as PoE herbicides for weed control in sugarcane + wheat inter-cropping system (Kamboj *et al.* 2008, Kumar *et al.* 2017).

Table 1. Effect of different weed control treatments on weed density and biomass in sugarcane + wheat intercropping system (2008-09 and 2009-10)

Treatment	Dose (g/ha)	Time (DAS)	Weeds density (no./m^2)*					Weeds biomass (g/m^2)				
			Phalaris minor		Broad-leaf weeds		Sedges	Grassy weeds		Broad-leaf weeds		Sedges
			08-09	09-10	08-09	09-10	08-09	08-09	09-10	08-09	09-10	08-09
Pendimethalin	1000	0-3	3.4(10.7)	5.6(30.0)	4.3(17.3)	2.3(5.3)	6.9(46.7)	36.0	40.2	30.3	4.3	5.1
Isoproturon	1000	35	4.0(14.7)	7.8(60.0)	6.7(44.0)	3.8(14.0)	7.7(59.3)	57.6	149.8	33.5	10.6	8.1
Sulfosulfuron	25	35	2.3(4.7)	2.6(6.0)	10.6(112.0)	5.6(30.0)	6.0(35.3)	12.2	5.4	41.8	15.5	7.4
Sulfosulfuron + metsulfuron (RM)	32	35	2.2(4.0)	3.5(11.3)	7.0(48.0)	2.8(6.7)	5.1(25.3)	7.9	8.9	13.1	4.0	4.8
Mesosulfuron + iodosulfuron (RM)	14	35	2.5(5.3)	4.2(18.0)	8.8(76.0)	1.4(1.3)	6.9(47.3)	8.4	12.9	23.6	0.5	5.3
Pinoxaden	50	35	1.0(0.0)	2.5(5.3)	11.3(126.7)	6.2(37.3)	7.5(56.0)	0.0	2.2	66.0	21.4	9.5
Pinoxaden + 2,4-D	50+500	35	1.4(1.3)	3.3(10.0)	6.7(44.7)	3.6(12.7)	3.6(12.0)	0.2	7.6	17.1	3.7	1.3
Pinoxaden + metsulfuron	50+4	35	1.8(2.7)	3.4(10.7)	6.2(38.0)	2.2(4.7)	7.1(50.7)	3.5	7.6	12.9	3.2	6.3
Pinoxaden *fb* carfentrazone	50 *fb* 20	35 *fb* 42	1.5(1.3)	4.2(16.7)	5.9(33.3)	4.2(17.3)	6.5(42.0)	3.1	12.2	20.9	11.5	6.7
Weed free			1.0 (0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)	0	0	0	0	0
Weedy check			6.6(43.3)	10.0(98.7)	12.0(142.0)	5.9(34.0)	6.5(41.3)	116.1	199.5	76.3	29.7	6.5
LSD (p=0.05)			0.63	0.88	0.67	1.43	1.16	8.9	15.3	12.2	5.0	2.2

*Original figures in parentheses were subjected to square root transformation (sin-1√X) before statistical analysis. RM, ready-mix; DAS, days after sowing; LSD, least significant difference; *fb*, followed by

Table 2. Effect of different weed control treatments on yield and yield attributes of wheat in sugarcane + wheat intercropping system (2008-09 and 2009-10)

Treatment	Dose (g/ha)	Time (DAS)	Plant height (cm)		Effective tillers/mrl		Ear head length (cm)		Grain yield (t/ha)		Phyto-toxicity (0-10 scale)	
			08-09	09-10	08-09	09-10	08-09	09-10	08-09	09-10	08-09	09-10
Pendimethalin	1000	0-3	83.5	85.5	93.6	103.0	9.6	9.7	5.17	3.28	0.0	0.0
Isoproturon	1000	35	83.6	86.8	87.4	92.3	9.6	9.5	4.92	2.95	0.0	0.0
Sulfosulfuron	25	35	84.3	86.8	104.3	105.9	9.7	9.9	5.64	3.60	0.0	0.0
Sulfosulfuron + metsulfuron (RM)	32	35	84.1	86.9	107.3	106.7	9.8	9.9	5.77	3.61	0.0	0.0
Mesosulfuron + iodosulfuron (RM)	14	35	84.3	85.1	109.5	108.1	9.7	9.9	5.78	3.52	0.1	0.0
Pinoxaden	50	35	84.5	86.4	106.4	113.7	9.7	10.1	5.78	3.74	0.0	0.0
Pinoxaden + 2,4-D	50 + 500	35	85.0	87.7	108.5	111.7	9.8	9.8	5.88	3.75	0.0	0.0
Pinoxaden + metsulfuron	50 + 4	35	84.3	87.3	109.5	113.2	9.8	10.0	6.05	3.82	0.0	0.0
Pinoxaden *fb* carfentrazone	50 *fb* 20	35 *fb* 42	84.1	86.7	107.3	107.7	9.8	10.1	5.92	3.70	0.2	0.0
Weed free			85.3	86.9	112.7	115.7	10.1	10.1	6.08	3.86	0.0	0.0
Weedy check			82.4	84.0	78.6	75.7	9.5	9.5	3.21	2.18	0.0	0.0
LSD (p=0.05)			1.2	NS	8.5	7.6	NS	NS	0.47	0.27		

DAS, days after sowing; mrl, meter row length; RM, ready-mix; NS, non-significant, LSD, least significant difference; *fb,* followed by

Table 3. Effect of different weed control treatments on growth and yield of sugarcane in sugarcane+ wheat intercropping system (2008-09 and 2009-10)

Treatment	Dose (g/ha)	Time (DAS)	Cane height (cm)		Millable canes (000/ha)		Cane girth (cm)		Cane yield (t/ha)		Phyto-toxicity (0-10 scale)			
											08-09		09-10	
			08-09	09-10	08-09	09-10	08-09	09-10	08-09	09-10	45 DAT	90 DAT	45 DAT	90 DAT
Pendimethalin	1000	0-3	201	210	78.5	82.2	2.0	2.2	76.1	80.6	0.0	0.0	0.0	0.0
Isoproturon	1000	35	192	201	75.3	76.6	2.0	2.1	71.1	72.1	0.0	0.0	0.0	0.0
Sulfosulfuron	25	35	205	214	84.6	89.9	2.2	2.3	82.0	90.6	0.0	0.0	0.0	0.4
Sulfosulfuron + metsulfuron (RM)	32	35	210	217	87.1	86.6	2.3	2.2	87.6	85.0	0.0	0.0	0.0	1.2
Mesosulfuron + iodosulfuron (RM)	14	35	208	216	83.5	88.3	2.2	2.3	81.6	88.3	0.0	0.0	0.0	0.2
Pinoxaden	50	35	208	218	85.8	90.0	2.3	2.3	83.0	92.6	0.0	0.0	0.0	0.0
Pinoxaden + 2,4-D	50 + 500	35	209	218	86.3	90.9	2.3	2.3	85.5	95.9	0.0	0.0	0.0	0.0
Pinoxaden + metsulfuron	50 + 4	35	210	220	88.6	91.0	2.3	2.4	88.5	96.7	0.0	0.0	0.0	0.0
Pinoxaden *fb* carfentrazone	50 *fb* 20	35 *fb* 42	194	202	72.2	84.6	2.1	2.2	62.0	84.3	2.0	1.0	2.5	0.3
Weed free			210	222	89.4	92.2	2.4	2.5	89.9	100.7	0.0	0.0	0.0	0.0
Weedy check			192	200	60.3	71.7	1.9	1.9	40.9	66.1	0.0	0.0	0.0	0.0
LSD (p=0.05)			NS	NS	5.2	4.6	NS	NS	8.4	13.7				

DAT, days after treatment; DAS, days after sowing; RM, ready-mix; NS, non-significant; LSD, least significant difference; *fb,* followed by

Table 4. Effect of different treatments on weeds control in sugarcane+ wheat intercropping system, and its effect on grain yield of wheat and cane yield in farmer participatory trials in Haryana (2010-11 to 2012-13)

Treatment	Dose (g/ha)	Time (DAS)	Weed control (%)*			Grain yield of wheat (t/ha)			Cane yield (t/ha)		
			2010-11	2011-12	2012-13	2010-11	2011-12	2012-13	2010-11	2011-12	2012-13
Sulfosulfuron	25	35	73.1(90.6)	65.7(82.8)	68.2(85.8)	4.52	4.56	4.70	87.7	82.7	87.3
Sulfosulfuron+ metsulfuron (RM)	32	35	76.7(93.6)	70.8(88.8)	73.1(91.0)	4.82	4.79	4.76	89.7	85.5	88.9
Mesosulfuron+ iodosulfuron (RM)	14.4	35	74.4(91.5)	72.9(90.8)	72.0(90.0)	4.78	4.85	4.72	88.8	85.6	89.5
Pinoxaden	50	35	81.3(96.9)	76.6(94.3)	80.8(96.5)	4.88	4.93	4.88	90.8	86.8	91.1
Weed free			90.0(100.0)	90.0(100.0)	90.0(100.0)	4.90	5.04	4.93	91.5	87.7	91.7
Weedy check			0.0(0.0)	0.0(0.0)	0.0(0.0)	2.78	3.00	2.99	57.1	55.6	53.3
LSD (p=0.05)			4.9	3.9	4.6	0.39	0.26	0.21	4.0	5.1	4.5

*Original figures in parentheses were subjected to angular transformation ($\sqrt{x+1}$) before statistical analysis; RM, ready-mix

It may be concluded that sulfosulfuron 25 g/ha, sulfosulfuron + metsulfuron (ready-mix) 32 g/ha, mesosulfuron + iodosulfuron (ready-mix) 14.4 g/ha or pinoxaden 50 g/ha could effectively be used to control grassy weeds particularly *P. minor* in sugarcane + wheat intercropping system. Clodinafop 60 g/ha, fenoxaprop 100 g/ha and carfentrazone showed phyto-toxicity to the sugarcane crop.

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Tillage and weed management influence on physico-chemical and biological characteristics of soil under cotton-greengram cropping system

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ABSTRACT

A field experiment was conducted during *Kharif*-Summer season of 2016-17 at research farm of AICRP-Weed Management, Anand Agricultural University, Anand, Gujarat to study the effect of different tillage and weed management options on physico-chemical and biological properties of soil under cotton-green gram cropping system. The tillage and weed management treatments did not show any significant effect on various physico-chemical properties of soil after harvest of cotton and greengram except on organic carbon content and available phosphorus. The tillage did not influence the microbial population in cotton but weed management options, IC + HW at 15, 30 and 45 DAS showed significant impact on total bacterial count and dehydrogenase activity in soil. The tillage had significant effect on actinobacteria count and dehydrogenase activity in greengram while weed management options exhibited significant effect on all the microbial observations except on total PSM count. It is inferred that combination of zero tillage + residue incorporation along with IC + HW at 15, 30 and 45 DAS in cotton and zero tillage + residue incorporation along with IC + HW at 20 and 40 DAS in green gram were most suitable option for cotton-greengram cropping system in Middle Gujarat condition.

INTRODUCTION

Cotton-greengram system is one of the major cropping system component adopted in Middle Western plains of Gujarat. Therefore, the role of tillage in this cropping system can play a substantial factor to minimize yield gap. Improved management practices such as reduced or no tillage management, addition of crop residue, crop rotation and balanced nutrient application improves agricultural sustainability (Six *et al.* 2002, West and Post 2002 and Vanden Bygaart *et al.* 2003). Conservation agriculture (CA) increases productivity and helps in improving soil health (Fowler and Rockstrom 2001, Hobbs 2007, Giller *et al.* 2009) and hence, there has been a positive shift towards the promotion of CA throughout the world (Melander *et al*. 2005, Sharma and Singh 2014 and Bajwa 2014).

To promote capture and conservation of water and nutrients in agricultural systems under arid and semi- arid regions, CA practices are important, because they can contribute to avoid soil degradation by compaction (Fernandez-Ugalde *et al.* 2009 and Kuzucua and Dokmenb 2015). Balancing of soil property is the core area to be taken care by the agriculturist or user of it. This study was conducted to assess effects of various tillage and weed management practices on physic-chemical and biological properties of soil in cotton-greengram cropping system.

MATERIALS AND METHODS

The present investigation was carried out during *Kharif*-summer season of 2016-17 at AICRP on Weed Management farm, Anand Agricultural University, Anand, Gujarat. The soil of the experimental field was sandy loam in texture with pH, EC, organic carbon, available nitrogen, phosphorus and potash of the soil ranged to 7.80, 0.17/dSm, 0.27% (low), 342.0 (medium), 48.0 (medium) and 298.0 (high) kg/ha, respectively. The soil samples from each plot were collected after harvest of the crop and analyzed for physico-chemical properties of soil using standard laboratory procedure.

The experiment was conducted in strip plot design wherein, cotton was grown in *Kharif* and *Rabi* season while greengram was grown in summer. In the first crop, the treatments were conventional tillage (CT), conventional tillage (CT), zero tillage

(ZT), zero tillage (ZT) and zero tillage + residue (ZT+R) were relegated to main plots while pendimethalin 900 g/ha pre-emergence treatment (PE) at 0-3 days *fb* IC + HW at 30 and 60 DAS, quizalofop-ethyl 50 g/ha post-emergence treatment (PoE) at 20 days *fb* IC + HW at 30 DAS and IC + HW at 15, 30 and 45 days after seeding (DAS) in subplot as a treatment. In second crop, the treatments were conventional-tillage (CT) followed by conventional tillage, conventional tillage (CT) followed by zero tillage (ZT), zero tillage (ZT) followed by zero tillage (ZT), zero tillage (ZT) followed by zero tillage + residue (ZT+R) and zero tillage + residue (ZT+R) followed by zero tillage + residue (ZT+R) relegated to main plot while pendimethalin 500 g/ha PE *fb* IC+HW at 30 DAS, imazethapyr 75 g/ha PoE *fb* IC + HW at 30 DAS and IC + HW at 20 and 40 DAS in sub-plots as a treatment. In *Kharif* season, cotton cultivar Guj. Cot. Hy. 8 (BG II) was sown the seed rate of 4.0 kg/ha at 120 cm row to row and 45 cm plant to plant distance. The crop was fertilized with 280 kg N/ha urea only. One fourth quantity of nitrogen (70 kg/ha) was applied as a basal and remaining quantity of nitrogen was applied in equal split at different growth stages of cotton, *viz.* square formation, flowering and boll formation stages as top dressing.

Similarly, in summer season, greengram cultivar '*GAM 5*' was sown using 20.0 kg/ha seed with 45 cm row to row spacing. The crop was fertilized with 20 kg N/ha and 40 kg phosphorus/ha. Entire quantity of nitrogen and phosphorous were applied using urea and single super phosphate as basal dose, respectively. The herbicides were applied as per the treatment in respective crop by knapsack sprayer fitted with flat-fan nozzle using 500 litres/ha water. All the recommended package of practices were followed to grow cotton and greengram crop.

The soil samples from each plot were collected before sowing of greengram and after harvest of cotton. These samples were analyzed for total soil bacteria, fungi, actinobacteria, diazotrophs, phosphate solubilizing microbial (PSM) populations and dehydrogenase activity in soil samples using standard laboratory procedure. For total count, soil samples were serially diluted and inoculated on respective agar media *i.e.* for bacteria nutrient agar, for fungi MRB agar, for actinomycetes agar and for PSM, PKVK agar medium were used. After incubation, microbial count in terms of CFU was recorded (Bera and Ghosh 2013). The overall data recorded for various parameters were statistically analyzed by the procedure described by Chochran and Cox (1957).

RESULTS AND DISCUSSION

Effect on weed dry biomass

At harvest, weed dry biomass (31.1 g/m^2) of total weed recorded significantly the highest under zero tillage treatment in cotton (**Table 1**). While the lowest total weed dry biomass was recorded under zero tillage practices. Dry biomass of monocot weeds at harvest was found significantly lower under zero tillage + residue when compared with conventional tillage treatment and at par with all other. Zero tillage and conventional tillage remain at par with each other but found significantly superior over other treatments for dry biomass of dicot weed (**Table 1**). Weed dry biomass of monocot, dicot and total were recorded significantly the lowest under IC + HW carried out at 15, 30 and 45 DAS except for dicot weed, which was at par with application of pendimethalin 900 g/ha PE *fb* IC + HW at 30 and 60 DAS. These results are in agreement with those reported by Patel *et al*. (2013). Least dry weight of sedges was recorded under application of quizalofop-ethyl 50 g/ha PoE *fb* IC + HW at 30 DAS at harvest in cotton.

Data presented in **Table 1** indicated that significant differences were achieved due to different tillage practices on weed density and dry biomass of monocot, dicot, sedges and total weeds at 30 DAS. The highest dry biomass of monocot weeds (11.7 g/m^2) was recorded under zero tillage followed by zero tillage + residue treatment. Similarly, dry biomass of dicot weed was recorded the highest under conventional tillage (3.49 g/m^2) treatment. Total weed dry biomass was recorded significantly the highest under zero tillage (12.5 g/m^2) followed by zero tillage + residue (10.2 g/m^2). Weed dry weight of monocot, sedges and total were found to be non significant due to different weed management practice. However, application of imazethapyr 75 g/ha PoE *fb* IC + HW at 30 DAS and IC + HW at 20 and 40 DAS remain at par with each other but found significantly superior over pendimethalin 500 g/ha PE *fb* IC + HW at 30 DAS with respect to dry weight of dicot weeds at 30 DAS.

Effect on yield

The highest seed cotton yield was achieved under conventional tillage treatment (2.52 t/ha) while the lowest seed cotton yield (1.88 t/ha) was recorded under zero tillage practices **(Table 1)**. Schwab *et al.* (2002) indicated that conventional tillage might have eliminated compaction of sub-surface soil due to deep tillage, which may enhanced root growth and subsequent nutrient and water uptake thereby produced higher seed cotton yield. Stalk yield was found non significant due to different tillage treatment (**Table 1**). Significant differences in seed cotton yield were not found due to different weed management practices. However, maximum and minimum seed cotton yield was recorded under application of pendimethalin 900 g/ha PE *fb* IC + HW at 30 and 60 DAS and IC+ HW at 15, 30 and 45 DAS, respectively.

Different tillage practices showed significant differences with respect to seed yield of greengram **(Table 1)**. Significantly the highest seed and haulm yields were recorded under zero tillage + residue followed by zero tillage + residue treatment (0.68 t/ha) whereas, significant differences among other treatment were not found. Application of pendimethalin 500 g/ha PE *fb* IC + HW at 30 DAS recorded significantly the highest seed (0.720 t/ha) and haulm (1.11 t/ha) yields. The higher yield may be due to effective weed control which resulted in increased the yield attributes and thereby yield. While application of imazethapyr 75 g/ha PoE *fb* IC + HW at 30 DAS recorded significantly the lowest seed (0.413 t/ha) and haulm (0.718 t/ha) yield.

Effect on physico-chemical properties of soil

Different tillage and weed management treatments had no effect on soil characteristics except on organic carbon and available phosphorus, respectively (**Table 2**). However, zero tillage with residue incorporation has enhanced organic carbon content in soil with no treatments in zero tillage treatment alone and interaction of all other treatments were statistically at par with each other.

Alam *et al*. (2014) observed that zero tillage along with addition of organic matter and crop residues in the cropping systems reported increased soil organic matter (SOM) significantly in the 0–25 cm soil layer compared to deep tillage after 4 years. Similarly, Zhu *et al*. (2014) also noticed similar result

Table 1. Effect of tillage and weed management practices on weed dry biomass, seed cotton yield and seed yield of greengram

Treatment	Weed dry biomass (g/m^2) at harvest in cotton				Seed cotton yield (t/ha)	Stalk yield (t/ha)
	Monocot	Dicot	Sedges	Total		
Tillage and crop residue management practices in cotton (T)						
CT	23.7(569)	8.69(108)	3.41(13.2)	25.9(690)	2.52	5.14
CT	25.6(703)	8.48(84.2)	4.80(27.3)	27.5(815)	2.48	5.13
ZT	23.7(642)	6.71(49.1)	2.31(4.52)	25.0(695)	1.88	4.90
ZT	30.4(949)	4.79(25.5)	3.06(10.4)	31.1(985)	1.95	4.36
ZT+R	22.4(572)	4.23(17.0)	2.65(6.84)	23.1(596)	2.19	4.98
LSD (p=0.05)	2.99	0.50	0.27	2.92	0.17	NS
Weed management practices in cotton (W)						
Pendimethalin 900 g/ha PE *fb* IC + HW at 30 and 60 DAS	23.2(570)	5.65(36.0)	4.53(23.0)	24.5(629)	2.33	5.08
Quizalofop-ethyl 50 g/ha PoE *fb* IC + HW at 30 DAS	32.7(1086)	8.48(102)	2.31(5.14)	34.4(1194)	2.12	4.47
IC + HW at 15, 30 and 45 DAS	19.5(405)	5.62(31.8)	2.90(9.24)	20.5(446)	2.17	5.16
LSD (p=0.05)	3.75	0.44	0.23	3.57	NS	0.27
Interaction M x W	4.51	0.73	0.53	4.47	NS	NS
Treatment	**Weed dry biomass (g/m^2) at 30 DAS in greengram**				**Seed yield (t/ha)**	**Haulm yield (t/ha)**
	Monocot	Dicot	Sedges	Total		
Tillage & crop residue management practices in greengram (T)						
CT	5.45(30.7)	3.49(11.6)	2.54(5.59)	6.90(47.8)	0.587	0.927
ZT	7.95(80.2)	2.28(4.36)	3.28(10.4)	9.12(94.9)	0.547	0.898
ZT	11.7(139)	2.79(7.26)	3.16(9.30)	12.5(156)	0.551	0.901
ZT + R	9.17(88.0)	2.00(3.29)	3.91(15.7)	10.2(107)	0.560	0.923
ZT + R	8.37(69.5)	2.08(3.46)	2.99(8.14)	9.02(81.1)	0.677	1.064
LSD (p=0.05)	0.62	0.19	0.19	0.60	0.067	0.060
Weed management practices in greengram (W)						
Pendimethalin 500 g/ha PE *fb* IC + HW at 30 DAS	8.79(81.4)	2.77(6.94)	3.14(9.05)	9.68(97.4)	0.720	1.112
Imazethapyr 75 g/ha PoE *fb* IC + HW at 30 DAS	8.04(73.6)	2.41(5.56)	3.32(10.4)	9.16(89.6)	0.413	0.718
IC + HW at 20 and 40 DAS	8.80(89.6)	2.41(5.46)	3.07(9.99)	9.83(105)	0.620	0.998
LSD (p=0.05)	NS	0.12	NS	NS	0.038	0.029
Interaction M x W	0.76	0.22	0.27	0.67	NS	NS

Note: Data subjected to $(\sqrt{x+1})$ transformation. Figures in parentheses are means of original values; CT=Conventional tillage - conventional tillage; ZT=Conventional tillage - zero tillage; ZT=Zero tillage - zero tillage; ZT+R=Zero tillage - zero tillage + residue; ZT+R=Zero tillage + residue - zero tillage + residue where, zero tillage had 4.3% SOM in the 0–30 cm soil layer compared to traditional tillage after 4 years. The zero tillage + residue treatment has also recorded higher available phosphorus and potassium compared to rest of the treatment.

Similarly, under sub-plot treatments, available phosphorus was found to be significantly higher only with application of quizalofop-ethyl 50 g/ha PoE *fb* IC + HW at 30 DAS (51.3 kg/ha) than in other weed management treatments. Other soil characteristics were not affected by weed management treatments.

In greengram, also significantly higher organic carbon (0.40%) content was recorded under zero tillage + residue treatment compared with rest of the treatments except zero tillage + residue (0.36%) **(Table 3)**. Thus, the residue incorporation slightly helped in increasing the organic carbon in soil. Luo Youjin *et al.* (2011) found the highest organic carbon in 0-10 cm soil layer under NT-rr (no-till and ridge culture with rotation of rice and rape) and the least was found in 20-30 cm soil layer under CT-r (conventional tillage with rotation of rice and winter fallow system). Urioste *et al.* (2006) reported that frequent and excessive tillage and residue removal in conventional tillage and deep tillage by chiseling resulted in significant loss of soil organic matter. Treatment of conventional tillage followed by conventional tillage (CT-CT) did not show any uniform trend on any of the soils physico-chemical properties. Amongst weed management treatments, higher available phosphorus (50.0 kg/ha) and available potassium (209 kg/ha) were significantly recorded only with imazethapyr 75 g/ha PoE *fb* IC + HW at 30 DAS.

Effect on microbial properties of soil

Among all the treatments tested, only total bacteria count and dehydrogenase activity were

Table 2. Effect of tillage and weed management treatments on physico-chemical characteristics of soil at cotton harvest

Treatment	pH	EC (dS/m)	Organic Carbon (%)	Available Nitrogen (kg/ha)	Available Phosphorus (P_2O_5) (kg/ha)	Available Potassium (K_2O) (kg/ha)
Tillage and crop residue management practices in cotton						
CT	8.2	0.31	0.31	333	44.9	181
CT	8.0	0.34	0.32	310	40.6	175
ZT	7.9	0.35	0.29	338	43.2	189
ZT	8.0	0.35	0.33	332	45.5	197
ZT + R	7.9	0.41	0.37	306	46.4	207
LSD (p=0.05)	NS	NS	0.04	NS	NS	NS
Weed management treatments in cotton						
Pendimethalin 900 g/ha PE *fb* IC + HW at 30 and 60 DAS	8.1	0.36	0.32	320	39.7	188
Quizalofop-ethyl 50 g/ha PoE *fb* IC + HW at 30 DAS	7.9	0.34	0.32	321	51.3	204
IC + HW at 15, 30 and 45 DAS	7.9	0.35	0.33	330	41.2	178
LSD (p=0.05)	NS	NS	NS	NS	2.66	NS
Interaction T X W	NS	NS	NS	NS	Sig.	NS

Table 3. Effect of tillage and weed management treatments on physico-chemical characteristics of soil at greengram harvest

Treatment	pH	EC (dS/m)	Organic Carbon (%)	Available Nitrogen (kg/ha)	Available Phosphorus (P_2O_5) (kg/ha)	Available Potassium (K_2O) (kg/ha)
Tillage and crop residue management practices in greengram (T)						
CT	7.9	0.31	0.32	367	46.4	197
ZT	8.0	0.34	0.35	396	45.5	207
ZT	7.9	0.39	0.34	414	43.2	182
ZT + R	7.9	0.31	0.36	377	40.6	181
ZT + R	8.0	0.40	0.40	370	44.9	180
LSD (p=0.05)	NS	NS	0.04	NS	NS	NS
Weed management treatments in greengram (W)						
Pendimethalin 500 g/ha PE *fb* IC + HW at 30 DAS	7.9	0.37	0.35	376	39	181
Imazethapyr 75 g/ha PoE *fb* IC + HW at 30 DAS	7.9	0.36	0.35	380	50	209
IC + HW at 20 and 40 DAS	8.0	0.32	0.36	400	42	178
LSD (p=0.05)	NS	NS	NS	NS	2.66	25.5
Interaction T X W	NS	NS	NS	NS	Sig.	NS

found significant under different weed management options (**Table 4**). The zero tillage + residue system helped in maintaining higher total bacteria, actinobacteria, total PSM and dehydrogenase activity in the soil wherein, IC + HW at 15, 30 and 45 DAS sustained all microbial properties in higher range. Lal *et al*. (2007) also suggested that improved SOC accumulation in soil is associated with a greater microbial and root growth, nutrient and water supply, soil aggregation and better pH and temperature regulation. The IC + HW at 15, 30 and 45 DAS treatment significantly affected total bacteria count (91.7 10^6 CFU/g soil) and dehydrogenase activity (23.0 µg TPF/g soil/24 hr.) Thus, there was no adverse effect due to different weed management treatments on microbial properties of soil and non-chemical weed management option helped in sustaining higher microbial counts and activity in soil without hampering their proliferation rate. Wardle and Parkinson (1990) observed that some herbicide may even stimulate the growth and activities of the microbial activities. However, some herbicides may affect non-target organisms including micro-organisms (Latha and Gopal 2010). Thus, combination of zero tillage + residue and IC + HW at 15, 30 and 45 DAS was found as the best combination with less soil disturbance, greater availability of soil moisture and nutrients due to residue incorporation which encouraged higher microbial counts in soil.

In succeeding crop, greengram encountered the similar results where total actinobacteria (76.7 10^4CFU/g soil) and dehydrogenase activity (22.7 µg TPF/g soil/24 hr.) were significantly influenced by ZT + residue practices **(Table 5)**.

In comparison to previous crop the overall activity of total bacteria, fungi and actinobacteria decreased while remaining microbial observations increased their counts in soil samples of succeeding greengram crop, may be due to change in weed management options (**Table 4**). This decrease in the population of total bacteria, fungi and actinobacteria may be due to competitive influence and toxic effect of different herbicides applied in soil environment.

Table 4. Effect of tillage and weed management treatments on soil microbial characteristics at cotton harvest

Treatment	Total bacteria (10^6 CFU/g soil) Initial: 64 X 10^5	Fungi (10^4 CFU/g soil) Initial: 45 X 10^3	Actinobacteria (10^4 CFU/g soil) Initial: 50 X 10^3	Total Diazotrophs (10^3 CFU/g soil) Initial: 25 X 10^3	Total PSM (10^3 CFU/g soil) Initial: 18 X 10^3	Dehydrogenase (µg TPF/g soil/24 h) Initial: 18
Tillage and crop residue management practices in cotton (T)						
CT	88.7	55.7	69.3	85.6	90.0	22.4
CT	89.0	55.3	69.4	85.2	89.6	22.3
ZT	90.0	56.3	71.2	86.6	91.5	22.6
ZT	90.1	56.3	71.3	86.0	91.5	22.6
ZT + R	90.1	56.2	71.8	86.1	91.7	22.8
LSD (p=0.05)	NS	NS	NS	NS	NS	NS
Weed management treatments in cotton (W)						
Pendimethalin 900 g/ha PE *fb* IC + HW at 30&60 DAS	89.4	55.13	70.1	85.2	90.5	22.4
Quizalofop-ethyl 50 g/ha PoE *fb* IC+HW at 30 DAS	87.6	54.6	70.4	85.7	90.1	22.2
IC + HW at 15, 30 and 45 DAS	91.7	58.2	71.3	86.7	91.9	23.0
LSD (p=0.05)	1.61	NS	NS	NS	NS	0.49

Table 5. Effect of tillage and weed management treatments on soil microbial characteristics at greengram harvest

Treatment	Total Bacteria (10^6 CFU/g soil) Initial: 70 X 10^5	Fungi (10^4 CFU/g soil) Initial: 85 X 10^4	Actinobacteria (10^4 CFU/g soil) Initial: 95 X 10^3	Total Diazotrophs (10^3 CFU/g soil) Initial: 43 X 10^3	Total PSM (10^3 CFU/g soil) Initial: 50 X 10^3	Dehydrogenase (µg TPF/g soil/24 h) Initial: 14
Tillage and crop residue management practices in greengram (T)						
CT	41.9	28.9	72.0	95.8	94.8	18.3
ZT	42.2	30.2	72.6	96.1	95.9	19.7
ZT	42.9	31.4	73.6	96.1	96.6	20.3
ZT + R	43.3	31.6	74.4	97.0	96.7	20.6
ZT + R	44.2	33.3	76.7	98.3	98.6	22.7
LSD (p=0.05)	NS	NS	2.3	NS	NS	1.8
Weed management treatments in greengram (W)						
Pendimethalin 500 g/ha PE *fb* IC + HW at 30 DAS	42.0	30.7	73.7	95.9	96.3	19.9
Imazethapyr 75 g/ha PoE *fb* IC + HW at 30 DAS	41.9	29.8	72.3	94.6	95.6	19.2
IC + HW at 20 and 40 DAS	44.8	32.8	75.5	99.5	97.5	21.9
LSD (p=0.05)	2.5	1.73	2.55	2.82	NS	2.12
Interaction T X W	NS	NS	NS	NS	NS	NS

Amongst various weed management options, IC + HW at 20 and 40 DAS recorded significantly higher activity of total bacteria, fungi, actinobacteria, total diazotrophs and dehydrogenase activity except total PSM **(Table 5)**. Treatment of IC + HW at 20 and 40 DAS recorded higher microbial activity followed by pendimethalin 500 g/ha PE *fb* IC+ HW at 30 DAS and the lowest under imazethapyr 75 g/ha PoE *fb* IC + HW at 30 DAS.

The pre-emergence herbicide pendimethalin 500 g/ha *fb* IC+ HW at 30 DAS and post-emergence herbicide imazethapyr 75 g/ha *fb* IC + HW at 30 DAS were found to be statistically at par with each other; on the other hand post-emergence herbicide imazethapyr 75 g/ha *fb* IC + HW at 30 DAS and IC + HW at 15, 30 and 45 found to be statistically at par with each other.

It may be concluded that impact of zero tillage + residue incorporation with IC + HW at 15, 30 and 45 DAS in cotton and zero tillage + residue incorporation with IC + HW at 20 and 40 DAS in greengram found to be most suitable option for cotton green cropping system of middle Gujarat in sustaining the maximum gain of all physico-chemical and microbial properties of soil along with yield profit.

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Effectiveness of different methods for controlling *Orobanche* in mustard

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ABSTRACT

To study the efficacy of neem cake, soil drenching of metalaxyl, post-emergence application of glyphosate at very low concentrations alone and in combination with 1% solution of $(NH_4)_2SO_4$ and 125% of recommended fertility, field experiments were conducted at the villages Ganghala and Bidhwan in Bhiwani district of Haryana during *Rabi* seasons of 2014-15 and 2015-16, respectively. Feasibility of adoption of results of studies conducted earlier on use of glyphosate 25 g/ha at 30 DAS and 50 g/ha at 55 DAS is being demonstrated by multi location field trials through farmers participatory approach in different parts of state during 2010-2016. Neem cake 400 kg/ha at sowing *fb* soil drenching of metalaxyl MZ 0.2% at 25 DAS *fb* glyphosate at 40 g/ha at 45 DAS or neem cake 400 kg/ha *fb* pendimethalin (PPI) at 0.75 kg/ha *fb* metalaxyl 0.2% at 25 DAS did not prove effective in minimizing density of *Orobanche*.

Post-emergence application of glyphosate at 25 and 50 g/ha with 1% solution of $(NH_4)_2SO_4$ at 30 and 55 DAS showed promise with 85- 91% control of this weed not only in experimental fields but in large scale demonstrations on farmers' fields.

INTRODUCTION

Broomrape locally known as *margoja, rukhri, khumbhi, gulli or bhuiphod* is an obligate root parasitic angiosperm. Being devoid of chlorophyll (Baccarini and Melandri 1967, Saghir *et al.* 1973) it obtains nourishment through specialized feeding structures called haustoria, which penetrate the host tissues until they reach the vascular system for uptake of water, nutrients and assimilates. The attached parasite strongly competes with the host plant for obtaining water, mineral nutrients and assimilates, thus acting as a strong metabolic sink, often named as "super-sink". The extent of damage due to *Orobanche* ranges from zero to total crop failure based on nature of infestation, environmental factors, soil fertility and crop response. In Indian mustard (*Brassica juncea* L.), infestation of *Orobanche* causes yield reduction up to the extent of 13.9-16.3 % (Sheoran *et al.* 2014) which may be up to 58 % (Prusty *et al.* 1996). This weed exhibits the tendency of mushrooming well under coarse textured soils with high pH and low in nitrogen status. The mustard fields in sand dunal areas of south-west Haryana are more prone to the infestation with this obnoxious weed. Pre-plant incorporation (PPI) and pre-emergence (PE) application of dinitroaniline herbicides along with hoeing earlier proved ineffective in minimizing the population of this weed. Post-emergence (PoE) application of glyphosate, paraquat and kerosene oil caused toxicity to mustard crop. Keeping this in view, the present investigation was planned to find out suitable option for the control of broomrape in Indian mustard.

MATERIALS AND METHODS

The experiment was conducted to study the bioefficacy of different weed management treatments for the control of broomrape in Indian mustard (var. '*RH-749*') at village Ganghala and Bidhwan in the district of Bhiwani (Haryana) during *Rabi* 2014-15 and 2015-16, respectively. Seven treatments were assigned in a randomized complete block design with three replicates in a individual plot size of 25 x 6 m^2. The mustard fields having previous history of heavy infestation with broomrape were selected for the study. Mustard crop variety '*RH-749*' was planted on 18-10-2014 and 21-10-2015 by using 5 kg/ha. The treatments in the study were glyphosate at 25 and 50 g/ha at 30 DAS and 55 DAS (recommended practice), recommended fertility (N&P) + glyphosate with 1% solution of $(NH_4)_2SO_4$ at 25 and 50 g/ha at 30 DAS and 55 DAS, 125% of recommended fertility (N&P) + glyphosate with 1% solution of $(NH_4)_2SO_4$ at 25 and 50 g/ha at 30 DAS and 55 DAS, neem cake 400 kg/ha at sowing *fb* soil drenching of metalaxyl MZ 0.2% at 25 DAS *fb* glyphosate at 40 g/ha at 45 DAS, neem cake 400 kg/ha *fb* pendimethalin (PPI) at 0.75 kg/ha *fb* metalaxyl 0.2% at 25 DAS, neem cake 400 kg/ha *fb* soil drenching of metalaxyl MZ at 0.2% at 25 DAS and weedy check (farmer's practice). Data on number of broomrape (*Orobanche*) panicles/m^2, per cent visual control of broomrape was obtained at 60, 90 and 120 days after sowing (DAS). During 2015-16, broomrape panicles did not appear in field up to 60 DAS, so no data on density of broomrape at 60 DAS was reported. Visual control of broomrape was also evaluated at 60, 90 and 120 DAS using 0-100 scale. Economics of various weed control treatments were also calculated by using benefit cost ratio of each treatment, separately.

RESULTS AND DISCUSSION

Neem cake in combination with either soil drenching with metalaxyl and glyphosate or pendimethalin and metalaxyl did not prove effective in minimizing the population of broomrape during both the years in comparison to two rounds of glyphosate application. Maximum number of broomrape panicles/m^2 at 90 and 120 DAS were recorded in weedy check which was followed by application of neem cake + pendimethalin (PPI) + metalaxyl (25 DAS), neem cake + soil drenching of metalaxyl MZ (25 DAS) and neem cake + soil drenching of metalaxyl MZ (25 DAS) + glyphosate (45 DAS), while it was lowered down at all the stages under 125% of recommended fertility (N&P) + glyphosate with 1% solution of $(NH_4)_2SO_4$ (30 and 55 DAS), and 100% recommended fertility (N&P) + glyphosate with 1% solution of $(NH_4)_2SO_4$ (30 and 55 DAS). Recommended fertility + glyphosate with 1% solution of $(NH_4)_2SO_4$ registered the highest weed control efficiency (91.7%) up to 120 DAS, and was followed by 125% of recommended fertility + glyphosate with 1% solution of $(NH_4)_2SO_4$ (90%) with the appearance of slight phyto-toxicity on mustard crop to the extent of 5% at 20 DAS, which was mitigated completely up to 30 DAS without any yield penalty (**Table 1**). The treatments involving the use of neem cake did not show any phyto-toxic symptoms on mustard crop.

Broomrape panicles emerge above soil at 40-120 DAS depending upon the temperature and causes losses to mustard crop remaining below the soil. So, broomrape attachments are to be killed before emergence to avoid losses. Broomrape seeds start to germinate 7 days after sowing of mustard in response to hormones secreted by roots of mustard. At 25-30 DAS, nut like structures of broomrape are found to attach with mustard roots which remains below the soil. So, systemic herbicide glyphosate is applied directly on leaves at 30 DAS which moves through phloem to the mustard roots killing broomrape nuts due to inhibition of amino acids in roots. Similarly, herbicide applied on leaves at 55 DAS moves symplastically to the roots resulting in death of broomrape. As, broomrape panicles which emerge above soil does not contain chlorophyll, so no post-emergence herbicide acts on these panicle.

Table 1. Effect of weed control treatments on broomrape population and seed yield of mustard at the village *Ganghala* (*Rabi*, 2014-15)

Treatment	*Orobanche* panicles /m^2			Crop phytotoxicity (%)			*Orobanche* control (%)			Seed yield (t/ha)	*B:C*
	60 DAS	90 DAS	120 DAS	10 DAT	20 DAT	30 DAT	60 DAS	90 DAS	120 DAS		
Glyphosate at 25 and 50 g/ha at 30 DAS and 55 DAS (recommended practice)	1.7 (2)	2.6 (5.7)	1.8 (2.7)	0	0	0	70.1 (88.3)	65.9 (83.3)	64.2 (81)	1.94	2.17
Recommended fertility (N&P) + glyphosate with 1% solution of $(NH_4)_2SO_4$ at 25 and 50 g/ha at 30 DAS and 55 DAS	1 (0)	1.6 (1.7)	1.7 (2)	5	5	0	85.7 (98.3)	76.2 (91.7)	76.2 (91.7)	1.96	2.15
125% of recommended fertility (N&P) + glyphosate with 1% solution of $(NH_4)_2SO_4$ at 25 and 50 g/ha at 30 DAS and 55 DAS	1 (0)	1 (0)	2.2 (4)	5	5	0	81.4 (96.7)	79.5 (95)	71.6 (90)	1.97	2.06
Neem cake 400 kg/ha at sowing *fb* soil drenching of metalaxyl MZ 0.2% at 25 DAS *fb* glyphosate at 40 g/ha at 45 DAS	2.7 (6.3)	6.4 (40.3)	6.1 (36)	0	0	0	55.7 (68.3)	63.5 (80)	53.7 (65)	1.66	1.53
Neem cake 400 kg/ha *fb* pendimethalin (PPI) at 0.75 kg/ha *fb* metalaxyl 0.2% at 25 DAS	4.17 (15.7)	10.3 (104.7)	10.6 (112)	0	0	0	18.4 (10)	14.8 (6.7)	10.4 (5)	1.50	1.27
Neem cake 400 kg/ha *fb* soil drenching of metalaxyl MZ at 0.2% at 25 DAS	4.6 (20)	9.9 (98)	9.1 (82)	0	0	0	1(0)	16.6 (8.3)	18 (10)	1.43	1.32
Weedy check (farmer's-practices)	4.3 (17.3)	11.5 (132.3)	11.1 (123)	0	0	0	1(0)	1(0)	1(0)	1.41	1.27
LSD (p=0.05)	0.6	0.6	0.5	-	-	-	6.6	11.2	11.2	0.04	-

DAT - Days after treatment; Original figures are given in parentheses

Maximum seed yield of mustard (1.97 and 2.14 t/ha) was observed with the use of 125% of recommended fertility (N&P) + glyphosate with 1% solution of $(NH_4)_2SO_4$ at 25 and 50 g/ha at 30 and 55 DAS which was at par with 100% recommended fertility (N&P) + glyphosate with 1% solution of $(NH_4)_2SO_4$ at 25 and 50 g/ha at 30 and 55 DAS (1.96 and 2.06 t/ha) and glyphosate at 25 and 50 g/ha at 30 and 55 DAS (1.94and 1.95 t/ha). Lowest seed yield of mustard was obtained under weedy check (1.41 and 1.32 t/ha) which was 28.4 and 38.4 % less in comparison to the best treatment of 125% of recommended fertility (N&P) + glyphosate with 1% solution of $(NH_4)_2SO_4$ at 25 and 50 g/ha at 30 and 55 DAS during 2014-15 and 2015-16, respectively. The highest B: C (2.17) was obtained with the use of glyphosate at 25 and 50 g/ha at 30 DAS and 55 DAS (glyphosate at 25 and 50 g/ha at 30 and 55 DAS: recommended practice) during 2014-15 while during 2015-16 the highest B: C (2.26) was obtained with recommended fertility (N&P) + glyphosate with 1% solution of $(NH_4)_2SO_4$ at 25 and 50 g/ha at 30 and 55 DAS. The lowest B: C (1.27 and 1.19) was recorded under weedy check and application of neem cake 400 kg/ha *fb* pendimethalin (PPI) at 0.75 kg/ha *fb* metalaxyl 0.2% at 25 DAS during both the years (**Table 2**).

Similar findings on the control of broomrape in mustard through glyphosate application were also reported (DWSR 2009, Punia *et al.* 2012, Punia *et.al.* 2016). Based on two-year study, it can be inferred that recommended fertility (N&P) + glyphosate with 1% solution of $(NH_4)_2SO_4$ at 25 and 50 g/ha at 30 and 55 DAS is the most effective treatment for the *Orobanche* control in mustard.

Efficacy of glyphosate was validated in large scale under multi-locational trials through farmers' participatory approach in Haryana state during the *Rabi* seasons of 2010-11 to 2016-17. A total of 758

Table 2. Effect of weed control treatments on broomrape population and seed yield of mustard at the village *Bidhwan* (*Rabi*, 2015-16)

Treatment	*Orobanche* panicles /m²		Crop phytotoxicity (%)			*Orobanche* control (%)		Seed yield (t/ha)	*B:C*
	90 DAS	120 DAS	10 DAT	20 DAT	30 DAT	90 DAS	120 DAS		
Glyphosate at 25 and 50 g/ha at 30 DAS & 55 DAS (recommended practice)	2.81 (7.0)	1.82 (2.7)	0	0	0	64.88 (81.7)	70.99 (88.7)	1.95	2.18
Recommended fertility (N&P) + glyphosate with 1% solution of $(NH_4)_2SO_4$ at 25 and 50 g/ha at 30 DAS & 55 DAS	1.47 (1.3)	2.27 (4.3)	5	5	0	71.49 (89.0)	67.94 (85.7)	2.06	2.26
125% of recommended fertility (N&P) + glyphosate with 1% solution of $(NH_4)_2SO_4$ at 25 and 50 g/ha at 30 DAS & 55 DAS	1.00 (0)	2.79 (7.0)	5	5	0	72.64 (90.3)	68.37 (86.0)	2.14	2.24
Neem cake 400 kg/ha at sowing *fb* soil drenching of metalaxyl MZ 0.2% at 25 DAS *fb* glyphosate at 40 g/ha at 45 DAS	6.99 (48.0)	6.44 (40.7)	0	0	0	55.01 (67.0)	50.79 (60.0)	1.56	1.44
Neem cake 400 kg/ha *fb* pendimethalin (PPI) at 0.75 kg/ha *fb* metalaxyl 0.2% at 25 DAS	10.10 (101.0)	10.48 (109.0)	0	0	0	12.91 (5.3)	12.74 (5.0)	1.40	1.19
Neem cake 400 kg/ha *fb* soil drenching of metalaxyl MZ at 0.2% at 25 DAS	9.62 (91.7)	8.88 (78.0)	0	0	0	12.13 (4.7)	13.87 (6.0)	1.37	1.26
Weedy check (farmer's-practices)	11.74 (137.0)	10.88 (117.3)	0	0	0	0.00 (0)	0.00 (0.0)	1.32	1.19
LSD (p=0.05)	0.71	0.75	-	-	-	9.88	8.52	0.21	-

DAT - Days after treatment

Table 3. Comparative performance of glyphosate application *vis-à-vis* farmers' practice for broomrape management and its subsequent effect on seed yield of mustard in large scale multi-locational trials

Year	No. of trials	Area covered (ha)	*Orobanche* control (%)	Seed yield (t/ha) Treated*	Seed yield (t/ha) FP*	Yield reduction (%) in FP plots
2010-11	12	5	82 (70-95)	1.72 (1.40-2.10)	1.49 (1.20-1.95)	15.5
2011-12	24	20	79 (65-90)	1.59 (1.20-2.20)	1.37 (0.90-1.80)	16.3
2012-13	86	156	72 (55-90)	1.75 (1.25-2.25)	1.54 (1.00-1.95)	13.9
2013-14	35	82	63 (40-90)	1.65 (1.25-2.40)	1.44 (1.10-2.10)	14.6
2014-15	119	486	80 (48-90)	1.85 (1.42-2.50)	1.50 (1.18-1.84)	23.4
2015-16	232	597	80.5 (79-87)	1.75 (1.13-2.22)	1.26 (0.71-1.66)	38.7
2016-17	250	485	79.3 (75-84)	1.83 (1.48-2.28)	1.40 (1.25-1.55)	30.1
Mean	758	1831	76.5	1.73	1.43	21.4

*Glyphosate 25 g/ha at 30 DAS and 50 g/ha at 55-60 DAS-2 sprays; **FP: Farmers' practice (one hoeing at 25-30 DAS); Figures in parentheses indicate range of the treatment effect on *Orobanche* control and mustard seed yield.

demonstrations were conducted in an area coverage of 1831 ha under mustard. It was observed that overall 76.5% (range 40-95%) reduction in *Orobanche* weed infestation with 21.4 % (range 13.9-38.7%) yield superiority was noticed with glyphosate treated plots (25 g/ha at 30 DAS followed by 50 g/ha at 55-60 DAS) when compared with the farmers' practice of one hoeing at 25-30 DAS (**Table 3**). This technology has now spread to the most *Orobanche*-infested mustard-growing areas of Haryana and the farmers are fully convinced of the benefits of this low-cost technology.

Based on two years finding, it can be concluded that post-emergence application of glyphosate at 25 and 50 g/ha with 1% solution of $(NH_4)_2SO_4$ at 30 and 55 DAS provides better control of this weed, not only in experimental fields but in large scale at farmers' fields. Also, by increasing the recommended dose up to 125%, setback caused to the crop can be nullified with some little enhancement of grain yield.

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Land configurations and mulches influence weed suppression, productivity and economics in ginger

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ABSTRACT

Ginger is known to be sensitive to weed infestation, which severely influences crop productivity and ultimately to the economic returns. Therefore, in-situ resource conservation like land configurations namely broad bed and furrow (BBF), ridge and furrow (R&F) and flatbed (FB) and mulches with *Imperata cylendrica* (IC), pine needle (PN), double mulching of paddy straw followed by weed biomass (PS) and no mulch (NM) were assessed in ginger. Results revealed that weed density and weed dry biomass at 60 and 120 days after planting (DAP) were considerably lower with BBF followed by R&F than NM. Among mulches, the application of PN recorded lower weed density and dry biomass at 60 and 120 DAP, whereas, at second sampling, there was dramatically reduction of weed dry biomass in PS than IC. The rhizome productivity was improved with BBF (39.3-47.3%) and PS (35.8-42.2%) than FB and NM, respectively. BBF configured plots obtained 46.7-55.3% higher net returns and per day returns with 27.4-34.7% improvement in benefit to cost ratio followed by R&F than FB. Similarly, PS recorded 43.1 to 46.7% higher net returns and per day returns with 34.3 to 40.7% higher benefit to cost ratio over NM. Therefore, suitable land configurations and the use of available crop residues and tree leaf litter as mulch are promising resource conserving sustainable production technologies for ginger cultivation.

INTRODUCTION

Ginger (*Zingibar officinale* Roscoe.) is grown in tropical and subtropical regions for its spice and medicinal value. India is a leading ginger producer in the world and it has been under cultivation since antiquity. It gives a good yield and being a cash crop provides higher profit than other crops grown during the period (Choudhary *et al.* 2015). In the recent past, the area under ginger cultivation has increased owing to its assured higher productivity, demand and market availability (Kushwaha *et al.* 2013). As the crop is slow initial sprouting and growing, yield loss due to weed competition is expected to be very high,which drastically reduces the crop yield. High rainfall and warm temperature in the eastern Himalayan region (EHR) is highly conducive for year-round emergence and growth of weeds such as *Ageratum conyzoides,Cynodon dactylon, Cyperus rotundus, Digitaria* spp., *Bidens pilosa, etc*. (Sah *et al.* 2017, Choudhary and Kumar 2019) which further exaggerate the problem. Weed causes yield losses and require much of monetary investment to save the crop (Choudhary and Kumar 2013). In EHR, excessive rain during the rainy season and dry spells before and after the rainy season is another major issue for taking long-duration crops like ginger. Ginger is very sensitive to excess of water; therefore, a proper land configuration is desired for safe disposal of water and also conserve the water during dry spells (Choudhary and Kumar 2019).

In EHR, abundance of tree leaf litters and crop residues are available which are not being utilized for any commercial purpose, hence, this can be used as potential mulch materials. Mulching has a positive effect on the soil moisture, air and temperature (Bu *et al.* 2002). Favourable water regimes under mulching increase the yield, protect the soil and is economically feasible (Choudhary *et al.* 2013). The surface application of mulch favourably influences the weed flora by suppressing their emergence and subsequent growth (Lalitha *et al.* 2001, Choudhary and Kumar 2019), and may also provide the nutrients by microbial decomposition of organic mulches (Ghosh *et al.* 2006).

Despite the diverse and competitive weed flora in ginger growing areas, very little information has been generated on weed management. Use of mulches in ginger have been reported by many researchers, but limited research has so far been done to study the combined effect of land configurations and mulches on weed dynamics, productivity and economic aspect especially at warm and humid areas. Therefore, the present study aimed to examine the different land configuration and mulch options for suppressing weeds, enhancing productivity and also the economic aspect of ginger production.

MATERIALS AND METHODS

A field study was conducted during two successive years (2011-12 and 2012-13) at the research farm of ICAR Research Complex for NEH Region, Basar (27° 95' North latitude and 94° 76' East longitude, with an altitude of 631 m above mean sea level), Arunachal Pradesh, India. The climate of the region is humid sub-tropical, with the daily temperature during a year varying widely between a minimum of 4°C and a maximum of 35°C. The soil of the experimental site was silt loam in texture, with pH 5.3, organic carbon 13.1 g/kg, available nitrogen (N) 96.2 mg/kg, available phosphorus (P) 5.1 mg/kg and exchangeable potassium (K) 104.9 mg/kg. The experimental site receives annual rainfall with a high degree of variation with the range of 1800 to 2900 mm/year.

Ginger cv. '*Nadia*' (a variety with 270–300 days maturity, slender rhizome with less fibre) was planted in split plot design and replicated thrice. Main plots were assigned to land configuration *viz*. broad bed and furrow (BBF), ridge and furrow (R&F) and flatbed (FB), whereas, sub-plots were assigned to mulches *viz*. *Imperata cylendrica* (IC; 4.0 t/ha), pine needles (PN; 4.0 t/ha), double mulching of paddy straw followed by weed biomass (PS; 4.0 t/ha *fb* 2.0 t/ha respectively) and no mulch (NM). The land was prepared with one pass of mouldboard plough, harrowing and cultivator and at final land preparation, 10 t/ha of well-decomposed farm yard manure was applied. On prepared land, rhizomes at 1.5 t/ha were planted. The rhizomes were treated with mancozeb at 3 g/lit of water for 30 min and dried in shade for 4 hours and planted with a spacing of 45 × 20 cm. Urea (46% N) at 75 kg N/ha was applied in two splits [50% at 45 days after planting (DAP) and 50% at 90 DAP]. Single super phosphate (16% P_2O_5) at 50 kg P_2O_5/ha and muriate of potash (60% K_2O) at 50 kg K_2O/ha were applied in the planting row just prior to planting. The rest of the management practices were in accordance with the recommended package of practice, where one hand weeding was uniformly performed at 60 DAP after weed sampling.

The density of grasses, sedges and broad-leaved weeds were measured separately from quadrate of 0.5 × 0.5 m at three randomly selected places in each plot at 60 and 120 DAP. After counting, roots were separated from the rest of the plants and above ground parts were dried in an oven at 70±1°C for 72 hours and weighed to record weed dry biomass. The weed data was extrapolated to 1.0 × 1.0 m for further analysis and interpretation. The weed density and dry biomass data were subjected to square root transformation [$(\sqrt{x+1})$]. Weed suppression efficiency (WSE) was calculated as described below: recorded using weed dry biomass in land configured and mulched plots in comparison to flatbed and no mulch.

$$WSE\ (\%) = [(WB_{control} - WB_{treatment}) / WB_{control}] \times 100$$

where WSE, weed suppression efficiency; $WB_{control}$, weed biomass in flatbed and no mulch plot; $WB_{treatment}$, weed biomass in land configured and mulched plots

Growth parameters, *viz.* number of stalks and leaf area index of ginger were measured from five selected plants from each sub-plot at 150 DAP. Similarly, yield attributes (mother, primary and secondary rhizome) and final rhizome yield were measured from the net plot of 2.4 × 4.0 m and were extrapolated to a hectare. Economic analysis was carried out by including all the variable costs (land preparation, rhizome, manure, chemicals, labour, mulch materials) and their respective units used during the experiment. The prevalent market price of the produce was considered to calculate gross and net return and finally benefit–cost ratio was calculated.

The different parameters of the experiments were analyzed using PROC GLM procedure of the SAS Version 9.3 (SAS Institute Inc., Carry NC USA) and mean comparisons were performed based on the least significant difference (LSD) at 0.05 probability. The ANOVA results of interaction effect was indicated non-significant; hence, the data were not presented.

RESULTS AND DISCUSSION

Weed suppression

The dominant broad-leaved weed species noticed in ginger crop during experimentation were *Ageratum conyzoides* (L.), *Galinsoga parviflora* (L.), *Commelina banghalensis* (L.), *Spilanthus acmella* (auct. non L.), and *Borreria hispida* (L.) K. Schum, while *Digitaria sanguinalis* (L.) Scop, *Echinochloa colona* (L.) Link.,*Eleusine indica* (L.) Gaertner, *Cynodon dactylon* (L.) Pers. were major grasses. *Cyperus rotundus* (L.) was only sedge present. Among the treatments, there was not much variation in the type of weed species.

The weed density changed in response to BBF and recorded the lowest at 60 and 120 DAP (**Table 1**). However, in both the years (2011-12 and 2012-13), the highest weed density was recorded with FB (165.8 and 139.8/m^2 at 60 DAP, and 54.5 and 40.8/m^2 at 120 DAP). The lowest weed density was recorded with BBF (87.1 and 72.6/m^2 and 30.7 and 23.9/m^2, respectively). The R&F plots recorded the weed density between BBF and FB at both the sampling times and years. However, it was considerably more than the BBF to the tune of 20.5 and 16.6%, respectively. Correspondingly, the weed dry biomass was highest with FB (104.0 and 84.8 g/m^2, and 41.5 and 31.2 g/m^2, respectively) and lowest with BBF. The weed dry biomass was recorded 14.3 and 11.1%, respectively higher over the years in R&F followed by FB (64.5 and 56.7%, respectively) than the BBF. During the experimentation, it was noticed that weed dry biomass followed the trend of weed density at both the sampling times and years but in second year of the experiment, both the parameters were lower. Among the different land configurations followed, the highest WSE was obtained to the tune of 39.4% in both the years at 60 DAP followed by R&F (30.0 and 31.1%, respectively) over FB irrespective of mulches. This indicated that WSE significantly varied with land configurations and BBF had advantage over others. The reduction of weed dry biomasses under BBF and R&F might be due to alteration of soil surface which retarded the weed seeds to germinate. Apart from these, the fast growth and better canopy coverage under BBF facilitated to cover the ground early. This also restricted solar radiation transmission resulting in lowered germination and emergence of weeds (Ghosh *et al.* 2006, Patel *et al.* 2009).

Placement of different mulches restricted the penetration of solar radiation to soil surface leading to hampering the germination and emergence of weeds. Therefore, in PN the weed densities were 3.8 folds lower at 60 DAP, whereas, at 120 DAP it was 3.5 folds lower over FB. Whereas, over the years, the weed density in IC obtained 11.5% higher at 60 DAP and further it increased to 27.5% at 120 DAP followed by PS (40 and 30%, respectively) than the BBF. No mulch recorded the highest weed density (247 and 209/m^2, respectively during years at 60 DAP and 82.3 and 60.7/m^2, respectively during years at 120 DAP). Lowering of the weed densities under PS than NM was also evident. Similarly, weed dry biomass followed the trend of weed densities and placement of PN recorded 3.1–3.2 folds lower dry biomass at 60 DAP, whereas, it was slightly improved by 3.3–3.4 folds lower at 120 DAP over NM. At 60 DAP, the placement of IC recorded higher weed dry biomass than the PN at 60 DAP and 120 DAP. Although at 60 DAP, the weed dry biomass was more in PS during both the years (18.6-26.6%), at 120 DAP, it dramatically came down and remained higher by only 7.8-12.2% than the PN. The highest weed dry biomass was recorded in NM at both the sampling time (158.8 and 127.5 g/m^2, respectively and 65.2 and 48.7 g/m^2, respectively). The reduction of weed dry biomass at 120 DAP was relatively higher with PS than the IC (**Table 1**). This might be due to the additional application of 2 t/ha weed biomass as mulch, which suppressed the successive emergence and growth of weeds. The findings

Table 1. Weed parameters as influenced by land configuration and mulches in ginger

Treatment	Weed density (no./plant)				Weed dry biomass (g/m^2)				Weed suppression efficiency (%)			
	60 DAP		120 DAP		60 DAP		120 DAP		60 DAP		120 DAP	
	2011-12	2012-13	2011-12	2012-13	2011-12	2012-13	2011-12	2012-13	2011-12	2012-13	2011-12	2012-13
Land configuration												
Broad bed and furrow	9.0(87)	8.2(73)	5.4(31)	4.8(24)	7.7(63)	7.0(52)	5.0(25)	4.5(21)	39.4	39.4	39.8	33.7
Ridges and furrow	9.9(105)	9.0(87)	5.9(36)	5.1(27)	8.3(73)	7.5(58)	5.3(29)	4.7(22)	30.0	31.1	29.6	27.9
Flatbed	12.3(166)	11.3(140)	7.1(54)	6.2(41)	9.9(104)	8.9(85)	6.2(41)	5.5(31)				
LSD (p=0.05)	0.42	0.39	0.35	0.30	0.34	0.29	0.31	0.25				
Mulches												
Imperata cylendrica	8.5(73)	7.8(60)	5.3(27)	4.7(22)	7.2(51)	6.6(43)	4.8(22)	4.4(19)	67.7	66.1	65.6	60.9
Pine needle	8.1(66.)	7.3(54)	4.8(23)	4.2(17)	7.1(50)	6.3(39)	4.5(19)	4.0(15)	68.4	67.4	70.1	69.4
Paddy straw *fb* weed biomass	9.5(91.)	8.7(76)	5.5(30)	4.8(23)	7.7(60)	7.1(50)	4.6(21)	4.2(17)	62.5	60.8	67.8	65.7
No mulch	15.6(247)	14.3(209)	9.0(82)	7.8(61)	12.5(159)	11.2(127)	8.1(65)	7.0(49)				
LSD (p=0.05)	1.71	1.59	0.99	0.83	1.15	1.03	0.71	0.59				

Figures in parentheses are original values demonstrated that weed density and weed dry biomass were significantly reduced with the application of mulches, though the extent of reduction largely depended on the type of materials used. In the same way, WSE ranged from 60.8–68.4% at 60 DAP and it was more or less similar at 120 DAP with the different mulches used. The highest WSE was obtained under PN followed by IC at 60 DAP, whereas at 120 DAP, PS was the next best to PN. Lesser weed germination and infestation by restricting the transmission of solar radiation under mulch resulted in higher WSE. Absence of application of mulch favoured the germination of weeds with considerably lower WSE was also reported earlier by Hiltbrunner *et al.* (2007) and Patel *et al.* (2009). Application of mulches reduced the weed species and provided the congenial conditions for crops to grow and develop (Moonen and Barberi 2004). The land configuration and mulches interaction did not vary significantly ($p<0.05$) with respect to weed density, weed dry biomass and WSE.

Growth parameters

Plant growth parameters *i.e.* number of stalk/ plant and leaf area index (LAI) were significantly influenced by land configuration and mulching in ginger (**Table 2**). Over the years, the plants under BBF recorded with 14.6% more stalks followed by R&F (7.1%) over the FB. Similarly, LAI was 41.3% more with BBF followed by R&F (13.5%) as compared to FB. The BBF provided better opportunities to express the growth parameters, whereas, the effect of R&F was less in relation to BBF but, better than the FB. Higher LAI utilized solar radiation more efficiently for photosynthesis and could translocate to various plant parts especially to the rhizome. BBF and R&F provided the congenial conditions to plants which encouraged the plant to uptake optimum water and nutrients from root zone (Khurshid *et al.* 2006, Choudhary and Kumar 2019).

Among the mulches applied, PS recorded 44.5% more stalks followed by PN (30.3%) than the NM. Similarly, LAI was just double in PS, whereas, in PN it was more by 47.0% than the NM. The effects of PN and IC were less in relation to PS but had significantly higher than NM. This indicated that plants under PS had edge over other mulches, PS might have provided the congenial conditions for the production of more vegetative parameters. It has been reported that mulching in ginger increased early sprouting and growth in terms of height and number of shoots, mainly due to change in the physical and chemical environment of the soil resulting in increased availability of phosphorus and potassium (Maybe *et al.* 2007, Barooah *et al.* 2010).

Yield attributes and rhizome yield

Yield attributes *i.e.* mother rhizome, primary and secondary rhizome, yield/plant were significantly influenced by land configuration and mulching in ginger (**Table 2**). Plants under BBF were noticed with 29.1% more mother rhizomes, 37.8% higher primary and 22.8% superior secondary rhizomes, and 43.3% higher rhizome yield/plant than the FB. The effect of R&F was also considerably better than NM. During both the years, the BBF plots attained 39.3 and 47.3% higher rhizome yield, which was followed by R&F (30.6 and 32.3%, respectively). The lowest rhizome yield was harvested in FB (16.8 and 18.9 t/ha, respectively) (**Table 3**). The higher yields under BBF and R&F were mainly due to better growth parameters, which might have helped in the

Table 2. Growth and yield attributes as influenced by land configuration and mulches in ginger

Treatment	Growth parameter				Yield attribute							
	Stalk (no./plant)		Leaf area index at 150 DAP		Mother rhizomes (no./plant)		Primary rhizomes (no./plant)		Secondary rhizomes (no./plant)		Rhizome yield (g/plant)	
	2011-12	2012-13	2011-12	2012-13	2011-12	2012-13	2011-12	2012-13	2011-12	2012-13	2011-12	2012-13
Land configuration												
Broad bed and furrow	4.6	5.0	4.0	4.3	1.3	1.6	7.0	8.2	11.9	14.1	209.4	251.9
Ridges and furrow	4.3	4.7	3.2	3.5	1.2	1.4	6.0	7.0	10.9	13.0	190.9	232.7
Flatbed	4.0	4.4	2.8	3.0	1.0	1.2	5.1	5.9	9.7	11.5	146.2	175.7
LSD (p=0.05)	0.23	0.25	0.42	0.46	0.08	0.10	0.30	0.34	0.41	0.48	22.97	27.63
Mulches												
Imperata cylendrica	4.1	4.5	3.0	3.2	1.1	1.3	5.9	6.8	10.9	12.8	176.5	208.8
Pine needle	4.5	5.0	3.4	3.7	1.2	1.4	6.3	7.3	11.0	13.4	189.4	228.5
Paddy straw *fb* weed biomass	5.0	5.5	4.7	5.0	1.3	1.5	6.5	7.5	11.5	13.5	212.5	255.7
No mulch	3.5	3.8	2.3	2.5	1.1	1.3	5.4	6.5	10.0	11.6	150.3	187.4
LSD (p=0.05)	0.35	0.38	0.65	0.71	0.16	0.18	0.85	0.98	1.00	1.22	33.91	41.34

accumulation of higher photosynthates and also helped to produce more yield attributes. Similar findings were corroborated by Choudhary *et al.* (2013) in maize and Choudhary and Kumar (2019) in turmeric.

Placement of mulches recorded considerably better yield attributing characters. Application of PS resulted in 17.0% more mother rhizomes, 18.6% higher primary and 15.6% secondary rhizomes, and 38.9% higher rhizome yield/plant than the NM (**Table 2**). The effects of the application of PN and IC were also considerably better than NM, but their effects were less pertinent to the effect of PS. Better yield attributes in PS led to 42.2 and 35.8%, respectively higher rhizome yield followed by PN (27.0 and 21.0%, respectively) and IC (16.4 and 12.5%, respectively) than the NM. The lowest rhizome yield was recorded in NM (17.06 and 20.37 t/ha, respectively). Improved growth parameters with PS helped the plant to produce more photosynthates and translocation towards the sink i.e. rhizome. This accumulation of photosynthates helped the plant to develop more number of mother, primary and secondary rhizomes. Therefore, yield/plant was comparatively higher and finally led to higher rhizome yield. A similar finding was also reported earlier (Tomar *et al.* 2006). The higher rhizome yield with an application of PS was mainly due to better yield attributes (**Table 3**), and this led to the final account in formation of more rhizome yield. Rhizome yield of ginger followed the quadratic relationship with weed smothering efficiency (R^2=0.57 and 0.46, **Figure 1a** and **b**).

Economic parameters

The economic parameters i.e. net returns, benefit-cost ratio and returns/day was influenced by land configuration and mulches in ginger (**Table 3**). The economic parameters largely depend on the economic yield of crop and production cost, however, the BBF recorded the highest net returns ₹ 29.7× 10^4 in 2011-12 and it was enhanced to ₹ 36.3 × 10^4 in 2012-13, which was followed by R&F and the lowest net return obtained with FB. Similarly, benefit-cost ratio was recorded the highest with BBF (6.48 and 7.71, respectively) followed by R&F (6.19 and 7.06, respectively). The lowest benefit-cost ratio recorded with FB (**Table 3**). These were mainly due to the production of higher rhizome yield under BBF and R&F by judicious use of resources. The returns

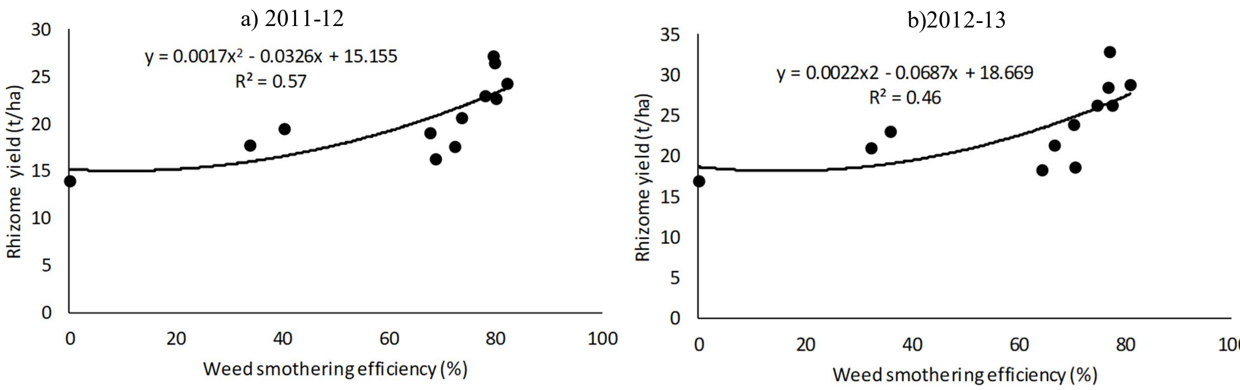

Figure 1. The relationship between rhizome yield of ginger and weed smothering efficiency as influenced by land configuration and mulches

Table 3. Rhizome yield and economic parameters as influenced by land configuration and mulches in ginger

Treatment	Rhizome yield (t/ha)		Net returns (x 10^4 ₹/ha)		Benefit: cost ratio		Returns (₹/day)	
	2011-12	2012-13	2011-12	2012-13	2011-12	2012-13	2011-12	2012-13
Land configuration								
Broad bed and furrow	23.40	27.83	29.68	36.33	6.48	7.71	1041.5	1274.6
Ridges and furrow	21.94	25.00	27.60	32.19	6.19	7.06	968.2	1129.4
Flatbed	16.79	18.89	20.24	23.39	5.09	5.72	710.1	820.7
LSD (p=0.05)	3.60	3.02					136.6	158.9
Mulches								
Imperata cylendrica	19.85	22.92	24.62	29.23	5.75	6.64	864.0	1025.6
Pine needle	21.67	24.66	27.39	31.88	6.33	7.20	961.0	1118.6
Paddy straw *fb* weed biomass	24.26	27.67	31.04	36.16	6.78	7.73	1089.2	1268.7
No mulch	17.06	20.37	20.30	25.27	4.82	5.75	712.2	886.5
LSD (p=0.05)	3.70	4.69	-	-	-	-	189.4	241.3

per day was also recorded highest with BBF (1041 and 1275 ₹/day, respectively) followed by R&F, whereas, the lowest return obtained with FB. Among the mulches, PS provided higher net returns (₹ 31.0 × 10^4 and 36.2 × 10^4, respectively), benefit–cost ratio (6.78 and 7.73, respectively) and return (1089 and 1269 ₹/day, respectively) followed by PN and IC, the lowest net returns, benefit-cost ratio and return/day recorded with NM. The effect of PN and IC were also considerably better than NM. However, their effect was less in relation to PS.

The results of the present study highlighted the significance of land configuration and mulches on weed suppression, productivity and economics for the production of ginger. The BBF suppressed the weeds considerably followed by R&F, whereas, application of mulches suppressed the weeds more than the FB and NM plots. The combined effects of BBF and PS were noticed with better growth and yield attributes, on account of higher rhizome yield. Economic parameters also improved with BBF and PS. BBF and R&F along with mulched plots attained with higher economic returns. In the region, mulch materials are available in plenty with no commercial use; may be potentially utilized along with suitable land configurations.

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Comparative efficacy of herbicides and hand weeding to control weeds in onion

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ABSTRACT

Effective and efficient weed management strategies are essential to raise a successful onion crop. Therefore, to find out the economically feasible weed management practice, a field experiment was conducted at Sher-e-Kashmir University of Agricultural Sciences and Technology, Jammu, during 2015-16 and 2016-17. Five herbicides namely pendimethalin1.0 kg/ha, oxyfluorfen 0.15 kg/ha, alachlor 1.0 kg/ha, butachlor 1.0 kg/ha and quizalofop-ethyl 0.05 kg/ha were applied alone or in different combinations replicated thrice in randomized block design. Data was recorded on weed density, dry matter accumulation of weeds, weed control efficiency, weed index, herbicide efficiency index and yield parameters. Pre-emergence application of oxyfluorfen 0.15 kg/ha *fb* one hand weeding at 40-60 days after transplanting recorded the highest weed control efficiency and the lowest values of weed density, dry matter accumulation of weeds and weed index. The pre-emergence application of oxyfluorfen 0.15 kg/ha *fb* post-emergence application of quizalofop-ethyl 0.05 kg/ha at 40 DAT was also found to be equally effective in controlling the weeds in onion. The yield attributing traits such as average bulb weight and total bulb yield also exhibited the same pattern. However, the highest B: C ratio was recorded with pre-emergence application of oxyfluorfen 0.15 kg/ha *fb* post-emergence application of quizalofop-ethyl 0.05 kg/ha applied 40 DAT. Hence, this treatment can be used for controlling the prevalent weed flora in onion crop under Jammu condition.

INTRODUCTION

Onion (*Allium cepa* L.) is a widely grown and most popular vegetable in India and around the World. India ranks second after China in terms of both area and production. Onion contributes 70% of the foreign exchange among the fresh vegetables. The yield level or average productivity of this crop is low due to various production constraints. Among these, weed infestation is the prime one. Due to its inherent characters such as short stature, non-branching habits and sparse foliage, onion cannot competes well with the weeds. Additionally, other cultural practices such as high fertilization and frequent irrigation helps in providing congenial environment for weed growth. The yield loss due to weed infestation has been reported to the tune of 40-80% (Channapagoudar and Biradar 2007, Sharma *et al*. 2009 and Ramalingam *et al*. 2013). Under J&K conditions particularly in Jammu province, the hand weeding is still a wide practice which is uneconomical, time consuming and often damages the crop. Moreover, due to shortage and non-availability of timely labour and unexpected rainfall during its peak growing season, it often gets delayed or left altogether. Therefore more farmers are switching towards chemical weed control as it may form an integral part of the modern crop production practices in this area. Thus, in order to eliminate crop-weed competition at all stages, there is a need to evaluate the efficacy and economics of various herbicides, its doses and time of application to obtain high yield and marketable produce.

MATERIALS AND METHODS

Field experiment was carried out during *Rabi* 2015-16 and 2016-17 at Chatha, Jammu (32-40^0 N latitude, 74-53^0 E longitude and 300 m above mean sea level). The soil of experimental site was silty loam in texture, slightly alkaline in reaction (pH 7.72), medium in available N (240 kg/ha) and P_2O_5 (12.1 kg/ ha) and low in available K_2O (134 kg/ha). Fourteen treatments comprised of application of pendimethalin 1.0 kg/ha and oxyfluorfen 0.15 kg/ha as pre-plant application, Pre-emergence application of pendimethalin 1.0 kg/ha, oxyfluorfen 0.15 kg/ha, alachlor 1.5 kg/ha and butachlor 1.0 kg/ha, combined application of pendimethalin 1.0 kg/ha (PE) *fb* post-emergence application of quizalofop-ethyl 0.05 kg/ha (40 DAT), oxyfluorfen 0.15 kg/ha (PE) *fb* quizalofop-ethyl 0.05 kg/ha, alachlor 1.5 kg/ha (PE) *fb* quizalofop-ethyl 0.05 kg/ha and butachlor 1.0 kg/ha (PE) *fb* quizalofop-ethyl 0.05 kg/ha, Directorate of Onion and Garlic (DOGR) recommendation oxyfluorfen 0.15 kg/ha (pre-emergence) *fb* one hand weeding 40-60 DAT, three hand weeding at 20, 40 and 60 DAT. (farmers practice), weedy check and weed free (continues manual weeding), respectively.

Eight weeks old healthy seedlings of onion cv. *N-53* were transplanted in second week of December at a spacing of 20 × 10 cm. The crop was fertilized with 100 kg urea, 50 kg P_2O_5 and 50 kg K_2O per hectare and a basal dose of 20 tonnes farm yard manure per hectare. All cultural operations and plant protection measures were adopted to maintain uniform plant population and ideal condition for proper growth and development of the crop. Observations on various weed parameters such as weed density (plant/m^2), weed dry matter accumulation (g/ha) was recorded and weed control efficiency (%) and weed index was determined. Crop phytotoxicity effect was also recorded visually by three persons without knowing the layout of the experiment at 5, 10, 15 and 20 DAHS. Its rating was done by using 0-10 scale given by Gupta (2010).

RESULTS AND DISCUSSION

Weed studies

The prominent weed species observed in experimental site were *Cyperus rotundus, Chenopodium album*, *Coronopus didymus, Chenopodium murale, Cynadon dactylon, Melilotus indica, Cannabis sativa, Anagallis arvensis, Parthenium hysterophorus, Rumex dentatus, Portulaca oleracea and Euphorbia hirta.* The lowest weed density was recorded in the herbicidal treatment plots with application of pre-emergence oxyfluorfen 0.15 kg/ha *fb* one hand weeding which were statistically at par with pre-emergence application of oxyfluorfen *fb* post-emergence quizalofop-ethyl at both 60 days after transplanting and harvesting time. Weed dry matter accumulation is the most important parameter to assess the weed competitiveness for the crop growth and productivity. All the herbicidal treatments significantly influenced the dry matter accumulation of both monocot and dicot weeds and significantly lowest dry matter was recorded in the treatments, *viz.* three hand weeding, pre-emergence application of oxyfluorfen 0.15 kg/ha *fb* one hand weeding 40-60 DAT and pre-emergence application of oxyfluorfen 0.15 kg/ha *fb* quizalofop-ethyl 0.05

Table 1. Effect of herbicidal treatments on weed density, dry matter of monocot weeds, dry matter of dicot weeds in onion (pooled data for two years)

Treatment	Weed density (plants/m^2)		Dry matter of monocot weeds (g/m^2)		Dry matter of dicot weeds (g/m^2)	
	60 DAT	At harvest	60 DAT	At harvest	60 DAT	At harvest
Pendimethalin 1.0 kg/ha PP	13.7(186)	12.0(143)	113.5	104.0	42.0	30.7
Oxyfluorfen 0.15 kg/ha PP	12.7(161)	11.8(138)	111.5	101.0	43.8	35.3
Pendimethalin 1.0 kg/ha PE	11.2(125)	10.4(108)	61.5	78.0	30.8	30.5
Oxyfluorfen 0.15 kg/ha PE	11.3(126)	10.3(105)	51.7	70.5	32.3	31.0
Alachlor 1.5 kg/ha PE	13.0(169)	11.9(139)	84.7	81.7	33.7	33.5
Butachlor 1.0 kg/ha PE	12.9(165)	11.6(134)	99.7	99.3	42.2	25.5
Pendimethalin 1.0 kg/ha PE *fb* quizalofop-ethyl 0.05 kg/ha at 40 DAT	9.1(82)	8.7(75)	40.5	38.7	17.0	11.2
Oxyfluorfen 0.15 kg/ha PE *fb* quizalofop-ethyl 0.05 kg/ha at 40 DAT	8.7(75)	8.2(67)	44.2	37.5	12.0	11.8
Alachlor 1.5 kg/ha PE *fb* quizalofop-ethyl 0.05 kg/ha at 40 DAT	10.5(110)	9.7(93)	48.5	63.3	12.0	21.5
Butachlor 1.0 kg/ha PE *fb* quizalofop-ethyl 0.05 kg/ha at 40 DAT	10.9(116)	10.0(98)	49.5	58.7	15.8	21.2
Oxyfluorfen 0.15 kg/ha PE *fb* one HW 40-60 DAT	8.5(70)	8.0(68)	40.7	36.0	16.7	11.3
Three HW 20, 40 and 60 DAT	6.6(41)	7.8(60)	35.7	35.8	11.7	10.2
Weedy check	16.8(279)	14.3(204)	140.0	125.0	40.7	50.2
Weed free	1.0	1.0	-	-	-	-
LSD (p=0.05)	0.28	0.32	5.4	4.8	4.6	3.3

PP= pre-plant application; PE=pre-emergence, DAT=days after transplanting, *fb*=followed by, value in parentheses are original mean kg/ha 40 DAT which were statistically at par with each other (**Table 1**). Comparatively lower weed dry matter accumulation was observed at harvesting stage than at 60 days after transplanting of the crop.

Weed control efficiency of different treatments ranged from (18.8-71.0%) at 60 days after transplanting and (18.3-62.8%) at harvesting stage (**Table 2**). Among different herbicidal treatments, treatments such as three hand weeding at 20, 40 and 60 DAT, pre emergence application of oxyfluorfen *fb* one hand weeding 40-60 DAT and pre-emergence application of oxyfluorfen *fb* post-emergence quizalofop-ethyl at 40 DAT were found equally effective at both stages of the crop after weed free plots. These results are in conformity with the studies conducted by Panse *et al*. (2014) and Sampat *et al.* (2014).

Weed index is the indicator of losses in the yield due to presence of the weeds and the lowest values of weed index were recorded in three hand weeding plots, pre-emergence application of oxyfluorfen *fb* one hand weeding and pre emergence application of oxyfluorfen *fb* post-emergence quizalofop-ethyl both at 60 days after transplanting and harvesting (**Table 2**). Maximum value was in weedy check plots due to prominent weed-crop competition, suppression of crop plants by the emerging weeds and more utilization of nutrients and moisture by the weed canopy. Kolse *et al.* (2010) also reported maximum weed index values (57.95%) under weedy check plots of onion under Maharashtra conditions. However, among the herbicidal treatments, the highest herbicide efficiency index (4.71) was recorded with application of pre-emergence application of oxyfluorfen 0.15 kg/ha *fb* post-emergence application of quizalofop-ethyl 0.05 kg/ha (**Table 2**).

All the weed management practices caused significant reduction in weed population compared with the weedy check during both year 2015-16 and 2016-17. However, magnitude of reduction in density and biomass of weed varied depending on the control measures adopted. The periodical weed density, weed dry matter accumulation and weed control efficiency varied at different stages of the crop. At 60 DAT, density and dry matter of weeds were more as compared to harvesting stage. But, in case of weed control efficiency it was found higher at 60 DAT than at harvesting, it might be due to the fate of herbicides like leaching, volatile movement and decomposition which ultimately decreases its efficiency with passage of the time. Similar results were reported by Kolse *et al.* (2010) and Sampat *et al.* (2014).

Crop phytotoxicity

None of the herbicidal treatments caused any phytotoxic symptoms in terms of leaf yellowing, leaf curling, leaf tip drying *etc*. and did not decreased the bulb yield. However, slight effect was observed in some treatments such as pendimethalin 1.0 kg/ha as pre-emergence *fb* quizalofop-ethyl 0.05 kg/ha at 40 DAT, oxyfluorfen 0.15 kg/ha as pre-emergence *fb* quizalofop-ethyl 0.05 kg/ha at 40 DAT and oxyfluorfen 0.15 kg/ha pre-emergence *fb* 1 HW 40-60 DAT at 5 days and 10 days after herbicidal spray

Table 2. Effect of herbicidal treatments on weed index, herbicide efficiency index (HEI; %), weed control efficiency (WCE; %) and crop phytotoxicity in onion (pooled data for two years)

Treatment	Weed index	HEI	WCE		Crop phytotoxicity		
			At 60 DAT	At harvest	5 DAHS	10 DAHS	15 DAHS
Pendimethalin 1.0 kg/ha PP	37.99	0.81	29.21	27.65	0	0	0
Oxyfluorfen 0.15 kg/ha PP	37.52	0.84	34.36	25.51	0	0	0
Pendimethalin 1.0 kg/ha PE	31.24	1.74	42.32	38.55	1	1	0
Oxyfluorfen 0.15 kg/ha PE	28.46	2.17	43.98	39.79	1	1	0
Alachlor 1.5 kg/ha PE	39.19	1.06	20.78	19.61	0	0	0
Butachlor 1.0 kg/ha PE	39.45	0.85	18.86	18.36	0	0	0
Pendimethalin 1.0 kg/ha PE *fb* quizalofop-ethyl 0.05 kg/ha at 40 DAT	13.16	4.51	68.22	57.08	1	1	0
Oxyfluorfen 0.15 kg/ha PE *fb* quizalofop-ethyl 0.05 kg/ha at 40 DAT	11.66	4.70	71.08	58.91	1	1	0
Alachlor 1.5 kg/ha PE *fb* quizalofop-ethyl 0.05 kg/ha at 40 DAT	16.84	3.90	50.38	46.66	0	0	0
Butachlor 1.0 kg/ha PE *fb* quizalofop-ethyl 0.05 kg/ha at 40 DAT	24.0	3.20	48.17	44.35	0	0	0
Oxyfluorfen 0.15 kg/ha PE *fb* one HW 40-60 DAT	10.56	-	68.32	58.29	1	1	0
Three HW 20, 40 and 60 DAT	9.19	-	68.98	62.82	-	-	-
Weedy check	63.69	-	-	-	-	-	-
Weed free	-	-	-	-	-	-	-
LSD (p=0.05)	4.85	-	3.74	2.99			

DAHS= days after herbicidal spray, 0 = none, 1-3 = slight; PP= pre-plant application; PE=pre-emergence but later on crop was fully recovered (**Table 2**). None of the studied herbicides had shown any phytotoxicity effect on crop and did not reduce yield and affect its quality. So all the herbicides used were found safer. Similar findings were reported by Kalthlen and Jeffery (1990) and Ramalingam *et al*. (2013).

Yield

Various yield attributes were significantly influenced by different herbicidal treatments. The yield attributes recorded higher values in weed free plots and minimum being recorded in weedy check (**Table 3**). More yields in weed free plots seems to be due to the favorable environment created by the clean crop culture resulting in more absorption of solar radiation and plant nutrients resulting in more photosynthetic rates and more dry matter accumulation. Among the herbicidal treatments, maximum yield attributes being recorded in the treatments plots of oxyfluorfen 0.15 kg/ha *fb* one hand weeding 40-60 DAT followed by pre-emergence application of oxyfluorfen 0.15 kg/ha *fb* post-emergence application of quizalofop-ethyl 0.05 kg/ha during both the year 2015-16 and 2016-17. Due to their ability to inhibit emerging weeds like broad-leaves, grasses and to some extent sedges also (**Table 3**). The yield attributes results are in conformity with the Kalhapure *et al.* (2014). The lowest yield attributes were recorded in weedy check plots owing to low chlorophyll content and photosynthetic rate due to unchecked weed growth there by reducing the availability of moisture, light and nutrients to the crop thus resulting in loss of yield. (Channappagoudar and Biradar 2007).

Table 3. Effect of herbicidal treatments on average bulb weight and total bulb yield in onion

Treatment	Avg. Bulb weight (g)	Total bulb yield (t/ha)		
		2015-16	2016-17	Mean
Pendimethalin 1.0 kg/ha PP	34.17	16.9	16.4	16.6
Oxyfluorfen 0.15 kg/ha PP	35.00	16.9	16.9	16.9
Pendimethalin 1.0 kg/ha PE	43.87	18.7	18.5	18.6
Oxyfluorfen 0.15 kg/ha PE	48.73	19.5	19.6	19.6
Alachlor 1.5 kg/ha PE	33.37	16.4	16.7	16.6
Butachlor 1.0 kg/ha PE	31.67	16.4	16.4	16.4
Pendimethalin 1.0 kg/ha PE *fb* quizalofop-ethyl 0.05 kg/ha at 40 DAT	69.50	23.7	23.5	23.6
Oxyfluorfen 0.15 kg/ha PE *fb* quizalofop-ethyl 0.05 kg/ha at 40 DAT	70.78	24.1	24.4	24.3
Alachlor 1.5 kg/ha PE *fb* quizalofop-ethyl 0.05 kg/ha at 40 DAT	64.40	22.6	22.5	22.6
Butachlor 1.0 kg/ha PE *fb* quizalofop-ethyl 0.05 kg/ha at 40 DAT	58.33	21.4	21.4	21.4
Oxyfluorfen 0.15 kg/ha PE *fb* one HW 40-60 DAT	72.47	24.6	24.6	24.6
Three HW 20, 40 and 60 DAT	73.33	24.8	25.2	25.0
Weedy check	24.23	9.7	9.9	9.8
Weed free	84.10	27.5	27.7	27.6
LSD (p=0.05)	4.15	3.0	5.2	4.1

Table 4. Effect of herbicidal treatments on economics of onion

Treatment	Cost of cultivation ($x10^3$/ha)	Gross returns ($x10^3$/ha)	Net returns ($x10^3$/ha)	B: C ratio
Pendimethalin 1.0 kg/ha pre plant	56.4	179.3	122.9	2.17
Oxyfluorfen 0.15 kg/ha pre plant	52.8	180.3	127.5	2.41
Pendimethalin 1.0 kg/ha PE	56.4	198.4	141.0	2.50
Oxyfluorfen 0.15 kg/ha PE	52.8	206.8	154.1	2.92
Alachlor 1.5 kg/ha PE	53.9	175.0	122.0	2.26
Butachlor 1.0 kg/ha PE	51.8	175.0	123.2	2.37
Pendimethalin 1.0 kg/ha PE *fb* quizalofop-ethyl 0.05 kg/ha at 40 DAT	57.4	250.4	191.3	3.33
Oxyfluorfen 0.15 kg/ha PE *fb* quizalofop-ethyl 0.05 kg/ha at 40 DAT	54.4	254.6	200.2	3.68
Alachlor 1.5 kg/ha PE *fb* quizalofop-ethyl 0.05 kg/ha at 40 DAT	55.9	239.7	185.1	3.31
Butachlor 1.0 kg/ha PE *fb* quizalofop-ethyl 0.05 kg/ha at 40 DAT	53.5	228.1	174.5	3.26
Oxyfluorfen 0.15 kg/ha PE *fb* one hand weeding 40-60 DAT	60.2	257.8	197.5	3.28
Three hand weeding 20, 40 and 60 DAT	73.6	262.0	188.4	2.55
Weedy check	51.1	103.9	52.8	1.03
Weed free	81.1	288.6	207.4	2.55

Economics

Significantly highest cost of cultivation, maximum gross return and net return were recorded in weed free plots, which was closely followed by herbicidal treatments plots of oxyfluorfen 0.15 kg/ha (pre-emergence) *fb* by one hand weeding (in case of gross return) and oxyfluorfen 0.15 kg/ha applied as pre-emergence *fb* quizalofop-ethyl 0.05 kg/ha (in case of net return). However, maximum benefit: cost ratio (3.68) was recorded in plots with pre emergence application of oxyfluorfen 0.15 kg/ha *fb* quizalofop-ethyl 0.05 kg/ha as post-emergence (**Table 4**). Minimum benefit: cost ratio (1.03) was observed in weedy check. In accordance with our findings Kalhapure *et al.* (2014) and Sampat *et al.* (2014) also got minimum B: C ratio under the unweeded plots.

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Appraisal of different floor management practices for weed management in ber (*Zizyphus mauritiana* Lamk.) orchards

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ABSTRACT

Glyphosate was the commonly used herbicide in ber orchards in Punjab, India. This herbicide has been banned by State Government recently in the state. Therefore, there is a dire need to develop non- chemical approaches to check weeds in ber (*Zizyphus mauritiana* Lamk.) orchard. An experiment was conducted to study the influence of different orchard floor management practices on weed biomass, fruit yield and quality of ber at Punjab Agricultural University, Ludhiana (India). Different floor management practices, *viz*. mulching (rice straw, white polythene, black polythene), mechanical, glyphosate and weedy check were evaluated. Weed biomass recorded at monthly intervals from November to March under all floor management practices exhibited a significant reduction in weed growth as compared to the weedy check. White polythene mulch recorded higher weed growth with reduced weed biomass as compared to black polythene mulch due to the penetration of solar radiation leading to weed emergence and disintegration of white polythene sheet. The weed biomass in inter-cultivation and herbicide treatments was increased up to January, however, with second cultivation and herbicide spray, the growth of weeds under these treatments was checked up to February and again showed an increasing trend. Although, glyphosate suppressed the weeds and mechanical weeding reduced the weed density but the resurgence of weeds resulted in comparatively higher weed biomass, while, rice straw mulch exhibited promising results, with 87.1 and 91.2% reduction in total weed biomass during 1st and 2nd year, respectively. Application of rice straw mulch at 12.5 t/ha may help in weed management in ber orchards.

INTRODUCTION

Weeds are a major hindrance in agricultural production systems predominantly in horticultural crops. These unwanted plants strive for nutrition, moisture and light with main crops, besides, they also provide protection for various pests and diseases. In case of severe weed infestation in fields, the main crop is adversely affected in terms of plant growth, fruit yield and quality along with additional expenditure on the management of main crops. The profitability of arable cropping system can be reduced by 34 per cent due to weeds (Bullock and Murphy 1986). The reduction in the tree growth due to weeds ranges from 15 to 96 per cent (Atkinson and White 1980), about 35 per cent loss in yield as a result of the adverse impact on fruit quality was recorded. Further, the yield reduction can be up to 50per cent in the stone fruits (Hussein *et al.* 2016, Oerke 2006). So the yield losses caused by weeds surpass the losses from any other category of pests of agricultural production systems (Abouziena and Haggag 2016). Rao (2000) also reported a 45 per cent annual loss of agricultural produce due to weeds as compared to 30 per cent by insects, 20 per cent by diseases and 5% by other pests. The loss in fruit yield depends upon the weed flora and its density, fruit crop species, prevailing season *etc*. Therefore, the management of weeds in fruit crops is of utmost importance to prevent yield loss. Further integrated and environment-friendly approaches for weed management required to be standardized for different fruit crops (Abouziena *et al.* 2008).

Ber (*Zizyphus mauritiana* Lamk.) is one of the important fruit crops in North-West states of India. Presently, India is producing 2.68 million tonnes of ber fruits from 2.54 million hectare plantation (NHB 2015). In Punjab, this fruit crop has an area of 1516 hectare with a total production of 25432 MT with an average productivity of 16.8 tonnes per hectare (Anonnymous 2018). In Ber, profuse vegetative growth, flowering and fruit setting start after rainy season under North-West Indian conditions. Due to extensive vegetative growth of trees from October onwards, it becomes very difficult to manage weeds in ber orchards which compete for water and nutrients. Moreover, the fruit development of ber coincides with cold weather which contributes to physiological fruit drop resulting in lesser crop yield. Furthermore, most of the ber plantation in this region exists in sandy soils and water scarcity resulting in water stress during peak fruit development phase causing an increment in physiological fruit drop. Floor management in orchards is of utmost importance for the reduction in competition for moisture and nutrition by suppressing the weeds to maintain the soil temperature optimum enough to encourage root and shoot growth of fruit plants.

In tree fruit crops, the weeds can be managed by following different strategies, *viz*. chemical, mechanical, manual, mulching and biological methods etc. Though; the chemical weed control is highly effective and easy for weed management, however, this method has certain constraints as crop injury, soil and water residues, human health apprehension and development of resistance to herbicides (Pot *et al.* 2011). In present-day agriculture, manual weed management is very expensive and labour intensive. Mechanical weed control is an effective means for short term management of weeds, however, in established orchards, it is quite difficult and less efficient owing to spreading tree canopies as well as limited coverage by agricultural equipment and potential damage to root and shoots of fruit plants. Shallow ploughing results in less harm to the tree roots, the tillage of orchard floor using rotavator gives good results. In present days, most of the fruit growers rely upon mechanical weed management using adjustable rotavators as this machine not only performs shallow ploughing but also has wider coverage under tree canopies. Covering the soil surface with mulches is a safer method for weed management as compared to the application of herbicides (Ramakrishna *et al.* 2006). The organic mulches are easily available and cheap, while, the plastic mulches are costly for weed management in orchards. Moreover, the organic mulches are beneficial for plant growth and yield and fruit quality in addition to a highly effective method for weed repression (Childers *et al.* 1995). Faber *et al.* (2001) also recorded substantial weed reduction with organic mulches in citrus as well as in avocado over four years period. Mechanical and chemical weed management reduced the intensity of weeds but resurgence of weeds resulted in significantly higher weed biomass compared to rice straw mulch in guava orchard (Brar *et al.* 2017). The use of plough-disc has resulted in the death of 19per cent of the peach trees in a 4 years period (Taylor 1972) and in apples by 10per cent (Ricks *et al.* 1993), while there was no death with herbicides.

Rice-wheat is the dominant cropping system in Northwest India. So, the straw of rice and wheat is easily available. Therefore, it was hypothesised that different orchard floor management practices will reduce the weed population and affect fruit yield and quality of ber. Hence, to manage weed biomass, reduction in physiological fruit drop, higher fruit yield and better fruit quality, different orchard floor management practices were investigated in ber orchard during 2016-17 and 2017-18.

MATERIALS AND METHODS

The experiment was laid out in Punjab Agricultural University, Ludhiana (India) during 2016-17 and 2017-18 on 15-year old ber (*Zizyphus mauritiana* Lamk.) cv. Umran plants at 7.5 × 7.5 m spacing. Under various orchard floor management treatments, a different type of mulches, *viz*. rice straw mulch (PSM), white polythene mulch (WPM) and black polythene mulch (BPM) was applied under the canopies of the trees, standard glyphosate at 1.2 kg/ha, mechanical management and weedy. The rice straw mulch at the rate of 70 kg per tree providing 8-10 cm thick layer amounting to about 12.5 t/ha was applied by spreading it under the tree canopies. The black, as well as white polythene mulch of 38 μ thickness, was also applied in similar fashion. Post-emergence herbicide application was given during November when the weeds attained the height of 15-20 cm. The mechanical weeding was done using disc harrow at the same time and the basins around the tree trunks were cleaned manually and these treatments were again repeated in January. The treatments were initiated in October after cleaning the orchard and application of recommended doses of inorganic fertilizers. The experiment was replicated thrice.

The weed density was estimated by using quadrat (1.0 × 1.0 m) placed randomly in all the replications. The grasses, sedges and broadleaf weeds were counted separately at a monthly interval from November to March. The weed biomass was recorded by drying the weeds at a monthly interval in a hot air oven at 65^{0}C temperature for 3-4 days. The weeds were removed at ground level after placing the quadrate at random places under for dry weight. The dry weight of weeds was expressed in g/m. The data of the actual number of weeds were transformed by square root transformation ($\sqrt{x+1}$) for statistical analysis. Statistical analysis of the data was done using CPCS1 software and comparisons were made at 5 per cent level of significance.

RESULTS AND DISCUSSION

Weed flora

The weed flora noted during the study comprised of mainly grasses (*Cynodon dactylon, Sorghum halepense, Panicum maximum*), sedges (*Cyperus rotundus, Cyperus compressus*) and Broadleaf weeds (*Cannabis sativa, Parthenium hysterophorus, Chenopodium album, Medicago denticulate, Rumex dentatus, Fumaria parviflora, Anagallis arvensis, Coronopus didymus* and *Malva neglecta).*

Weed biomass

Biomass of broad-leaf weeds (BLW) and grass weeds were significantly less under all the treatments as compared to weedy check (**Table 1 and 2 and Figure 2**). After putting mulch in the field and other floor management treatments in the middle of October during 1st year, weeds started emerging at the end of October. Moreover, there was profuse weed growth in the weedy plot (70 g/m^2) up to 3rd week of November, however, under PSM it was only 7.0 g/m^2 followed by 17 g/m^2 in cultivated field and 12 g/m^2 under herbicide treatment. The weeds flourished up to February under WPM and weedy plots throughout the study period, however, in case of herbicidal and inter-cultivation treatments, the weed growth was suppressed in February with the second spray of herbicide and inter-cultivation done in 3rd week of January. In March, there were only 16 g/m^2 weed biomass under PSM as compared to 177 g/m^2 in weedy plots. No weed growth was recorded throughout the season under BPM. Rice straw mulch was found to be effective among all floor management treatments for weed management, only 9.0 per cent weed growth was recorded as compared to the weedy check. Similarly, under inter-cultivation and chemical weed management, weed growth remained under check and it was only 26.3 and 20.4per cent of weedy fields under both the treatments, respectively. White polythene mulch was not effective due to disintegration of mulch sheet which might be due to the direct entrance of solar

Table 1. Effect of different orchard management treatments on broad-leaf weed biomass (g/m^2) in ber (Nov to Mar, 2016-17 and 2017-18).

Treatment	November		December		January		February		March	
	2016-17	2017-18	2016-17	2017-18	2016-17	2017-18	2016-17	2017-18	2016-17	2017-18
PSM	1.34 (1)	1.38 (1)	1.49 (1)	1.44 (1)	1.81 (2)	1.62 (2)	2.49 (2)	2.00 (3)	2.12 (3)	1.94 (3)
WPM	1.85 (2)	3.36 (10)	2.37 (5)	3.78 (13)	2.72 (6)	3.95 (14)	5.86 (16)	3.33 (10)	4.46 (19)	4.46 (19)
BPM	1.00 (0)	1.00 (0)	1.00 (0)	1.00 (0)	1.00 (0)	1.00 (0)	1.00 (0)	1.00 (0)	1.00 (0)	1.00 (0)
Inter-Cultivation	2.63 (6)	2.70 (6)	3.07 (8)	3.61 (12)	4.40 (18)	4.31 (18)	4.50 (19)	4.29(17)	4.91 (23)	4.84 (14)
Chemical	2.41(5)	2.37 (5)	2.79 (7)	2.95 (8)	2.88 (7)	3.33 (10)	3.62 (12)	3.32 (10)	4.15 (16)	4.15 (10)
Control (weedy)	3.35 (10)	3.64 (12)	3.93 (14)	3.98 (15)	4.12 (16)	4.55 (20)	4.89 (23)	4.51 (19)	5.38 (28)	5.15 (25)
LSD (p=0.05)	0.18	0.17	0.10	0.19	0.11	0.19	0.14	0.12	2.02	0.21

*Data is subjected to square root transformed. Original figures are in bracket; PSM: Paddy straw much; WPM: White polythene mulch; BPM: Black polythene mulch

Table 2. Effect of different orchard management treatments on grass weed biomass (g/m^2) in ber orchard (Nov to Mar, 2016-17 and 2017-18)

Treatment	November		December		January		February		March	
	2016-17	2017-18	2016-17	2017-18	2016-17	2017-18	2016-17	2017-18	2016-17	2017-18
PSM	2.61 (6)	2.32 (4)	2.65 (6)	2.47 (5)	3.19 (9)	2.84 (7)	3.52(11)	3.06 (8)	3.73 (13)	3.24 (10)
WPM	4.70(21)	5.58(30)	5.09(25)	5.60(30)	5.54(30)	6.16(37)	6.27(38)	6.93 (47)	7.78 (59)	7.78 (59)
BPM	1.00 (0)	1.00 (0)	1.00 (0)	1.00 (0)	1.00 (0)	1.00 (0)	1.00 (0)	1.00 (0)	1.00(0)	1.00 (0)
Inter-Cultivation	3.45(11)	3.61(12)	3.87(14)	4.00(15)	4.66(21)	4.92(23)	5.05(24)	5.53(30)	8.97(79)	8.63(73)
Chemical	2.78 (7)	2.78 (7)	3.98(15)	3.95(15)	4.90(23)	4.91(23)	5.27(27)	5.50 (29)	6.02(35)	6.02 (35)
Control (weedy)	7.80(60)	7.56(56)	8.07(64)	8.31(68)	9.15(83)	9.27(85)	9.56(90)	10.43(108)	12.23(149)	11.27 (126)
LSD (p=0.05)	0.26	0.23	0.20	0.28	0.22	0.18	0.14	0.42	0.20	0.20

*Data is subjected to square root transformed. Original figures are in bracket; PSM: Paddy straw much; WPM: White polythene mulch; BPM: Black polythene mulch

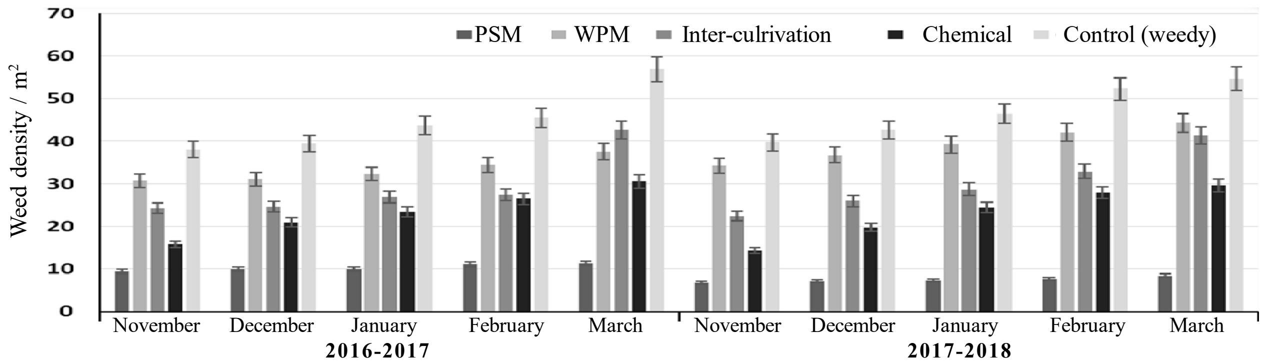

Figure 1. Weed density (no. of weeds/m^2) under different orchard floor management treatments from November to March (2016-17and 2017-18). Vertical bars represents mean S.E.

radiation through it leading to germination of weeds which ruptured the polythene sheet and emerged on the surface. Lesser biomass of sedges and grass weeds was recorded as compared to broad-leaf weeds throughout the season.

During the second year, the weed pressure under all treatments was comparatively less than the first year (**Table 2**). The weed biomass was significantly less under all treatments as compared to weedy check. This could be due to less weed density recorded in these treatments because of less light transmission under the mulches leading to reduced germination of weed seeds; hence less weed seed bank as reported by Golzardi *et al.* 2015. Weed biomass was only 5 g/m^2 under PSM as compared to 68 g/m^2 in weedy plots during November. Rice straw mulch exhibited a significant reduction in weed biomass in guava orchard (Brar *et al.* 2017). Rice straw mulch gave 85-98 per cent control of weeds in papaya (Hassan and El-Shammaa 2001) and 89 to 95per cent, in olive groves (Huqi *et al.* 2009).

The weed biomass in the same month under WPM, inter-cultivation and herbicide treatment was 40, 18 and 12 g/m^2, respectively. Manual weeding and herbicide combination of 0.5 kg glyphosate + 1.0 kg 2,4-D per hectare was quite effective in providing weed control in guava orchard (Maji *et al.* 2008). Bajwa *et al.* (1993) also opined the application of glyphosate to be effective in killing weeds in ber. Mechanical weed management is the pertinent method for suppression of weeds when the use of chemicals is not desirable (Chicouene 2007). The increment in weed growth was observed under all treatments up to March except in inter-cultivation and herbicide treatments, whereas, other treatments resulted in checking of weed growth in the month of February. There were only 12, 51, and 78 and 95 g/m^2 weed biomass under PSM, chemical, WPM and inter-cultivation respectively, up to March. Among all treatments, the proportion of grassy weeds was less than broad-leaf weeds during both the years. The increase in weed growth after February was due to irrigation to the ber orchard coupled with the rise in temperature after cold winters. Cumulative weed biomass was significantly higher under weedy check, while it was only 9.0% of weedy check under PSM (**Figure 2**). About 85- 98 per cent weed control was reported by covering the soil with two layers of cattail or rice straw mulch under mandarin trees (Abouziena *et al.* 2008). Cumulative weed biomass under chemical treatment, inter-cultivation and WPM was 20.4, 26.3 and 45.2% in weedy check, respectively. Different types of plastic mulches have specific properties of optimization of soil microclimate, soil moisture conservation, weed management etc. White or transparent mulch had a slight effect on weeds, while, weed emergence was quite less under coloured mulches such as brown, black, blue or double coloured films (Bond and Grundy 2001). Abouziena *et al.* (2008) obtained the effective control of weeds with the plastic mulch (200 or 150 µm) and three mulch layers of rice straw. Black polyethene mulch gave maximum weed control efficacy as compared to green, blue, yellow and white mulching in apple orchard (El-Metwally and Hafez 2007).

Weed density

The average weeds density after one month of treatments increased instantly under weedy check with 38.9 weeds/m^2 of different species followed by 37.6/m^2 under WPM which was ripped due to excessive weed growth beneath the polythene sheet (**Figure 1**). The minimum number of weeds (8.1/m^2) have emerged under PSM followed by chemical (15/m^2) and mechanical (23.3/m^2) methods of orchard management, although it was nil under BPM. During the second month, the weed density was slightly increased under all treatments except under chemical treatment where the increment in the number of weeds was more than 25%. Similarly, in following months, the weed density exhibit showed an increased trend up to the month of

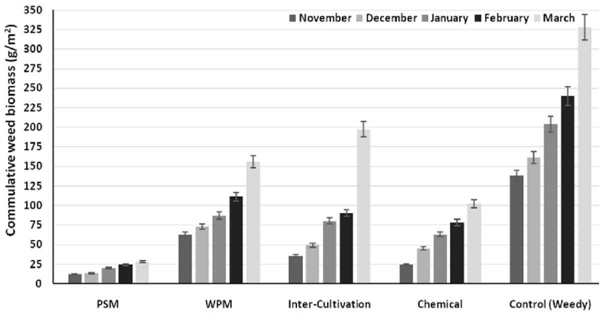

Figure 2. Cumulative weed biomass (g/m^2) under different orchard floor management treatments from November to March (2016-17 and 2017-18). Vertical bars represents mean S.E.

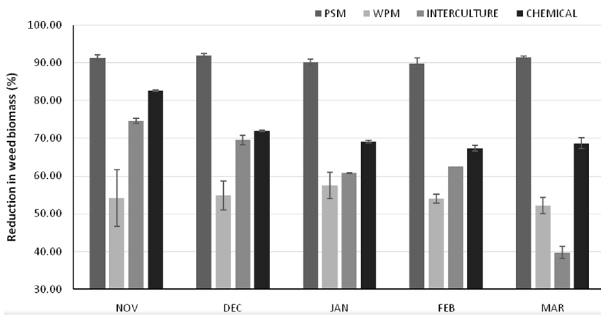

Figure 3. Reduction in weed biomass (g/m^2) under different orchard floor management treatments as compared to weedy check. Vertical bars represents mean S.E..

March. In the last month of observations, the number of weeds per square meter area was maximum (55.8) in weedy check, followed by under WPM (46.0), under inter-cultivation (41.9) and herbicide treatment (30.1). Rice straw mulch consistently suppressed the weed population during the study period with minimum weed population of 9.9/m^2. The overall slow increase in weed population under all treatments and weedy check was due to prevailing low-temperature conditions under North-West India during the period of study. Although, the weed density increased slowly, but the biomass increased at a faster rate due to the growth and development of weeds that emerged during the initial months.

The increased weed population under all treatments was observed under all treatments from November to February at slow pace probably due to dip in atmospheric temperature. Increase in weed density due to reduced herbicide effectiveness under chemical treatments, loosening of soil surface followed by application of irrigation water and occurrence of rainfall under mechanical treatment, ripping of WPM. However, after February, the weed density and biomass was increased at comparatively faster rate due to increasing atmospheric temperature.

The weed density under various treatments confirmed the effectiveness of all the floor management treatments particularly BPM and PSM for weed suppression. The plastic and organic mulches cause hindrance in weed emergence by restricting the light, thereby, suppressing weed growth. Black plastic mulches restrict the water and light penetration on the soil surface to provide high weed control efficiency. Weed reduction was also recorded with BPM and grass mulching in drip irrigated 'Nagpur mandarin' (Shirgure *et al.* 2013). While, white and green coverings had little effect on preventing weeds emerging (Bond *et al.* 2003).

Yield and economics: The data in **Table 3** revealed that the cost on rice straw mulching was only ₹ 2.5/ m^2 area as compared to ₹ 16/- and ₹ 17.5/- in case of white and black polythene mulches, respectively. Although, the cost on the management of weeds through inter-cultivation and chemical means was only ₹ 2.5 and ₹ 2.0 per square meter area but, the fruit yield was significantly less than PSM under these treatments which renders them uneconomical. With rice straw mulching higher fruit yield and low cost on mulching resulted net gain of ₹ 22167/- and ₹ 24980/- per hectare area during first and second year of investigations over the control, respectively.

The inhibitory effect of organic mulch on weeds may be due to both the physical (the reduced passage of solar radiation and temperature range on soil

Table 3. Economic aspects of mulching in ber orchards

Treatment	Yield/tree (kg)		Average rate (₹/kg)	Gross income/ha (x10^3/₹)		Cost of mulching (₹)		Net income/ha (x10^3/₹)		Increase or decrease in income over control (₹)	
	2017	2018		2017	2018	(m^2)	(x10^3 /ha)	2017	2018	2017	2018
Paddy straw mulch (PSM)	108.68	123.8	12.5	244.53	278.55	2.5	17.50	227.03	261.05	22167	24980
White polythene mulch (WPM)	102.61	106.83	12.5	230.87	240.37	16.0	112.00	118.87	128.37	-85990	-107703
Black polythene mulch (BPM)	106.58	120.31	12.5	239.80	270.70	17.5	122.50	117.30	148.20	-87557	-87872
Inter-cultivation	99.6	113.16	12.5	224.10	254.61	2.5	17.50	206.60	237.11	1737	1040
Chemical	100.44	110.56	12.5	225.99	248.76	2.0	14.00	211.99	234.76	7127	-1310
Control	91.05	104.92	12.5	204.86	236.07	0.0	-	204.86	236.07	-	-
LSD (p=0.05)	5.85	7.1	-	-	-	-	-	-	-	-	-

superficial layer) effect of emergence suppression and the possible chemical effects arising from allele chemicals released by straw that may have contributed to emergence reduction (Oliveira *et al.*2014). In addition to this, allelopathic interaction and chemical/biological influences of mulching on pH and nutrients dynamics in the surface soil also contributes towards growth of herbs under tree canopies. Hence, it may be concluded that the PSM has potential to check weed population in ber orchards and to improve soil health as organic mulches, not only increase soil fertility significantly but improve soil physical characters (0–10 cm depth) compared to other mulches also (Qu *et al.* 2019). Furthermore, it fits scrupulously with 'ber' crop and rice straw availability *i.e.* PSM is applied after application of second split of inorganic fertilizer in the month of October and at the same time there is ample availability of rice straw as after mid-October, rice is generally harvested under Punjab conditions.

It is concluded that rice straw mulch at 12.5 t/ha recorded the highest ber yield and may be recommended to the farmer's for effective control of weeds in ber orchards.

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Adoption level and impact of weed management technologies in rice and wheat: Evidence from farmers of India

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ABSTRACT

Weed invasions change the natural diversity and balance of ecological communities which threaten the survival of many plants and animals. Therefore, weed management is important as far as crop production is concerned. Further, impact assessment has been proven as a means of measuring the effectiveness of any agricultural technology in improving productivity, reducing the poverty and increasing the livelihood security of the farmers. Present study focuses on highlighting socio-economic status of the farmers and agencies which play significant role in dissemination of weed related information as well as effect of weed management technologies on weed intensity in rice and wheat crops. Results revealed that before adoption, some weeds like *Cyperus difformis, Fimbristylis milliacea* and *Ludwigia parviflora* were found in very high severity (>75%) level in rice, however, after adoption of improved weed management technologies they reached to low and moderate severity (<50%) in farmers' fields. According to 4.3% of the farmers, *Phalaris minor* is still present in wheat with very high level of severity (>75%) in most of their fields. Analytic Hierarchy Process (AHP) revealed the major agencies which play important role in disseminating the weed management technologies to the farmers. Findings of study stress on sensitizing different agencies and increasing their role in dissemination of weed management solutions to the farmers.

INTRODUCTION

It is accepted at all levels that weeds are destructive, troublesome, and competitive plants within croplands. Unlike the other pests, weeds grow in a similar trophic level with crop plants, and cause enormous yield losses as a result of strong competition with them for scarce resources (Ramesh *et al*. 2017). Weed invasions change the natural diversity and balance of ecological communities and these changes threaten the survival of many plants and animals (Pysek *et al*. 2012). Therefore, weed management is important as far as crop production is concerned. Keeping in view the importance of weed management in India, many government/non-government agencies are involved in disseminating weed management technologies to the farmers. However, impact of these interventions are of great importance as increasing attention to aid effectiveness of the technology has increased emphasis on establishing quantifiable impacts on productivity of farm as well as livelihood security of the farmers over the last decade. Impact assessment has been proven as a means of measuring the effectiveness of any agricultural technology in improving productivity, reducing the poverty and increasing the livelihood security of the farmers. So, present study focuses on highlighting socio-economic status of the farmers and agencies which play significant role in dissemination of weed related information as well as effect of weed management technologies on weed intensity.

MATERIALS AND METHODS

Present work was carried out at ICAR-Directorate of Weed Research, Jabalpur during 2014-17. Total 412 respondents were selected using purposive sampling and information was collected using interview schedule from different states of India through centre of All India Coordinated Research Project on Weed Management. Respondents belong to 18 states, *viz*. Assam, Bihar, Chhattisgarh, Gujarat, Haryana, Himachal Pradesh, Jharkhand, Karnataka, Kerala, Madhya Pradesh, Maharashtra, Odisha, Punjab, Tamil Nadu, Telangana, Uttar Pradesh, Uttarakhand and West Bengal. Using the agro-ecological zones characteristics, groups were formed of those states which fall in same agro-ecological Zone. Details of groups are given (**Table 1**).

Table 1. Groups comprising the states of India

Group	States
Group I	Gujarat, Haryana, Part of Madhya Pradesh (Gwalior), Punjab, Uttar Pradesh
Group II	Karnataka, Part of Maharashtra (Dapoli), Telangana
Group III	Part of Madhya Pradesh (Jabalpur)
Group IV	Bihar, Jharkhand, Odisha, West Bengal
Group V	Himachal Pradesh, Uttarakhand

Information on awareness and adoption level of farmers on weed management was collected through some questions. These questions were quite enough to explain the importance of weed management in current era with farmers' point of view. They were based on different aspects such as (i) weeds as major obstacle (ii) importance of weed management in traditional farming system (iii) adoption of IWM (improved weed management) at farmers' level and (iv) their knowledge on preventive method of weed management. Information was also collected on their knowledge on chemical method of weed control. Different aspects include (i) use of precautionary measures during spraying (ii) awareness on spurious chemical and their availability in the market (iii) use of right type of nozzle for herbicide spray (iv) mixing of herbicides with other chemical.

Data analysis and interpretation were performed using some statistical tools such as descriptive statistics and Analytical Hierarchy Process (AHP). For some questions, respondents were requested to give their answers in descriptive way which were presented in percentage form.

Use of AHP for selection of appropriate agency

Analytic hierarchy process (AHP) as illustrated by Giri and Nejadhashemi (2013) and Young *et al.* (2010) was used for selection of best agency disseminating the weed management technologies to the farmers of India. AHP was first developed by mathematician Thomas L. Saaty (Saaty 1980). It is an algorithm able to assist complex decision-making problems. Major characteristic of AHP is that, although it deals with complex matrix, it can be used successfully without having much knowledge of multi-criteria decision-making theory. The AHP works on developing priorities for alternatives available based on the criteria used to judge the alternatives.

RESULTS AND DISCUSSION

Socio-economic profile of the respondents in the sample

Educational level: Results showed that 46% of the farmers were educated upto secondary level across the groups, however, some of them (17.7%) were also under-graduate. Group I had slightly higher percentage of respondents educated upto secondary level (53.3%), however, 23% of the respondents were educated upto middle. On the other hand, a reverse trend was observed in Group II where, big proportion of them (45.7%) were educated only upto primary level and 17% of them were educated upto secondary level. All other groups follow the same trend as present in combined data. Data also showed that 6.3% of them were illiterate and had no formal education indicating relatively high literacy rate among selected farmers. The trend was similar across the groups except in the case of Group II where 20% of them were illiterate. It is expected that educated farmers are more inclined to adoption of any new technologies than any less educated or illiterate farmer (Okoye *et al.* 2004, Ajibefun and Aderinola 2004, Udensi *et al.* 2012). Thus, education helps farmers to decide to adopt modern technology and thereby, increase output. To be brief, old economic theories assume that education is a catalyst of production. However, new theories (endogenous growth models-Romer 1986 & 1990; Lucas 1988) have given more importance on the knowledge level of human capital (Dev and Hussain 1996).

Primary occupation: Across groups, more than 95% of the respondents had agriculture as the main occupation and source of income except in Group V where, 82% farmers practicing agriculture as their primary occupation and remaining as their secondary source of income.

Farming experience: Among all respondents, almost half (48.7%) of the farmers have 15-30 years of experience and the trend was similar in all groups except Group II where 37% of the farmers carrying the 15-30 years of experience. Owing to the risk involved by adopting a new technology, a farmer with more experience may be adopter or non-adopter because this variable may affect the farmer's decision positively or negatively in adopting any chemical method of weed control (Udensi *et al.* 2012).

Annual income: Annual income is also one of the factors which affect the adoption level of farmers. Farmers with more annual income are expected to be early and fast adopters due to their risk bearing ability. In the study, average annual income of the respondents were calculated as ₹ 263458/- which is expected to be earned from their primary occupation *i.e.* farming. However, more than half of the respondents (55%) have income less than ₹ 2 lakh.

Total owned land: It was observed that average land holding was 7 acres across groups. Among all, 37% respondents owned land less than 2.5 acres. However, average owned land was quite high in

Group I and Group III with 11.7 and 11.9 acres, respectively. On the other hand, in Group II and V, more than 70% of the respondents have land less than 2.5 acres. However, maximum farmers from Group I and III owned land more than 10 acres.

Area under cultivation: As 37% of respondents owned land less than 2.5 acres, 49% of the total respondents cultivate the area less than 2.5 acres. Remaining farmers were distributed evenly in other three categories.

Effect on weed intensity as affected by adoption of weed management technologies

Weeds act as an impediment to food security and national economic growth (Vanco and Akan 2005, Udensi *et al*. 2012). It is widely known, in most cases, losses caused by weeds exceeded the losses from any category of agricultural pests (Gharde *et al.* 2018). This is an assumption that if all the weeds in food crops were controlled, the current world's food production would be higher by 10 to 25% (Rao 2000, Abouziena and Haggag 2016). In the present study, in order to understand the severity of weeds in the farmers' fields before and after the adoption of weed management technologies, farmers were asked to mention the major weeds of rice and wheat crops and rate the severity of weeds using 4-point Likert scale; 1= low (0-25%), 2= moderate (25-50%), 3=high (50-75%), 4= very high (>75%). The severity was recorded for the field situation before and after the adoption of weed management technologies in rice (**Figure 1**) and wheat (**Figure 2**).

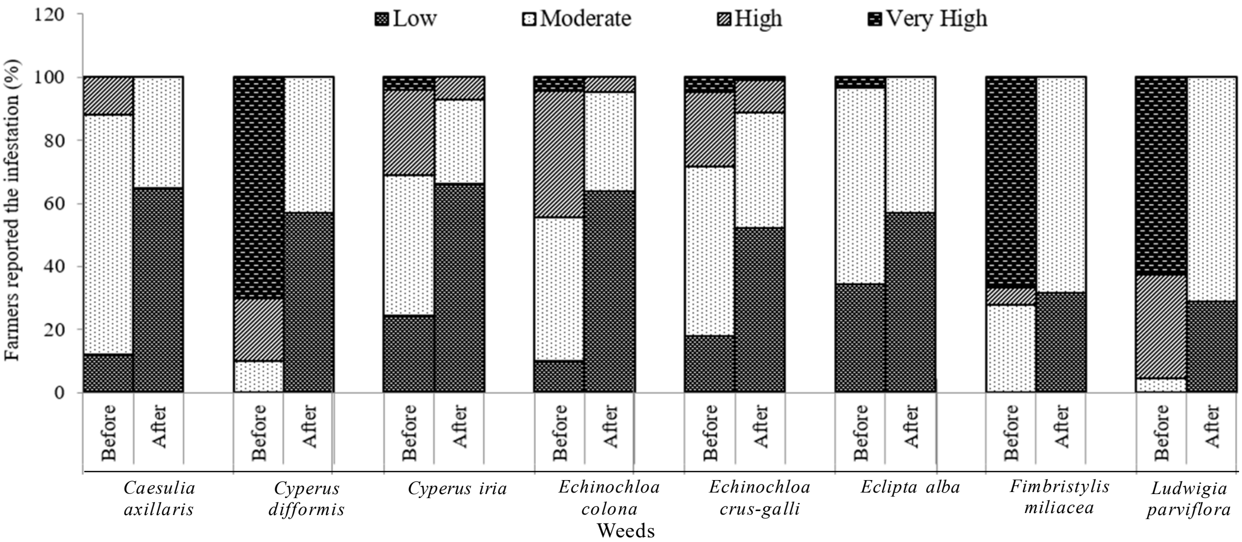

Figure 1. Response of farmers on weed severity (%) in rice crop

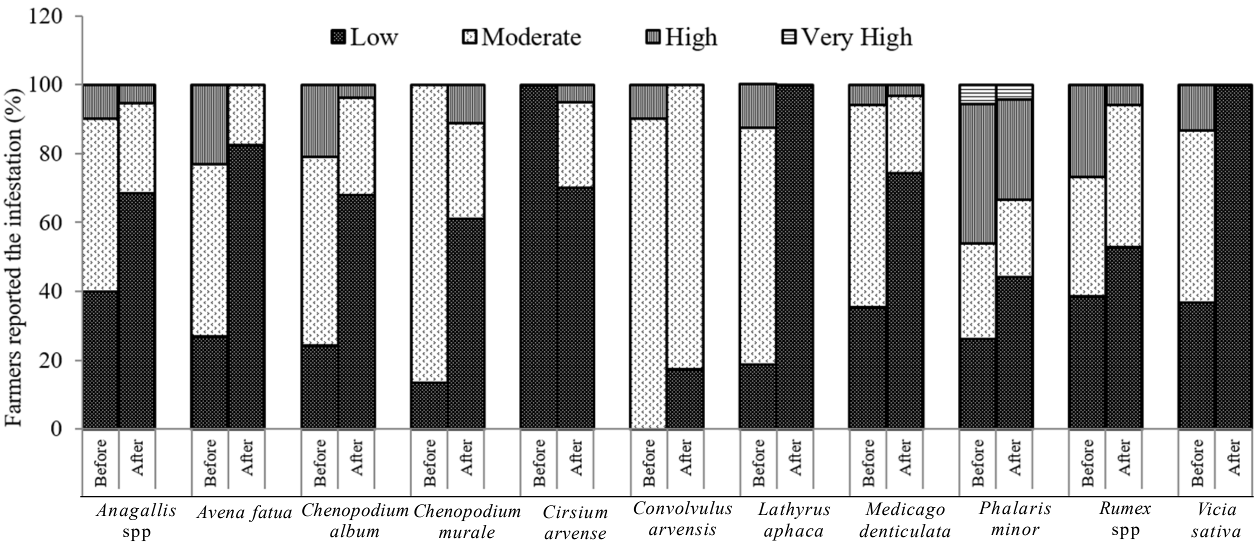

Figure 2. Response of farmers on weed severity (%) in wheat crop

Data on weed severity in rice before adoption revealed that *Setaria glauca* was reported by very few farmers with moderate level (25-50%) of infestation. However, this weed disappeared and new weeds such as *Aeschynomene* spp, *Phyllanthus niruri* and *Physalis minima* emerged with low severity level after the adoption of weed management technologies. Before adoption, some weeds like *Cyperus difformis, Fimbristylis miliacea, Ludwigia parviflora* were found in very high severity (>75%) level in rice crop, however, after adoption of weed management technologies they reached to low and moderate severity (<50%) in farmers' fields.

In case of wheat, few farmers reported *Melilotus indica* with low and moderate severity, however, it was not reported as problem weeds after adoption. On the other hand, *Polygonum* spp was reported with low and moderate severity after adoption. Some weeds like *Avena fatua, Chenopodium album, Phalaris minor* and *Rumex* spp were reported with high severity by >20% of the farmers before adoption. However, they were reported with low and moderate intensity after adoption. Few weeds like *Lathyrus aphaca* and *Vicia sativa* were reported with low level of severity after adoption of weed management technologies. Moreover, all weeds were reported with high level of severity (upto 75%) except *Phalaris minor*. According to 4.3% of the farmers, *Phalaris minor* is still present with very high level of severity (>75%) in most of their fields.

Awareness and adoption level of farmers on weed management

Information on awareness and adoption level of farmers regarding weed management technologies was collected with the help of interview schedule. These responses are presented though stacked bar diagram in **Figure 3 (a)** and **(b)**.

A1-Weeds are one of the major obstacles in crop production; A2-In traditional farming system, weed management was not given due importance; A3-Used demonstrated Improved Weed Management technologies later on; A4-Use of preventive methods of weed management.

B1-Use of precautionary measure such as mask, cloth, gloves during spraying; B2-Idea on spurious herbicides and their availability in the local market; B3-Use of separate nozzle like flat fan for spraying herbicides; B4-Destruction of herbicide container after use; B5-Mixing of herbicide with other pesticides.

Results revealed that farmers still not aware about the importance of weed management as they feel in case of other pests. However, 98% of the farmers use or have an idea of preventive methods to reduce the infestation of weeds in the crop. These preventive methods are (i) cleaning of seeds before sowing; (ii) cleaning of agricultural implements (iii) cleaning of irrigation channels and (iv) use of decomposed organic matter in the field. As far as chemical method is concerned, only around 50% farmers were well aware about the precautionary measures during spraying and spurious herbicides in the market. However, more than 80% farmers are mixing herbicides with other pesticides during spraying.

Major agencies involved in dissemination of weed management technologies

Analytic Hierarchy Process (AHP) was used to find out the major agencies which play important role in disseminating the weed management technologies. The AHP model used in this study is a qualitative technique which depend on the judgement and experience of decision makers to prioritize information for further better decisions. To arrive at the decision, different criteria and options (different

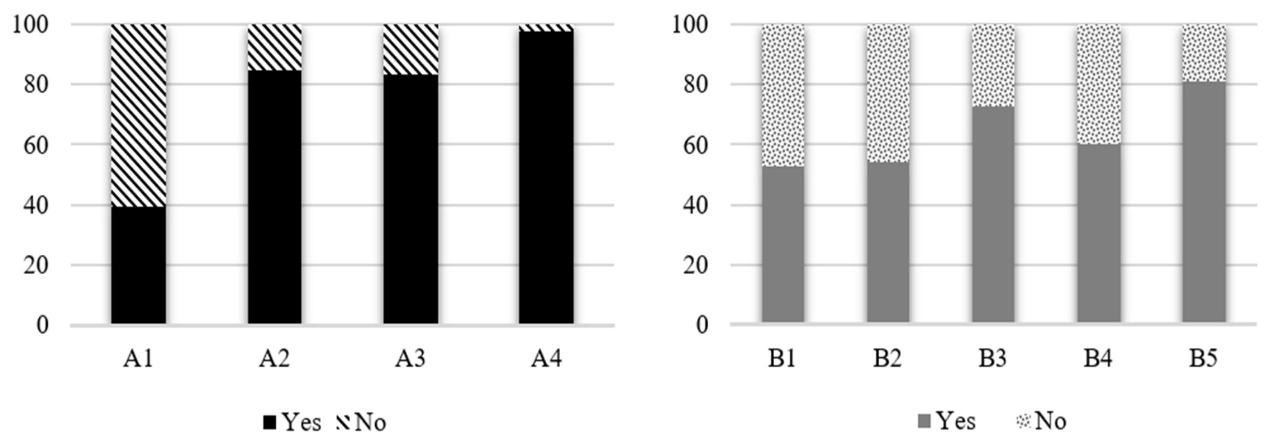

Figure 3(a). Farmers' perception on importance of weed management (b) Farmers' awareness level on chemical weed control

Table 2. Final priority of the agencies for disseminating the weed management technologies as a result of Analytic Hierarchy Process (AHP)

Agency	Final priority				
	Group I	Group II	Group III	Group IV	Group V
DWR/DWR centres / SAUs	0.34	0.28	0.37	0.56	0.35
Participation in OFR / demonstration conducted by DWR/DWR centres / SAUs	0.20	0.18	0.37	0.13	0.14
KrishiVigyan Kendra (KVK)	0.24	0.21	0.04	0.07	0.20
Kisan Mobile Seva	0.06	0.02	0.08	0.06	0.03
TV / Radio / News Paper / Literature	0.12	0.14	0.04	0.13	0.17
Private company / Local dealer / Others	0.03	0.17	0.09	0.04	0.10

agencies) were used and based on the feedback from farmers, AHP technique was used to arrive at the decision. Criteria used in AHP are (i) Contact with agency (ii) Frequency of contact to agency (iii) Information on weed management (iv) Receiving appropriate and useful information (v) Attempted received information (vi) Adopted recommended practice.

Table 2 revealed that ICAR-Directorate of Weed Research (DWR) and its centres located in different State Agricultural Universities played major role in disseminating weed management information to the farmers across all groups followed by farmers' participation in on-farm research /demonstrations conducted by these centres. In Group III, Krishi Vigyan Kendras were not found actively involved in spreading the information on weed control. As compared to Kisan Mobile Seva, TV/radio/ newspaper/literature and private company/local dealer/others also provided more information on weed management technologies to the farmers. There could be bias arising due to the inclusion of those farmers who were beneficiaries of DWR/DWR centres/SAUs for adopting those technologies. However, findings of this study may be used to know the other agencies which were not actively reaching to the farmers with weed management technologies. Therefore, there is need to sensitize those agencies and increase their role in providing weed management solutions to the farmers.

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Integrated weed management in elephant foot yam

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ABSTRACT

An experiment was conducted to find out the most effective method of weed management in elephant foot yam. The experiment was conducted under 10 different agro-climatic conditions of India including plains, hills and islands, etc. using RBD with 8 treatments and 3 replications, during 2017 and 2018. *Cyperus rotundus, Cynodon dactylon* and *Commelina benghalensis* were the predominant weeds at most of the locations. Among different treatments, hand weeding thrice at 30, 60, 90 days after planting (DAP) recorded taller plants (80.85 cm) with more pseudo stem girth, canopy spread (97.07 cm), leaf area (5435.37 cm^2), corm yield (38.0 t/ha), and net returns (₹ 387253), which was at par with weed control ground cover mat mulching and application of glyphosate thrice at 30, 60 and 90 DAP. Lower weed density and biomass were recorded in treatment with weed control ground cover mat mulching, which was at par with glyphosate applied at 30, 60 and 90 DAP.

INTRODUCTION

Elephant foot yam [*Amorphophallus paeoniifolius* (Dennst.) Nicolson] is a tuberous vegetable crop grown in tropical and subtropical regions, particularly in South-East Asia. The area and production of elephant foot yam in India is reported as 26,000 ha and 6.59 lakh metric tons, respectively (NHB 2017). In the present scenario of climate change, it has assumed more importance than before due to some un-parallel edges over other crops like producing optimal yields during adverse climatic conditions (Singh *et al*. 2018). Its farming is eco-friendly because of lesser use of agrochemicals. The underground stem tuber (corm) is used in the preparation of various cuisines and has been reported to have medicinal properties (Dey *et al*. 2010). Elephant foot yam is a highly nutritive vegetable (Gopalan *et al*. 1999). Weeds are potentially major constraints in producing higher yield and quality produce in tuber crops as they compete with the roots for applied resources and sometimes weed roots penetrate into the underground storage organs of tuber crops and reduce the quality of produce (Suresh *et al.* 2019). Elephant foot yam is susceptible to weed growth especially during initial growth phases due to the time gap between planting and sprouting, and slower canopy spread in first few months (Ravindran *et al*. 2010). Weed infestation at the early stage of crop development causes severe yield reduction upto 100% in wide-spaced plantings (Nedunchezhiyan *et al*. 2018). Weeds compete for all available resources both below (water, nutrients, space) and above ground (space, light) and thereby reduce the crop growth and yield. Weeds are alternative hosts to many pests and disease causing organisms. Weeding alone requires more than 30% of the total labour in this crop and it is approximately 150-200 mandays/ha (Nedunchezhiyan *et al.* 2018). Manual weeding is expensive, tedious and time consuming where the labour is scarce or where farm size is large. Application of herbicides for weed control as pre- or post-emergence can reduce dependency on manual weeding and reduce cost of production. The present study was undertaken at different locations of India by centres under the All India Coordinated Research Project on Tuber Crops to find out the most effective integrated weed management (IWM) option in elephant foot yam.

MATERIALS AND METHODS

Field experiments were conducted during 2017 and 2018 at 10 locations representing different agro-climatic conditions of India by centres under the All India Coordinated Research Project on Tuber Crops. The locations included hilly state of Himachal Pradesh at CSKPHKV, Palampur (Western Himalayan zone); Island of Andaman & Nicobar at ICAR-CIARI (Islands zone); Eastern plains at BCKV, Kalyani, West Bengal (Lower Gangetic plains zone) and Dr RPCAU, Dholi, Bihar (Middile Gangetic plains zone); North Eastern plains at ICAR-RC, Lembucherra, Tripura (Eastern Himalayan zone); East Coast plains at Dr YSRHU, Kovvur, Andhra Pradesh (East Coast plains and hills zone); North West at NAU, Navsari, Gujarat (Gujarat plains and hills zone); Southern part at TNAU, Coimbatore, Tamil Nadu (Southern plateau and hills zone); West Coast at Dr BSKKV, Dapoli, Maharashtra (West Coast plains and hills zone); Central part of India at BAU, Ranchi, Jharkhand (Eastern plateau and hills zone). The experiment was laid out in a randomized block design with three replications and eight treatments, *viz*. pendimethalin 1000 g/ha (PE) + glyphosate 860 g/ha (PoE) at 45 and 90 DAP, pendimethalin 1000 g/ha (PE) + hand weeding 45 and 90 DAP, raising green manure cow pea in interspaces along with planting and incorporation 45-60 DAP + glyphosate 860 g/ha (PoE) at 90 DAP, hand weeding 45 DAP + glyphosate 860 g/ha (PoE) at 90 DAP, glyphosate 860 g/ha (PoE) at 30, 60 and 90 DAP, weed control ground cover mat (120 gsm) mulching, hand weeding at 30, 60 and 90 DAP, control (no weeding). The size of plots was 4.5 x 4.5 m, spacing followed was 90 x 90 cm to accommodate 25 plants in each plot. All other agronomic practices were followed according to the package of practices recommendations (Mohan *et al.* 2000). Healthy cut corm pieces with central bud intact of elephant foot yam cv. '*Gajendra*', weighing 500 g, treated with cow dung slurry (10 kg of fresh cow dung dissolved in 10 L of water and mixed with 50 g of fungicide) one day before. The pre-emergence herbicide pendimethalin was applied one day after planting corms; care was taken for maintaining minimal soil moisture while applying the herbicide for its best results. The post-emergence herbicide glyphosate was applied directly on weeds as per treatments. Herbicides were applied without drift on elephant foot yam plants with a manually operated knapsack sprayer with a flat-fan nozzle attached to a hood using a spray volume of 500 litres/ha. Weed control ground cover mat mulching (120 GSM) done immediately after planting, proper care has taken to allow the growing shoot of corm to penetrate without any hurdles by ground cover mat mulching. Uniform need based plant protection measures were also taken up to control the pests and diseases.

From each net plot five plants were marked randomly as the representative sample for recording observations. Plant height, pseudo stem girth and canopy spread were recorded from the selected five plants at 3 and 5 MAP (months after planting). Leaf area was estimated according to Ravi *et al.* (2010). Weed data collected on parameters such as occurring weed species, weeds density and biomass, weed index (WI) and weed control efficiency (WCE). The weed index (WI) defined as "the reduction in yield due to the presence of weeds in comparison with no weed plot" was worked out for each plot with the formula suggested by Gill and Kumar (1996) and expressed in percentage. $WI= [(X-Y)/X] * 100$

Where, X= Yield from weed free plot; Y= Yield from the treated plot.

The weed control efficiency (WCE) was calculated by the following formula suggested by Patil and Patil (1993) and expressed in percentage. $WCE= [(DMC-DMT)/DMC]*100$

Where, DMC= dry matter of weed in control plot; DMT= dry matter of weed in treatment plot.

Corm yield, gross returns, cost of cultivation, net returns and B:C ratio were calculated after the crop harvest. Data on weeds and plant parameters over the locations were pooled and analysed in SAS statistical software (Version 9.4, SAS Institute, Inc., Cary, NC, USA). Analysis of variance (ANOVA) was carried out appropriate to the design of experiment. Treatment means were compared using least significant difference (LSD) at 5% probabilities.

RESULTS AND DISCUSSION

The analysis of variance for experimental design (**Table 1**) revealed highly significant mean squares differences due to treatments, locations and their interactions for all the characters studied. This indicates existence of diversity with treatments and locations.

Table 1. Effect of "Location", "Treatment" and their interaction on different characters in elephant foot yam under integrated weed management

Factors		Location	Treatment	Location* Treatment	Error	Total
Degrees of freedom		9	7	63	158	239
Weed density	F	1181.8	469.1	61.0		
	P	***	***	***		
Dry weight of weeds	F	184.9	107.7	27.6		
	P	***	***	***		
Plant height at 3MAP	F	77.0	18.5	5.1		
	P	***	***	***		
Plant height at 5MAP	F	123.3	30.0	5.7		
	P	***	***	***		
Pseudo stem girth at 3MAP	F	74.2	25.6	3.0		
	P	***	***	***		
Pseudo stem girth at 5MAP	F	118.7	26.5	3.1		
	P	***	***	***		
Canopy spread at 3MAP	F	239.0	30.0	5.4		
	P	***	***	***		
Canopy spread at 5MAP	F	143.5	63.9	10.4		
	P	***	***	***		
Leaf area at 3MAP	F	439.0	29.6	4.4		
	P	***	***	***		
Leaf area at 5MAP	F	1003.3	71.5	14.7		
	P	***	***	***		
Corm yield / plant	F	98.7	91.2	7.0		
	P	***	***	***		
Corm Yield/ ha	F	381.6	102.1	9.2		
	P	***	***	***		
Gross returns/ha	F	516.3	87.0	5.1		
	P	***	***	***		
Net return/ha	F	281.2	65.3	4.7		
	P	***	***	***		
B:C ratio	F	357.2	62.4	5.8		
	P	***	***	***		

F-values and statistical significance levels; * $P < 0.05$; NS: non-significant; ** $P < 0.01$; NS: non-significant; *** $P < 0.001$; NS: non-significant

Weed flora

The major weed species observed (**Table 2**) in the elephant foot yam field were: one sedge - *Cyperus rotundus* L.; Eleven grasses- *Brachiaria reptans* (L.); *Chloris barbata* Sw.; *Cynodon dactylon* L., *Digitaria sanguinalis* L., *Dinebra arabica* (syn of *D. retrofexa*) Jacq., *Echinochloa crusgalli* (L.) Beauv., *Echinocloa colona*, *Eleusine indica* (L.) Gaertn., *Paspalum scrobiculatum* L., *Setaria glauca* (L.) Beauv., *and Sorghum halepense* (L.) Pers.; Twenty one broad-leaved weed species – *Ageratum conyzoides* L., *Alternanthera paronichyoides, Amaranthus spinosus* L., *Calopogonium mucunoides* L., *Cannabis sativa* L., *Cleome viscosa* L., *Commelina benghalensis* L., *Digera arvensis* L., *Digera muricata* (L.) Mart., *Euphorbia hirta* L., *Euphorbia prostata*, *Merremia tridentate* (L.) Hallier f., *Mimosa pudica* L., *Parthenium hysterophorus* L., *Phyllanthus niruri* Hook. f., *Solanum nigrum* L., *Trianthema portulacastrum* L., *Tridax procumbens* L., *Vernonia cinerea* (L.) and *Xanthium strumarium* L. Among all the mentioned species, *Cyperus rotundus, Cynodon dactylon* and *Commelina benghalensis* were the dominant specie in most of the locations studied.

Weed density, weed biomass and weed control efficiency

Lower weed density and biomass were recorded with weed control ground cover mat mulching, which reduced total weed biomass, owing to complete cover of the ground which did not allow weeds to germinate and emerge. It was at par with glyphosate applied at 30, 60 and 90 DAP. The total weeds biomass is directly related to weed control

Table 2. List of observed weed species in experimental plots of elephant foot yam at different locations in India

Weed species observed in the experimental plots	Location
Amaranthus spinosus, Brachiaria reptans, Chloris barbata, Cynodon dactylon, Cyperus rotundus, Euphorbia hirta, Euphorbia prostrata, Parthenium hysterophorus, Trianthema portulacastrum,	TNAU, Coimbatore
Cynodon dactylon, Cyperus rotundus, Parthenium hysterophorus, Cleome viscosa, Tridax procumbens, Chloris barbata, Phyllanthus niruri, Vernonia cinerea	Dr. YSRHU, Kovvur
Amaranthus spp., *Cannabis sativa, Cleome viscose, Cynodon dactylon, Cyperus rotundus, Digera arvensis, Euphorbia sp., Leucas aspera, Parthenium hysterophorus, Physalis minima, Sorghum halepense*	RPCAU, Dholi
Alternanthera paronychioides, *Amaranthus spinosus*, *Brachiaria reptans*, *Cynodon dactylon*, *Cyperus rotundus*, *Digitari*a sp., *Echinochloa* sp., *Vernonia cinerea*	BSKKV, Dapoli
Cynodon dactylon, *Cyperus rotundus*, *Solanum nigrum*, *Mimosa pudica*, *Ageratum conyzoides*, *Euphorbia hirta*, *Xanthium strumarium*	BCKV, Kalyani
Celosia argentea, Commelina benghalensis, *Cynodon dactylon, Euphorbia, Setaria glauca, Cyperus rotundus, Digitaria sanguinalis, Eleusine indica, Echinochloa colona*	BAU, Ranchi
Abelmoschus moschatus, Alternanthera paronychioides, Digera muricata, Digera arvensis L., *Dinebra retroflexa, Echinochloa colona*, *Merremia tridentata, Phyllanthus fraternus, Physalis minima*, *Portulaca quadrifida*	NAU, Navsari
Ageratum conyzoides, *Amaranthus spinosus*, *Calopogonium mucunoides*, *Chloris barbata*, *Colocasia (wild)*, *Euphorbia hirta*, *Solanum nigrum*	CIARI, Port Blair
Commelina benghalensis, Cynodon dactylon, Cyperus rotundus, Digitaria sanguinalis, Echinochloa crus-galli, Paspalum sp.	CSK HPKV, Palampur
Ageratum sp., *Chloris* sp., *Cynodon* sp., *Cyperus rotundus* L., *Digitaria* sp., *Echinochloa* sp., *Eleusine* sp., *Galinsoga* sp., *Mimosa* sp., *Setaria* sp.	ICAR, RC, NEH, Lembucherra

efficiency (WCE). The WCE of different weed management treatments ranged 68.95-86.06% (**Table 3**). Higher WCE of 86.1% was achieved with weed control ground cover mat mulching and it was followed by 83.6% with raising green manure cow pea in interspaces along with planting and incorporation at 45-60 DAP followed by glyphosate application at 90 DAP because of their lower weed biomass. Significantly higher weed density and biomass were recorded in weedy check. Weed index (WI) was ranged from 1.55 to 48.73. Maximum weed index was recorded in the weedy check and the effective weed control treatment with lower weed index was weed control ground cover mat mulching. Better WCE with weed control ground covermat mulching in elephant foot yam was reported by Nedunzhiyan *et al*. (2013), George and Sindhu (2017), Nedunzhiyan *et al*. (2018); and in cassava (Nedunzhiyan *et al*. 2017).

Crop growth and yield attributes

The plant height, pseudo stem girth, canopy spread and leaf area were significantly ($p<0.05$) influenced by different weed control treatments (**Table 4**). All the treatments resulted in significantly taller plants than weedy check. Lesser weed infestation (weed biomass) in the treatments reduced competition for water, nutrients and space. It was aptly indicated by high WCE in the treatments (**Table 3**). At three months after planting treatment, glyphosate applied at 30, 60 and 90 DAP recorded taller plants with more pseudo stem girth, canopy spread and leaf area. The weed control ground cover mat mulching and hand weeding thrice at 30, 60 and 90 DAP were on par with it. In the initial stage, glyphosate, weed control ground cover mat mulching and hand weeding thrice effectively controlled the growth of the weeds and recorded similar results. At five months after planting, hand weeding thrice at 30, 60 and 90 DAP recorded taller plants with more pseudo stem girth, canopy spread and leaf area, and which was at par with treatment of glyphosate three sprays at 30, 60 and 90 DAP. Lower crop growth and yield attributes due to suppression of weeds led to lower yield (40.87 - 50.72% reduction) in weedy check in all the locations. This may be due to season

Table 3. Effect of different treatments on weed density, biomass and weed control efficiency in elephant foot yam (pooled analysis of 10 locations at 3 months after planting)

Treatment	Weed density (no/m^2)	Weed biomass (g/m^2)	Weed control efficiency (%)
Pendimethalin 1000 g/ha (PE) + glyphosate 860 g/ha (PoE) at 45 and 90 DAP	96.79^c	59.40^c	69.85
Pendimethalin 1000 g/ha (PE) + hand weeding 45 and 90 DAP	97.63^c	61.17^c	68.95
Raising green manure cow pea in interspaces along with planting and incorporation 45-60 DAP + glyphosate 860 g/ha (PoE) at 90 DAP	76.13^b	32.25^a	83.63
Hand weeding 45 DAP + glyphosate 860 g/ha (PoE) at 90 DAP	108.70^d	49.02^{bc}	75.12
Glyphosate 860 g/ha (PoE) at 30, 60 and 90 DAP	61.66^a	34.82^{ab}	82.33
Weed control ground cover mat (120 gsm)	58.91^a	27.46^a	86.06
Hand weeding at 30, 60 and 90 DAP	80.23^b	51.19^c	74.02
Control (no weeding)	264.20^e	197.02^d	0
LSD (p=0.05)	8.55	14.80	-

Mean values in each column with same alphabet in the superscript does not differ significantly, PE- pre-emergence, PoE- post-emergence, DAP- Days after planting

Table 4. Plant biometric parameters as affected by different integrated weed management treatments in elephant foot yam (pooled analysis of 10 locations)

Treatment	Plant height (cm)		Pseudo stem girth (cm)		Canopy spread (cm)		Leaf area (cm^2)	
	3 MAP	5 MAP	3 MAP	5 MAP	3 MAP	5 MAP	3MAP	5MAP
Pendimethalin 1000 g/ha (PE) + glyphosate 860 g/ha (PoE) at 45 and 90 DAP	58.3^{bc}	77.7^{abc}	13.2^b	17.2^c	69.6^c	90.4^b	3113.8^{bc}	51537^b
Pendimethalin 1000 g/ha (PE) + hand weeding 45 and 90 DAP	56.6^{cd}	74.9^c	13.3^b	16.9^{cd}	67.7^{cd}	83.8^d	3074.4^{bc}	4890.9^c
Raising green manure cow pea in interspaces along with planting and incorporation 45-60 DAP + glyphosate 860 g/ha (PoE) at 90 DAP	58.7^{abc}	77.2^{bc}	13.3^b	17.5^{bc}	69.3^c	87.1^c	3177.0^{bc}	4909.7^c
Hand weeding 45 DAP + glyphosate 860 g/ha (PoE) at 90 DAP	55.5^d	71.2^d	12.4^c	16.0^d	65.1^d	81.2^d	3062.8^c	4837.3^c
Glyphosate 860 g/ha (PoE) at 30, 60 and 90 DAP	60.6^a	79.3^{ab}	14.5^a	19.1^a	74.2^a	94.2^a	3431.8^a	5261.0^{ab}
Weed control ground cover mat (120 gsm)	59.2^{ab}	75.6^c	13.3^b	17.5^{bc}	70.1^{bc}	83.1^d	3243.8^b	4871.6^c
Hand weeding at 30, 60 and 90 DAP	60.1^{ab}	80.8^a	14.3^a	18.4^{ab}	72.7^{ab}	97.1^a	3461.6^a	5435.4^a
Control (no weeding)	50.0^e	60.8^e	10.5^d	13.1^e	56.1^e	69.0^e	2357.6^d	3424.2^d
LSD (p=0.05)	2.2	3.2	0.7	1.0	2.8	3.0	175.1	202.3

*Mean values in each column with same alphabet in the superscript does not differ significantly, MAP- Months after planting

Table 5. Yield and economics of elephant foot yam as affected by different integrated weed management treatments (pooled analysis of 10 locations)

Treatment	Corm yield/ plant (kg)	Corm yield (t/ha)	Weed index	Gross returns (x10³ ₹/ha)	Net returns (x10³ ₹/ha)	B:C ratio
Pendimethalin 1000 g/ha (PE) + glyphosate 860 g/ha (PoE) at 45 and 90 DAP	2.47[b]	32.91[cd]	14.74	546.05[c]	316.86[d]	1.90[bc]
Pendimethalin 1000 g/ha (PE) + hand weeding 45 and 90 DAP	2.50[b]	34.59[b]	10.39	559.08[c]	321.65[d]	1.79[c]
Raising green manure cow pea in interspaces along with planting and incorporation 45-60 DAP + glyphosate 860 g/ha (PoE) at 90 DAP	2.52[b]	34.37[bc]	10.96	568.50[c]	335.38[cd]	1.91[b]
Hand weeding 45 DAP + glyphosate 860 g/ha (PoE) at 90 DAP	2.30[c]	31.89[d]	17.38	541.07[c]	313.50[d]	1.79[c]
Glyphosate 860 g/ha (PoE) at 30, 60 and 90 DAP	2.57[b]	34.65[b]	10.23	603.90[b]	377.15[ab]	2.10[a]
Weed control ground cover mat (120 gsm)	2.76[a]	38.60[a]	0.00	614.14[ab]	356.41[bc]	1.83[bc]
Hand weeding at 30, 60 and 90 DAP	2.75[a]	38.00[a]	1.55	632.84[a]	387.25[a]	1.92[b]
Control (no weeding)	1.36[d]	19.79[e]	48.73	325.47[d]	122.33[e]	1.03[d]
LSD (p=0.05)	0.13	1.61	--	28.73	28.64	0.11

* Mean values in each column with same alphabet in the superscript does not differ significantly, LSD-least significant difference at the 5% level of significance, PE- pre emergence, POE- post emergence, DAP- Days after planting.

long crop-weed competition in weedy check plots, which was indicated by lower WCE, as well as lower crop growth and yield attributes (**Table 4** and **5**). Treatments with weed control ground cover recorded higher yields, which was at par with hand weeding thrice at 30, 60 and 90 DAP. Effective control of weeds and marked improvement in the crop growth and yield attributes led to higher corm yield in these treatments (**Table 5**).

Economics

Maximum cost of cultivation was incurred in weed control ground cover mat mulching due to its higher price per unit area (₹ 22/m^2). As the durability of soil covering ground cover mat is five years, if it is reused for more years can reduce expenditure on purchase of soil covering ground cover mat mulch. Higher gross and net returns were obtained with hand weeding thrice at 30, 60 and 90 DAP, which was closely followed by weed control ground cover mat mulching and three applications of glyphosate at 30, 60 and 90 DAP. Significantly higher B:C ratio was recorded by glyphosate applications at 30, 60 and 90 DAP due to less cost of cultivation as compared to higher price of weed control ground cover mat and higher human labour requirement and their wages in hand weeding.

It may be concluded that hand weeding is an effective and economical weed management option for managing weeds in elephant foot yam in India.Weed control ground cover mat mulch and post-emergence application of glyphosate may be advised as better alternative weed management options, where laborers are scarce and costly.

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Bio-efficacy of bentazone 48% SL as post-emergence against weeds in direct-seeded rice

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ABSTRACT

The experiment was conducted during *Kharif* season of 2017 at Research Farm of Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur, Madhya Pradesh. The soil of experimental site was sandy clay loam in texture, medium in organic carbon (0.62%), available nitrogen (285 kg/ha), available phosphorus (17.45 kg/ha) and potassium (260 kg/ha) with neutral pH (7.1). The dominant weeds associated with direct-seeded rice in the experimental field were mainly comprised of monocot (*Echinochloa colona*), sedge (*Cyperus iria*) and dicot weeds (*Mollugo pentaphylla*, *Phylanthus niruri*, *Eclipta alba*, *Corchorus olitorius* and *Alternanthera philoxeroides*).Experiment consisted of total ten treatments comprising of seven doses of bentazone 600, 800, 1000, 1200, 1600, 1800 and 2000 g/ha, 2,4-D 380 g/ha as post-emergence, hand weeding twice (20 and 40 DAS) including weedy check, were laid out in a randomized block design with 3 replications. The post-emergence application of bentazone at higher doses *i.e.* 1800 and 2000 g/ha was found effective in reducing the weed density of dicot weeds to a great extent.

Rice (*Oryza sativa* L.) is the most important staple food crop of millions of mankind from the dawn of civilization. India is the 2nd largest producer and consumer of rice in the world. Rice provides 50-80% daily calorie intake to the consumer (Choudhary *et al*. 2011). In India, it is grown in nearly 43.39 mha area with the production of 104.32 MT and productivity of 2404 kg/ha. In Madhya Pradesh, it occupies an area of 2.02 mha with production of 3.58 MT and productivity of 1768 kg/ha (Anonymous 2016).

Direct seeding of rice (DSR) has more benefits as compared to traditional transplanting like easier planting, timely sowing, less drudgery, early crop maturity by 7 to 10 days, less water requirement better soil physical condition for next crop and low production cost and more profit. Weeds are the number one biological constraint and major threat to the production and adoption of DSR system (Chauhan 2012) and can cause yield losses up to 50 per cent and the risk of yield loss is greater than transplanted rice and as high as 50-90% (Chauhan and Opena 2012a). Use of herbicides to keep the crop weed free at critical crop weed competition stages will help in minimizing the cost of weeding as well as managing the weeds below the damaging level. Hand weeding is very easy and environment-friendly but tedious and highly labour intensive. Farmers very often fail to remove weeds due to unavailability of labour at peak periods. Therefore, hand weeding becomes difficult at early stages of growth due to morphological similarity.Generally pre-emergence herbicides like pretilachlor, butachlor, anilophos, and post-emergence herbicides like 2,4-D, Almix and Bispyribac-Na are used frequently to control grassy and broad-leaf weeds in DSR. Continuous application of these herbicides may also result in weed flora shift and development of herbicidal resistance in weeds. This situation warrants for initiating research efforts to develop and evaluate new and alternate herbicides to overcome the problem of herbicidal resistance in weeds.

Bentazone has been found effective post-emergence herbicide for controlling broad-leaf weeds in soybean in different parts of the country. In this context, the effectiveness of bentazone in case of DSR at different doses was planned to be evaluated in present investigation.

The present experiment was conducted at Product Testing Unit, Adhartal, Jawaharlal Nehru Krishi Vishwa Vidyalaya, Jabalpur (M.P.). during *Kharif* 2017. Ten treatments, *viz*. bentazone at different doses (600, 800, 1000, 1200, 1600, 1800 and 2000 g/ha) and 2,4-D 380 g/ha as well as hand weeding at 20 and 40 DAS and weedy check were evaluated. Experiment was laid out in a randomized block design with three replications. All herbicides were applied using knap-sack sprayer fitted with flat-fan nozzle at spray volume of 500 l/ha at 15 days after sowing. Sowing of seeds in each plot was done in rows 20 cm apart atthe depth of 2-3 cm on July 7th 2017. The crop was raised by following recommended packages of practices for rice. The data on weed density and weed dry weight were collected from each unit plot before application, 15, 30, 45 DAA and at harvest by quadrate count method. The quadrate of 0.25 square meters' (0.5 x 0.5 m) was placed randomly twice or thrice and weed species within the quadrate were identified and their number was counted. The weeds uprooted, cleaned and then oven dried for further investigation. Dry matter of weeds was recorded. The data on weed count and weed biomass were subjected to square root transformation i.e. $\sqrt{x+0.5}$, before carrying out analysis of variance and comparisons were made on transformed values. Weed control efficiency (WCE) was calculated on the basis of weed biomass as per the formula recommended by Mani *et al.* (1968).

Effect on weeds

Weed density of grassy weeds and sedge was not affected due to different weed control treatments except in hand weeding treatments, where weeds were uprooted manually. Weed density was almost similar in all the herbicidal treatments including weedy check plots where no herbicides were applied (**Table 1**). It was observed that different weed control treatments did not cause any adverse effect on weed density of the grassy weeds. However, hand weeding twice reduced the density of grassy weeds to the maximum extent and was appreciably superior over all the weed control treatments (**Table 1**).

Weed control treatments caused significant reduction in the density of broad-leaf weeds like *Mullogo pentaphylla, Phylanthus niruri, Eclipta alba, Corchorus olitorius* and *Alternanthera philoxeroides* on the application of the herbides (**Table 1**). The density of these weeds was maximum under weedy check plots where no herbicides were applied. The application of bentazone at different doses (600 and 2000 g/ha) and 2,4-D (380 g/ha) caused reduction in the density of broad-leaf weeds and proved significantly superior to weedy check plots where weeds were not controlled throughout the growing season. However, none of the herbicidal treatments surpassed the hand weeding twice which reduced the density of dicot weeds to the maximum extent. Almost similar views were endorsed by Tiwari and Mathew (2002), Christopher *et al.* (2005) and Zeinab and Saeedipur (2015).

Effect on dry weight of weeds

The dry weight of monocot weeds were not affected due to various herbicidal treatments. Dry weight was almost similar in all the herbicidal treatments including weedy check plots where weeds were not controlled by any means (**Table 2**). However, hand weeding twice at 20 and 40 DAS was found superior to other herbicidal treatments as it curbed the dry weight of monocot weeds to great extent. Data on dry weight of broad-leaf weeds at 30 days after application (DAA) under different weed control treatments are shown in **Table 2**. All the weed control treatments including hand weeding twice had significantly reduced the dry weight of broad-leaf weeds when compared with the weed control

Table 1. Density of grassy weed, sedge and broad-leaf weeds at different intervals as influenced by different treatments

Treatment	Weed density (m^2)/ 30 days after application						
	Grassy weed	Sedge	Broad-leaf weeds				
	Echinochloa colona	*Cyperus iria*	*Mollugo pentaphylla*	*Phylanthus niruri*	*Eclipta alba*	*Corchorus olitorius*	*Alternanthera philoxeroides*
Bentazone 600 g/ha	7.40(54.25)	5.96(35.00)	4.04(16.08)	3.58(12.33)	2.74(7.00)	2.77(7.17)	2.94(8.17)
Bentazone 800 g/ha	7.46(55.17)	5.92(34.58)	3.94(15.00)	3.39(11.00)	2.58(6.17)	2.55(6.00)	2.74(7.00)
Bentazone 1000 g/ha	7.51(55.83)	5.91(34.42)	3.83(14.17)	3.25(10.08)	2.35(5.00)	2.40(5.25)	2.60(6.25)
Bentazone 1200 g/ha	7.41(54.42)	5.93(34.67)	3.65(12.83)	3.05(8.83)	2.20(4.33)	2.27(4.67)	2.50(5.75)
Bentazone 1600g/ha	7.48(55.50)	6.01(35.67)	3.39(11.00)	2.77(7.17)	1.87(3.00)	1.94(3.25)	2.12(4.00)
Bentazone 1800 g/ha	7.42(54.58)	5.90(34.33)	3.26(10.08)	2.55(6.00)	1.73(2.50)	1.73(2.50)	1.89(3.08)
Bentazone 2000 g/ha	7.50(55.75)	5.94(34.83)	2.25(6.00)	2.12(4.00)	1.55(1.92)	1.58(2.00)	1.41(1.50)
2,4-D 380 g/ha	7.51(55.92)	5.99(35.42)	3.54(12.00)	2.93(8.08)	2.06(3.75)	2.12(4.00)	2.35(5.00)
Hand weeding (20 and 40 DAS)	1.52(1.83)	1.44(1.58)	1.35(1.33)	1.38(1.42)	1.29(1.17)	1.26(1.08)	1.22(1.00)
Weedy check	7.49(55.58)	6.00(35.50)	7.47(55.33)	6.79(45.67)	5.99(35.33)	5.85(33.67)	5.55(30.33)
LSD(p=0.05)	0.15	0.09	0.08	0.06	0.10	0.10	0.07

Figures in parentheses are original values treatments. Maximum dry weight of dicot weeds was recorded under weedy check plots (5.56, 4.83, 4.26, 4.55 and 4.11 g/m^2) due to uninterrupted growth of weeds during critical period of crop-weed competition. Post-emergence application of bentazone at different doses (600 to 2000 g/ha) and check herbicide 2,4-D (380 g/ha) reduced the dry weight of broad-leaf weeds. However, hand weeding twice was appreciably superior among all the weed control treatments in reducing the dry weight of *Mollugo pentaphylla*, *Phylanthus niruri, Eclipta alba, Corchorus olitorius* and *Alternanthera philoxeroides* (0.94, 0.96, 0.91, 0.93 and 0.89 g/m^2 respectively) to a great extent. Singh *et al.* (2012) and Chauhan and Opena (2013) also made similar observations and reported minimal density and dry weight of weeds under hand weeding.

The weed control efficiency was maximum (98.3%) under hand weeding twice. Whereas weed control efficiency on the application of bentazone 800 g/ha was 81.37%, which increases when applied at higher doses *i.e.* 1000, 1200, 1600, 1800 and 2000 g/ha (83.92, 85.38. 89.38, 91.67 and 94.99%, respectively) in case of dicot weeds but higher doses are not economically feasible. The similar observations weremade by Soni *et al.* (2012).

Effect on yield

Growth parameters of rice were higher in plots receiving bentazone 800 g/ha among all the herbidal treatments. Whereas, maximum values of these parameters and dry matter accumulation in plants were recorded under hand weeding twice (20 and 40) due to complete elimination of weeds (**Table 3**). These findings were in conformity to those of Chandra and Solanki (2003) and Chauhan *et al.* (2013).

Among different weed control treatments significantly higher yield attributes were observed under hand weeding twice followed by bentazone as

Table 2. Dry weight of grassy weed, sedge and broad-leaf weeds at different intervals as influenced by different treatments

Treatment	Dry weight (m^2)/ 30 days after application						
	Grassy weed	Sedge	Broad-leaf weeds				
	Echinochloa colona	*Cyperus iria*	*Mollugo Pentaphylla*	*Phylanthus niruri*	*Eclipta alba*	*Corchorus olitorius*	*Alternanthera philoxeroides*
Bentazone 600 g/ha/ha	8.68(74.87)	6.83(46.20)	2.75(7.08)	2.43(5.40)	1.89(3.08)	2.07(3.80)	1.98(3.43)
Bentazone 800 g/ha	8.85(77.78)	6.79(45.65)	2.64(6.45)	2.24(4.52)	1.77(2.65)	1.90(3.12)	1.84(2.87)
Bentazone 1000 g/ha	8.87(78.16)	6.75(45.10)	2.51(5.80)	2.13(4.03)	1.62(2.12)	1.79(2.72)	1.71(2.43)
Bentazone 1200 g/ha	8.76(76.29)	6.80(45.76)	2.42(5.38)	2.00(3.52)	1.52(1.81)	1.70(2.38)	1.60(2.07)
Bentazone 1600 g/ha	8.81(77.15)	6.92(47.44)	2.15(4.13)	1.79(2.72)	1.32(1.25)	1.43(1.56)	1.40(1.47)
Bentazone 1800 g/ha	8.87(76.41)	6.77(45.32)	1.98(3.44)	1.63(2.16)	1.20(0.95)	1.27(1.11)	1.26(1.10)
Bentazone 2000g/ha	8.89(78.60)	6.84(46.32)	1.57(1.98)	1.35(1.32)	1.08(0.67)	1.13(0.78)	1.01(0.52)
2,4-D 380 g/ha	8.91(78.84)	6.90(47.11)	2.22(4.42)	1.92(3.19)	1.42(1.51)	1.61(2.08)	1.50(1.74)
Hand weeding (20 and 40 DAS)	1.45(1.61)	1.33(1.26)	0.94(0.39)	0.96(0.42)	0.91(0.33)	0.93(0.37)	0.89(0.30)
Weedy check	8.85(77.81)	6.91(47.22)	5.56(28.21)	4.83(22.83)	4.26(17.66)	4.55(20.20)	4.11(16.37)
LSD (p=0.05)	0.17	0.11	0.06	0.05	0.08	0.07	0.08

Figures in parentheses are original values

Table 3. Number of tillers and effective tillers of direct-seeded rice as influenced by different treatments at different time intervals

Treatment	Tiller (m^2)				Plant height (cm)			
	30 DAS	60 DAS	90 DAS	At harvest	30 DAS	60 DAS	90 DAS	At harvest
Bentazone 600 g/ha	230.00	324.30	360.30	360.30	12.40	50.07	78.33	78.15
Bentazone800 g/ha	232.00	430.45	455.83	455.83	13.13	52.87	84.73	84.30
Bentazone1000 g/ha	231.40	419.20	448.71	448.71	13.09	51.90	82.27	82.17
Bentazone1200 g/ha	232.00	408.12	442.14	442.14	12.96	51.57	80.03	79.97
Bentazone1600 g/ha	232.20	380.15	417.46	417.46	12.79	50.90	78.07	78.65
Bentazone1800 g/ha	230.00	360.92	408.75	408.75	12.67	50.73	78.64	78.57
Bentazone2000 g/ha	231.00	340.20	388.24	388.24	12.53	50.23	78.40	78.27
2,4-D 380 g/ha	232.40	401.79	435.72	435.72	12.89	51.40	79.63	79.53
Hand weeding (20 and 40 DAS)	231.00	470.50	500.29	500.29	13.57	55.57	88.55	87.37
Weedy check	230.00	266.13	325.11	325.11	12.17	48.70	74.47	75.27
LSD (p=0.05)	N.S.	20.40	24.76	24.76	N.S.	0.35	0.20	0.36

Table 4. Influence on grain yield, straw yield, harvest index, weed index and yield attributes under different treatments

Treatment	Grain yield (t/ha)	Straw yield (t/ha)	Harvest index (%)	Weed index (%)	Effective tillers (no./m^2)	Panicles (no./m^2)	Grains/ panicle	Test weight (g)
Bentazone 600 g/ha/ha	2.48	4.61	34.93	40.39	341.40	341.40	168.72	21.33
Bentazone 800 g/ha	3.65	5.74	38.88	12.21	434.75	434.75	189.14	21.80
Bentazone 1000 g/ha	3.40	5.39	38.78	17.86	427.62	427.62	185.40	21.50
Bentazone 1200 g/ha	3.14	5.37	38.74	18.22	420.10	420.10	182.14	21.53
Bentazone 1600 g/ha	3.11	5.17	37.56	25.23	398.42	398.42	176.36	21.47
Bentazone 1800 g/ha	3.07	5.15	37.38	26.04	385.50	385.50	174.24	21.30
Bentazone 2000 g/ha	2.63	4.69	35.89	36.84	360.20	360.20	170.68	21.17
2,4-D 380 g/ha	3.34	5.28	38.72	19.76	412.69	412.69	180.48	21.60
Hand weeding (20 and 40 DAS)	4.16	6.24	40.00	0	482.20	482.20	194.54	22.27
Weedy check	1.96	4.01	32.78	52.89	304.10	304.10	150.80	21.20
LSD (p=0.05)	0.22	0.10	-	-	19.55	19.55	3.16	NS

post-emergence 800 g/ha (**Table 4**). These findings were in close collaboration with the findings of Chandra and Solanki (2003) and Dubey *et al.* (2017).

The maximum grain and straw yield were observed under hand weeding twice (4.16 and 6.24 t/ha respectively) followed by the application of bentazone 800 g/ha as post-emergence (3.65 and 5.74 t/ha, respectively) and was found to be the economical viable treatment among all the weed control treatments (**Table 4**). Similar results were also reported by Chauhan and Opena (2013), Kumar *et al.* (2014) and Chander and Pandey (2001). Harvest index was maximum (40.0%) under hand weeding twice followed by bentazone as post-emergence 800 g/ha (38.88%) and minimum with weedy check plots (32.78%). While the lowest weed index was recorded under hand weeding twice (0.00%) followed by bentazone as post-emergence 800 g/ha (12.21%). These results were in close conformity to the findings of Chandra and Solanki (2003).

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Biology and phenology of predominant weed species in lowland rice ecosystems

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ABSTRACT

A field survey was taken up in Coimbatore, Tamil Nadu state to know the dominant weed species competing in the lowland rice ecosystems to identify the major weeds and study the biology and phenology of the weed species. Barnyard grass *(Echinochloa crus-galli)*, blistering ammannia *(Ammania bacciffera)*, false daisy *(Eclipta alba)* and Viper grass *(Dinebra retroflexa)* were found predominant in lowland and were selected for the study. The seeds of selected weeds were collected along with the inflorescence from the field pot culture and field studies. It was found that among the four lowland weeds, *Echinochloa crus-galli* and *Eclipta alba* germinated 6 days after sowing both in the pot as well as field study. *Ammania bacciffera* was germinated earlier in pot culture (7 days) and *Dinebra retroflexa* germinated earlier (7 days) in field condition. Weeds grown in field condition came to 50% flowering earlier than grown in pot culture. Total dry weight per plant at flowering was higher in *Dinebra retroflexa* both in field and pot culture and at maturity, it was higher with *Echinochloa crusgalli.* Total dry weight at maturity was 8-12 times more than at flowering for all the weeds. The numbers of seeds/plant was higher with *Echinochloa crus-galli* in both in pot culture and field study with 650 and 850 seeds/ plant respectively.

Rice is one of the most important food crops of India in terms of area, production and consumer preference. India is the second largest producer and consumer of rice in the world. In India, rice is grown in an area of 43.8 million hectares in different agro-climatic regions with a production of 112.91 million tonnes during 2017-2018 (MoA 2019). In Tamil Nadu, 7.28 million tonnes of rice has been produced with a productivity of 3923 kg/ha during 2017-18. This will not be sufficient to meet the needs of the growing population and the demand will increase by 69% by 2025 A.D. However, production and productivity are restricted because of infestation by biotic stress *i.e.* weeds, insects and diseases.

Among the yield limiting biotic factors, weeds play a major role. Uncontrolled growth of weeds in rice reduced the grain yield by 75.8, 70.6 and 62.6% in dry-seeded rice, wet-seeded rice and transplanted rice, respectively (Singh *et al*. 2005). Gharde *et al.* (2018) estimated that the total economic loss due to weeds in 10 major crops in India is around USD 11 billion. Although the number of species recorded in the lowlands were lower and more stable over time, there was an increase in problem grass weeds, such as *Echinochloa crus-pavonis* (Kunth.) Schult in the irrigated lowlands and *Leersia hexandra* Sw. in the rain-fed lowlands (Johnson and Kent 2002). So, it is necessary to manage the weeds to the level that it may not cause economic yield loss. Weed biology relates to the plant attributes such as morphology, seed dormancy and germination, physiology of growth, competitive ability and reproductive biology. Knowledge of weed biology is essential for the development of both economically and environmentally acceptable weed management systems. However, the growth of weeds varies in field conditions and controlled conditions. Taking this into consideration a pot culture and field study was taken up with the objective of studying the biology of predominant weed species in wetland ecosystems.

A field survey was conducted to study biology and phenology of predominant weed species in lowland rice ecosystems in wet land farm of Tamil Nadu Agricultural University, Coimbatore and sorrounding villages. Lowland rice fields in surrounding villages located in the region were surveyed during 2015. Major weed species in the rice fields were identified according to Harada *et al.* (1996). Weed species selection was done by a field survey to know the dominant weed species occupying the wet land and the major weeds were identified. The seeds of selected weed species were collected along with the inflorescence from the field in advance and were cleaned to get the seeds. Then the seeds were shade-dried to the optimum moisture level. The seeds thus collected were used for both pot culture experiment and field study.

For the pot culture study, the pots were filled with wet land soil up to ¾th level. Then 30 seeds were sown for each pot and soil was sprinkled for uniform coverage of seeds. This was irrigated by sprinkling water. For field study, one square metre were selected in the wetland 30 seeds were sown for each plot and this was replicated thrice. Folloaing biological and phenological parameters, were take by adopting the standard procedures: days to emergence, germination percentage, seedling fresh weight (g/plant) at 10 days after sowing (DAS), Seedling dry weight (g/plant) at 10 DAS, seedling fresh weight (g/plant) at 15 DAS, seedling dry weight (g/plant) at 15 DAS, days for initiation of flowering, days to 50% flowering, number of tillers/branch, total fresh weight at flowering (g/plant), total dry weight at flowering (g/plant), leaf area at flowering (cm^2/plant), total fresh weight at maturity (g/plant), total dry weight at maturity (g/plant), leaf area at maturity (cm/plant), number of seeds or fruits per plant, thousand seed weight (g).

The experimental data were subjected to statistical scrutiny as per methods suggested by Gomez and Gomez (1984) and executed with the software AGRES by Tamil Nadu Agricultural University. Wherever the results were significant, critical differences were worked out at probability level p d" 0.05 / 0.01 using the ANOVA.

Weed flora

Weed count observation indicated more than 14 number of weed species belonging to 10 families were identified from the plots (Data not shown). According to the weed species identified, the top three largest families were found to be Poaceae (21%), Lythraceae (16%) and Asteraceae (8%). Of these four predominant weeds from lowland were selected for the current study. The predominant weeds were: *Echinochloa crus-galli, Ammania bacciffera, Eclipta alba, Dinebra retroflexa.* The specifications with full details about the weeds were given in **Table 1.**

Biology and phenology of weeds

Barnyard grass *(Echinochloa crus-galli)*

Seedling emergence of *Echinochloa crus-galli* was at 6 DAS in both pot culture and the field condition (**Tables 1** and **2)**. However, the germination percentage was higher in the field than pot culture condition. Dry matter accumulation of seedlings at 10 DAS, 15 DAS, flowering and at maturity was higher in the field than pot culture condition. The rate of dry matter accumulation was slow in early growth stages and it was higher at later stages. It accumulated to an extent of 6.41 g/plant and 4.50 g/plant in field and pot culture conditions, respectively at the maturity stage. Days for initiation of flowering were 46 days and 48 days in the field and pot culture conditions, respectively showed that field sown weeds initiated flowering early. However, 50% flowering was earlier in pot culture condition. Leaf area was higher in the field (431.7 cm^2/plant) at flowering and at maturity (485.6 cm^2 /plant). The number of seeds/plant was higher in field conditions than pot culture. It produced to the maximum extent of 650 to 850 seeds/plant. However, there was no significant difference in 1000-seed weight between pot culture and field condition (Ann *et al.* 2001).

False daisy *(Eclipta alba)*

Eclipta alba seedlings emerged within 6 DAS in both conditions. Germination percentage was higher in the field (87%) than pot culture (74%). Seedlings grown under the field produced higher dry matter than pot culture at 10 DAS, 15 DAS and at flowering. The dry matter accumulation at maturity was however higher in pot culture than field condition which was to the tune of 4.187 g/plant in pot culture. Flower initiation started at 41 DAS and 42 DAS in field and pot culture conditions, respectively. The same trend was followed in 50% flowering also, which were 45 DAS and 46 DAS in field and pot culture conditions, respectively. The number of branches and leaf area was higher in the field than pot culture. The maximum leaf area/plant was 163.74 cm^2 in the field condition. The number of seeds/plant was higher in the field (735) compared to pot culture (576). However, 1000-seed weight have no significant difference in field and pot conditions.

Blistering ammannia (*Ammania bacciffera*)

Ammania bacciffera germinated at 7 DAS in pot culture and one day later in field condition. Germination percentage was higher in the field (54.4%) than pot culture. Dry matter accumulation in 10 DAS, 15 DAS, flowering and maturity was higher in the field than pot culture. The maximum dry matter accumulation was 5.47 g/plant at maturity in field condition. A similar trend was followed for leaf area at flowering and at maturity. A higher leaf area of 146.16 cm^2/plant was recorded in the field at maturity. However, there was no variation in days for initiation of flowering (35 DAS) and 50% flowering (42 DAS) occurred in both conditions. The number of capsules was 118 in field and 102 in pot culture. Since the seeds are very small, it was not possible to estimate 1000-seed weight (Ann *et al.* 2001, Shibayama 2001).

Table 1. Phenological characteristics (mean values) of major wet land weeds (pot culture experiment)

Parameter	Weed species(mean values)			
	Echinochloa crusgalli	*Eclipta alba*	*Ammania bacciffera*	*Dinebra retroflexa*
Days to emergence	6	6	7	8
Germination %	66.700	74.400	33.300	71.100
Seedling fresh wt (g/pt) at 10DAS	0.055	0.084	0.044	0.016
Seedling dry wt (g/pt) at 10 DAS	0.007	0.010	0.005	0.004
Seedling fresh wt (g/pt) at 15 DAS	0.082	0.159	0.073	0.029
Seedling dry wt (g/pt) at 15DAS	0.013	0.016	0.007	0.006
Days for initiation of flowering	48.000	42.000	35.000	38.000
Days to 50% flowering	53.000	46.000	42.000	44.000
No of tillers /branches	2.330	3.330	1.660	4.330
Total fresh wt at flowering (g/plant)	2.399	3.604	3.953	3.341
Total dry wt at flowering (g/plant)	0.449	0.497	0.345	0.819
Leaf area at flowering cm^2/plant	398.310	42.150	4.960	105.480
Total fresh wt at maturity (g/plant)	6.210	17.330	20.060	3.320
Total dry wt at maturity (g/plant)	4.503	4.187	2.407	1.633
Leaf area at maturity cm^2/plant	412.850	112.324	98.130	168.340
Seeds / fruits / plant	650.000	576.000	102.000	4.100
1000 seed wt (g)	1.640	0.71	-	0.130
LSD (p=0.05)	34.700	23.730	6.240	8.720

Table 2. Phenological characteristics (mean values) of major wet land weeds (field experiment)

Parameter	Weed species (mean values)			
	Echinochloa crusgalli	*Eclipta alba*	*Ammania bacciffera*	*Dinebra retroflexa*
Days to emergence	6	6	8	7
Germination percentage	78.900	86.700	54.400	77.800
Seedling fresh wt (g/pt) at 10DAS	0.076	0.095	0.045	0.016
Seedling dry wt (g/pt) at 10DAS	0.008	0.010	0.005	0.003
Seedling fresh wt (g/pt) at 15DAS	0.107	0.207	0.095	0.038
Seedling dry wt (g/pt) at 15DAS	0.018	0.023	0.010	0.008
Days for initiation of flowering	46.000	41.000	35.000	36.000
Days to 50% flowering	54.000	45.000	42.000	42.000
No of tillers/branches	3.300	4.000	2.300	5.300
Total fresh wt at flowering (g/plant)	3.487	3.766	4.103	5.513
Total dry wt at flowering (g/plant)	0.662	0.527	0.451	1.103
Leaf area at flowering cm^2/plant	431.700	49.920	6.730	123.950
Total fresh wt at maturity g/plant	34.600	16.530	29.770	10.990
Total dry wt at maturity g/plant	6.410	3.527	5.446	2.307
Leaf area at maturity cm^2/plant	485.620	163.740	146.160	138.240
Seeds / fruits / plant	850.000	735.000	118.000	4.300
1000 seed wt (g)	1.658	0.718	-	0.136
LSD (p=0.05)	42.790	30.320	8.180	8.330

Viper grass *(Dinebra retroflexa)*

Dinebra retroflexa seedling emergence was 7 DAS at the field and one day later in pot culture. The germination percentage was higher in the field than pot culture. Total dry matter accumulation was higher in the field than pot culture at all stages of plant growth. The maximum dry matter accumulation was 2.31 g/plant at maturity in field condition. Flowering initiation was at 36 DAS in field and 2 days later in pot culture. Similarly, 50% flowering was at 42 DAS in both conditions. The number of tillers was 5.3/plant in field than 4.3/plant in pot culture. Leaf area/plant was higher in the field at flowering and it was higher at maturity in pot culture which was 168.34 cm^2/plant. Thousand seed weight was 0.136 g in field and it was 0.130 g in pot culture. Similar finding was also reported by Honek and Martinkova (2002).

Among all weeds, *Echinochloa crus-galli* germinates very early *i.e.* within 6 DAS which should to be taken into consideration in its management under field condition. It has also high dry matter accumulation potential among all weeds. From these observations, it was clear that weed growth occurs within 46 days after rice sowing/planting which may propagate by seeds and propagules or by both. The perennial weeds create the most serious problem in rice fields. Major weeds produce a large number of seeds, which may remain in the soil and serve as a soil seed bank for the next cropping season. It can be emphasized that major weeds should be controlled at the proper time to check reduction in rice yield, and they must be removed before flowering and fruiting to reduce the production of seeds that remain as a soil seed bank for the following years. The present results will be useful for setting the economic thresholds for weed control. The competition of 25 barnyard grass plants/m^2 caused approximately 50% yield loss in rice in Vietnam (Duong Van 2001). Moreover, from this study, it is suggested that weed control practices should be completed before rice tillering for could lead to improved yield in rice. Besides, if the perennial weeds are controlled well before flowering, then subsequent rice crop can be saved from weed infestation, which will ultimately result in higher productivity of rice.

From the present field study, it was concluded that weed seeds grown under field condition has a higher growth rate than pot culture condition. This may be due to the fact that field grown seedlings get higher solar insolation and more ground area per plant. Among all weeds, *Echinochloa crus-galli* germinated very early *i.e.* within 6 DAS which should be taken into consideration in its management under field condition. It has also high dry matter accumulation potential among all weeds.

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Weed management through rice straw mulching and herbicide use in maize

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ABSTRACT

The field experiments were carried out at Ludhiana and Gurdaspur during *Kharif* 2017 to find out the influence of rice straw mulching and weed management treatments on weed density, weed dry matter and grain yield in maize. Use of rice straw mulch (PSM) at 9.00 and 6.25 t/ha recorded an average of 19.9 and 11.4% higher grain yield (5.91-6.21 and 5.46-5.81 t/ha), compared with no mulching (4.82-5.31 t/ha), respectively. The results showed that there was a reduction in average grain yield of 9.80 kg/ha with every increase in dry matter accumulation of weeds by 1.0 g/m^2. Post-emergence application of tembotrione (0.088 and 0.110 kg/ha) proved to be more effective than the pre-emergence application of atrazine (0.8 and 1.0 kg/ha) for controlling different weed species in maize. Both the doses of tembotrione (0.088 and 0.110 kg/ha) in combination with rice straw mulch at 9.00 t/ha displayed significantly lower weed growth and higher grain yield of maize in comparison to other treatments. The results showed that tembotrione at 0.088 kg/ha (PoE) in combination with PSM at 9.00 t/ha can be applied in maize for getting higher productivity, as this combination helps to reduce 20% dose of herbicide.

Maize (*Zea mays* L.) is adapted to diverse climatic conditions prevailing from tropical to temperate regions in India. The most suitable temperature for its maximum productivity is 20-27ºC although it can be grown at low temperature of 10ºC in a frost-free season. There is a lot of scope to increase the yield level due to its wider soil and climatic adaptability. Weed infestation is one of major factors that leads to reduction in maize yield due to wider row spacing and co-incidence of crop with rainy season, favouring severe crop-weed competition (Oerke and Dehne 2004). The infestation of weeds like *Acrachne racemosa, Brachiaria reptans* and *Commelina benghalensis* etc. are increasing day by day in maize growing belt of Punjab (Kaur *et al.* 2016).

Control of grasses, broad-leaved weeds (BLWs) and sedges remains a problem for the farmers, especially when too high or too low soil moisture hinders the intercultural operations along with the scarcity of labour during critical stages of weeding (Swetha *et al.* 2015). Moreover, manual weeding is time-consuming and cost-prohibitive. In absence of manual weeding, framers in irrigated areas rely on pre-emergence (PE) herbicides for controlling weeds (Rana *et al.* 2017) although it becomes ineffective many a times due to different constraints at farm level. Under these situations, the post-emergence (PoE) herbicides at about 40-45 days after sowing (DAS) appear to be an alternate option for minimizing the weed pressure at later period of crop growth (Kumar and Angadi 2014). But continuous and injudicious use of any herbicide may cause shift in weed flora, resistance in weeds and environment pollution. Rotational use of PE and PoE herbicides at temporal variation may help in avoiding these problems (Sahoo *et al.* 2016). In addition, different non-chemical measures like mulching can be explored since mulches exert positive effect on moisture, heat and air regime in the soil, thereby restricting moisture evaporation and weed growth (Choudhary and Kumar 2014). Mulching may also influence the effectiveness of herbicide use. In this view, the present study was carried out to study the combined efficacy of mulching and herbicide use toward weed management for improving growth and yield of maize.

The field experiments were conducted simultaneously at Punjab Agricultural University Ludhiana, and Regional Research Station, Gurdaspur in Punjab during *Kharif* season of 2017. The soil of two experimental sites at Ludhiana and Gurdaspur were of different textures (loamy sand and sandy loam) with pH values of 7.5 and7.4, and varying contents of available N (138.1 and 136.6kg/ha), available P (17.2 and 18.9kg/ha) and available K (179.1and 195.3 kg/ha), respectively. Three levels of mulching *viz*. no mulch, rice straw mulch (PSM) 6.25 and 9.00t/ha, and six different weed management treatments, *viz*. atrazine (Atrataf 50 WP) at 1.0 kg/ha (PE at 1 DAS), atrazine at 0.8 kg/ha (PE at 1 DAS), tembotrione at 0.110 kg/ha (PoE at 20 DAS), tembotrione at 0.088 kg/ha (PoE at 20 DAS), weed free and unweeded check were assigned in a factorial randomized block design with three replications at both the sites. As per treatment schedule, PSM was applied in between the lines immediately after the emergence of crop seedlings. The herbicides were also applied as per treatments with knap-sack sprayer fitted with flat-fan nozzle using spray volume of 500 and 375 L/ha for PE and PoE herbicides, respectively. Pre-sowing irrigation was applied to ensure adequate soil moisture at the time of sowing. At an optimum soil moisture condition, the field was prepared by giving two cultivations with tractor drawn cultivators, followed by (*fb*) planking. Maize variety '*PMH 1*' was sown by dibbling at the seed rate of 20 kg/ha and spacing of 60 × 20 cm on June 22 and June 06, 2017 at Ludhiana and Gurdaspur, respectively.The crop was fertilized with 125-60-30 kg N-P_2O_5- K_2O/ha, applying P_2O_5 and K_2O as basal and N in three splits (one-third basal, one-third at knee-high stage, and one-third nitrogen at pre-tasselling stage). First irrigation was given at 32 DAS, *fb* another one (Gurdaspur) to two irrigations (Ludhiana) in accordance with the crop requirement and rainfall receipt.

Floristic composition of weeds was recorded in unweeded check plots. The species-wise count of predominant weeds at 40 DAS was recorded by randomly placing the quadrate of 50 ×50 cm at two places, and the weed density was reported as number/m^2. For dry matter accumulation (DMA), the samples of all the species of different weed categories from two randomly selected spots in the quadrate of 50 ×50 cm were cut at the ground level at 40 DAS, and then dried in hot air oven at 60±2ºC till the constant weight was obtained. The DMA of weeds was expressed in g/m^2. Maize plants were harvested from each net plot area (13.2 m^2) on September 29 and 15, 2017 at Ludhiana and Gurdaspur, respectively. The produce was kept in the field for sun-drying for 15 days and shelled with maize thresher, and the grain yield was adjusted to 15% moisture. Grain and stover yields along with yield attributes were recorded at harvest. Data on weed density and DMA were subjected to square root transformation $(\sqrt{x+1})$ before statistical analysis. All the data were statistically analyzed using the SAS Proc GLM (SAS 9.3). The treatment comparisons were made at 5% level of significance by using Duncan's Multiple Range Test.

Weed flora

The experimental plots at Ludhiana were infested with *Cyperus rotundus, C. compressus* (sedges), *Dactyloctenium aegyptium, Eleusine indica, Commelina benghalensis, Eragrostis tenella, Digitaria sanguinalis, Acrachne racemosa*, *Echinochloa colona* (grasses), *Trianthema portulacastrum, Portulaca oleracea, Digera arvensis* and *Mollugo nudicaulis* (BLWs) whereas Gurdaspur site had *C. rotundus* (sedge), *D. aegyptium, E. indica, C. benghalensis, Cynodon dactylon* (grasses), *T. portulacastrum, D. arvensis, Euphorbia hirta, Alternanthera philoxeroides, Phyllanthus niruri, Amaranthus viridis, Veronica agrestis* and *Conyza stricta* (BLWs).The weed species *Eragrostis tenella* and *Digitaria sanguinalis* were only observed at Ludhiana site.

Effect of density of predominant weeds

Among different weed species, there were three most dominant weeds *viz. Cyperus rotundus* (sedge), *Dactyloctenium aegyptium* (grass) and *Trianthema portulacastrum* (BLW) as recorded in accordance with the density at both the sites of experimentation.

***Cyperus rotundus*:** There was a significant effect on interaction between mulching and weed management treatments on the density of *C. rotundus* at both the sites (**Figure 1a-1b**). Application of PSM 6.25 and 9.00 t/ha resulted in significantly lower density (no./m^2) of *C. rotundus* (27 and 23 at Ludhiana, 146 and 82 at Gurdaspur, respectively) in comparison to no mulch (62 at Ludhiana and 196 at Gurdaspur), irrespective of weed management treatments. The lowest density of *C. rotundus* was recorded under weed free treatment (0 at both sites), whereas it was the highest under unweeded check (112 at Ludhiana and 305 at Gurdaspur) as compared to all other weed management treatments, irrespective of mulching treatments. Among the herbicide treatments, the lowest density of *C. rotundus* was observed under tembotrione at either of the doses (0.088 and 0.110 kg/ha) in combination with PSM 9.00 t/ha (7 and 3 at Ludhiana, 54 and 53 at Gurdaspur, respectively), and both the combinations were significantly better than the others at both the sites. Next in order were tembotrione at both the doses, applied in combination with PSM 6.25 t/ha (8 and 8 at Ludhiana, 103 and 105 at Gurdaspur), and atrazine 1.0 kg/ha in combination with PSM at 9.00 t/ha (10 at Ludhiana and 97 at Gurdaspur) for lowering the density of *C. rotundus*. At both the sites, it was observed that significantly less density of *C. rotundus* was recorded under atrazine at lower dose of 0.8 kg/ha in combination with PSM 9.00 t/ha in comparison to its higher dose without mulch. Similarly, tembotrione 0.088 kg/ha in combination with PSM 6.25 t/ha recorded significantly less density of *C. rotundus* as compared to tembotrione at 0.110 kg/ha without mulch at both the sites, thus indicating the advantage of PSM to control *C. rotundus*. Significantly higher density of *C. rotundus* was observed in unweeded check under no mulch treatment as compared to all other treatment combinations. Under no mulch treatment, the lowest density of *C. rotundus* was recorded under weed free treatment (0 and 0), *fb* tembotrione 0.110 kg/ha (17 and 133), tembotrione 0.088 kg/ha (20 and 134), atrazine 1.0 kg/ha (59 and 233), atrazine 0.8 kg/ha (92 and 253) and unweeded check(183 and 425) at Ludhiana and Gurdaspur, respectively. Pandey *et al*.(2001) also reported *C. rotundus* as the most dominant weed in maize fields.

Dactyloctenium aegyptium: At Ludhiana and Gurdaspur, the lowest density of *D. aegyptium* was recorded under weed free treatment and the highest under unweeded check as compared to all other weed management treatments, irrespective of mulching practices (**Figure 1c-1d**). Use of PSM 9.00 and 6.25 t/ha resulted in significantly lower density (no./m^2) of *D. aegyptium* (2 and 6 at Ludhiana, 1 and 3 at Gurdaspur, respectively)as compared to no mulching (31 at Ludhiana and 8 at Gurdaspur), irrespective of weed management treatments. Among the herbicide-mulch combinations, significantly lower density of *D. aegyptium* was recorded with both the doses of tembotrione in combination with PSM 9.00 t/ha(0 at both sites), and both the combinations were significantly better in comparison to the others. The data further revealed that atrazine at lower dose (0.8 kg/ha) in combination with PSM (either 6.25 or 9.00 t/ha)recorded significantly lower density of *D. aegyptium* than that obtained under higher dose (1.0 kg/ha) of the same herbicide applied without mulching. Sole use of PSM 9.00 t/ha without any herbicide application (unweeded check) resulted in significantly lower density of *D. aegyptium* (7 at Ludhiana and 3 at Gurdaspur) as obtained under atrazine at 1.0 kg/ha without mulch (33 at Ludhiana and 4 at Gurdaspur). In case of no mulch treatment, both tembotrione and atrazineat lower doses recorded comparatively more density of *D. aegyptium* (9, 49 at Ludhiana and 2, 7 at Gurdaspur, respectively) than their respective higher doses(6, 33 at Ludhiana and 1, 4 at Gurdaspur, respectively). The present study confirmed the findings of Yadav *et al.* (2018) who also observed that post-emergence application of tembotrione 120 g/ha along with surfactant (1000 ml/ha) was most effective against *D. aegyptium* as compared to atrazine 1.0 kg/ha and unweeded check. However, both the herbicides in combination with PSM 6.25 t/harecorded significantly lower density of *D. aegyptium* than their respective higher doses under no mulching. Thus, the results showed that tembotrione could be applied at either of the doses in combination with PSM 9.00 t/ha for minimizing the density of *D. aegyptium* in maize.

Trianthema portulacastrum: The interaction effect was significant with respect to the density of *T. portulacastrum* (**Figure 1e-1f**). At Ludhiana, use ofPSM (6.25 and 9.00t/ha) was found to significantly lower the density(no./m^2)of *T. portulacastrum* (0.5 and 0.4 at Ludhiana, 0.2 and 0 at Gurdaspur, respectively) as compared to no mulch treatment (5 at Ludhiana and 2 at Gurdaspur), irrespective of weed management treatments. The weed was effectively controlled under both the herbicides at both the doses, as well as weed free treatment, when imposed in combination with PSM (either 6.25 or 9.00 t/ha). All of these treatment combinations were significantly superior to the others. Use of atrazine at lower dose in combination with PSM 6.25 t/ha and sole application of PSM 9.00 t/ha without any herbicide (unweeded check) recorded statistically similar density of *T. portulacastrum* as obtained under atrazine at higher dose without mulching. Tembotrione at lower dose in combination with PSM 6.25 t/ha recorded significantly less weed density as compared to its higher dose without mulching. The highest density of *T. portulacastrum* was recorded in unweeded check under no mulch treatment. However, at Gurdaspur, all the combinations of straw mulching and weed management treatments effectively controlled the density of *T. portulacastrum*, excepting the application of atrazine at both doses without mulch and unweeded check under no mulch and PSM (6.25 t/ha) treatments. Significantly higher density of *T. portulacastrum* was observed in unweeded check under no mulch treatment as compared to all other treatment combinations. Saeed *et al.* (2010) reported that *T. portulacastrum*, being a strong competitor of maize, caused substantial yield losses depending upon the intensity of infestation.

Effect on dry matter accumulation of weeds

The interaction effect between mulching and weed management treatments was significant with

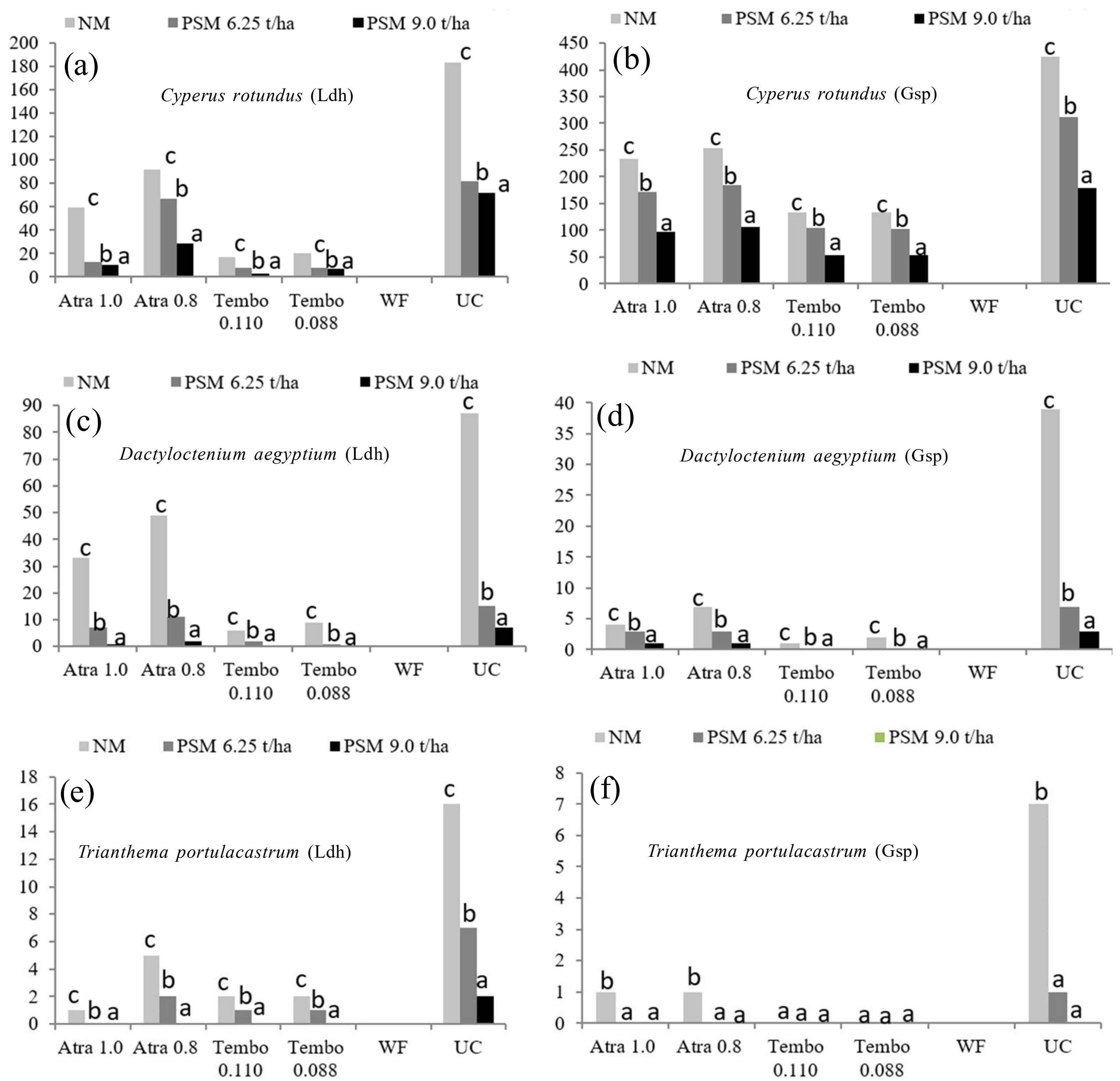

Figure 1(a-f). Density (no./m²) of different predominant weed species at 40 DAS as influenced by mulching and weed management treatments (Graphs with letters on bars represent the significant level of interaction. Different letters on grouped bars for each weed management treatment indicate significant difference between two bars. All herbicide doses are in kg/ha. Ldh, Ludhiana; Gsp, Gurdaspur; Atra, atrazine; Tembo, tembotrione; WF, Weed free; UC, Unweeded check)

respect to total DMA of weeds at Ludhiana and Gurdaspur **(Figure 2a-2b)**. Use of PSM at 9.00t/ha produced significantly lower DMA of weeds as compared to PSM 6.25 t/ha and no mulch treatments, irrespective of weed management treatments at both the sites. This showed the beneficial effect of PSM in controlling total weed biomasssince mulches did not provide necessary conditions for weed seed germination as well as weed growth (Patel *et al.* 2019). In case of weed management treatments, total weed DMA was the highestunder unweeded check, whereas it was the lowest under weed free, irrespective of mulching. Among the herbicide treatments, significantly lower value of total weed DMA was obtained under both the doses of tembotrione (0.088 and 0.110 kg/ha) as compared to atrazine (1.0 and 0.8 kg/ha), irrespective of mulching treatments. The results of present study are in consonance with the findings of Yadav *et al.* (2018) and Rana *et al.* (2017) who also observed that DMA of weeds in maize was significantly reduced with the application of tembotrione. Use of tembotrione (either

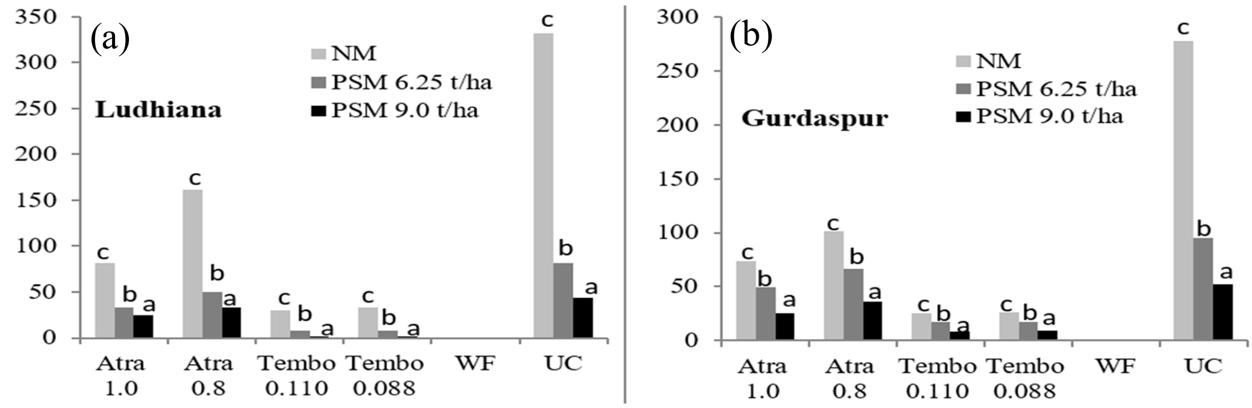

Figure2(a-b). Weed dry matter accumulation (g/m^2) at 40 DAS as influenced by mulching and weed management treatments. (Graphs with letters on bars represent the level of significant interaction. Different letters on grouped bars for each weed management treatment indicate significant difference between two bars. All herbicide doses are in kg/ha)

0.088or 0.110 kg/ha)in combination with PSM 9.00 t/ha recorded significantly lower DMA of total weeds than all other combinations. Next in order were the combinations of tembotrione (either 0.088 or 0.110 kg/ha)with PSM 6.25 t/ha. Tembotrione at lower dosein combination with PSM 6.25 t/haresulted in significantly lower total weed DMA than tembotrione applied at 0.110 kg/ha without mulching. Moreover, tembotrione at lower dose of 0.088 kg/ha in combination with PSM 9.00 t/ha was more effective than the same herbicide at either of its doses in combination with PSM 6.25 t/ha. Atrazine at lower dose in combination with PSM 6.25 t/ha recorded comparatively lower total weed DMA than the sole application of the same herbicide at higher dose without mulching. These findings indicated that PSM helped to reduce the dose of both the herbicides by 20%. Reduction in herbicide dose through PSM application was due to their physical presence on the soil surface that acted as barrier for light penetration required for weed seed germination, ultimately less weed population was observed that required less volume of water as well as herbicide use. Chauhan and Abugho (2013) also reported that combined use of mulch and herbicide can help in better management of weedsand maximizing the grain yield.

Yield and yield attributes

Grain yield, stover yield, no. of rows/cob, no. of grains/cob and 1,000-grain weight varied significant due to mulching practices (**Table 1**). Among the mulching treatments, PSM at 9.00 t/ha produced significantly higher maize grain yield in comparison to PSM 6.25 t/ha and no mulching. There were previous reports of significantly higher grain yield under mulching as compared to no mulch (Dutta *et al.* 2016, Uwah and Iwo 2011, Shah *et al.* 2014). Straw mulch significantly enhanced the grain yield by 14.4% as observed by Bahar (2013). Use of PSM at 6.25 and 9.00 t/ha significantly enhanced the grain yield by an average of 11.4% and 19.9% in comparison to no mulching, respectively, as also reflected similarly on different yield attributes (no. of rows/cob, no. of grains/cob, and 1000-grain weight) and stover yield. Enhanced stover yield under straw mulched treatments might be attributed to better soil surface conditions which were conductive for better crop growth. The lowest level of grain and stover yield along with yield attributes were recorded under no mulching at both the sites. The use of mulches possibly helped in better root growth that helped in better crop nutrition and higher productivity, compared with no mulching.

Weed management treatments significantly influenced the yield and yield attributes of maize at both the sites (**Table 1**). Weed free treatment produced maximum grain yield, which was statistically at par with tembotrione (0.088 and 0.110 kg/ha) and significantly superior to atrazine (0.8 and1.0 kg/ha) and unweeded check. Yadav *et al.* (2018), Rana *et al.* (2017) and Swetha*et al.* (2015) also reported higher grain yield with the application of tembotrione. Even the grain yield was significantly more in atrazine treatments than unweeded check, which was in consonance with the findings of Barla *et al.* (2016), Gul *et al.* (2016) and Mavunganidze *et al.* (2014). Higher values of yield attributes (no. of rows/cob, no. of grains/cob, and 1000-grain weight) along with grain and stover yields were also recorded under weed free treatment as well as both the doses of tembotrione in comparison to atrazine and unweeded check. Higher crop productivity under weed free and tembotrione was attributed to better weed control efficiency as well as improved crop

Table1. Yield and yield attributes as influenced by mulching and weed management treatments

Treatment	No. of rows/cob		No. of grains/cob		1,000-grain weight (g)		Grain yield (t/ha)		Stover yield (t/ha)	
	Ldh*	Gsp**	Ldh*	Gsp**	Ldh*	Gsp**	Ldh*	Gsp**	Ldh*	Gsp**
Mulching										
No mulch	13.3c	13.1c	408.8c	404.1c	263.8c	253.6c	5.31c	4.82c	11.25c	11.44c
PSM 6.25 t/ha	14.2b	14.1b	428.6b	422.6b	276.4b	266.6b	5.81b	5.46b	12.77b	13.07b
PSM 9.00 t/ha	14.5a	14.4a	441.4a	436.3a	282.2a	272.1a	6.22a	5.91a	13.85a	14.09a
Weed management										
Atrazine 1.0 kg/ha (PE)	14.0b	13.8b	420.0b	415.5b	273.6b	263.3b	5.62b	5.27b	12.69b	12.95b
Atrazine 0.8 kg/ha (PE)	13.5c	13.4c	409.8c	404.3c	268.7c	257.7c	5.33c	4.89c	11.78c	12.09c
Tembotrione 0.110 kg/ha (PoE)	14.6a	14.5a	445.1a	440.3a	279.4a	270.2a	6.24a	5.92a	13.69a	13.74a
Tembotrione 0.088 kg/ha (PoE)	14.4a	14.3a	443.9a	438.0a	278.9a	269.3a	6.23a	5.86a	13.61a	13.71a
Weed free	14.5a	14.4a	445.9a	440.9a	280.6a	271.4a	6.32a	5.97a	13.77a	13.89a
Unweeded check	12.9d	12.8d	393.0d	387.0d	263.7d	252.7d	4.94d	4.48d	10.22d	10.51d

In a column, means followed by same letter do not vary significantly at 5% level by DMRT. * Ludhiana **Gurdaspur

growth as compared to other treatments. Application of atrazine at higher dose also recorded significantly higher yield and yield attributes in comparison to the same herbicide at lower dose and unweeded check. Similar results with atrazine were reported earlier by Sahoo *et al.* (2016) and Gul *et al.* (2016).The lowest level of yield and yield attributes were recorded in unweeded check at both the sites.

Relationship between grain yield and weed growth (weed data at 40 DAS)

The combination of mulching and herbicide treatments not only helped in reducing the weed pressure and increasing crop productivity, it also helped in reducing the dose requirement for herbicide use. Kumar and Angadi (2014) reported that the combined effect of mulching and atrazine application helped in improving the no. of rows/cob, no. of grains/cob and grain yield in maize as compared to unweeded check. At both the sites, the grain yield of maize displayed a negative linear relationship with weed density and DMA with respect to straw mulch and weed management treatments (**Figure 3-4**). Rana *et al.*(2017) reported that the grain yield of maize was negatively correlated with DMA of weeds.

In case of straw mulching, the weed density at 40 DAS was responsible for 96.6 to 99.5% variation in grain yield, whereas in case of weed management treatments it was responsible for 91.3 to 94.1% variation in grain yield. However, weed dry matter accumulation at 40 DAS was responsible for 95.8 to 97.6% variation in grain yield under straw mulching treatments, whereas it was responsible for 87.6 to 88.5% variation in grain yield under weed management treatments.

It was concluded that use of rice straw mulch 9.00 t/ha was more effective in terms of reducing the weed density and increasing the grain yield compared with no mulching. Application of tembotrione at 0.088 and 0.110 kg/ha (PoE) was superior to atrazine 0.8 and 1.0 kg/ha (PE)in reducing of density of different weed species and weed DMA. Tembotrione (0.088 or 0.110 kg/ha) in combination with PSM at 9.00t/ha was found to be the best combination for lowering the weed growth and increasing grain yield. Hence forgetting higher productivity, tembotrione at 0.088 kg/ha (PoE) in combination with PSM at 9.00 t/ha can be applied in maize, as this combination helps to reduce 20% dose of herbicide.

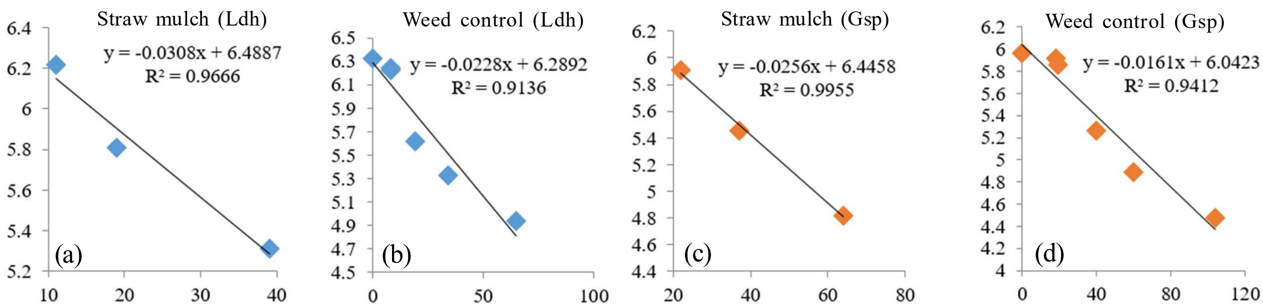

Figure 3(a-d). Relationship between grain yield (t/ha at y-axis)and weed density (no./m² at x-axis) in maize. The lines represent a linear model of regression.

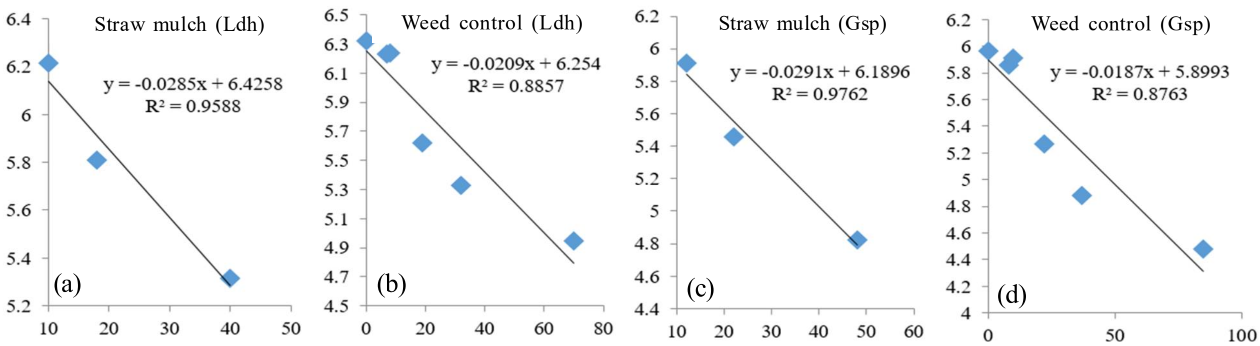

Figure 4(a-d). Relationship between grain yield (t/haat y-axis)andweed dry matter (g/m^{2}at x-axis)in maize. The lines represent a linear model of regression

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On-farm assessment of conservation tillage for wheat planting in rice-wheat cropping system

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ABSTRACT

A farmer's participatory field experiment was conducted during two consecutive *Rabi* seasons of 2015-16 and 2016-17 at farmer's fields in Badkisarari village of Gwalior district of Madhya Pradesh on clay loam soils to validate zero-till sowing of wheat crop in rice-wheat cropping system for realizing higher yield. Zero till sown wheat had significantly lesser weed dry biomass per unit area as compared to wheat sown in conventional and reduced tillage besides advancement of sowing by 20-25 days over conventional and reduced tillage sowing of wheat crop. The population of *Phalaris minor, Avena ludoviciana, Avena fatua, Chenopodium album, Melilotus indica* and *Anagallis arvensis* was reduced significantly under zero tillage as compared to conventional tillage. Excellent suppression in weed density and weed dry weight with higher levels of weed control efficiency and yield were obtained with zero till sown wheat. Zero tillage was also found better in terms of lesser cost of cultivation, higher net returns and B:C ratio.

Rice–wheat is the world's largest agricultural production system occupying around 12.3 Million ha in India (Bhatt *et al*. 2016). Wheat (*Triticum aestivum* L.) crop is grown in 5.91 and 1.36 m ha area in state of Madhya Pradesh and Gwalior district, respectively during the year 2015-16 with the average productivity of 3.11 and 3.78 t/ha, respectively in the state of Madhya Pradesh and Gwalior district (Anonymous 2015-16). Wheat is grown in rotation with rice on 40 and 60% area in the country and Gwalior district, respectively during the year 2015-16. It was observed in the participatory rural appraisal survey of the village Badkisarai in Harsi command area of the Gwalior district that very less switch over time is left to the farmers for subsequent sowing of wheat after rice harvest at the recommended time. Due to this reason sowing of wheat crop was delayed by at least 20-25 days. The delayed sowing was observed as big stumbling block in realizing the yield potential of newer varieties of wheat despite a seed replacement rate of above 40% among the farmers in the villages.

Farmers were realizing the consequences of late planting of wheat in terms of less tillering and forced maturity in crop due to increased terminal atmospheric temperature. Delay in time of sowing in the rice-wheat cropping system is perhaps one of the major factors responsible for low crop yield (Kasana *et al*. 2015).

Invasion of wheat crop with weeds like *Phalaris minor*, *Avena ludoviciana* and *Avena fatua* were also reported by the farmers during the pre-adoption participatory survey of the village beside the increased cost of cultivation and reduced yield of the subsequent wheat crop in rice- wheat system. When land is cultivated to raise crops, weeds spring-up naturally along with the crop plants. Weeds represent one of the greatest limiting factors to efficient crop production (Kasana *et al.* 2018).Zero till seed drill machine is able to sow the wheat crop after the harvest of transplanted rice in standing rice stubbles. The reduction in wheat yield due to delay in sowing has been recorded as one per cent of total yield/ha/day (Pal *et al.* 1996). Zero tillage has an advantage of early planting, reduced cost of production as well as chances of green-house gas emission (Hobbs 2002). It has been established in various field experiments under climate resilient technology development research projects in Indo-Ganagetic plains (IGP) that zero tillage technique not only overcomes the problem of delayed planting of wheat, but also reduced the infestation of weeds like *Phalaris minor*, *Avena ludoviciana* and *Avena fatua*. Keeping in view above eventualities of rice-wheat system the present investigation was planned to assess the performance and profitability of zero till wheat sowing technique in clay loam soils atfarmer's fields in the adopted village *Badkisarai* under *Bhitarwar* block of district Gwalior.

Farmers' participatory on-farm trials (OFTs) were conducted for two consecutive years during *Rabi* seasons 2015-16 and 2016-17 at farmer's fields of village Badkisarai in Bhitarwar block of Gwalior district to validate zero till sowing of wheat crop in rice-wheat system for timely sowing of wheat in realizing higher yield. Ten on-farm trials were conducted during each season at randomly selected farmer's fields in Badkisarai village under Harsi canal command area in Gwalior district of Madhya Pradesh.

The soil of the farmer's fields was clay loam in texture with low organic carbon (0.3-0.8%) and available nitrogen (N, 201-242 kg/ha), medium in available phosphorous (P, 15.5-18.6 kg/ha) and available potassium (K, 180-240 kg/ha) with pH 8.2-8.6. The experiments were laid out in a randomized block design comprising three planting methods of wheat after rice harvest *viz.* conventional tillage, reduced tillage and zero tillage on 10 farmers' fields considering each field as separate replication. Wheat variety '*MP4010*' was sown during last week of November and first week of December during the year 2015-16 and 2016-17 in zero tillage and during last week of December and first week of January in conventional tillage practice which include burning of rice residues 8-10 days after its harvesting followed by pre-sowing irrigation and 3-4 cultivations after getting workable field conditions in 20-25 days after application of pre sowing irrigation during both the year. The wheat crop was sown in rows, 20 cm apart, while wheat crop was sown after one follow up cultivation after rice harvest followed by pre sowing irrigation, and one cultivation under reduced tillage treatment. The zero tillage (ZT) treatment consisted of direct drilling of wheat seed (100 kg/ha) with di- ammonium phosphate (125 kg/ha), urea (80 kg/ha) and mureate of potash (66 kg/ha) by using zero till seed–cum-ferti drill without any pre-sowing tillage operation in presence of sufficient moisture condition after rice harvest in anchored residues. The remaining dose of nitrogen was applied through two equal doses of urea (65 kg/ha each) in split application after first and second irrigation at the appropriate moisture level in fields. The reduced tillage (RT) consisting of burning of crop residues *fb* pre-sowing irrigation due to loss of residual moisture after burning of rice crop residues 8-10 days after its harvesting and 2 ploughings with simultaneous planking operation before sowing. While the conventional tillage (CT); the farmers practice (FP) consisted of burning of rice crop residues 8-10 days after its harvest *fb* one pre-sowing irrigation *fb* 3-4 ploughings with planking and sowing with conventional seed cum ferti-drill. Uniform dose of nutrients was applied in all the tillage treatments. The ZT and RT sowing were carried out in advance by 25-30 and 2-5 days, respectively as compared to CT/FP on the farmer's fields. The crop was grown with all other similar package of practices under all the planting methods.

The population and above ground weed dry weight was also recorded at 60 DAS by using a quadrate of 0.5 x 0.5 m for major grassy weeds and broad-leaved weeds. Standard methods were followed for weed, crop and economical analysis. The data collected were analyzed statistically using MS Excel Analysis Tool Pack-two factors without replication and LSD test was applied at 5% probability level to compare treatment means.

In economical analysis, the cost of cultivation was worked out taking into account the prevailing lobour and field operation charges in the locality, cost of inputs and the extra treatment costs in ₹/ha. The gross returns was calculated on the local market prices of wheat and its straw and expressed on per hectare basis.

Effect on weed

The farmer's fields in Harsi canal command area under rice-wheat cropping system were profoundly infested with grassy weeds, *viz. Phalaris minor*, *Avena ludoviciana* and *Avena fatua* beside broad-leaved weeds mainly *Chenopodium album, Chenopodium murale, Anagallis arvensis, Melilotus alba* and *Rumex dentatus* under wheat crop sown in conventional tillage (FP) and reduced tillage. On the other hand zero till sowing resulted in very effective suppression of narrow-leaved weeds with a fewer number of BLWs, *viz. Chenopodium album, Chenopodium murale, Anagallis arvensis, Melilotus alba* and *Rumex dentatus*. Zero till planting of wheat gave significantly lower weed density and weed dry weight for narrow-leaved weeds (NLWs) during both the years over farmers practice (CT) which gave 85.8 and 89.2% control efficiencies for NLWs in the year 2015-16 and 2016-17, respectively at 60 DAS **(Table 1)**. The similar trends were also observed by Sinha and Singh (2005), Prasad *et al.* (2005) and Radhey Shyam *et al.* (2014). The control efficiencies for NLWs under zero till planting method were statistically superior to the rest of the two planting methods used for wheat in rice-wheat system. Singh (2014) also reported better control of narrow-leaved weeds in ZT planting of wheat in rice-wheat cropping system. The poor performance of CT in managing the NLWs in rice–wheat system might be due to movement of weed seeds from lower layers to upper layer (0-5 cm) of the soil by excessive tillage operations. These seeds got the opportunity to germinate under favorable micro ecological conditions under CT planting of wheat crop.

The planting methods could not produce any significant difference with respect to dry weight of broad-leaved weeds however these were observed in fewer numbers at different locations **(Table 1)**. Statistically, significant difference was observed for the density of BLWs under different planting methods. Significantly lower broad-leaved weeds density was recorded under ZT and RT as compared to CT during both the years.

Effect on crop

Wheat sown under ZT recorded significantly higher number of effective tillers/m^2 and test weight over reduced and conventional tillage systems during both the years **(Table 2)**. Significantly higher values for the test weight of wheat seed under ZT planting could be ascribed to higher accumulation of photosynthates in seed due to congenial ambient temperature, the crop received during maturity under ZT due to advanced planting. Higher dry matter accumulation was also reported by Jat *et al.* (2013) under ZT planting in wheat after mungbean. Further, lesser competition received by the crop from NLWs for growth resources under ZT planting of wheat over the rest of the two planting methods which had an added advantage for enhanced growth and development of the crop. The higher values for the yield attributes, *viz*. effective tillers and test weight, might be transformed into significantly higher grain yield under ZT over RT and CT. The ZT produced 5.74 and 4.81 t/ha grain yield of wheat in 2015-16 and 2016-17, respectively which was 15.31 and 11.86% higher over CT. The present findings corroborated the results obtained by Singh (2014) and Radhey Shyam *et al.* (2014).

Economics

The maximum net returns and benefit: cost ratio was observed for ZT during both the years, followed by the RT **(Table 3)**. The lowest net returns (₹ 52449 and ₹ 47377/ha) and B: C (3.35 and 3.00), during 2015-16 and 2016-17, respectively, were recorded under conventional tillage. The highest values of the economical parameter could be attributed by higher grain yield and reduced cost of cultivation under ZT and RT as compared to CT. Similar findings were reported by Bhatt *et al*. (2016) in conservation agricultural practices.

Table 1. Effect of tillage practices on weeds in wheat crop at farmers' field

Treatment	Weed density NLWs (no./m^2)		Weed dry weight NLWs (g/m^2)		Weed control efficiency -NLWs (%) at 60 DAS		Weed density BLWs (no./m^2)		Weed dry weight BLWs(g/m^2)		Weed control efficiency- BLWs (%) at 60 DAS	
	2015-16	2016-17	2015-16	2016-17	2015-16	2016-17	2015-16	2016-17	2015-16	2016-17	2015-16	2016-17
Zero tillage (ZT)	24.6	14.8	22.6	20.6	86.18	90.30	17.65	19.04	29.22	28.43	1.65	6.93
Reduced tillage	132.6	120.5	102.6	96.5	25.64	21.00	19.60	19.63	29.94	29.90	-0.75	2.33
Farmers practice (CT)	178.6	152.6	116.4	112.6	0.00	0.00	21.85	19.07	29.72	30.14	0.00	0.00
LSD (p=0.05)	5.4	2.5	108.1	97.0	2.33	1.51	0.55	0.58	NS	NS	-	-

NLWs- Narrow-leaved weeds; BLWs- Broad-leaved weeds, DAS- Days after sowing

Table 2. Effect of tillage practices on yield attributes and yields of wheat crop at farmers' field Add straw yield, and some more yield attributes like number of grains/spike, spike length

Treatment	Effective tillers (no./m^2)		Test weight (g)		No. of grains/spike		Spike length (cm)		Grain yield (t/ha)		Straw yield (t/ha)	
	2015-16	2016-17	2015-16	2016-17	2015-16	2016-17	2015-16	2016-17	2015-16	2016-17	2015-16	2016-17
Zero tillage (ZT)	408	395	42.2	40.8	48.88	45.35	9.65	9.0	5.74	4.81	6.89	5.82
Reduced tillage (RT)	390	382	41.5	38.6	45.18	42.87	9.20	8.40	5.15	4.45	6.35	5.43
Farmers practice (CT)	326	308	38.5	37.4	41.18	40.47	8.20	7.80	4.86	4.24	6.13	5.35
LSD (p=0.05)	6	4	0.9	1.2	1.7	1.8	1.0	0.5	0.17	0.16	0.2	0.2

Table 3. Economics of different tillage practices in wheat crop at farmers' field

Treatment	Gross cost of cultivation (x10^3 ₹/ha)		Gross returns (x10^3 ₹/ha)		Net returns (x10^3 ₹/ha)		B:C ratio	
	2015-16	2016-17	205-16	2016-17	2015-16	2016-17	2015-16	2016-17
Zero tillage (ZT)	18.35	19.65	87.81	80.00	69.46	60.35	4.79	4.07
Reduced tillage	19.95	20.53	79.04	74.04	59.09	53.51	3.96	3.61
Farmers practice (CT)	22.35	23.65	74.80	71.03	52.45	47.38	3.35	3.00

Sale price of wheat during 2015-16 (₹ 13500/t) and 2016-17 (₹ 14500/t) and for straw 2015-16 (₹ 1500/t) and 2016-17 (₹ 1750/t). Total cost of cultivation was calculated on the basis of prevailing prices of Inputs used.

On the basis of two year farmers led field experimentation, it was concluded that ZT wheat sowing was found much effective in suppression of weed density and weed dry weight of narrow-leaved weeds, *viz*. *Phalaris minor*, *Avena ludoviciana* and *Avena fatua* in comparison to CT which was also observed significantly lower over reduced till sowing of wheat crop. However, differences among planting methods with respect to weed density of broad-leaved weeds were not observed statistically significant. The significantly higher grain yield of wheat and higher monitory returns were also achieved under ZT during both the year over the rest of the planting methods.

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Integrated weed management in altered crop geometry of irrigated maize and residual effects on succeeding Bengal gram

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ABSTRACT

A field experiment was carried out at Tamil Nadu Agricultural University, Coimbatore during *Kharif* and *Rabi* seasons of 2018-19 to study the effect of altered crop geometry without changing the total plant population with integrated weed management methods in irrigated maize (*Zea mays* L.) and their residual effects on succeeding Bengal gram (*Cicer arietinum*). Based on the results, it could be ascertained that planting pattern of 60 x 25 cm proved to be effective in reducing weed biomass and recorded significantly higher grain yield of about 6.48 t/ha which was at par with the spacing of 75 x 20 cm. Pre-emergence (PE) application of atrazine at 1.0 kg/ha + hand weeding or twin wheel hoe weeding at 35 DAS was at par with hand weeding twice at 20 and 35 DAS with respect to grain yield. Herbicidal methods of weed management like 2, 4-D and atrazine application did not exert any residual effect on the succeeding Bengal gram.

Maize (*Zea mays* L.) is one of the important cereal crops in many developed and developing countries across the world. Maize occupies a predominant position in Indian agriculture, as it is the third most important crop after rice and wheat with respect to area and productivity. India accounts for about 25.89 million tonnes of maize production and productivity of 2.69 t/ha (indiastat.com 2016-17). Weeds are considered to be the major threat and cause 34% yield loss globally (Oerke 2006). Weeds compete for water, nutrients and light which results in reduction of crop productivity. The critical period of crop-weed competition for maize is 15 to 40 DAS and the per cent yield reduction ranges from 40 to 60%. Therefore, weed management is important for optimizing the grain yield.

Integrated weed management (IWM) is a multi-disciplinary approach that combines cultural, mechanical and chemical methods for controlling weeds in systemic manner and provides the significant advances in weed control technology (Verschwele *et al.* 2016).

While adopting mechanical methods as a component in IWM, plant damage is the major problem. Alteration in crop geometry may adopt as a strategy in order to reduce the plant damage percent. In the case of chemical method, the persistence of herbicides in the soil may cause adverse effects to succeeding crop growth and development (Shobha 2014). However, at present farmers are following two hand weeding at 20 and 35 DAS for controlling weeds but this practice demands higher labour, cost and consumes time. Moreover, scarcity of labour during peak periods also creates the necessity for the implementation of integrated weed management for weed suppression. Hence, the present study was conducted to evaluate the different integrated weed management methods under altered crop geometry in irrigated maize and the residual effect of herbicidal weed control on succeeding bengal gram.

The experiment was carried out in the field no. 36 E, Eastern Block, Department of Agronomy, Tamil Nadu Agricultural University, Coimbatore during *Kharif* and *Rabi,* 2018-19 to evaluate the different integrated weed management practices in irrigated maize under altered crop geometry and its residual effects on succeeding Bengal gram. The geographic co-ordinates of Coimbatore are 11° North latitude and 77° East longitude with an altitude of 427 m above the mean sea level. The soil is sandy clay loam with the medium level of available nitrogen (314 kg/ha), low in available phosphorus (6.02 kg/ha) and high in available potassium (489 kg/ha). The experiment was laid out in factorial randomized block design with the consideration of two factors - crop geometry and weed management treatments. The plot size of 24 m^2

(6 x 4 m) was taken for this experimental study. The treatment details with 2 replications of 3 levels of crop geometry and 8 levels of weed management methods were as follows, *viz.* crop geometry includes 60 x 25 cm (conventional), 75 x 20 cm, paired row method 90: 30 x 25 cm and weed management involves twin wheel hoe weeding at 20 and 35 DAS, power weeding at 20 and 35 DAS, atrazine at 1.0 kg/ha + twin wheel hoe weeding at 35 DAS, atrazine at 1.0 kg/ha + power weeding at 35 DAS, atrazine at 1.0 kg/ha + hand weeding at 35 DAS, fodder cowpea as live mulch + brown manuring with 2,4-D at 0.5 kg/ha on 35 DAS, two hand weeding at 20 and 35 DAS and unweeded check. TNAU maize hybrid CO 6 was sown and maintained with all general cultivation practices except for spacing and weed management methods. The observations recorded were weed density, weed biomass, yield attributes, yield of maize and their economic returns. Followed by maize, residue crop bengal gram '*JAKI 9218*' variety was sown and the observations recorded in bengal gram were germination, weed density, weed biomass and yield. Weed data were subjected to square root transformation ($\sqrt{x+0.5}$) for statistical analysis.

Weed flora

The dominant group of weeds found in the experimental field of maize were broad-leaved weeds (54.70%) followed by grassy weeds (43.63%) and sedges observed to be at lower proportion (1.67%). Among different weeds, the major weed species were present in the experimental site consisted of *Trianthema portulacastrum, Digera arvensis, Echinochloa colonum, Digitaria longiflora, Dactyloctenium aegyptium and Parthenium hysterophorus.*

Effect on weeds

Experimental results revealed that the wider spacing interval of crop rows observed to have higher weed density and weed growth rate. Maize with spacing 60 x 25 cm recorded lower weed density 3.54 no./m^2 and weed biomass 4.20 g/m^2 and it was found to be significantly higher. It was followed by the crop geometry 75 x 20 cm with the weed density 3.90 no./m^2 and weed biomass 4.69 g/m^2. Paired row method of planting recorded higher weed density 4.21 no./m^2 and also weed biomass of about 5.52 g/m^2. The results are in accordance with the findings of Sunitha *et al.* (2010) who had reported that narrow row spacing 60 cm had provided lesser space for weed emergence, which in turn reduced the light interception to the soil to induce the weed growth and development.

Among the different weed management practices, two hand weeding at 30 and 45 DAS and application of atrazine at 1.0 kg/ha as pre-emergence + one hand weeding at 35 DAS had recorded lower weed density and weed biomass. However, hand weeding at 30 and 45 DAS was significantly higher and recorded lower weed biomass 2.19 g/m^2 and it was statistically at par with PE atrazine at 1.0 kg/ha + one hand weeding at 35 DAS 2.60 g/m^2 and it was followed by PE atrazine application at 1.0 kg/ha + twin wheel hoe weeding at 35 DAS recorded the weed biomass of about 2.79 g/m^2, respectively. Similar results were earlier observed by Kandasamy (2017) who had concluded that the hand weeding twice resulted in effective weed control and also atrazine at 1.0 kg/ha + one hand weeding at 35 DAS would be better, thus atrazine inhibits the weed germination at initial period of crop growth and aids in weed free conditions for the critical period. The data on the effect of weed management methods under altered crop geometry at 60 DAS on weed density and weed biomass in irrigated maize are given in **Table 1**.

Interaction of conventional crop geometry with two hand weeding twice recorded lower weed density 2.78 no./m ^{2} and weed biomass 1.86 g/m^2 and it was found to be significantly higher. However, it was statistically at par with the weed management practice of application of atrazine at 1.0 kg/ha + hand weeding at 35 DAS and followed by atrazine application + twin wheel hoe weeding at 35 DAS. The results are in accordance with Hussein *et al.* (2008) findings that interaction of maize sown at 60 x 25 cm and weed management by integrating PE herbicide application followed by mechanical method had produced higher grain yield. This might be due to the optimum resource utilization by the crop and considerably reduced weed biomass at critical crop growth period.

Effect on weed control efficiency

Weed control efficiency (WCE) indicates the magnitude of reduction in weed biomass over weedy check by different weed control treatments. The efficiency of different integrated methods on weed control was worked out in terms of weed biomass in treated plot over control plot. At 60 DAS, hand weeding twice recorded higher WCE (93.82%) followed by PE atrazine application of 1.0 kg/ha + hand weeding on 35 DAS (90.95%). However, the difference between PE application atrazine at 1.0 kg/ha + hand weeding on 35 DAS and PE atrazine application of 1.0 kg/ha + twin wheel hoe weeding on 35 DAS (89.51%) was insignificant (**Table 2**). Mynavathi *et al.* (2015) who had observed the similar results that wheel hoe weeding had higher weed control efficiency (94.6% at 45 DAS) with increased maize grain yield to the significant level and concluded that wheel hoe weeding offered less time, less labour and cover maximum area with minimum cost of operation than hand weeding.

Weed control efficiency was highly influenced by the interaction of altered crop geometry and weed management methods as it exerted significant effect on weed biomass. It was observed that the paired row method of planting provides larger area for weed growth and while, for operating mechanical weeders, weeds in between the pairs are not effectively controlled which then leads to lowering of weed control efficiency when compared with 75 x 20 cm and 60 x 25 cm (conventional). Higher weed control efficiency was observed in narrow row spacing than wider ones. Crop row spacing 60 cm recorded lower weed biomass and effective control of weeds due to lesser space and resource availability for weed growth and decreased crop weed competition than 75 and 90 cm and this result is in accordance with the findings of Mahingaidze *et al.* (2009).

Effect on yield attributes

The yield components such as number of grains/cob and 100-grain weight were significantly influenced by altered crop geometry. Crop geometry of maize with 60 cm x 25 cm resulted in higher 100 grain weight and increased number of grains per cob which was on par with the crop geometry 75 x 20 cm (**Table 3**). Apparently, test weight and number of grains formed per cob was registered lower with paired row planting 90: 30 x 25 cm. The results were in confirmation with Peter *et al.* (2000) who reported that the effect of row spacing on yield components like number of grains formed and test weight of maize grains has significant effect and this might be due to effective growth resources availability and utilization by the crop which was present in the optimum plant arrangement with 60 cm row spacing.

Table 1. Effect of altered crop geometry and integrated weed management methods on total weed density and weed biomass of maize (60 DAS)

Treatment	Total weed density(no./m^2)				Total weed biomass(g/m^2)			
	C_1	C_2	C_3	Mean	C_1	C_2	C_3	Mean
Twin wheel hoe weeding at 20 and 35 DAS	3.91(14.8)	4.26(17.6)	4.72(19.7)	4.30(17.4)	5.18(26.7)	6.28(39.0)	6.62(43.3)	6.02(36.2)
Power weeding at 20 and 35 DAS	3.59(12.4)	4.15(16.7)	4.37(18.6)	4.04(15.9)	4.82(22.7)	5.59(30.8)	6.09(36.5)	5.50(30.0)
Atrazine at 1.0 kg/ha + twin wheel hoe weeding at 35 DAS	3.15(9.4)	3.53(11.9)	3.81(14.0)	3.50(11.8)	2.42(5.3)	2.66(6.6)	3.29(10.3)	3.22(7.4)
Atrazine at 1.0 kg/ha + power weeding at 35 DAS	3.49(11.7)	3.74(13.5)	3.97(15.3)	3.73(13.5)	3.28(10.3)	3.48(11.6)	3.89(14.7)	4.23(18.0)
Atrazine at 1.0 kg/ha + hand weeding at 35 DAS	2.94(8.1)	3.36(10.8)	3.63(12.7)	3.31(10.5)	2.08(3.8)	2.49(5.7)	3.05(8.8)	2.60(6.1)
Fodder cowpea as live mulch + brown manuring with 2,4-D at 0.5 kg/ha on 35 DAS	4.04(15.8)	4.09(16.2)	4.69(21.5)	4.27(17.8)	5.62(31.1)	5.83(33.5)	7.55(56.4)	6.33(40.3)
Two hand weeding at 20 and 35 DAS	2.78(7.2)	3.21(9.8)	3.38(10.9)	3.12(9.3)	1.86(3.0)	2.05(3.7)	2.65(6.6)	2.19(4.4)
Unweeded check	4.41(19.0)	4.83(22.8)	5.09(25.4)	4.78(22.4)	8.01(63.6)	8.48(71.3)	9.17(83.6)	8.35(69.5)
Mean	3.54(12.3)	3.90(14.9)	4.21(17.3)		4.20(20.8)	4.69(24.8)	5.52(33.9)	
	C	W	C x W		C	W	C x W	
LSD(p=0.05)	0.19	0.31	0.54		0.27	0.45	0.78	

C_1 – 60 cm x 25 cm (conventional); C_2 - 75 x 20 cm; C_3 - paired row method 90: 30 x 25 cm ; Figures in parentheses are means of original values; Data subjected to square root transformation

Table 2. Effect of altered crop geometry and integrated weed management methods on weed control efficiency (%) of maize (60 DAS)

Treatment	C_1	C_2	C_3	Mean
Twin wheel hoe weeding at 20 and 35 DAS	58.75	46.38	48.24	47.79
Power weeding at 20 and 35 DAS	46.97	47.37	51.45	56.78
Atrazine at 1.0 kg/ha + twin wheel hoe weeding at 35 DAS	91.61	89.28	81.74	87.54
Atrazine at 1.0 kg/ha + power weeding at 35 DAS	83.88	70.19	69.67	74.58
Atrazine at 1.0 kg/ha + hand weeding at 35 DAS	93.97	90.63	82.45	89.02
Fodder cowpea as live mulch + brown manuring with 2,4-D at 0.5 kg/ha on 35 DAS	51.15	45.41	32.50	43.02
Two hand weeding at 20 and 35 DAS	95.33	94.00	85.21	91.51
Unweeded check	-	-	-	-
Mean	74.52	69.04	64.47	

C_1 – 60 x 25 cm (conventional); C_2 - 75 x 20 cm; C_3 - paired row method 90: 30 x 25 cm; Data not statistically analyzed

Weed management has shown a significant effect on the number of grains per cob and 100 grain weight. Hand weeding twice plots had recorded significantly higher yield attributes like grain test weight and grain number per cob and it was statistically at par with PE atrazine application + hand weeding at 35 DAS followed by PE atrazine + twin wheel hoe weeding at 35 DAS. Weedy check recorded a distinctly lower number of grains per cob and 100-grain weight. These results were in confirmation with Saini *et al.* (2013). The lower yield components might be due to increased crop weed competition thus finally could result in reduced growth and development of the crop. Though weed management methods had significant effect on yield attributes, interaction of crop geometry and weed management methods has no significant effect on 100-grain weight but other yield parameter number of grains per cob was found to be significant. Combination of conventional spacing with two hand weeding was found to be significantly higher. These results are in accordance with the findings of Sunitha *et al.* (2010).

Effect on yield

As crop geometry highly influenced the resource availability for crop growth, grain yield was also greatly affected. The result showed that narrow row spacing 60 cm had recorded a significantly higher yield (6.48 t/ha) and it was statistically at par with 75 cm (6.44 t/ha) (**Table 4**). Maqbool *et al.* (2006) findings were found to be in accordance with these results and indicated that optimum maize row spacing of about 60 cm had been more appropriate due to higher resources availability and their utilization by the crop which ultimately resulted in higher yield.

Weeds are considered to be the major competitor for crop growth thus, its management practices have significant effects on grain and stover yield of maize. Significant higher grain yield was

Table 3. Effect of altered crop geometry and integrated weed management methods on yield attributes of maize

Treatment	No. of grains/cob				100 grain weight (g)			
	C_1	C_2	C_3	Mean	C_1	C_2	C_3	Mean
Twin wheel hoe weeding at 20 and 35 DAS	339	351	349	346	34.28	32.40	33.19	33.59
Power weeding at 20 and 35 DAS	352	348	329	343	35.37	34.03	33.77	34.39
Atrazine at 1 kg/ha + twin wheel hoe weeding at 35 DAS	496	487	468	484	37.22	35.15	34.85	35.74
Atrazine at 1 kg/ha + power weeding at 35 DAS	429	433	428	430	36.18	34.18	35.10	35.30
Atrazine at 1 kg/ha + hand weeding at 35 DAS	513	507	474	498	39.53	37.84	35.50	37.64
Fodder cowpea as live mulch + brown manuring with 2,4-D at 0.5 kg/ha on 35 DAS	346	342	353	347	35.61	33.35	32.87	34.08
Two hand weeding at 20 and 35 DAS	519	511	481	504	40.18	39.11	36.06	38.45
Unweeded check	291	297	273	287	33.09	31.96	30.43	31.83
Mean	411	409	394		36.65	34.75	33.98	
	C	W	C x W		C	W	C x W	
LSD (p=0.05)	13	48	83		2.47	4.04	NS	

C_1 – 60 x 25 cm (conventional); C_2 - 75 x 20 cm; C_3 - paired row method 90: 30 x 25 cm

Table 4. Effect of altered crop geometry and integrated weed management methods on yield of maize

Treatment	Grain yield (t/ha)				Stover yield (t/ha)			
	C_1	C_2	C_3	Mean	C_1	C_2	C_3	Mean
Twin wheel hoe weeding at 20 and 35 DAS	5.48	5.57	4.56	5.20	9.44	9.58	7.85	8.96
Power weeding at 20 and 35 DAS	5.22	5.36	4.51	5.03	8.96	9.22	7.75	8.64
Atrazine at 1 kg/ha + twin wheel hoe weeding at 35 DAS	7.91	7.94	6.99	7.61	13.99	14.04	12.36	13.47
Atrazine at 1 kg/ha + power weeding at 35 DAS	6.68	6.77	5.74	6.40	11.60	11.75	9.95	11.10
Atrazine at 1 kg/ha + hand weeding at 35 DAS	8.27	8.17	7.12	7.85	14.66	14.49	12.63	13.93
Fodder cowpea as live mulch + brown manuring with 2,4-D at 0.5 kg/ha on 35 DAS	5.43	5.42	4.47	5.11	9.29	9.27	7.66	8.74
Two hand weeding at 20 and 35 DAS	8.41	8.29	7.22	7.97	15.19	14.97	13.03	14.40
Unweeded check	4.39	4.11	3.44	3.98	7.42	6.94	5.81	6.72
Mean	6.47	6.45	5.51		11.32	11.28	9.63	
	C	W	C x W		C	W	C x W	
LSD (p=0.05)	0.38	0.61	1.06		0.66	1.08	1.88	

C_1 – 60 x 25 cm (conventional); C_2 - 75 x 20 cm; C_3 - paired row method 90: 30 x 25 cm obtained in hand weeding twice on 20 and 35 DAS (7.97 t/ha) and it was on par with PE atrazine application + hand weeding at 35 DAS (7.61 t/ha). These results are in confirmation with the findings of Prithwiraj *et al.* (2018) who had concluded that PE atrazine application followed by hand weeding at 35 DAS can be adopted as remunerative strategies in case of two hand weeding thus it would resulted in reduction of labour requirement and recorded higher grain yield and B:C ratio. However, PE atrazine application + twin wheel hoe weeding at 35 DAS was statistically at par with these treatments since twin wheel hoe weeding effectively reduced the weed growth and recorded the grain yield of about 7.6 t/ha. Mynavathi *et al.* (2015) findings showed that the twin wheel hoe weeding had significantly improved the maize grain yield to a certain extent. Significant interaction was observed with the altered crop geometry and integrated weed management practices in influencing economic grain yield of maize. It was observed that the yield of maize at the crop geometry of normal row spacing 60 x 25 cm with the weed control practice of two hand weeding at 20 and 35 DAS (60 x 25 cm (conventional) two hand weeding at 20 and 35 DAS) was significantly higher.

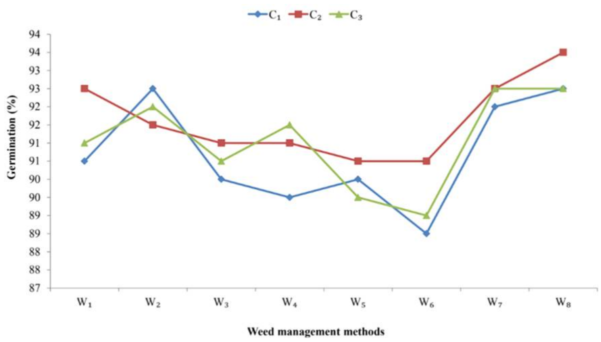
Effect on succeeding Bengal gram

The presence of herbicides in the soil as its original form (phytotoxic nature) even after its mission, then it is referred to as persistence and the quantity of herbicides that exist is termed as residue. (Sondhia 2014). Germination of the following crop Bengal gram was found to be unaffected and exerted its normal growth and development (**Figure 1**). This might be due to the degradation of phytotoxic form of herbicides by several ways and resulted in less persistence rate of herbicides.

The residual effect of integrated weed management methods of maize on total weed density and weed biomass of succeeding Bengal gram was found to be significant at 30 DAS. The results showed that the two hand weeded plot and PE application of atrazine + one mechanically weeded plots had recorded lower weed density and biomass. The results are in confirmation with Verma *et al.* (2009) findings that the lowered weed emergence and growth was due to reduced weed seed production in proceeding crop period ultimately leads to decreased weed biomass production. However, the weedy check with higher weed seed bank was observed to have the increased weed biomass production in the succeeding crop.

The growth and yield of succeeding Bengal gram crop were not having any adverse effect due to the weed management practices for preceding maize. This is in accordance with Aladesanwa and Adejoro (2000) suggested that the crop sown next to maize without suffering a concomitant reduction in crop growth and yield of following crop and concluded that 2,4-D herbicide have negligible effect on succeeding pulse. Herbicide residual effect of atrazine and 2,4-D on subsequent crops were negligible if the interval of herbicide application and succeeding crop was longer and vice versa due to the increased degradation time availability and reduced the persistence of phytotoxic forms of chemicals. Crop rotation with pulses without suffering a yield reduction after maize with the chemical weed control may be adopted. Thus, herbicidal weed management with atrazine and 2,4-D for maize did not impart any significant effect on growth and yield of succeeding Bengal gram.

Application of atrazine at 1.0 kg/ha + hand weeding at 35 DAS recorded higher grain yield with spacing 60 cm x 25 cm and it was followed by PE application of atrazine + twin wheel weeding at 35 DAS (**Table 5**). However, 75 x 20 cm also recorded significant grain yield in comparable to conventional spacing and observed to have higher net returns and B: C ratio when compared to conventional spacing. Since, 75 x 20 cm had consumed less labour requirement and reduced time consumption for field operations. Thus, it is concluded that PE atrazine application at 1.0 kg/ha + twin wheel hoe weeder weeding at 35 DAS adopted in 75 x 20 cm resulted lower plant damage, higher grain yield, net returns and B:C ratio.



C_1– 60 x 25 cm (conventional), C_2– 75 x 20 cm, C_3– paired row method 90: 30 x 25 cm and weed management involves W_1– twin wheel hoe weeding at 20 and 35 DAS, W_2– power weeding at 20 and 35 DAS, W_3– atrazine at 1 kg/ha + twin wheel hoe weeding at 35 DAS, W_4– atrazine at 1 kg/ha + power weeding at 35 DAS, W_5– atrazine at 1 kg/ha + hand weeding at 35 DAS, W_6– fodder cowpea as live mulch + brown manuring with 2,4-D at 0.5 kg/ha on 35 DAS, W_7– two hand weeding at 20 and 35 DAS and W_8– unweeded check

Figure 1. Effect of altered crop geometry and integrated weed management of preceding maize on germination of succeeding Bengal gram

Table 5. Effect of altered crop geometry and integrated weed management of preceding maize on grain and haulm yield of succeeding Bengal gram

Treatment	Grain yield (kg/ha)				Haulm yield (t/ha)			
	C_1	C_2	C_3	Mean	C_1	C_2	C_3	Mean
Twin wheel hoe weeding at 20 and 35 DAS	662	659	673	665	1.59	1.57	1.58	1.58
Power weeding at 20 and 35 DAS	681	671	688	680	1.62	1.64	1.66	1.64
Atrazine at 1 kg/ha + twin wheel hoe weeding at 35 DAS	659	662	672	664	1.57	1.56	1.58	1.57
Atrazine at 1 kg/ha + power weeding at 35 DAS	675	684	691	683	1.58	1.66	1.64	1.63
Atrazine at 1 kg/ha + hand weeding at 35 DAS	692	691	669	684	1.64	1.66	1.64	1.65
Fodder cowpea as live mulch + brown manuring with 2,4-D at 0.5 kg/ha on 35 DAS	667	677	681	675	1.59	1.60	1.60	1.59
Two hand weeding at 20 and 35 DAS	691	686	679	685	1.64	1.66	1.63	1.64
Unweeded check	687	680	677	681	1.65	1.61	1.60	1.62
Mean	677	676	676		1.61	1.62	1.61	
	C	W	C x W		C	W	C x W	
LSD (p=0.05)	NS	NS	NS		NS	NS	NS	

C_1 – 60 x 25 cm (conventional); C_2 - 75 x 20 cm; C_3 - paired row method 90: 30 x 25 cm

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Screening of herbicides for broomrape (*Orobanche*) control in mustard

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ABSTRACT

A field study was conducted for two years during *Rabi* season of 2012-13 and 2013-14 on the fields of farmers' of Jhunjhunu and Bikaner districts infested with broomrape (*Orobanche*) to test the efficiency of herbicides in mustard crop under AICRP on Weed Management at Agriculture Research Station, Swami Keshwanand Rajasthan Agricultural University, Bikaner. The experiment comprising ten weed control treatments consisting of neem cake (200 kg/ha) + pendimethalin 1.0 kg/ha, neem cake (200 kg/ha) + glyphosate 25 g/ha at 25 DAS, pendimethalin 0.75 kg/ha + glyphosate 35 g/ha + 55 g/ha at 25 and 55 DAS, pendimethalin 1.0 kg/ha, glyphosate 25 g/ha + 50 g/ha at 25 and 55 DAS, glyphosate 50 g/ha + 50 g/ha at 25 and 55 DAS, oxyfluorfen (200 g/ha), imazethapyr (20 g/ha), manual weeding and weedy check in a randomized block design with three replications. Among the different herbicides, application of glyphosate at 25 g/ha + 50 g/ha at 25 and 55 DAS controlled broomrape effectively with nil phytotoxicity and produced significantly the highest seed yield in mustard during both the years over all the other herbicidal treatments.

Mustard (*Brassica juncea*) is an important oil seed crop being third world's important oil seed crop after soybean and palm contributing 28.6% in the total production of oil seeds with 34.19 mha area, 63.09 mt production and 1.85 t/ha productivity. In India it is the second most important edible oil seed after groundnut sharing 27.8% in the India's oil seed economy with 6.8 mha area, 8.2 mt production and 1.18 t/ha productivity in Rajasthan it stand at first with 3.7 mha area, 4.4 mt production and 1.20 t/ha productivity. Weed growth is an important constraint in proper harvest of the crop. Simultaneous emergence and rapid growth of weeds lead to severe crop-weed competition for light, moisture, space and nutrients. Broomrape (*Orobanche* spp.) is an annual, root holoparastic herb propagated by seeds. It is one of the most serious weed in the mustard crop. The host root exudates induce germination of seed within soil. *Orobanche* or broomrape (*Orobanche* spp.) locally known as *margoja, rukhri, khumbhi* or *gulli* or *bhumiphod* is a phanerogamic, obligate, troublesome root parasite that lack chlorophyll (Baccarini and Melandri 1967, Saghir *et al.* 1973) and obtain carbon, nutrients, and water through haustoria which connect the parasites with the host vascular system (Punia *et al.* 2012). The attached parasite functions as a strong metabolic sink, often named "supersink", strongly competing with the host plant for water, mineral nutrition and assimilate absorption and translocation. The parasite seedlings then infect the nearby host roots forming haustoria on them. Soon thereafter, the broomrape emerges through the soil as pale shoots devoid of chlorophyll. Broomrape is thus a total parasite. Each plant produces more than a million seeds in a short period of about eight weeks. Considering the importance of management practices on broomrape (*Orobanche ramosa*.) control in mustard, the present experiment was conducted.

A field study was conducted for two consecutive years during *Rabi* season of 2012-13 and 2013-14 on the fields of farmers' of Jhunjhunu and Bikaner districts, infested with *Orobanche* in mustard crop under AICRP on weed management at Agriculture Research Station, Swami Keshwanand Rajasthan Agricultural University, Bikaner. The experiment comprising ten weed control treatments consisting of neemcake (200 kg/ha) before sowing + pendimethalin 1.0 kg/ha at pre-emergence, neem cake (200 kg/ha) before sowing + glyphosate 25 g at 25 DAS, pendimethalin 0.75 kg/ha at pre-emergence + glyphosate 35 g/ha + 55 g/ha at 25 and 55 DAS, pendimethalin 1.0 kg/ha at pre-emeergence, glyphosate 25 g/ha + 50 g/ha at 25 and 55 DAS, glyphosate 50 g/ha + 50 g/ha at 25 and 55 DAS, oxyfluorfen (200 g/ha) at pre-emergence, imazethapyr (20 g/ha) at 25 DAS, manual weeding and weedy check in a randomized block design with three replications. During 2012-13, mustard variety '*Bio-902*' was sown on 28.10.2012 in plot size of 10 x 10 m^2 while during 2013-14, sowing was done on 29.10.2013, 05.11.2013 and 01.11.2013 at Varishpura, Derwala and Shekhsar villages, respectively. During both the years of study, fields selected were heavily infested with *Orobanche*. Various treatments were imposed as per schedule as given in **table 1**. Data on per cent visual control of the weed was recorded at 80 days after sowing. Results obtained from these trials were further validated in large scale multi location trials conducted at different locations in Bikaner, Jhunjhunu and Churu districts of Rajasthan through farmers' participatory approach during the *Rabi* seasons of 2013-14 to 2015-16. A total of 40 on farm trials (OFTs) were conducted in mustard growing area of Rajasthan state.

Effect on weed

Application of glyphosate 25 g/ha + 50 g/ha at 25 and 55 DAS recorded significantly the lowest count of broomrape, *i.e.* 0.33 and 0.78/m^2 during 2012-13 and 2013-14, respectively but it was statistically at par with glyphosate 50 g/ha at 25 DAS + 50 g/ha at 55 DAS, pendimethalin 0.75 kg/ha + glyphosate 35 g/ha + 55 g/ha at 25 and 55 DAS and imazethapyr 20 g/ha (**Table 1**). Significantly lowest weed density was recorded by imazethapyr 20 g/ha and manual weeding during both the years. It might be due to manual weeding, which was most efficient and widely practiced method in India for all crops that suffer from their parasites. The present findings were supported from the results reported by Krishnamurthy and Rao (1976), Dhanapal (1996) and Prasad (2011). Glyphosate 25 g + 50 g/ha at 25 and 55 DAS provided 70-80% control of *Orobanche* even up to harvest without any crop injury with yield improvement from 7 to 54% over the farmers' practice during both the years of study. Similar findings on the control of *Orobanche* in mustard through herbicide application were also reported by the scientists at Gwalior and Bikaner (DWSR 2009). The tolerance of plants to glyphosate was mainly attributed to readily degradation of this herbicide to non-toxic metabolites (Punia *et al.*2010, Punia and Singh 2012). It is readily absorbed by the mustard plant foliage and translocated to the young parasites attached to the roots, leaves and meristems, thereby inhibiting the synthesis of enzyme 5-enolpyruvylshikimate-3-phosphate (EPSP) synthetase leads to the production of aromatic amino acids(phenylalanine, tyrosine and tryptophan) and thus protein synthesis and growth (Amerhein *et al.* 1980).

These results were further validated in large scale multi-locational trials conducted at different locations in Bikaner, Jhunjhunu and Churu districts of Rajasthan through farmers' participatory approach during the *Rabi* seasons of 2013-14 to 2015-16. A total of 40 on farm trials (OFTs) were conducted in mustard growing area of Rajasthan state. The result of OFT on *Orobanche* indicated that *Orobanche* was not observed at 30 and 60 DAS while infestation started at 90 DAS onwards. Application of glyphosate at 25 and 50 g/ha + 1% ammonium sulphate at 25 and 55 DAS, respectively reduced the population of the parasitic weed at all locations. The weed reduction

Table 1. Effect of weed control measures on *Orobanche* population, weed intensity, seed yield and phytotoxicity of mustard

Treatment	*Orobanche*/ m^2		Weeds/m^2		Seed yield (t/ha)		Phytotoxicity (0-100 scale)	
	2012-13	2013-14	2012-13	2013-14	2012-13	2013-14	2012-13	2013-14
Neem cake (200 kg/ha) + pendimethalin 1.0 kg/ha	45.0	24.2	25.8	21.2	0.98	1.01	0	0
Neem cake (200 kg/ha) + glyphosate 25 g	21.0	7.7	32.5	27.3	1.08	1.10	0	0
Pendimethalin 0.75 kg/ha + glyphosate 35 + 55 g	0.3	1.4	17.5	16.4	1.14	1.16	10	8
Pendimethalin 1.0 kg/ha	39.7	28.3	22.1	20.4	0.97	0.89	0	0
Glyphosate 25 g + 50 g	0.3	0.8	32.4	31.3	1.26	1.24	0	0
Glyphosate 50 g + 50 g	0.3	0.1	21.4	20.1	1.06	0.91	15	15
Oxyfluorfen (200 g/ha)	46.7	29.1	11.5	7.6	0.52	0.43	0	60
Imazethapyr (20 g/ha)	1.0	0.5	4.3	3.6	0.76	0.82	30	30
Manual weeding	8.7	10.1	5.8	3.6	1.18	1.12	0	0
Weedy check	33.3	30.0	41.7	40.9	0.81	0.80	0	0
LSD (p=0.05)	10.1	3.6	3.5	4.5	0.11	0.12	-	-

was in the range of 72-82 per cent at four locations and consequently increased the seed yield of mustard as compared to neem cake treatment.

Effect on yield

Among the different herbicidal treatments, seed yield of mustard was found maximum with the treatment received glyphosate 25 g/ha + 50 g/ha at 25 and 55 DAS which was significantly superior to all other herbicides but statistically at par with manual weeding and imazethapyr 20 g/ha during 2012-13, however, significantly superior to weedy check, pendimethalin 1.0 kg/ha, imazethapyr 15 g/ha and 20 g/ha but statistically at par with manual weeding during both the years. Effective control of weeds by herbicides might have resulted in better availability of soil moisture and nutrients as evidenced by the beneficial effect on crop growth. The higher seed yield in glyphosate 25 g/ha + 50 g/ha at 25 and 55 DAS might be due to suppression of weed seed germination and seedling development at early stages due to pre-emergent herbicides. The proper time and dose of glyphosate have better efficacy of herbicide application as repetitive/higher/lower than the recommended dose may lead to adverse impact on mustard crop or may result in development of herbicide-resistant weeds.

The present study has shown that glyphosate, if used at desired concentrations can be very helpful in reducing the parasitic weed infestation while affording tolerance to the mustard crop. This would definitely obviate the *Orobanche* seed bank to further increase as well as improve the overall productivity and economic well-being of the mustard growing farmers' fraternity.

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