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Smart weed management: A small step towards doubling farmers' income

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ABSTRACT

Increasing incomes by reducing crop losses due to various pests and improving productivity and input-use efficiency, are some of the major recommendations of the report on Doubling Farmers' Income by 2022. Weeds are unwanted intruders into agro-ecosystems that compete for limited resources and reduce crop yields and farmers' income. It was estimated that on an average the weed control costs around INR 6000/ha (USD 92.42/ha) in rainy season crops and around INR 4000/ha (USD 61.61/ha) for winter crops, which accounts for around 33% and 22% of total cost of cultivation, respectively. Thus, efficient weed management can help in increasing the farmers' income by reducing the losses caused by weeds, decreasing the cost of production, and increasing the productivity through efficient utilization of resources. The present paper deals with the importance of weeds in crop production and farmers' income, and role of smart weed management practices in reducing cost of production, and improving input-use efficiency and crop productivity.

INTRODUCTION

With a population of 1.35 billion, India is the second most populous country in the world (www.worldometers.info). The population is expected to reach 1.7 billion by 2050, making it as the most populated country in the world. To feed the increasing population food production must increase by 70%. This challenge is critical in view of the declining per capita availability of natural resources, adverse effect of climate change on agricultural production and environment. The low and highly fluctuating agricultural productivity and farm income are causing a detrimental effect on the interest in farming, and farm investment, and forcing more and more farmers, particularly younger group, to leave farming (Saxena *et al.* 2017). It is apparent that income earned by a farmer from agriculture is crucial to address agrarian distress and promote farmers welfare. Realizing the need to pay special attention to the plight of farmers, the Hon'ble Prime Minister of India announced to double the farmers income by 2022 to promote farmers welfare, reduce agrarian distress and bring parity between income of farmers and those working in non-agricultural profession. Increasing incomes by improving productivity and input-use efficiency, and reducing crop losses due to various pests are some of the major recommendations of the report on Doubling Farmers Income by 2022 (Anonymous 2016). The recent budget proposal presented by the Government of India for 2018-19 has provided a number of policy interventions for achieving this goal. This apart, several technologies developed by agricultural scientists over the years are available that aim at reducing the cost of cultivation and increasing the efficiency of various inputs used in crop production. The higher crop productivity thus achieved will result in improved farmers' livelihood. In this paper, an attempt has been made to highlight adoptable weed management technologies with the expectation that our extension system will take them to the farmers.

Losses due to weeds

Weeds are a perennial problem with the farmers. They are omnipresent and reduce yield and quality of crops substantially. Farmers spend a lot of resources to reduce their impact, many a times quite unsuccessfully. In India, the highest loss (33%) is caused by weeds, followed by pathogens (26%), insects (20%), storage pests (7%), rodents (6%) and others (8%) (Kulshrestha and Parmar 1992). Based on the average loss (20%) due to pests as estimated by the Ministry of Agriculture, it approximates to around INR1400 billion (USD 21.56 billion), of which weeds are responsible for more than INR 460 billion (USD 7.09 billion) (Agarwal 2007). Yaduraju (2012) estimated a total economic loss in arable crops equivalent to approximately USD 13 billion per annum. More recently, in a more scientific study, Gharde *et al.* (2018) reported an annual loss of USD 11 billion in 10 major crops due to weeds alone. In addition to the direct effect on crop yield, weeds result in a considerable reduction in the efficiency of inputs used and food quality. The precious and costly inputs such as fertilizers and irrigation water which are otherwise meant for realizing the potential yield will be usurped by the weeds. Indirectly, weeds interfere with agricultural operations and also act as an alternate host for many crop pests.

Costs of weed control

The data collected from ICAR-Directorate of Weed Research (DWR), Jabalpur show that with the traditional weed control methods, farmers are losing close to 15-20% crop yield and there is a tremendous scope for enhancing crop yield by adopting recommended weed control practices. Weed control is one of the costliest practices in crop production. It has been estimated that on an average the weed control costs around INR 6000/ha (USD 92.42/ha) in rainy season crops and around INR 4000/ha (USD 61.61/ha) for winter crops, which comes to the tune of 33% and 22%, respectively of the total cost of cultivation (**Table 1**) (Commission for Agril. Costs and Prices, Deptt. of Agriculture, Government of India, 2015). Efficient and effective methods of weed control, that are not only efficient but are also cost-effective, are needed as they invariably ensure higher crop productivity and eventually increase the net returns of the farmers. There are opportunities for employing methods, which are not only efficient but are also cost-effective. Such an approach would eventually increase the net returns of the farmers. Large majority of the farmers follow manual and mechanical methods to manage weeds, which are labour-intensive and are often inefficient. The increasing migration of rural population and employment opportunities under several social security schemes have led to serious shortage of labour in agriculture. Data compiled by DWR, Jabalpur of the research carried out at AICRP on Weed Control have shown that weed control using herbicides resulted in significantly more yield over farmer's practice, with nearly one-third saving in the cost on weed control. However, the proven technologies are not yet been fully adopted by the farmers due to a variety of reasons.

Weed management and input-use efficiency

Weeds compete with crop plants for water, nutrients, and sunlight, thereby reducing crop yields and consequently input-use efficiency. Inherently, most weeds accumulate higher concentration of

Table 1. Cost of cultivation *vis-a-vis* weed control

Crops	Cost of cultivation* (INR/ha)	Cost of weed control (INR/ha)	% Share of weed control in total cost of cultivation
Rainy season			
Rice	30070 (463.18)	6500 (100.12)	21.62
Maize	22491 (346.44)	5000 (77.02)	22.23
Sorghum	19358 (298.18)	5000 (77.02)	25.83
Pearl millet	14380 (221.50)	5000 (77.02)	34.77
Pigeonpea	23008 (354.41)	6500 (100.12)	28.25
Greengram	13688 (210.54)	6500 (100.12)	47.55
Blackgram	14410 (221.97)	6500 (100.12)	45.11
Soybean	15913 (245.12)	6500 (100.12)	40.85
Average	19165 (295.21)	5937 (91.45)	33.27%
Winter season			
Wheat	26687 (411.08)	3000 (46.21)	11.24
Chickpea	18875 (290.74)	4500 (69.32)	23.84
Lentil	13941(214.74)	4500 (69.32)	32.28
Mustard	20203 (311.20)	4500 (69.32)	22.28
Average	19927 (306.94)	4125 (63.54)	22.41%

Values in parentheses are in USD. Conversion rate: 1USD=64.92 INR (as on 27th February 2018)

***Source**: Commission for Agril. Costs and Prices, Deptt. of Agriculture, Government of India (2015)

Cost of weed control includes assumption that: use of herbicide +1 manual weeding in *Kharif* crops; and herbicide mixture/ sequential application in wheat; 1 manual weeding in *Rabi* pulses and oilseeds.

nutrients compared to crop plants. There are few weeds like *Amaranthus* spp., which are nitrophilous in nature accumulate more than 3% N on dry matter basis. Similarly, *Anagallis arvensis* and *Achyranthus aspera* contain more than 3.36% phosphorus; and *Chenopodium album* and *Portulaca oleracea* species are known as potassium lovers and contain more than 4.0% potassium on dry weight basis. *Setaria lutescens* accumulates as high as 585 ppm of zinc in its dry matter. This is about three times more than by cereal crops. They also have a unique ability to absorb higher amounts of nutrients in view of deeper and extensive root growth. Thus, poor weed management would amount to diverting of costly inputs for weed growth which are otherwise meant for crop plants. For example; the nitrogen requirements of wheat could be reduced by 67% to produce the same yield if weeds were controlled by applying pre-emergence herbicides (Agrawal and Singh 1985).

Competition for water in a crop-weed situation increases water stress for the crop due to presence of weeds. Some weeds consume more water than crop plants. For example, the consumptive use of water for *Chenopodium album* has been estimated to be 550 mm against 479 mm for wheat (Shahi 1978). The author further noted that the weeds removed moisture evenly from up to 90 cm soil depth, while moisture uptake by wheat was limited to the top 15 cm of soil. In sugarcane, giving irrigation in a weedy situation increased the cane yields by 1-3 t/ha against 10-28 t/ha increase in weed free plots (Saini *et al.* 1993). The transpiration coefficients 'Q' (the amount of water transpired to produce unit quantity of dry matter) of some of the weeds like *Cynodon dactylon* (813), *Digitaria sanguinalis* (696), *Echinochloa colona* (674), *Tephrosia purpurea* (1108) and *Tridax procumbens* (1402) was higher than that of maize (352) and sorghum (394) (Kanitkar *et al.* 1960). Proper weed control increases available soil water for crop production. The effect of water stress on crop is a function of the developmental stage at which the stress occurs, duration and severity of stress and weed species present. Under weedy situations, plants develop water stress symptoms (*i.e.* lower leaf water potential, reduced leaf stomatal conductance, reduced leaf photosynthesis) earlier than when grown in the absence of weeds, suggesting limited water availability under weedy conditions. This might be due to less developed root systems under weedy conditions, rather than water availability *per se* (Rajcan and Swanton 2001). It is, therefore possible to maintain higher crop productivity and input-use efficiency even under lower levels of nutrient and irrigation by timely and efficient management of weeds.

Weed-crop competition

Untimely weeding and the poor crop stand are believed to be the two major factors responsible for the dominance of weeds. It is to be understood that there is no substitute for timely weeding. Keeping the crop weed free or with minimal weed interference during the critical period of weed competition (CPWC) is of paramount importance. Weed competition during this period causes irreparable loss in crop growth ultimately resulting in lower crop yield. The next factor is the inability of majority of the farmers in raising a good crop. Fryer (1983) stated that '*a good crop is the best weed killer'*. The recommended cultivation practices starting with selection of a crop cultivar, timely planting, optimum seed rate, timely application of fertilizers and irrigation, management of insect pests and diseases, etc., are instrumental in establishing a good crop. Extensive reviews on the role of crop competition in managing weeds can be found in a special issue of Crop Protection (Volume 95, 2017).

The following sections attempts to analyze how each weed control method could be practiced in an ideal way so as to get maximum productivity of crops with relatively lower investment. The objective of this paper is not to review each method extensively but to sensitize the weed science community the vast opportunity of exploring the potential of several such methods- many of them involve least or no additional investment- in achieving effective and economic weed control.

Preventive methods

Prevention is better than control and it is the most cost-effective measure. With less or no extra investment they can be employed to minimize infestation and competition by weeds substantially. However, it is seldom appreciated by the farmers and the extension personnel alike. Some of these methods include the use of weed-free crop seed and farm-yard manure (FYM), use of clean farm machinery, control of weeds along bunds and irrigation canals, preventing weeds from setting seeds, etc. Everyone concerned must be reminded of the old adage *one year seeding is seven years weeding!* Good control of weeds in nursery will ensure transplanting of crop plants free of weed seedlings in the main field. Soil is a big reservoir of weed seeds and perpetuates weed infestation for several years even if one attempts to achieve almost the impossible task of not permitting the addition of fresh weed seeds in to the soil. Several techniques could be employed to reduce the load of weed seed bank in the soil. Readers may refer to Rao *et al.* (2017) for more information on the impact of preventive weed control measures on weed seed bank.

Cultural methods

All production practices followed in raising the crop affect infestation and competition by weeds either directly or indirectly. The practices which encourage crop growth also encourage weed growth. But research has shown that it is possible to manipulate some of the agronomic practices which would have greater impact on crop growth than on weeds. Some of them are the time-tested practices such as crop rotation, summer tillage, stale seed bed preparation, weed competitive crop cultivars, green manuring, mixed/intercropping, intercultural operations, *etc*. Very often such practices require no or minimal additional investments. There is good scope for minimizing the loss of nutrients by resorting to placement of fertilizers nearer to the crop root zone rather than broadcasting. Similarly, the water use efficiency could be enhanced by adopting suitable methods such as, irrigation in the alternate furrows or basin application in wide spaced vegetable, plantation and fruit crops or more desirably through drip irrigation. Such simple nutrient and water management practices often referred to as selective crop stimulation techniques result in significant reduction in the infestation of weeds and enhance input use efficiency. Similarly, intercropping with fast canopy forming crops suppress weed growth substantially. Enhanced crop competitive ability against weeds has been suggested by several weed scientists for reducing the costs of weed control and as an environmentally-compatible tool for farmers. It has been shown that an investment close to INR 2000-2500/ha could be saved by resorting to zero or minimum cultivation through reduction in cost of land preparation. As a bonus, the technology has been found to decrease the incidence of some of the weeds (for example *Phalaris minor* and *Chenopodium album* in wheat) as well.

Chemical methods

Herbicides offer convenient, easy, flexible and an efficient option of weed control. Due to the fact, the labour is scarce and expensive, chemical weed control is gaining wider acceptability with the farmers. A wide range of herbicides is available to suit all crops and cropping systems to control a diverse spectrum of weeds. They could be applied at planting and during early stages of crop growth and also under adverse soil and weather conditions. There are two ways how the farmers could increase their income through use of herbicides; Firstly, by increasing the herbicide efficacy and secondly by minimizing the crop injury. How this could be achieved is discussed in the following sections.

Increasing herbicide efficiency

Selection of herbicide: Crop is infested with a wide-spectrum of weeds which vary with crop, cropping system, soil, climatic and management conditions. The choice of an herbicide depends on weed flora, time of application, crop rotation and whether the crop is grown sole or intercropped. For any given situation, if there are many herbicides available, it is quite natural to go for an herbicide which is relatively cheaper. Selection also depends on what would be the ideal time of application- either before or after crop emergence. There are a good number of herbicides available for application in most cereals both as pre- and post-emergence. However, the availability of herbicides that could be applied post-emergence in pulses and oilseeds are relatively few.

Herbicide dose: The major consideration for optimal dose is soil type and growing conditions. Light soil with low organic matter content requires lower dose than heavy soils with higher organic matter content. The pre-emergence herbicides perform better when applied to soil with sufficient soil moisture. Hence there is good scope for reducing the herbicide dose in irrigated crops. With post-emergence herbicides, the time of application is more critical. They perform better when applied early. Young and fast growing weeds are more sensitive to herbicide treatment. Ensure optimum soil moisture for maximum effect, stressed plants exhibit resistance to herbicides.

Herbicide application: Unlike other pesticides, the application plays an important role in determining herbicide efficacy. Calibration of the sprayer is must so as to apply the herbicide at the recommended dose over a given area. Choosing the right kind of a sprayer, nozzle and the application pressure are critical in ensuring uniform application. In India, farmers give least attention to application of herbicides. Inappropriate application not only lowers weed control efficiency but may also result in crop injury. More care is required while using spray booms. It is common to see patches of weeds not controlled or patches of crop plants showing phytotoxicity symptoms because of incorrect alignment of nozzles and faulty height of the spray boom. Both these conditions result in poor crop growth and yield.

Use of adjuvants: Most of the herbicides are formulated for ready use by farmers. However, there is scope for improving the efficacy of herbicides by use of adjuvants. Adjuvants increase retention of spray on the foliage and better spreading of droplets thereby increasing the absorption and translocation of the herbicide. For instance, it is well documented that addition of ammonium sulfate enhances the efficacy of glyphosate against many perennial weeds.

Herbicide mixtures: Crop fields are infested with broad-spectrum of weeds. Selective herbicides are known to be effective against a few of them. With continuous use of the same herbicide, the population of weeds which are less susceptible would increase over time. It is therefore ideal to use a mixture of two or more herbicides. Herbicide industry has responded to this concern and has commercialized quite a many 'Ready-mix' herbicides, which are quite popular with farmers. Use of such mixtures provides good control of diverse weeds sustainably for a number of years. Herbicide mixtures are also known to delay the development of herbicide resistant (HR) weeds. Any attempt to delay development of HR in weeds is worth pursuing as managing them later is highly challenging. Alternative herbicides recommended for managing HR weeds would normally be very expensive. It is also a good idea not to use the same herbicide or herbicides belonging to the same group year after year. It is recommended to follow herbicide rotation - meaning alternative use of herbicide(s) belonging to different groups.

Time of application: As has been discussed earlier, targeting the weed at their early growth stage is beneficial. This may entail the use of a lower dose of herbicides. More importantly, better weed control could be realized by exploiting the soil and weather conditions, which are favourable for increased herbicide activity. A well-prepared seedbed with sufficient soil moisture enhances the efficacy of the pre-emergence herbicides. By and large, higher levels of temperature, relative humidity and solar radiation enhance the activity of many herbicides applied post-emergence. Greater herbicide efficacy could be achieved by coinciding herbicide application with such weather parameters. Rainfall however has the maximum impact. Herbicide application is to be avoided, if rain is expected within the next 2-4 hours of application. The interval, however, may vary from herbicide to herbicide. Paraquat, for instance, is known to control weeds effectively even if it rains within 15 to 30 minutes of spraying.

There has been contrasting reports with regard to what time of the day the herbicide be applied for better weed control. Early morning hours are generally considered ideal for herbicide spray as there is less wind. Heavy wind encourages spray drift. Spraying paraquat towards the end of daylight hours on a cloudy day is reported to boost the efficacy. These usually result in longer lasting weed control. A group of weed scientists from several universities from the USA have observed that glyphosate application made at 5.00 AM resulted in 16% control of glyphosate-resistant *Amaranthus palmeri* as compared to 56% when applied at 11.00 AM. (http://www.southeastfarmpress.com/cotton/herbicides-time-day-you-spray-can-make-difference). Almost similar results were noticed with glufosinate, 2,4-D and dicamba. Therefore, it is worth exploring the opportunities for increasing the efficacy of herbicides by timing the herbicide application.

Conclusion

It may be stated that there is enormous scope for enhancing the farmers income by lowering the cost on weed control and by achieving higher productivity. Timely weeding and raising a healthy crop are critical in our fight against the onslaught of weeds. A number of preventive and cultural methods and minor changes in agronomic practices have a very significant bearing on weed competition. Several of these involve no or insignificant additional expenditure. The impact of these practices may not appear significant when followed individually, but will have a substantial effect when more than one are integrated and followed collectively. Herbicides by virtue of their merit will be an important component of Integrated Weed Management (IWM). With judicious use and clever integration with other methods of weed management, herbicides will enable farmers to achieve better weed control at reduced cost and very often with enhanced productivity of crops. However, IWM being a knowledge intensive activity requires the support and patronage of weed scientists and extension personnel. Farmers need to be sensitized in popularizing the benefits of the technology. Every effort must be made to prevent the introduction of new weeds. One should be particularly wary of invasive weeds, perennial weeds and parasitic weeds as they are known for their competitive ability, elasticity and resistant to weed management strategies. Periodical scouting of the field for new introductions and their eradication, if found, therefore assumes significance.

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Herbicide weed management on weed dynamics, crop growth and yield in direct-seeded rice

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ABSTRACT

Effect of herbicide combinations were evaluated in Raipur (Chhattisgarh) on crop growth, weed suppression and rice yield in direct-seeded rice (DSR) system during 2014 and 2015. Results revealed that combination of pyrazosulfuron + pretilachlor provided wide spectrum weed control at 15 + 600 g/ha to 30 + 1200 g/ha (61.6 - 81.5%), which was comparable to two hand weeding at 15 and 30 days after sowing. Weed control efficiency was recorded to the tune of 40.0 - 89.9%, with highest in two hand weeding (84.6 - 89.9%) and lowest in pendimethalin and lowest dose of pyrazosulfuron + pretilachlor in 2014 (40.0%) and pyrazosulfuron alone in 2015 (48.5%). The crop growth parameters (tillers, total dry matter/hill and leaf area index), yield attributes (panicle length, panicle weight, filled grains/panicle) and grain yield were recorded highest in two hand weeding (2.69 t/ha in 2014 and 5.87 t/ha in 2015) followed by pyrazosulfuron + pretilachlor at 15 + 600, 16.88 + 675 and 30 + 1200 g/ha. However, the least rice grain yield was recorded under weedy plot (1.45 t/ha in 2014 and 2.17 t/ha in 2015). The results suggested that pyrazosulfuron + pretilachlor at 15 + 600, 16.88 + 675 and 30 + 1200 g/ha were the best broad spectrum effective herbicide in order to minimize the diverse weed flora in DSR system.

INTRODUCTION

Rice (*Oryza sativa* L.) is predominantly grown by transplanting seedlings, this practice consumes about 150 ha-cm of water and engagement of labour for transplanting and weeding (Mahajan and Chauhan 2016). Manual transplanting is labour cumbersome and scarcity of labour during peak season force to shifting of crop establishment methods from transplanting to direct-seeded rice (DSR) (Choudhary 2017, Choudhary *et al.* 2017). It has several advantages such as requirement of 35-57% less water and 67% less labour over transplanting rice. Apart from these, DSR requires less use of machine, and have lesser methane emissions (Chauhan *et al.* 2012). However, weeds are major biological constraint in DSR, mainly due to absence of impounding of water at crop emergence, hence, production and weed management are crucial for increasing the productivity of rice (Chauhan 2012). The extent of yield reduction of rice due to weeds has been estimated up to 95% in India (Naresh *et al.* 2011), 71-96% in the Philippines (Chauhan and Johnson 2011) and 33-80% in Pakistan (Khaliq *et al.* 2012). Manual weeding is considered to be the best, but due to labour scarcity and escalating wages, the fields left un-weeded at critical growth stages. In this condition, herbicides have been considered to be an alternative to hand weeding in DSR rice (Singh *et al.* 2006).

It is suggested to use pre-emergence herbicides in DSR to prevent the simultaneous emergence of weeds with rice crop and to favour the crop to establish under relatively weed free condition (Baloch *et al.* 2005). Although the application window is narrow for pre-emergence herbicides. However, the efficacy of pre-emergence herbicides can vary from molecule to molecule and the operating environmental condition (Mahajan and Chauhan 2013). Therefore, farmers need chemicals having high efficiency, no phyto-toxicity to rice. Since, area under DSR is rapidly increasing and weeds are the major constraints, generation of data on the effect of herbicide under DSR system is essential. Considering the above fact, the present experiment was done to assess the relative bio-efficacy of pre-mix herbicide molecule pyrazosulfuron + pretilachlor for broad spectrum weed control.

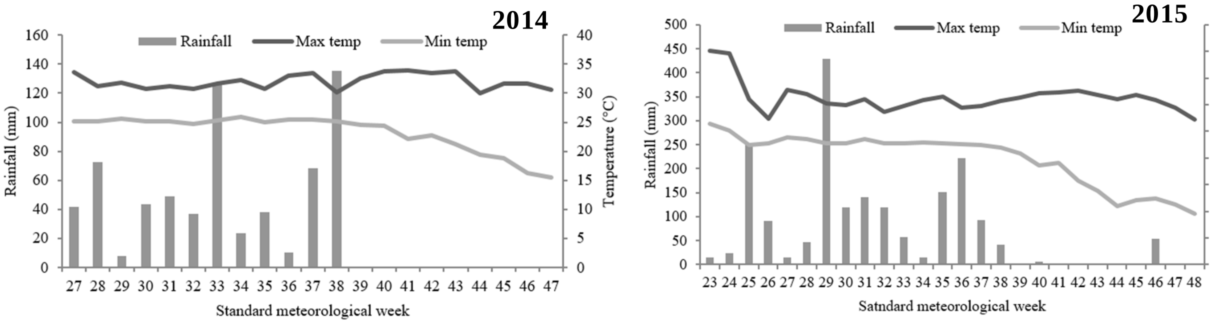

Figure 1. Maximum and minimum temperature, and rainfall during the growing season 2014 and 2015

MATERIALS AND METHODS

Two years field study was conducted during 2014 and 2015 at research farm of the ICAR-National Institute of Biotic Stress Management, Raipur (Chhattisgarh). The study area receives average annual rainfall of 1200-1400 mm, with temperature ranged from 12 °C in December to 45 °C in May (**Figure 1**). The soil of the experimental site was loamy texture with 0.34% organic matter, and pH of 6.8. Available N, P and K content in the soil was 217.3, 15.8 and 323.0 kg/ha, respectively. Rice *cv* '*Swarna*' (145 days duration) seeds of 80 kg/ha were sown with hand in rows at 20 × 10 cm planting geometry during both the years. Crop was subjected to 80:60:40 kg N, P_2O_5 and K_2O/ha, P_2O_5 and K_2O were supplied at basal and N was applied with three splits (50% basal, 25% at tillering, and 25% at panicle initiation). The experiment was laid out in a randomized block design with three replications. The details of the treatments and their scheduling are given in **Table 1**. The required amount of herbicides was sprayed using 375 l/ha of water with knapsack sprayer fitted with a flat fan nozzle.

At sampling time (45 and 75 days after sowing; DAS), a quadrate of 50 × 50 cm was placed at two places in each plot to determine the density and dry weight of different weeds. Weed dry weight was recorded after drying the weed samples at 70 °C for 48 h. Weed control efficiency was calculated based on the data recorded at 45 and 75 DAS in rice as per standard formula.

Plant height (cm), tillers/hill, total dry matter (g/hill^2), and leaf area index were measured at flowering stage of the crop. Panicle/m^2, panicle length (cm), filled grains/panicle, panicle weight (g), chaffy grains/panicle, grain and straw yield (kg/ha), and harvest index was recorded just before harvesting. The grain and straw yield was recorded from 5 m^2 area, and rice grain yield was expressed at 14% moisture content. Data were analysed using the PROC GLM in SAS version 9.2 to evaluate the difference between the treatments. Weed density and dry weight were square root transformed, before analysis. However, for better understanding, original values are given in parenthesis. While the ANOVA indicated significant treatment effects, means were separated at $p<0.05$ and adjusted with Fisher's protected least significant difference (LSD) test.

RESULTS AND DISCUSSION

Weed flora

Weed flora of experimental plots were comprised of broad-leaved weeds (BLW) like *Eclipta alba, Eclipta prostrata, Trianthema portulacastrum, Portulaca oleracea, Commelina communis, Commelina benghalensis, Ludwigia parviflora, Parthenium hysterophorus, Physalis minima, Alternanthera sessilis* and *Ageratum conyzoides;* grasses like *Echinochloa colona, Echinochloa crusgalli, Cynodon dactylon, Leptochloa chinensis, Digitaria sanguinalis, Eleusine indica, Dactyloctenium aegyptium,* and *Eragrostis tenella,* and sedges like *Cyperus iria, Cyperus compressus, Cyperus halapan, Fimbristylis miliacea* and *Fimbristylis dichotoma.*

Weed dynamics at 45 and 75 DAS

The effect of weed control treatment and years has significant ($p<0.05$) effect on BLW, grasses and sedges density (**Table 1**). Among the weeds, the BLW density ranged from 23–207/m^2 in 2014 and 17–147/m^2 in 2015 at 45 DAS and 83–323/m^2 in 2014 and 11–208/m^2 in 2015 at 75 DAS. The highest BLW was recorded in weedy plots, whereas lowest density obtained in two hand weeding at 15 and 30 DAS. Similarly, the densities of grasses and sedges followed the trend of BLW and were recorded 23–71/m^2 and 7–96/m^2, respectively in 2014, and 5-53/m^2 and 12-96/m^2, respectively in 2015 at 45 DAS and it was further increased to 44-117/m^2 and 28-77/m^2, respectively in 2014, and 3-99/m^2 and 8-121/m^2, respectively in 2015 at 75 DAS. The weedy check plots had the highest and two hand weeding at 15 and

30 DAS recorded with lowest weed densities. It was measured that among the ready mix of pyrazosulfuron + pretilachlor at 16.88 + 675 g/ha and its higher doses considerably controlled the BLW and grasses, whereas sedges were suppressed in pyrazosulfuron + pretilachlor at 15 + 500 g/ha onwards during both the years. Pyrazosulfuron at 15 g/ha was reasonably effective in controlling BLW during both the years, but pendimethalin and pretilachlor were less effective against BLW.

The total weed density followed the trend of individual group of weeds and it was observed in the range of 51-331/m^2 in 2014 and 36-339/m^2 in 2015 at 45 DAS and 157-517/m^2 in 2014 and 21-428/m^2 in 2015 at 75 DAS (**Table 1**). The lowest total weed density was recorded in two hand weeding at 15 and 30 DAS, whereas, the highest total weed density obtained in weedy check plots during both the sampling time and years. Among the herbicides, the plots treated with pyrazosulfuron + pretilachlor at 15 + 600 g/ha to 30 + 1200 g/ha have almost comparable weed density in 2014 and 2015. Between the years, the total weed density was considerably more in 2014 than 2015. The lonely applied herbicides also performed superior but combination of pyrazosulfuron + pretilachlor at 15+600 g/ha onwards outperformed than others. The weed severity increases in DSR mainly due to the absence of impounding water, dry tillage, and alternate wetting and drying during growth period encourage the multiple flush of weeds (Chauhan 2012, Khaliq *et al.* 2014). It was also noticed that the emergence of some of the weeds, such as *Celosia argentea, Physalis minima* and *Phyllanthus niruri* was delayed in DSR system. Previous study also revealed that grasses and BLW were major problem in DSR system and this further led to shift in weed flora towards difficult-to-control weeds (Singh *et al.* 2006).

Weed dry weight and weed control efficiency at 45 and 75 DAS

The weed dry weight was significantly influenced by weed control treatments and years, it was measured that the weed dry weight ranged from 9.5-63.1 g/m^2 in 2014 and 6.5- 64.9 g/m^2 in 2015 at 45 DAS and 39.4-111.9 g/m^2 in 2014 and 5.1-101.4 g/m^2 in 2015 at 75 DAS (**Table 2**). The highest weed dry weight recorded in weedy plots, whereas two hand weeding at 15 and 30 DAS recorded with minimum. Among the herbicides, pyrazosulfuron + pretilachlor at 30 + 1200 g/ha measured lowest weed dry weight but lower dose of pyrazosulfuron + pretilachlor from 15 + 600 and 16.88 + 675 g/ha also registered the lower weed dry weight during both the years. In 2015, the performance of pyrazosulfuron + pretilachlor at 13.13 + 525 g/ha was also better than

Table 1. Effect of weed management practices on broadleaf weeds, grasses, sedges and total weed density at 45 and 75 DAS in direct seeded rice in 2014 and 2015

Treatment	Broad-leaf weeds		Grasses		Sedges		Total weed density (no./m^2)	
	2014	2015	2014	2015	2014	2015	2014	2015
45 DAS								
Pyrazosulfuron + pretilachlor (13.13+525 g/ha) 6 DAS	11(115)	6(39)	7(53)	4(20)	5(29)	4(16)	14(196)	9(75)
Pyrazosulfuron + pretilachlor (15+600 g/ha) 6 DAS	8(63)	5(27)	5(29)	4(19)	4(15)	4(13)	10(107)	8(59)
Pyrazosulfuron + pretilachlor (16.88+675 g/ha) 6 DAS	7(47)	5(25)	6(32)	5(21)	4(17)	3(11)	10(96)	8(57)
Pyrazosulfuron + pretilachlor (30+1200 g/ha) 6 DAS	7(51)	5(25)	5(24)	4(19)	5(24)	4(12)	10(99)	8(56)
Pyrazosulfuron-ethyl (15 g/ha) 3 DAS	7(47)	8(67)	7(49)	7(55)	5(24)	6(37)	11(120)	13(159)
Pretilachlor (600 g/ha) 3 DAS	11(115)	8(69)	6(35)	7(52)	4(17)	5(24)	13(167)	12(145)
Pendimethalin (1500 g/ha) 3 DAS	12(155)	7(47)	5(29)	7(47)	6(26)	6(33)	15(220)	11(127)
Two hand weeding 15 and 30 DAS	5(23)	4(17)	5(23)	3(7)	2(5)	4(12)	7(51)	6(36)
Weedy check un-weeded	14(207)	12(147)	8(71)	10(96)	7(53)	10(96)	18(331)	18(339)
LSD (p=0.05)	0.99	0.89	1.07	1.40	0.60	1.54	1.05	1.25
75 DAS								
Pyrazosulfuron + pretilachlor (13.13+525 g/ha) 6 DAS	11(233)	8(57)	9(80)	6(31)	7(52)	5(27)	19(365)	11(115)
Pyrazosulfuron + pretilachlor (15+600 g/ha) 6 DAS	10(109)	4(20)	7(51)	4(16)	6(39)	4(17)	14(199)	7(53)
Pyrazosulfuron + pretilachlor (16.88+675 g/ha) 6 DAS	10(96)	4(20)	7(44)	4(17)	5(29)	4(16)	13(169)	7(53)
Pyrazosulfuron + pretilachlor (30+1200 g/ha) 6 DAS	11(112)	4(17)	7(44)	3(11)	6(39)	4(17)	14(195)	7(45)
Pyrazosulfuron-ethyl (15 g/ha) 3 DAS	10(101)	8(64)	9(84)	8(60)	6(41)	6(31)	15(227)	12(155)
Pretilachlor (600 g/ha) 3 DAS	14(199)	10(109)	7(53)	7(48)	7(44)	6(37)	17(296)	14(195)
Pendimethalin (1500 g/ha) 3 DAS	16(245)	11(112)	7(47)	6(36)	8(57)	7(56)	19(329)	14(204)
Two hand weeding 15 and 30 DAS	9(83)	3(11)	7(47)	2(3)	5(28)	3(8)	13(157)	5(21)
Weedy check un-weeded	18(323)	14(208)	11(117)	10(99)	9(77)	11(121)	23(517)	21(428)
LSD (p=0.05)	1.08	1.18	1.23	0.96	1.50	1.16	1.28	1.32

LSD, least significant difference at the 5% level of significance; DAS - Days after sowing; the figures in the parentheses were original values the lonely applied herbicides and all the herbicides applied plots had lower weed dry weight than weedy plot. Pendimethalin alone was less effective than the other herbicides in 2014, whereas, pyrazosulfuron alone was less effective among herbicides in 2015 but all the herbicides were better than weedy plot during both the years.

The weed control efficiency was largely depended on weed dry weight but influenced largely by weed control treatments and years (**Table 2**). The highest weed control efficiency was obtained with two hand weeding at 15 and 30 DAS (84.6% in 2014 and 89.9% in 2015) at 45 DAS, whereas, at 75 DAS, it was 64.5% in 2014 and 90.2% in 2015 followed by pyrazosulfuron + pretilachlor at 30 + 1200 g/ha (65.9 and 81.5%, respectively at 45 DAS). Plots treated with pyrazosulfuron + pretilachlor at various doses were almost comparable to each other (61.6 - 65.9%) except to pyrazosulfuron + pretilachlor at 13.13 + 625 g/ha in 2014. Plots treated with pyrazosulfuron + pretilachlor from lowest to highest dose had difference of only 5.9% in 2015, but in 2014, gap was wider with 15.9%. It clearly indicated that the performance of pyrazosulfuron + pretilachlor was better in 2015 than 2014. It was visualized (**Table 2)** that weed control efficiency in 2014 at 75 DAS was decreased from the initial sampling at 45 DAS, this was due to poor control of weeds, which suppressed the crop and weeds become more dominant. In contrary to this, in 2015, the weed control efficiency at 75 DAS increased from 45 DAS, mainly due to better weed suppression at 45 DAS, which encouraged the plants for early canopy closure/ coverage, led to increased weed control efficiency. The better weed control during 2015 was recorded due to timely sowing of crop and herbicide application, which are prerequisite to obtain the better efficacy. In 2014, crops were sown late and coincide with rain events, led to reduction in efficacy of herbicides resulted in poor control of weeds and it further reduced as advancement of crop growth. Previous study reported that sequential application of pre-emergence herbicides followed by post-emergence or tank mixture of two herbicides are more effective against wide spectrum of weed flora. Combining of other herbicide widens the spectrum of weed control (Singh *et al.* 2010). Pre-mix of pyrazosulfuron + pretilachlor increased broad spectrum weed control (grasses, BLW and sedges).

The weed density and dry weight data derived from the study suggest that the application of pretlachlor effectively control grasses and to some extent BLW, but its efficacy was poor on sedges. Pyrazosulfuron applied plots had lesser BLW and sedges, than the grasses. The pre-mix of pyrazosulfuron + pretilachlor had additive effect on controlling wide range of weeds and effective against grasses, broad-leaf and sedges. These findings are also supported by earlier findings which found that combination of compatible herbicides with different mode of action provides wide spectrum weed control (Mahajan and Chauhan 2013, Awan *et al.* 2015).

Crop growth parameters

Plant biometric parameters such as plant height, tillers/hill, total dry matter (g/hill), and leaf area index were significantly ($p<0.05$) influenced by weed control treatments and years (**Table 3**). The rice plants were taller in weedy plots in 2014 and pendimethalin applied plots in 2015, whereas no specific trend was recorded during both the years. The highest tillers/hill, total dry matter/hill and leaf area index was measured in two hand weeding at 15 and 30 DAS followed by pyrazosulfuron + pretilachlor at 30 + 1200 g/ha during 2014 and 2015. Although application of pyrazosulfuron + pretilachlor

Table 2. Effect of weed management practices on weed dry weight and weed control efficiency at 45 and 75 DAS in direct seeded rice in 2014 and 2015

Treatment	Total weed dry weight (g/m^2) at 45 DAS		Total weed dry weight (g/m^2) at 75 DAS		Weed control efficiency (%) at 45 DAS		Weed control efficiency (%) at 75 DAS	
	2014	2015	2014	2015	2014	2015	2014	2015
Pyrazosulfuron + pretilachlor (13.13+525 g/ha) 6 DAS	6.1(37.2)	4.0(16.0)	9.6(92.6)	5.8(33.1)	40.0	75.6	16.7	64.4
Pyrazosulfuron + pretilachlor (15+600 g/ha) 6 DAS	5.0(24.2)	3.8(13.9)	7.5(56.3)	4.0(15.5)	61.6	78.8	49.4	80.7
Pyrazosulfuron + pretilachlor (16.88+675 g/ha) 6 DAS	4.8(22.7)	3.8(13.8)	7.1(50.3)	4.1(16.7)	63.8	78.6	54.6	79.4
Pyrazosulfuron + pretilachlor (30+1200 g/ha) 6 DAS	4.7(21.5)	3.5(12.0)	7.3(53.0)	3.5(12.2)	65.9	81.5	52.4	83.6
Pyrazosulfuron-ethyl (15 g/ha) 3 DAS	5.0(24.7)	5.8(33.2)	8.0(64.3)	6.5(41.3)	60.7	48.5	41.9	55.9
Pretilachlor (600 g/ha) 3 DAS	5.7(32.3)	5.2(27.0)	8.9(78.3)	7.0 (48.8)	48.1	57.8	29.0	48.7
Pendimethalin (1500 g/ha) 3 DAS	6.1(37.3)	4.7(21.6)	8.7(75.7)	6.9(47.8)	40.4	66.6	31.6	50.4
Two hand weeding 15 and 30 DAS	3.2(9.5)	2.6(6.5)	6.3(39.4)	2.4(5.1)	84.6	89.9	64.5	90.2
Weedy check un-weeded	8.0(63.1)	8.1(64.9)	10.6(112)	10.1(101)	-	-	-	-
LSD (p=0.05)	0.69	0.65	0.78	0.96				

LSD, least significant difference at the 5% level of significance; DAS - Days after sowing; the figures in the parentheses were original values

Table 3. Effect of weed management practices on crop growth parameters in direct-seeded rice in 2014 and 2015

Treatment	Plant height (cm)		Tillers/hill		Total dry matter (g/hill)		Leaf area index	
	2014	2015	2014	2015	2014	2015	2014	2015
Pyrazosulfuron + pretilachlor (13.13+525 g/ha) 6 DAS	82.7	98.8	4.5	6.0	15.0	16.8	1.67	2.48
Pyrazosulfuron + pretilachlor (15+600 g/ha) 6 DAS	80.3	96.5	4.8	6.6	16.1	17.9	2.28	2.56
Pyrazosulfuron + pretilachlor (16.88+675 g/ha) 6 DAS	80.3	97.4	5.5	6.5	16.7	18.2	2.30	2.53
Pyrazosulfuron + pretilachlor (30+1200 g/ha) 6 DAS	85.0	100.4	6.1	7.1	16.8	18.2	2.45	2.57
Pyrazosulfuron-ethyl (15 g/ha) 3 DAS	78.0	100.6	4.7	5.8	16.2	15.2	2.18	2.37
Pretilachlor (600 g/ha) 3 DAS	81.3	94.8	4.2	5.3	15.7	15.3	1.89	2.31
Pendimethalin (1500 g/ha) 3 DAS	82.0	100.9	4.1	5.1	15.0	16.3	1.77	2.22
Two hand weeding 15 and 30 DAS	85.7	94.5	6.5	7.5	18.3	19.1	2.50	2.68
Weedy check un-weeded	94.3	88.8	3.3	4.4	13.5	13.4	1.67	1.87
LSD (p=0.05)	5.60	7.84	0.95	1.02	1.12	1.16	0.10	0.12

LSD, least significant difference at the 5% level of significance; DAS - Days after sowing; the figures in the parentheses were original values

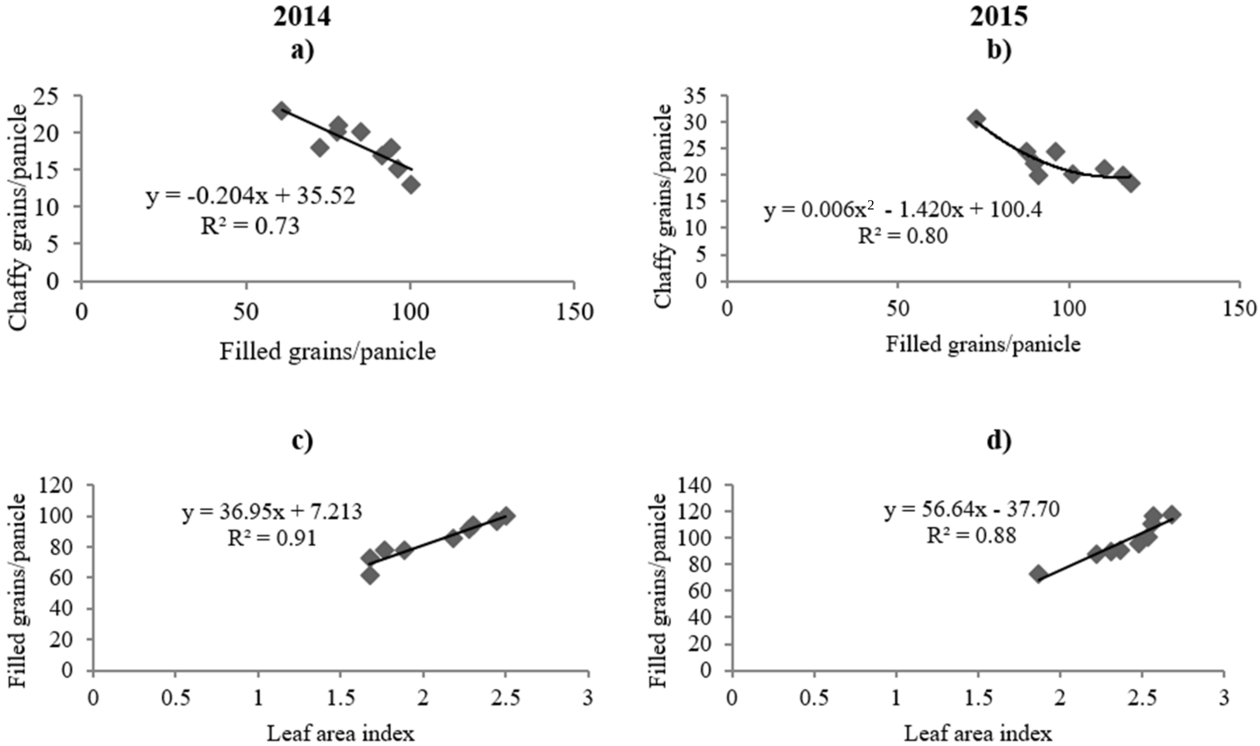

Figure 2. The relationship between filled grains and chaffy grains (a and b), and leaf area index and filled grains/panicle (c and d)

at all the doses improved the crop growth parameters, yet their effect was less pertinent in comparison to two hand weeding at 15 and 30 DAS. In this condition, rice plant may take up optimum water and nutrients led to better crop growth parameters such as plant height, tillers/hill, total dry matter and leaf area index resulting in higher grain yield. Our finding were corroborated with Bloach *et al.* (2005). It was noticed that appropriate use of herbicides not only reduce the weed density and dry weight but also have some additive effect on the crops. Plots treated with pyrazosulfuron + pretilachlor had noticed with taller plants, more tillers/hills, higher total dry matter accumulation/hills and longer and wider leaves led to more leaf area index, which might reduced the further growth and development of weeds. Similarly, in our study it was also noticed that more panicles/m^2, longer and heavier panicles, more numbers of filled grain, and lesser chaffy grains/panicle in rice were measured, which led to higher rice grain yield. Similar reports are also reported by Kumar and Ladha (2011), Khaliq *et al.* (2012), Singh *et al.* (2016). There was strong negative linear relationship between filled grains and chaffy grains in 2014 with R^2=0.73 (**Figure 2a**), and quadratic relationship in 2015 with R^2=0.80 (**Figure 2b**). However, positive linear relationship was established during 2014 and 2015 between leaf area index and filled grains/panicle with R^2=0.91 and 88, respectively (**Figure 2c** and **d**).

Yield attributes

Yield attributes such as panicle length, number of filled grains/panicle, panicle weight and chaffy grains/panicle were influenced by weed management during both the years. It was measured that panicles were longer, more number of filled grains/panicle, heavier panicles and fewer chaffy grains were observed in two hand weeding at 15 and 30 DAS followed by pyrazosulfuron + pretilachlor at 30 + 1200 g/ha (**Table 4**). However, shorter panicles, less filled grains/panicle, lighter panicles and more number of chaffy grains/panicle were noticed in weedy plots. Although pyrazosulfuron + pretilachlor at 15 + 600 g/ha and at 16.88 + 675 g/ha improved these parameters, yet their effect were less pertinent in comparison to two hand weeding at 15 and 30 DAS. The trends were similar during both the years, but, better yield attributes were measured in 2015.

Grain and straw yield

Rice grain yield was significantly ($p<0.05$) affected by the weed control treatments in both the years (**Table 5**). The highest grain yield 2.69 t/ha in 2014 and 5.87 t/ha in 2015 was recorded in two hand weeding at 15 and 30 DAS followed by pyrazosulfuron + pretilachlor at 30 + 1200 g/ha (2.45 and 5.28 t/ha, respectively). The lowest rice grain yield was recorded in weedy plot (1.45 and 2.17 t/ha, respectively). The grain yield in pyrazosulfuron + pretilachlor at 15 + 600 and 16.88 + 675 g/ha was comparable to each other. It was noticed that in 2015 the rice grain yield under pyrazosulfuron + pretilachlor at 15 + 600 g/ha was statistically comparable to two hand weeding at 15 and 30 DAS. It was also recorded that application of single herbicide also improved the grain yield and followed the trend with highest to lowest pyrazosulfuron> pretilachlor>pendimethalin during both the years. In the study, weeds in the weedy plots reduced grain yield by 46.0 to 63.1%. This was corroborated by Singh *et al.* (2007) and Chauhan *et al.* (2012). It was reported that there was >90% of yield loss in DSR (Chauhan and Johnson 2011). Rice grain yield and weed dry weight at 75 DAS had noticed with negative linear relationship during both the years with coefficient of determination of 0.93 in 2014 and 0.97 in 2015 (**Figure 3a** and **b**). Straw yield was significantly ($p<0.05$) influenced under weed control treatments during both the years (**Table 5**). The highest straw yield was recorded with two hand weeding at 15 and 30 DAS (4.07 and 8.71 t/ha, respectively) followed by pyrazosulfuron + pretilachlor at 30 + 1200 g/ha in 2014 and pyrazosulfuron + pretilachlor at 16.88 + 675 g/ha in

Table 4. Effect of weed management practices on yield attributing parameters in direct-seeded rice in 2014 and 2015

Treatment	Panicle length (cm)		Filled grains/panicle		Panicle weight (g/panicle)		Chaffy grains/panicle	
	2014	2015	2014	2015	2014	2015	2014	2015
Pyrazosulfuron + pretilachlor (13.13+525 g/ha) 6 DAS	20.1	21.4	72.3	96.2	1.8	2.2	18.0	24.4
Pyrazosulfuron + pretilachlor (15+600 g/ha) 6 DAS	21.2	21.8	91.7	110.7	2.2	2.4	17.0	21.1
Pyrazosulfuron + pretilachlor (16.88+675 g/ha) 6 DAS	21.6	21.3	94.0	100.9	2.2	2.2	18.0	20.2
Pyrazosulfuron + pretilachlor (30+1200 g/ha) 6 DAS	21.4	21.8	96.3	116.1	2.3	2.4	15.0	20.1
Pyrazosulfuron-ethyl (15 g/ha) 3 DAS	20.6	21.1	85.0	91.2	1.7	2.1	20.0	20.0
Pretilachlor (600 g/ha) 3 DAS	20.5	21.0	77.7	89.9	1.6	2.0	20.0	22.1
Pendimethalin (1500 g/ha) 3 DAS	20.8	20.2	78.0	87.9	1.6	1.7	21.0	24.4
Two hand weeding 15 and 30 DAS	22.6	21.9	100.3	118.0	2.4	2.4	13.0	18.3
Weedy check un-weeded	19.6	19.4	61.0	72.7	1.3	1.6	23.0	30.7
LSD (p=0.05)	0.83	1.00	12.23	18.39	0.30	0.37	4.56	7.74

LSD, least significant difference at the 5% level of significance; DAS - Days after sowing; the figures in the parentheses were original values

Table 5. Effect of weed management practices on grain and straw yield and harvest index in direct seeded rice in 2014 and 2015

Treatment	Grain yield (t/ha)		Straw yield (t/ha)		Harvest index	
	2014	2015	2014	2015	2014	2015
Pyrazosulfuron + pretilachlor (13.13+525 g/ha) 6 DAS	1.68	4.86	2.62	7.63	0.391	0.389
Pyrazosulfuron + pretilachlor (15+600 g/ha) 6 DAS	2.22	5.24	3.43	8.28	0.394	0.387
Pyrazosulfuron + pretilachlor (16.88+675 g/ha) 6 DAS	2.28	4.89	3.49	8.41	0.395	0.366
Pyrazosulfuron + pretilachlor (30+1200 g/ha) 6 DAS	2.45	5.28	3.74	8.01	0.396	0.398
Pyrazosulfuron-ethyl (15 g/ha) 3 DAS	2.11	4.48	3.23	6.91	0.395	0.393
Pretilachlor (600 g/ha) 3 DAS	2.05	4.31	3.15	6.82	0.395	0.389
Pendimethalin (1500 g/ha) 3 DAS	1.85	4.06	2.84	6.37	0.394	0.388
Two hand weeding 15 and 30 DAS	2.69	5.87	4.07	8.71	0.398	0.400
Weedy check un-weeded	1.45	2.17	2.21	5.15	0.396	0.298
LSD (p=0.05)	0.19	0.96	0.27	1.05	NS	0.051

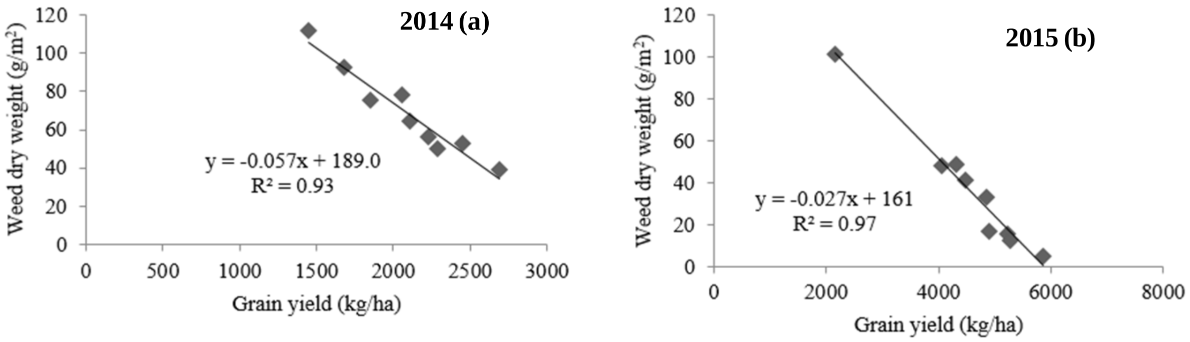

Figure 3. The relationship between grain yield and weed dry weight at 75 DAS (a and b)

2015. The lowest straw yield was recorded in weedy plots (2.21 and 5.15 t/ha, respectively). In DSR, weed control at initial 30 to 45 days are very crucial, owing to slow growth of plants and poor canopy coverage by the crop (Mahajan and Chauhan 2013).

The harvest index was ranged from 0.391-0.398 during 2014, which was statistically comparable, whereas, in 2015 (**Table 5**), it was recorded significantly higher in two hand weeding at 15 and 30 DAS (0.40) followed by pyrazosulfuron + pretilachlor at 30 + 1200 g/ha. The lowest harvest index was recorded in weedy check plot (0.298).

It was concluded that in order to obtain the optimum rice grain yield in DSR system, growers may use two hand weeding at 15 and 30 DAS as per the availability of labours, or the ready-mix of pyrazosulfuron + pretilachlor at 15 + 600 g/ha at 6 days after sowing in order to control the wide spectrum of weeds in the DSR system.

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Effect of tillage, water regimes and weed management methods on weeds and transplanted rice

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ABSTRACT

Field experiments were conducted during 2016 rainy and winter seasons to study the effect of tillage, water regimes and weed management methods on weeds and transplanted rice. The design was split plot with combinations of tillage and water regimes as main plot treatments and weed management methods as subplot treatments. The weed biomass was significantly reduced and the rice performance was superior under intensive tillage (three ploughings followed by (*fb*) puddling), when compared to the conventional farmers' practice of land preparation. Among the water regimes, continuous deep water ponding (> 7.5 cm water) either till panicle initiation or grain filling stage suppressed weed growth better than that under the recommended practice of maintaining about 5 cm water level with intermittent drainage. Weed control efficiency (WCE) was maximum under azimsulfuron 35 g/ha applied at 15 days after transplanting (DAT), followed by pre-plant application of oxyflourfen *fb* one hand weeding at 20 DAT.

INTRODUCTION

The attainment of optimal crop productivity in rice is hindered by several factors, of which weeds are recognized as the major biological constraint. The yield loss caused by weeds resulted from their competition for growth factors, *viz.* nutrients, soil moisture, light, space, *etc.* (Walia 2006, Rao and Nagamani 2010). In order to achieve higher benefits from applied inputs, weeds must be kept below economic threshold level through strategic management practices. Good land preparation, effective water management and use of herbicides are often considered as cost-effective alternatives to manual weeding. Subramanyam *et al.* (2007) reported that intensive puddling with continuous submergence could effectively reduce weed biomass in rice. Varughese (1996) observed that germination of grassy weeds could be effectively prevented by field submergence. According to De Datta (1981) herbicides are the most practical, effective and economical means of weed management in rice. The present study was therefore taken up to evaluate the effect of tillage, water regimes and weed control methods on weeds and crop performance in transplanted rice.

MATERIALS AND METHODS

The field experiment was conducted at the State seed farm, Kottarakkara, Kollam district, Kerala during rainy and winter seasons of 2016. The selected wetlands experienced humid tropical climate and there was a predominance of grassy weeds in the field (**Table 1**). The soil was sandy clay loam in texture with acidic pH (4.52). It was high in organic carbon (1.69%), available N (303.34 kg/ha), available P (13.52 kg/ha) and available K (153.42 kg/ha). The experiment was laid out in split plot design with 3 replications. Combinations of tillage and water regimes were the main plot treatments and weed management methods were taken as the sub-plot treatments. The tillage treatments included were: intensive tillage (three ploughings *fb* puddling) and farmers' practice (two ploughings *fb* puddling). The water regimes were: continuous deep water ponding *i.e.* > 7.5 cm from 7 days after transplanting (DAT) till grain filling stage, deep water ponding *i.e.* >7.5 cm from 7 DAT to panicle initiation and saturation thereafter and maintaining about 5 cm water level with intermittent drainage (KAU 2011). The weed management practices in the subplot treatments were: oxyflourfen 0.15 kg/ha *fb* HW at 20 DAT, azimsulfuron 35 g/ha, bispyribac sodium + metamifop

70 g/ha, fenoxaprop-*p*-ethyl 60 g/ha, hand weeding twice at 20 and 40 DAT and un-weeded control.

The winter crop was taken immediately after the harvest of rainy season crop without disturbing the field layout. The water regimes as per the treatments were maintained by providing 50 cm bunds to avoid seepage between plots. As the experimental site was part of a large block of paddy field, away from natural streams and main canals, the water regime was assumed to be influenced only by the treatments. Among the herbicides, oxyflorfen was applied as pre-plant, three days before transplanting and the other herbicides were given as post-emergence spray at 15 DAT. The composition of the weed spectra in the experimental site was observed initially from composite weed samples collected using quadrats (0.5 x 0.5 m) and the relative density (RD) were computed using the equations developed by Philips (1969). The weed samples from the crop were collected at 15, 30, 45 and 60 DAT and crop growth and yield attributes were taken at harvest. Application of manures and fertilizers as well as the other management practices were done as per the Package of practices (POP) recommendation of KAU (2011).

RESULTS AND DISCUSSION

Effect on weeds

The weed spectra in the experimental field comprised of two grass species, three sedges and eight broad leaved weeds and it was observed that there was a clear predominance of blood grass (*Isachne miliacea* Roth ex Roem. et Schult) in the field (**Table 1**). The weed biomass and WCE data revealed that during both seasons and all stages of observations, intensive tillage involving three ploughings suppressed rice weeds more efficiently than the conventional farmers' practice of land preparation (**Table 2** and **3**), confirming previous reports (Chauhan *et al*. 2014). Arguably, under intensive tillage the weed propagules in soil seed bank which germinated after the initial tillage operations were destroyed during the third round of ploughing and those seedlings which emerged later from deeper layers were less vigorous for establishment.

Rice tolerates low oxygen (hypoxic) conditions better than most weeds and thus flooding has traditionally been used as an effective method for control of many weed species. Hence in the present study also significant influence, of water depth on the weed control efficiency of the management practice, was observed. Irrespective of the seasons, the weed biomass and WCE recorded under deep water ponding were significantly lower than that under the recommended practice of maintaining approximately 5 cm water level with intermittent drainage. Between the two higher water regimes, water impounding till maturity registered comparatively lower weed biomass even though the variation fell short of statistical significance in some of the observations. Juraimi *et al.* (2009) observed that submergence of rice fields hindered weed germination and suppressed the population of most of the germinated weeds. Growth of many of the grass weeds is favoured by saturated and below saturation conditions, while increase in flooding depth and flooding duration encourages broad leaved weeds and sedges (Kent and Johnson 2001). The predominance of the grass species in the experimental site, which are reported to be more sensitive to higher water regimes, must have been another reason for the enhanced WCE of the flooding treatments.

The relative efficiency of the weed management practices during the crop growth period during both seasons was found to be more or less consistent. It was also observed that the weed biomass recorded during the winter season was less than that during rainy season. This was probably because of the carry over effect of the applied treatments, since the

Table 1. Weed flora composition in the experimental field

Family	Scientific name	Common name	Relative density
Araceae	*Cryptocoryne spiralis*	Spiral water trumpet	1.00
Asteraceae	*Eclipta alba*	False daisy	0.25
Commelinaceae	*Cyanotis axillaris (*L.) D. Don	Spreading day flower	0.25
Cyperaceae	*Fimbristylis miliacea*(L.) Vahl.	Globe finger rush	3.00
	Cyperus iria L.	Rice flat sedge	1.00
	Cyperus difformis L.	Umbrellla sedge	1.00
Elatinaceae	*Bergia capensis* L.	Bergia	0.25
Linderniaceae	*Lindernia crustacea* F. Muell.	Malaysian false pimpernel	0.25
Marsileaceae	*Marsilea quadrifolia* L.	Water clover /Water shamrock	2.00
Onagraceae	*Ludwigia perennis* L.	Water primrose	2.00
Poaceae	*Isachne miliacea* Roth ex Roem . et Schult	Blood grass	84.00
	Panicum repense L.	Ginger grass/ Torpedo grass	2.00
Pontederiaceae	*Monochoria vaginalis* (Burm. f.) C. Presl ex Kunth	Pickerel weed	3.00

second crop was taken soon after the rainy season without disturbing the field layout. At 15 DAT the highest WCE was recorded under pre-plant application of oxyflourfen 0.15 kg/ha *fb* one hand weeding but at all the later stages, azimsulfuron 35 g/ha applied at 15 DAT was significantly superior to the other weed control treatments. However at later stages also the pre-emergent herbicide continued to be the next best treatment probably since it involed integration of chemical and physical methods resulting in broad spectrum of weed control as observed by Sahu *et al.* (2015). When compared to the weedy check, the other two herbicides, *ie*. (bispyribac sodium + metamifop) and fenoxaprop- *p*-ethyl, also recorded >80% WCE. Similar results on broad spectrum WCE of these herbicides have been reported by several earlier researchers (Abraham *et al.* 2010, Rajagopal 2013, Rana *et al.* 2012, Nithya *et al.* 2012, Raj and Syriac 2016).

Effect on crop performance

The results of the present study were indicative of the importance and significance of efficient weed management for enhancing growth, vigour and yield parameters of rice crop (**Table 4** and **5**). Intensive tillage was found to have significant positive effect on the plant height, number of tillers and dry matter production of rice during both seasons, which could

Table 2. Effect of tillage, water regimes and weed management on total weed biomass (g/m^2) in transplanted rice

Treatment	Rainy				Winter			
	15 DAT #	30 DAT #	45 DAT *	60 DAT *	15 DAT #	30 DAT #	45 DAT *	60 DAT *
Tillage								
Intensive tillage	3.39(11.0)	3.29(13.9)	1.23(29.9)	1.51(49.6)	3.12(9.4)	2.96(11.3)	1.15(25.2)	1.47(43.7)
Farmers' practice	3.95(14.9)	3.90(18.5)	1.34(35.3)	1.59(59.6)	3.79(13.7)	3.53(15.2)	1.29(32.0)	1.55(55.1)
LSD(p=0.05)	0.08	0.13	0.02	0.02	0.06	0.07	0.02	0.02
Water regime								
>7.5cm till grain filling stage	3.54(12.0)	3.34(14.1)	1.23(28.8)	1.48(46.6)	3.23(10.0)	3.00(11.5)	1.16(24.7)	1.44(41.7)
> 7.5cm till PI stage	3.57(12.2)	3.39(14.4)	1.24(29.4)	1.53(50.7)	3.26(10.1)	3.10(11.9)	1.16(24.9)	1.49(49.8)
5 cm with intermittent drainage	3.89(14.7)	4.06(20.1)	1.39(39.6)	1.63(66.6)	3.86(14.5)	3.63(16.3)	1.35(36.2)	1.60(70.3)
LSD(p=0.05)	0.09	0.15	0.02	0.03	0.07	0.08	0.03	0.03
Weed management								
Oxyflourfen 0.15 kg/ha *fb* HW	2.25(4.3)	2.22(4.1)	1.13(14.0)	1.35(24.3)	2.07(3.6)	1.99(3.1)	1.07(12.6)	1.32(23.0)
Azimsulfuron 35 g/ha	3.96(14.8)	1.61(1.7)	0.68(5.1)	0.91(8.5)	3.60(12.1)	1.46(1.2)	0.52(3.6)	0.83(07.1)
Bispyribac Na + metamifop 70 g/ha	3.94(14.6)	3.22(9.7)	1.30(20.3)	1.60(40.5)	3.63(12.4)	2.89(7.9)	1.27(19.1)	1.59(39.2)
Fenoxaprop- *p*-ethyl 60 g/ha	3.90(14.3)	3.84(14.1)	1.39(24.8)	1.65(45.7)	3.80(13.6)	3.38(10.7)	1.37(23.9)	1.65(45.3)
Hand weeding at 20 and 40 DAT	3.96(14.8)	2.92(7.8)	1.15(14.4)	1.54(35.0)	3.76(13.3)	2.58(5.8)	1.10(12.9)	1.52(33.7)
Unweeded control	3.98(15.0)	7.78(59.8)	2.06(117.0)	2.23(173.6)	3.87(14.3)	7.17(50.7)	1.99(99.5)	2.16(148.2)
LSD(p=0.05)	0.10	0.15	0.03	0.04	0.10	0.14	0.03	0.05

DAT- days after transplanting, HW- hand weeding, PI-Panicle initiation, # original figures in parenthesis subjected to $(\sqrt{x+1})$ transformation, *original figures in parenthesis subjected to logarithmic transformation

Table 3. Effect of tillage, water regimes and weed management methods on weed control efficiency (%) in transplanted rice

Treatment	Rainy				Winter			
	15 DAT #	30 DAT #	45 DAT #	60 DAT #	15 DAT #	30 DAT #	45 DAT #	60 DAT #
Tillage								
Intensive tillage	6.34(42.2)	8.94(81.8)	8.79(79.7)	8.78(78.6)	7.48(56.9)	8.93(82.1)	8.96(81.5)	8.91(79.9)
Farmers' practice	4.31(22.0)	8.46(75.8)	8.46(76.0)	8.39(74.3)	5.89(37.0)	8.44(75.9)	8.52(76.5)	8.44(74.7)
LSD (p=0.05)	0.35	0.09	0.09	0.05	0.17	0.05	0.06	0.05
Water regime								
>7.5cm till grain filling stage	5.87(37.2)	8.94(81.6)	8.89(80.4)	8.90(79.9)	7.33(54.2)	8.93(81.8)	9.00(81.8)	8.98(80.9)
> 7.5cm till PI stage	5.85(36.2)	8.92(81.1)	8.85(80.0)	8.79(78.2)	7.27(53.4)	8.89(81.0)	8.99(81.8)	8.89(79.3)
5 cm with intermittent drainage	4.24(23.0)	8.24(73.7)	8.14(73.1)	8.07(71.3)	5.45(33.3)	8.23(74.2)	8.22(73.5)	8.16(71.8)
LSD (p=0.05)	0.43	0.11	0.12	0.06	0.21	0.07	0.07	0.06
Weed management								
Oxyflourfen 0.15 kg/ha *fb* HW	8.82(77.3)	9.78(94.6)	9.56(90.5)	9.51(89.5)	9.18(83.6)	9.81(95.1)	9.58(90.8)	9.51(89.5)
Azimsulfuron 35 g/ha	4.56(22.7)	9.94(97.8)	9.88(96.5)	9.87(96.3)	6.65(44.4)	9.95(98.1)	9.92(97.3)	9.89(96.7)
Bispyribac Na + metamifop 70 g/ha	4.71(23.5)	9.39(87.2)	9.34(86.2)	9.14(82.5)	6.56(43.3)	9.40(87.5)	9.33(86.0)	9.11(82.0)
Fenoxaprop- *p*-ethyl 60 g/ha	4.93(25.1)	9.08(81.5)	9.17(83.2)	9.02(80.3)	6.04(37.3)	9.16(83.0)	9.13(82.4)	8.96(79.2)
Hand weeding at 20 and 40 DAT	4.59(22.7)	9.52(89.7)	9.55(90.2)	9.27(84.9)	6.15(38.7)	9.58(90.8)	9.57(90.5)	9.25(84.6)
Unweeded control	-	-	-	-	-	-	-	-
LSD (p=0.05)	0.44	0.13	0.17	0.10	0.25	0.12	0.08	0.06

DAT- Days after transplanting, HW- Hand weeding, PI-Panicle initiation, #original figures in parentheses subjected to $(\sqrt{x+1})$ transformation

Table 4. Effect of tillage, water regimes and weed management methods on growth attributes of transplanted rice

Treatment	Plant height (cm)		Tillers (no./m^2)		Dry matter accumulation at 60 DAT (t/ha)	
	Rainy	Winter	Rainy	Winter	Rainy	Winter
Tillage						
Intensive tillage	99.7	95.0	422.7	496.1	7.34	8.23
Farmers' practice	92.0	87.9	409.7	475.2	6.92	7.78
LSD (p=0.05)	3.94	2.03	7.44	5.63	0.39	0.24
Water regime						
>7.5cm till grain filling stage	99.2	95.7	430.0	485.6	7.31	8.25
> 7.5cm till PI stage	97.5	92.7	431.6	509.9	7.34	8.18
5 cm with intermittent drainage	90.9	85.9	386.9	461.4	6.74	7.56
LSD (p=0.05)	4.83	2.49	9.12	6.89	0.47	0.30
Weed management						
Oxyflourfen 0.15 kg/ha *fb* HW	97.8	93.3	445.8	549.1	7.93	8.80
Azimsulfuron 35 g/ha	98.3	93.9	470.4	581.4	8.11	9.09
Bispyribac Na + metamifop 70 g/ha	97.1	92.7	458.6	524.5	7.70	8.46
Fenoxaprop- *p*-ethyl 60 g/ha	96.1	91.5	448.4	504.1	7.50	8.29
Hand weeding at 20 and 40 DAT	97.3	93.0	442.1	514.8	7.93	9.10
Unweeded control	88.8	84.3	231.7	240.1	3.61	4.26
LSD (p=0.05)	5.81	0.69	15.55	11.16	0.56	0.30

DAT- Days after transplanting, HW- hand weeding, PI –Panicle initiation

Table 5. Effect of tillage, water regimes and weed management methods on yield attributes and yield of transplanted rice

Treatment	Productive tillers (no./m^2)		Thousand seed weight (g)		Sterility (%)		Grain yield (t/ha)		Straw yield (t/ha)	
	Rainy	Winter	Rainy	Winter	Rainy	Winter	Rainy	Winter	Rainy	Winter
Tillage										
Intensive tillage	398.2	460.2	25.94	25.87	11.57	11.28	5.23	5.92	6.15	6.78
Farmers' practice	383.9	439.8	22.93	22.39	13.63	13.76	4.71	5.37	6.02	6.86
LSD (p=0.05)	5.59	5.38	0.28	0.51	0.29	0.37	0.22	0.13	ns	Ns
Water regime										
>7.5cm till grain filling stage	405.2	450.4	26.19	25.31	11.53	11.38	5.12	5.86	6.30	7.04
> 7.5cm till PI stage	406.4	473.8	24.13	24.32	12.32	12.20	5.20	5.84	6.18	6.78
5 cm with intermittent drainage	361.7	425.9	22.99	22.76	13.95	13.98	4.59	5.23	5.86	6.65
LSD (p=0.05)	6.84	6.58	0.35	0.62	0.35	0.46	0.27	0.16	NS	NS
Weed management										
Oxyflourfen 0.15 kg/ha *fb* HW	420.1	513.5	25.24	24.75	10.93	10.87	5.58	6.30	6.72	7.54
Azimsulfuron 35 g/ha	443.3	543.6	26.23	26.09	9.64	9.41	5.85	6.61	6.73	7.39
Bispyribac Na + metamifop 70 g/ha	433.3	486.2	24.98	24.54	11.45	11.69	5.24	6.01	6.70	7.29
Fenoxaprop- *p*-ethyl 60 g/ha	422.3	466.2	24.77	24.24	11.88	12.16	5.15	5.78	6.48	7.07
Hand weeding at 20 and 40 DAT	416.5	477.6	25.05	24.36	11.09	11.24	5.65	6.37	6.64	7.70
Unweeded control	211.1	213.1	20.35	20.81	20.59	19.73	2.35	2.79	3.25	3.93
LSD (p=0.05)	10.54	11.37	0.64	1.08	0.46	0.65	0.34	0.23	0.59	0.41

DAT- Days after transplanting, HW- Hand weeding, PI –Panicle initiation

be attributed to the favourable environment created through reduced crop - weed competition as discussed earlier. When compared to the farmers' practice, the plots which received three ploughings recorded significantly more number of productive tillers, thousand grain weight, lower sterility percentage and higher grain yield also while the increase in straw yield was found statistically non-significant. Improvement in growth and yield attributes of rice under reduced resource constraints is well established by earlier workers like Sahu *et al.* (2015).

From the data on effect of water regime on growth and yield attributes of rice, it was evident that when compared to the POP recommendation, the growth attributes were better under the higher levels of water regimes. However, when water ponding was maintained till grain filling stage, the number of tillers was less than that under ponding till panicle initiation stage. Rajagopal (2013) has also reported that in spite of the weed free condition, rice plants under field submergence for longer periods were less vigorous. The positive effect on the yield attributes like number of productive tillers, thousand grain weight and sterility percentage was reflected in the enhanced grain yield also but the improvement in straw yield was non-significant. The beneficial effect of season long weed suppression under deep water ponding on improving crop performance is supported by Ismail *et al.* (2015) who reported that in transplanted rice, under 10, 15 and 20 cm water depth, the yield increase over saturation was to the tune of 84, 85 and 85.5% respectively.

None of the herbicide treatments showed crop phytotoxicity and thus were selective for transplanted rice. The positive effect of reduced weed competition on crop performance was quite evident during both seasons and when compared to the weedy check, all the treated plots recorded significantly superior yield attributes. The maximum values on growth and yield attributes were recorded under azimsulfuron 35 g/ha. During rainy season, the yield enhancement was on par with oxyflourfen 0.15 kg/ha + HW as well as hand weeding twice but was significantly superior to all the other treatments. Evidently reduced competition for growth resources throughout the critical growth stages was helpful in realising the enhanced crop performance. It was also observed that when compared to bispyribac sodium + metamifop and fenoxaprop-*p*-ethyl, crop performance was better under hand weeding twice. However manual weeding being tedious, time consuming and expensive in large scale rice cultivation, farmers are increasingly looking for efficient herbicides for weed management in rice.

It may be concluded that in transplanted rice infested predominantly with grassy weeds, the practices of intensive tillage (three ploughings *fb* puddling) as well as continuous ponding (> 7.5 cm of water) were effective for suppressing weed growth and enhanced crop performance also. Among the herbicides, azimsulfuron 35 g/ha recorded the maximum weed control efficiency and was followed by pre-plant application of oxyflourfen 0.15 kg/ha + one hand weeding.

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Efficacy of propanil for the mixed weed flora in direct-seeded rice

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Weeds

ABSTRACT

A field experiment was carried out at G.B. Pant University of Agriculture and Technology, Pantnagar, U.S. Nagar, Uttarakhand during rainy season of 2015 and 2016 to evaluate the efficacy of propanil 80% WG against mixed weed flora in direct-seeded rice. The most dominant weeds were: *Echinochloa colona, Echinochloa crus-galli, Leptochloa chinensis, Eleusine indica* and *Digitaria sanguinalis* among grassy weeds; Celosia argentea as broad-leaved weed and *Cyperus* spp. as sedge. Results revealed that propanil 4000 g/ha being on a par with 3000 g/ha was found most effective for controlling grassy as well as broad-leaved weeds as compared to other herbicidal treatments. The lowest weed biomass (11.9 g/m2) and the highest weed control efficiency (73.6%) were also recorded with this treatment. Propanil 4000 g/ha being on a par with 3000 g/h recorded maximum grain yield (4.6 t/ha) which was superior to rest of the herbicidal treatments.

INTRODUCTION

Rice (*Oryza sativa* L.) is the leading cereal of the world, and more than half of the human race depends on rice for their daily sustenance (Chauhan and Johnson 2011). It is grown in an area of 43.95 million ha annually with a production of 104.80 mt, with an average productivity of 2.4 t/ha in India (GoI 2015). The crop is conventionally grown by transplanting in puddled soil with continuous flooding. However, this method requires huge amount of water, labour and energy for land preparation, nursery raising, transplanting and weeding leading to high cost of cultivation. Furthermore, puddling also affects soil health due to the dispersion of soil particles, soil becoming compact and making tillage operations difficult requiring more energy in succeeding crops such as wheat (Singh *et al.* 2002 Hobbs *et al.* 2002). An alternative to puddling and transplanting could be aerobic direct seeding because it requires less inputs in term of water, labour and capital.

The direct-seeded crop also matures earlier (7-10 days) than the transplanted crop, thus allowing timely planting of the succeeding wheat crop (Giri1988, Singh *et al.* 2006). However, weed management is the major challenge in direct-seeded rice (DSR). DSR systems are subjected to much higher weed pressure than puddled transplanted rice (PTR) system (Rao *et al.* 2007) in which weeds are suppressed by first puddling, standing water and transplanted rice seedlings, that provide 'head start' over germinating weed seedlings. In DSR, weeds emerge simultaneously with crop seedlings and grow more quickly in moist soil than in PTR (Khaliq and Matloob 2011) resulting in severe competition for resources to the crop. Therefore, weeds present in the field are main biological constraint to the success of DSR and failure to control of weeds result in yield losses ranging from 50 to 90% (Chauhan and Opena 2012). The traditional methods of weed control in rice include handweeding by hoe or hand pulling but this is becoming less common because of labour scarcity at critical period of weeding and increasing labour costs (Chauhan 2012, Kumar and Ladha 2011). Moreover, seedlings of some grassy weeds such as *Echinochloa crus-galli* (L.) look similar to rice seedlings making hand weeding more tedious and highly labour intensive. Farmer's are very often failing to remove weeds due to un-availability of labours at peak periods. However, adoption of DSR technology usually leads to shift in weed flora composition towards difficult-to-control weeds (Singh *et al.* 2013). In this situation, use of herbicides is becoming more popular in DSR because they are more effective, easy to apply, provide selective control and economical (Walia *et al.* 2012).Keeping this in view, the present investigation was carried out to find out the appropriate dose of propanil 80% WG against mixed weed flora and higher yield of direct-seeded rice.

MATERIALS AND METHODS

A field experiment was conducted during rainy season of 2015 and 2016 at G.B. Pant University of Agriculture & Technology, Pantnagar to evaluate the bio-efficacy of propanil 80% WG as post-emergence against mixed weed flora in direct seeded rice. The soil of the experimental site was silty clay loam in texture, medium in organic carbon (0.66%), available phosphorus (27.5 kg/ha) and potassium (243.5 kg/ha) with pH 7.3. Treatments consisted of four doses of propanil 80% WG, *viz*; 1000, 2000, 3000 and 4000 g /ha, oxyflurofen 23.5% EC 240 g/ha and cyhalofop-butyl 10% EC 80 g/ha as standard checks as well as twice hand weeding at 15 and 30 DAS and weedy check. The treatments were laid out in a randomized block design with three replications. All the doses of propanil 80% WG were applied at 12 days after sowing (DAS). However, standard checks, oxyfluorfen 23.5% EC and cyhalofop-butyl 10% EC were applied at two days after sowing with the help of knapsack sprayer fitted with flat-fan nozzle by using 375 litre water/ha. Observations on weed density and weed biomass were recorded at 45 and 75 days after application of treatments. Data pertaining to density and dry weed biomass were subjected to square root transformation ($\sqrt{x+1}$) prior to statistical analysis because big variations were recorded in the data of weed density and weed biomass. Finally weed control efficiency was calculated on the basis of weed biomass recorded at 45 and 75 days after application. Yield attributes and yield (t/ha) of rice were recorded at the time of harvesting. Since propanil 80% WG was the testing molecule and it is not available in the local market, therefore, its sale price is not known. Thus economic analysis part of this research article could not be included.

RESULTS AND DISCUSSION

Effect on weed density

Common weed species infesting the experimental site during both the years were *Echinochloa colona*, *Echinochloa crus-galli*, *Eleusine indica* and *Digitaria sanguinalis* among grasses, *Celosia argentea* as broad leaf weed and *Cyperus* spp. as sedge (**Table 1** and **2**). Among different categories of weeds, sedge was recorded in higher density followed by grassy and broad-leaf weeds at 45 and 75 days after application (DAA) (**Table 1** and **2**). During both the years, density and weed dry biomass at 45 and 75 DAA were significantly reduced by all the weed control treatments over the weedy check. Application of propanil 4000 g/ha being at par with its lower dose 3000 g/ha caused significant reduction in the density of grassy weeds, *viz. E. colona, E. crus-galli, L. chinensis* and *D. sanguinalis* as compared to rest of the herbicidal treatments. The lowest density of *C. argenta* was also recorded with propanil 4000 and 3000 g/ha at 45 and 75 DAA over rest of the herbicidal treatments. All the herbicidal treatments controlled the density of *C. argentea* except cyhalofop-butyl 80 g/ha. All the herbicidal treatments were on a par with each other in reducing the density of *Cyperus* spp. At 45 and 75 DAA, total weed density was significantly reduced by propanil 4000 g/ha which was at par with its lower dose 3000 g/ha and significantly lower than rest of the herbicidal treatments. The effective control of weeds by

Table 1. Weed density as influenced by propanil at 45 DAA in direct-seeded rice (pooled data of 2015 and 2016)

Treatment	Weed density at 45 DAA (no./m^2)							
	E. *colona*	*E. crus-galli*	*E. indica*	*L. chinensis*	*D. sanguinalis*	*C. argentea*	*Cyperus* spp.	Total
Propanil (1000 g/ha)	3.7(12.0)	3.1(8.7)	3.3(10.0)	3.3(10.0)	2.1(4.0)	3.3(10.0)	5.0(27.3)	9.1(82.0)
Propanil (2000 g/ha)	3.4(11.2)	2.9(7.3)	2.8(7.3)	2.7(6.7)	1.8(2.7)	2.8(7.3)	4.9(23.3)	8.0(65.8)
Propanil (3000 g/ha)	2.8(7.2)	2.0(3.3)	2.3(4.7)	1.8(3.3)	1.4(1.3)	2.1(4.0)	4.3(18.0)	6.4(42.0)
Propanil (4000 g/ha)	2.3(4.8)	1.6(2.0)	1.7(2.7)	1.4(1.3)	1.2(0.7)	1.6(2.0)	4.0(15.3)	5.3(28.7)
Oxyflourfen (240 g/ha)	3.3(9.6)	3.9(16.7)	2.9(7.3)	2.7(6.7)	2.7(7.3)	4.0(15.3)	5.3(28.0)	9.5(90.9)
Cyhalofop-butyl (80 g/ha)	4.5(19.2)	5.2(30.7)	3.8(14.7)	2.8(8.0)	2.8(7.3)	5.2(26.0)	5.4(29.3)	11.6(135.2)
Hand weeding at 15 and 30 DAS	2.1(4.0)	1.8(2.7)	1.6(2.0)	1.0(0.0)	1.0(0.0)	1.7(2.7)	2.7(9.3)	4.0(20.7)
Weedy check	6.1(39.2)	7.0(48.7)	4.8(22.0)	8.9(80.0)	4.3(18.0)	6.7(56.0)	6.0(36.0)	17.3(299.9)
LSD (p=0.05)	0.5	0.8	0.3	0.8	0.3	0.5	1.5	0.4

Values within parentheses are original. Data are subjected to square root transformation ($\sqrt{x+1}$) DAA-Days after application

Table 2. Weed density as influenced by propanil at 75 DAA in direct-seeded rice (pooled data of 2015 and 2016)

Treatment	Weed density at 75 DAA (no./m^2)								
	Dose g/ha	*E. colona*	*E. crus-galli*	*E. indica*	*L. chinensis*	*D. sanguinalis*	*C. argentea*	*Cyperus* spp.	Total
Propanil (1000 g/ha)	1000	3.3(10.7)	2.9(8.0)	2.9(8.0)	3.0(8.0)	2.2(4.0)	3.1(8.7)	4.6(24.0)	8.4(71.4)
Propanil (2000 g/ha)	2000	2.8(8.0)	2.6(6.0)	2.5(6.0)	2.6(6.0)	1.6(2.0)	2.6(6.0)	4.5(19.3)	7.3(53.3)
Propanil (3000 g/ha)	3000	2.0(4.0)	1.8(2.7)	1.6(2.0)	1.5(2.0)	1.0(0.0)	1.8(2.7)	3.9(14.7)	5.3(28.1)
Propanil (4000 g/ha)	4000	1.6(2.0)	1.2(0.7)	1.0(0.0)	1.2(0.7)	1.0(0.0)	1.0(0.0)	3.2(9.3)	3.6(12.7)
Oxyflourfen (240 g/ha)	240	3.3(10.0)	3.8(16.0)	2.6(6.0)	2.9(8.0)	2.8(11.3)	3.8(14.0)	5.0(25.3)	9.5(90.6)
Cyhalofop butyl (80 g/ha)	80	4.2(16.7)	4.3(23.3)	2.8(7.3)	2.9(8.0)	2.4(5.3)	4.9(23.3)	5.1(26.0)	10.4(109.9)
Hand weeding at 15 & 30 DAS	-	1.5(2.0)	1.2(0.7)	1.0(0.0)	1.2(0.7)	1.0(0.0)	1.6(3.3)	1.7(2.7)	3.1(9.4)
Weedy check	-	6.0(36.7)	6.3(40.0)	4.2(17.3)	6.4(42.7)	4.4(19.3)	8.1(73.3)	5.7(32.0)	16.1(261.3)
LSD (p=0.05)	-	0.7	0.4	0.7	0.9	0.5	0.6	2.0	1.7

Table 3.Weed dry weight and WCE as influenced by propanil at 45 and 75 DAA in direct-seeded rice (pooled data of 2015 and 2016)

Treatment	Weed dry weight (g/m^2)									
	45 DAA				WCE (%)	75 DAA				WCE (%)
	Grasses	BLW	Sedges	Total		Grasses	BLW	Sedges	Total	
Propanil (1000 g/ha)	8.5(72)	3.8(14)	9.9(99)	13.6(186)	65.2	10.2(104)	4.0(16.1)	10.9(120)	15.5(240)	55.3
Propanil (2000 g/ha)	8.4(71)	3.2(10)	9.5(90)	13.0(171)	68.0	9.9(98)	3.6(13.2)	10.9(118)	15.2(230)	57.1
Propanil (3000 g/ha)	6.0(37)	2.3(5)	8.6(87)	11.3(129)	75.9	7.5(57)	2.6(6.9)	10.2(103)	12.9(167)	68.9
Propanil (4000 g/ha)	5.6(31)	1.8(3)	8.9(80)	10.7(115)	78.6	6.7(45)	2.0(4.2)	9.6(93)	11.9(142)	73.6
Oxyflourfen (240 g/ha)	9.8(97)	7.6(58)	10.1(102)	16.1(258)	51.6	12.1(147)	6.7(44.4)	11.5(133)	18.0(324)	39.6
Cyhalofop butyl (80 g/ha)	11.6(134)	5.4(29)	9.9(99)	16.2(262)	50.9	12.7(162)	6.0(36.2)	12.4(153)	18.7(351)	34.5
Hand weeding at 15&30 DAS	4.8(23)	2.3(5)	5.5(30)	7.6(58)	89.1	4.8(23)	3.1(9.65)	7.8(61)	9.7(94)	82.5
Weedy check	13.2(174)	4.9(24)	18.4(337)	23.1(535)	-	14.1(200)	8.1(65.9)	16.5(271)	23.2(537)	-
LSD (p=0.05)	2.1	0.7	1.2	1.5	-	1.9	0.8	0.7	0.8	-

Values within parentheses are original. Data are subjected to square root transformation ($\sqrt{x+1}$) DAA-Days after application

propanil can be explained by its mode of action as it is an inhibitor of photosynthesis at photosytem II by binding to D1 proteins of the photosystem II complex in chloroplast thylakoid membrane. Thus, herbicide bind at this protein which blocks electron transport and stops CO_2 fixation and production of energy needed for plant growth. Blocking electron transport in PS II systems promotes the formation of highly reactive molecules that initiate a chain of reactions causing lipid and protein membrane destruction resulted in membrane leakage allowing cells and cell organelles to dry and rapidly disintegrate. Significantly the lowest biomass of grassy and broad leaf weeds and the highest weed control efficiency (78.6 and 73.6%) were recorded with propanil 4000 g/ha which was on a par with its lower dose of 3000 g/ha and statistically superior over rest of the herbicidal treatments at both the stages of observations (**Table 3**). Among the herbicidal treatments, the maximum total dry weed mass and the lowest weed control efficiency was recorded with oxyfluorfen 240 g/ha and cyhalofop-butyl 80 g/ha. Similar results were also reported by Harding *et al.* (2012).

Table 4. Effect of propanil 80% WG on yield attributing characters and yield of direct-seeded rice (pooled data of 2015 and 2016)

Treatment	No. of tillers /m^2	No. of grains/ panicle	Wt. of grains/ panicle (g)	1000-grain wt. (g)	Yield (t/ha)
Propanil (1000 g/ha)	193	100.8	1.7	21.9	2.8
Propanil (2000 g/ha)	213	105.0	2.5	22.1	3.1
Propanil (3000 g/ha)	243	115.9	3.0	23.9	4.4
Propanil (4000 g/ha)	258	116.5	3.1	24.6	4.6
Oxyflourfen (240 g/ha)	177	93.0	0.4	21.0	3.5
Cyhalofop butyl (80 g/ha)	163	91.5	0.3	21.2	2.4
Hand weeding at 15&30 DAS	263	120.0	2.9	24.2	4.3
Weedy check	57.3	42.5	1.6	19.2	1.7
LSD (p=0.05)	16.9	9.6	0.3	1.5	1.1

DAA-Days after application

Effect on crop

Pooled data revealed that average number of tillers/m^2, number of grains/panicle, weight of grains/ panicle; 1000-grain weight and grain yield were improved significantly by all the herbicidal treatments over weedy check (**Table 4**). These yield attributes were superior in plots treated with propanil 4000 g/ha (closely followed by its lower dose 3000 g/ha) as compared to rest of the herbicidal treatments. Among the herbicidal treatments, the highest grain yield of rice (4.6 t/ha) was recorded with propanil 4000 g/ha being on a par with its lower dose of 3000 g/ha and twice hand weeding at 15 and 30 DAS. On an average, uncontrolled weeds in weedy check plots caused yield reduction to the extent of 63.0 and 61.4 % when compared with propanil 4000 and 3000 g/ha. The lowest grain yield of 2.4 t/ha was recorded with cyhalofop-butyl 80 g/ha as compared to rest of the herbicidal treatments. These results are also in conformity with the findings of Abbassi *et al*. (2012).

On the basis of two years study, it can be inferred that post-emergence application of propanil 3000 g/ha could be a standard dose in direct-seeded rice for effective control of weeds and higher grain yield.

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Planting methods and weed management to improve yield in dry-seeded rice

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ABSTRACT

A field experiment was conducted to evaluate the effect of planting methods and weed management in direct dry-seeded rice during summer season of 2012 and 2013 at Agricultural Research Farm, Institute of Agricultural Sciences Banaras Hindu University, Varanasi (Uttar Pradesh). The treatment comprised of five rice planting treatments, *viz*. conventional tillage normal spacing [row to row (R × R) -18 cm], conventional tillage square planting (R×R-20 cm, plant to plant (P × P)-20 cm), conventional tillage paired row (9-27-9 cm), reduced tillage paired row (9-27-9 cm), reduced tillage square planting (R × R -20 cm, P×P-20 cm) in main plot and sub-plot consisted of four weed management treatments, *viz*. weedy, two hand weeding, pendimethalin 1.0 kg/ha *fb* azimsulfuron 17.5 g/ha + bispyribac 25 g/ha (tank mixed) at 15 DAS *fb* one hand weeding (HW), oxadiargyl 50 g/ha *fb* metsulfuron-methyl 2 g/ha + chlorimuron-ethyl 2 g/ha (ready mix) at 20 DAS *fb* 1 HW. Significant reduction in weed density and biomass was recorded in two hand weeding fb pendimethalin 1.0 kg/ha fb azimsulfuron 17.5 g/ha + bispyribac 25 g/ha (tank mixed) at 15 DAS *fb* 1 HW which resulted in improved growth and yield attributes and yield of rice. Amongst rice planting methods, conventional tillage normal spacing (R × R -18 cm) and conventional tillage paired row (9-27-9 cm) were able to compete with weeds more as compared to other rice planting methods resulting in lower weed density and weed biomass, enhanced rice growth and yield attributing characters and yield.

INTRODUCTION

In recent years, dry-seeded rice (DSR) has been introduced as an alternative to puddled-manually transplanted rice in India. At present, 23% of rice is direct-seeded globally (Rao *et al.* 2007). DSR needs only 34% of the total labour requirement and saves 29% of the total cost of transplanted crop (Ho and Romli 2000). However, heavy weed infestation is one of the major constraints in DSR causing severe yield losses especially in dry field conditions (Rao *et al.* 2007). Yield losses due to weeds varied from 40-100% in direct-seeded rice (Choubey *et al.* 2001). In dry-seeded rice, weed flora tends to be more diverse and weeds emerge in several flushes during the crop growth cycle.

Rice planting methods play an important role in influencing weed and crop growth and productivity. Mahajan and Chauhan (2011) observed that paired row planting pattern (15-30-15-cm row spacing) in DSR had a greater influence on weeds as compared to normal row planting system (23-cm row spacing). Paired row planting greatly facilitates weed suppression by maintaining rice plant's dominant position over weeds through modification in canopy structure. Roy *et al.* (2009) also reported that the yield of DSR can be enhanced with square planting (20 × 20 cm).

Chemical method of weed control is the most practical and cost-efficient (Bastiaans *et al.* 2008) and is an essential tools to control weeds in DSR. Most of the herbicides recommended for DSR are applied as pre-emergence to control weeds during initial period; however, a combination of herbicides may be more effective to control various flushes of weed. In general, herbicides used in DSR have a narrow weed control spectrum and do not provide season-long weed control. Azimsulfuron and ethoxysulfuron were found to effectively control a wide range of broad-leaf weeds and sedges (Walia *et al.* 2008), while pendimethalin was effective on grasses, and oxadiargyl on broad-leaf weeds (Ahmed and Chauhan 2014). The sequential application of pendimethalin and bispyribac sodium effectively controlled *Echinochloa* sp. and *Digitaria sanguinalis* while the control of *Eragrostis* spp. and *Leptochloa chinensis* was poor (Brar and Bhullar 2012). Singh *et* *al*. (2015) reported 14-27% less rice grain yield with pendimethalin followed by bispyribac-sodium compared with the weed-free check due to biomass of weeds that escaped the herbicide applications. Mehta *et al*. (2010) reported good control of *E. crus-galli* with application of bispyribac-Na 30 g/ha, while azimsulfuron17.5 g/ha was effective on broad-leaf weeds and sedges including *Cyperus rotundus*. Therefore, for managing mixed type of weed flora, herbicides mixtures may be needed for broad-spectrum weed control. Hence, an experiment was conducted to study the effect of planting methods and weed management practices on weeds and the crop growth in dry-seeded rice.

MATERIALS AND METHODS

A field trial was conducted at Institute of Agricultural Sciences, Banaras Hindu University, Varanasi ($25^0$18'N latitude and $88^0$36'E latitude at an altitude of 129 metres above the mean sea level), Uttar Pradesh (India) during summer seasons of 2012 and 2013. Climatologically, the region has a subtropical climate and is subjected to extremes of weather conditions *i.e*., extremely hot summer and cold winter. The area also receives some winter showers due to western disturbances during December to February. The maximum temperature usually fluctuates between 22 °C and 40.7 °C while minimum temperature varied from 8.6-29.9 °C. Total rainfall of 715.8 mm and 1137.7 mm was received during rice crop seasons of 2012 and 2013, respectively.The soil of the experimental field was sandy clay loam in texture, slightly alkaline in reaction (pH 7.56) with low organic carbon content (0.43%) and available nitrogen (183.6 kg/ha), and medium in phosphorus (18.6 kg/ha) and potassium (218.9 kg/ha). Rice cultivar '*MTU 7029*' was direct-seeded and the experiments were laid out in a split plot design on 28^{th} June 2012 and 26^{th} June 2013 with 20 treatment combinations replicated thrice.

Main plot consisted of five planting methods treatments, *viz*. i) Conventional tillage normal spacing [row to row (R × R) -18 cm)]; ii) Conventional tillage square planting [(R × R-20 cm, plant to plant (P × P)-20 cm)]; iii) Conventional tillage paired row (9-27-9 cm); iv) Reduced tillage paired row (9-27-9 cm); v) Reduced tillage square planting (R × R -20 cm, P×P-20 cm) and sub-plot consisted of four weed management treatments, *viz*. weedy, two hand weeding (HW) at 20 and 40 DAS , pendimethalin 1 kg/ha pre emergence(1- 3 DAS) followed by (*fb*) azimsulfuron 17.5 g/ha +bispyribac 25 g/ha (tank mixed) at 15 DAS *fb* 1 HW at 40 DAS, oxadiagryl 50 g/ha pre-emergence(1- 3 DAS) *fb* metsulfuron-methyl 2 g/ha + chlorimuron-ethyl 2 g/ha at 20 DAS *fb* 1 HW at 40 DAS.

The seed was sown manually in paired and square planting at appropriate planting geometry with the help of *Kudal* (local iron made tool fixed with wooden handle for furrow maker) whereas in conventional tillage plots, seeds were sown with zero till seed drill implement. In conventional tillage plots the seeds bed was prepared by deep ploughing followed by two harrowing. In reduced tillage plots the field was harrowed once followed by sowing of rice seeds. A uniform fertilizer dose of 120, 60 and 60 kg N, P_2O_5 and K_2O/ha in the form of urea, single super phosphate and muriate of potash was applied to each experimental unit. Half dose of nitrogen and full dose of phosphorus and potassium were applied as basal to rice crop at the time of sowing. The required quantity of herbicides were applied with manually operated knapsack sprayer fitted with flat-fan nozzle using spray volume 300 L water/ha. Weed density and bio-mass were recorded at 60 DAS and at harvest stages, with the help of a quadrate (0.5 x 0.5 m) placed randomly at two spots in each plot. All the biometrical observations on crop and weeds were observed as per the standard practices. The crop was harvested at full physiological maturity, sun-dried for a week and threshed manually. All the data were subjected to analysis of variance and treatment means were compared using LSD (p=0.05) (Gomez and Gomez 1984). The data on weed density and weed biomass were subjected to square-root ($\sqrt{X+1}$) transformation before statistical analysis to normalize their distribution.

RESULTS AND DISCUSSION

Effect on weed

Major weed species present in experimental field were *Cynodon dactylon* (4%), *Echinochloa colona* (21%), *E. crus-galli* (11%) among grasses; *Cyperus iria* (10%),*Cyperus difformis* (9%), *Fmbristylis miliacea* (2%) among sedges and *Ammania baccifera* (7%), *Caesulia axillaris*(12%), *Commelina benghalensis* (5%), *Eclipta alba* (3%) and *Ludwigia parviflora* (13%) among broad-leaved weeds and other minor weeds were approximately 3%.

The rice planting methods had significant effect on total weed density at 60 DAS and at harvest during both the years (**Table 1**). The minimum weed density was recorded under CT paired row method which was found significantly superior to CT normal spacing at 60 DAS. However, both treatments were at par with each other, at harvest stage during both the years. Paired row planting might have facilitated weed suppression by maintaining rice plant's dominant position over weeds through modification in canopy structure. Similar findings were also reported by Mahajan and Chauhan (2011) wherein paired row spacing stressed weeds more as compared to conventional method of sowing. The maximum weed density was recorded under RT square planting method followed by CT square planting and RT paired row method during 2012 and it was at par during 2013 at 60 DAS. Nevertheless, at harvest stage, the maximum weed density was found in RT square planting method which was at par with CT square planting and RT paired row rice planting method during both the years. Amongst weed management treatment, the minimum weed density and biomass was recorded under two hands weeding, which was significantly superior over other weed management treatments during both the years. However, all the weed management treatments were superior to weedy which recorded lower density of weeds during both the years. Similar finding was reported by Rana *et al.* (2016)

At 60 DAS, the minimum weed biomass was recorded in CT paired row planting which was at par with CT normal spacing rice planting methods during both the years. However, at harvest stage, the minimum weed biomass was recorded in CT square planting which was significantly superior over rest of the methods during 2012 and it was at par during 2013. Further, at 60 DAS, RT square planting recorded the maximum weed biomass which was at par with CT square planting during both the years. However, at harvest stage, weed biomass was significantly higher in RT square planting than other rice planting methods during 2012. During 2013, RT square planting and CT square planting had statistically comparable weed biomass with each other.

The highest weed control efficiency (WCE) was recorded in CT paired row method followed by CT normal spacing at 60 DAS and at harvest stages (**Table 1**). Amongst weed management practices, highest WCE was recorded in two hand weeding treatment followed by pre- emergence application of pendimethalin 1.0 kg/ha followed by post-emergence application of azimsulfuron 17.5 g/ha+ bispyribac 25 g/ha at 15 DAS *fb* one HW. These results corroborated with previous findings of Mahajan *et al.* (2014), who reported lowest weed biomass in paired row planting coupled with sequential application of pendimethalin followed by bispyribac-sodium.

Table 1. Effect of rice planting and weed management methodson weed density, weed biomass, weed control efficiency of weeds (no./m^2) at 60 DAS and at harvest of dry-seeded rice

Treatment	Weed density (no./m^2)		Weed biomass (g/m^2)		Weed control efficiency (%)	
	2012	2013	2012	2013	2012	2013
Rice planting method at 60 DAS						
CT Normal Spacing(R × R -18 cm)	6.74(62)	6.94(63)	13.4(249)	13.7(250)	67.6	63.3
CT Square planting(R × R-20 cm, P × P-20 cm)	6.84(63)	7.15(66)	15.7(327)	15.8(333)	63.7	61.4
CT Paired Row(9-27-9 cm)	5.86(45)	6.30(49)	13.4(226)	13.4(227)	68.9	68.4
RT Paired Row(9-27-9 cm)	6.78(61)	7.13(68)	14.5(280)	14.7(286)	66.1	62.3
RT Square Planting(R × R -20 cm, P×P-20 cm)	7.24(67)	7.58(70)	16.4(365)	16.6(371)	62.0	54.7
LSD (p=0.05)	0.38	0.45	0.98	1.11		
Weed management at 60 DAS						
Pendimethalin *fb* azimsulfuron + bispyribac *fb* 1 HW	6.28(40)	6.50(42)	16.1(266)	16.4(270)	53.9	51.0
Oxadiagryl *fb* metsulfuron + chlorimuron *fb* 1 HW	7.01(49)	7.43(55)	17.8(322)	18.0(328)	43.9	44.1
Two hand weeding	1.38(2)	1.82(3)	0.7(0)	0.7(0)	99.1	100
Weedy	12.1(146)	12.3(152)	23.7(571)	23.9(576)	0.0	0.0
LSD (p=0.05)	0.36	0.41	0.74	0.90		
Rice planting method at harvest						
CT Normal Spacing(R × R -18 cm)	4.78(30)	5.31(35)	11.8(192)	12.0(199)	75.5	74.9
CT Square planting(R × R-20 cm, P × P-20 cm)	5.33(38)	5.80(43)	12.7(224)	13.0(233)	75.1	74.3
CT Paired Row(9-27-9 cm)	4.57(29)	5.18(34)	11.4(178)	11.6(185)	75.7	75.5
RT Paired Row(9-27-9 cm)	5.15(36)	5.64(41)	12.4(211)	12.6(218)	75.5	74.7
RT Square Planting(R × R -20 cm, P×P-20 cm)	5.74(43)	6.12(48)	13.2(241)	13.4(248)	74.1	73.5
LSD (p=0.05)	0.47	0.71	0.32	0.69		
Weed management at harvest						
Pendimethalin *fb* azimsulfuron + bispyribac *fb* 1 HW	4.43(19)	5.06(25)	12.8(165)	13.2(173)	65.6	64.7
Oxadiagryl *fb* metsulfuron + chlorimuron *fb* 1 HW	5.31(28)	5.83(34)	13.8(192)	14.2(201)	60.0	59.1
Two hand weeding	1.10(1)	1.59(2)	0.7(0)	0.7(0)	100	100
Weedy	9.61(92)	9.95(99)	21.9(480)	22.1(492)	0.0	0.0
LSD (p=0.05)	0.25	0.38	0.25	0.52		

DAS=Days after seeding; HW=hand weeding; CT=Conventional tillage; RT= Reduced tillage; Pendimethalin *fb* azimsulfuron + bispyribac *fb* 1 HW = Pendimethalin 1 kg/ha PE *fb* azimsulfuron 17.5 g/ha + bispyribac 25 g/ha 15 DAS *fb* 1 HW; Oxadiagryl *fb* metsulfuron + chlorimuron *fb* 1 HW = Oxadiagryl 50 g/ha (Pre.) *fb* metsulfuron-methyl 2 g/ha + chlorimuron-ethyl 2 g/ha 20 DAS *fb* 1 HW

Effect on crop

Significantly, higher rice dry matter accumulation was recorded under CT normal spacing which was at par with CT paired row rice planting methods whereas RT paired row rice planting method resulted in lower dry matter accumulation (**Table 2**). This may be due to reduced competition by weeds in these treatments. CT paired row rice planting method registered the maximum number of tillers which was at par with RT paired row method. LAI was observed maximum under CT paired row rice planting method which was at par to CT square planting, CT normal spacing and RT paired row and significantly superior over RT square planting during both the years.

Amongst weed management treatments, two hand weeding had the maximum plant height, dry matter accumulation, number of tillers/m^2 and it was found significantly superior over rest of the treatments during both the years. Two hand weeding treatment had the maximum LAI which was at par to pendimethalin 1.0 kg/ha *fb* azimsulfuron 17.5 g/ha+ bispyribac 25 g/ha 15 DAS *fb* 1 HW and oxadiagryl 50 g/ha *fb* metsulfuron-methyl 2 g/ha + chlorimuron-ethyl 2 g/ha 20 DAS *fb* 1 HW treatment. Tank mixture of herbicides had broadened the spectrum of weed control in such a way that each herbicide controls the weeds missed by other one as reported by Kumar and Ladha (2011). At the same time, pre-emergence application of herbicide followed by broad spectrum control of weeds by combination of herbicides and manual weeding might have controlled weeds appearing in several flushes, resulting in better performance of growth attributes in these treatments. Pendimethalin 1.0 kg/ha *fb* azimsulfuron 17.5 g/ha + bispyribac 25 g/ha 15 DAS *fb* 1 HW and oxadiagryl 50 g/ha *fb* metsulfuron-methyl 2 g/ha + chlorimuron-ethyl 2 g/ha 20 DAS *fb* 1 HW treatment was significantly superior over the weedy for all the growth attributes during both the years. The lowest plant height was recorded in weedy check followed by oxadiagryl 50 g/ha *fb* metsulfuron-methyl 2 g/ha + chlorimuron-ethyl 2 g/ha 20 DAS *fb* 1 HW.

Significantly higher number of panicles/m^2 was recorded under CT paired row followed by CT square planting rice planting methods. (**Table 3**) However, significantly higher number of grains per panicle was recorded under RT square planting which was at par with CT square planting and CT paired row planting. CT paired row rice planting method had the maximum test weight which was significantly superior to CT normal spacing.

Two hand weeding treatment resulted in longer panicle length which was at par to pendimethalin 1 kg/ha *fb* azimsulfuron 17.5 g/ha + bispyribac 25 g/ha 15 DAS *fb* 1 HW and oxadiargyl 50 g/ha *fb* metsulfuron-methyl 2 g/ha + chlorimuron-ethyl 2 g/ ha 20 DAS *fb* 1 HW and weedy during 2012. Two hand weeding treatment recorded the maximum number of panicles, number of grains per panicle and test weight followed by pendimethalin 1 kg/ha *fb* azimsulfuron 17.5 g/ha+ bispyribac 25 g/ha 15 DAS *fb* 1 HW treatment. All the weed management treatments showed significantly superior yield attributing characters as compared to weedy during both the years.

Effect on rice yield

Amongst rice planting methods, CT paired row method recorded the maximum rice grain and straw yields which was at par with CT normal spacing, CT square planting and RT paired row method and it was found significantly superior over RT square planting

Table 2. Effect of rice planting and weed management methods on dry-seeded rice plant height (cm), dry matter accumulation (g/running m), no. of tillers/m^2, leaf area index at 60 days after rice seeding

Treatment	Plant height (cm)		Dry matter accumulation (g/running m)		No. of tillers/m^2		Leaf area index	
	2012	2013	2012	2013	2012	2013	2012	2013
Rice planting method								
CT Normal Spacing(R × R -18 cm)	51.0	49.8	96.2	94.8	223.5	222.5	3.13	3.10
CT Square planting(R × R-20 cm, P × P-20 cm)	50.1	49.0	76.5	75.1	217.7	216.8	3.23	3.15
CT Paired Row(9-27-9 cm)	50.7	49.7	95.6	93.4	244.7	243.7	3.34	3.22
RT Paired Row(9-27-9 cm)	49.9	48.9	65.9	64.0	244.0	243.0	2.97	2.89
RT Square Planting (R × R -20 cm, P×P-20 cm)	49.6	48.7	69.8	68.2	207.2	206.3	2.48	2.41
LSD (p=0.05)	NS	NS	2.27	2.60	9.90	10.77	0.39	0.36
Weed management								
Pendimethalin 1.0 kg/ha (Pre.) *fb* azimsulfuron 17.5 g/ha + bispyribac 25 g/ha 15 DAS *fb* 1 HW	51.1	50.0	87.0	85.1	235.4	234.4	3.21	3.14
Oxadiagryl 50 g/ha (Pre.) *fb* metsulfuron-methyl 2 g/ha + chlorimuron-ethyl 2 g/ha 20 DAS *fb* 1 HW	49.2	48.3	70.5	68.4	227.4	226.5	3.15	3.05
Two hand weeding	53.1	52.0	106.7	105.3	287.1	286.1	3.32	3.25
Weedy	47.7	46.6	59.0	53.7	159.8	158.8	2.43	2.37
LSD (p=0.05)	0.75	0.83	3.98	4.15	9.71	9.54	0.20	0.20

*DAS=Days after seeding; HW=Hand weeding; CT=Conventional tillage; RT= Reduced tillage

Table 3. Effect of rice planting and weed management methods on dry-seeded rice yield attributes and yield

Treatment	Panicle length (cm)		No. of panicles/m^2		No. of grains/panicle		Test weight (g)		Grain yield (t/ha)		Straw yield (t/ha)	
	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013	2012	2013
Rice planting method												
CT Normal Spacing (R × R -18 cm)	24.1	24.6	413.7	410.6	115.0	113.7	23.5	23.2	5.8	5.6	8.4	8.2
CT Square planting(R × R-20 cm, P × P-20 cm)	25.2	25.0	427.7	420.8	116.9	115.6	23.3	23.0	5.7	5.5	7.7	7.5
CT Paired Row(9-27-9 cm)	24.7	24.4	481.0	473.7	115.8	114.5	24.2	23.8	5.9	5.7	9.0	8.8
RT Paired Row(9-27-9 cm)	24.9	24.6	382.3	376.3	109.7	108.4	22.2	21.9	5.7	5.5	8.4	8.2
RT Square Planting(R × R -20 cm, P×P-20 cm)	25.0	24.7	350.3	344.2	119.0	117.7	22.4	22.0	5.1	4.9	6.5	6.3
LSD (p=0.05)	NS	NS	17.8	18.2	3.90	4.84	0.6	0.6	.46	.37	1.59	1.6
Weed management												
Pendimethalin 1.0 kg/ha (Pre.) *fb* azimsulfuron 17.5 g/ha + bispyribac 25 g/ha 15 DAS *fb* 1 HW	25.1	24.8	446.7	441.9	125.2	123.7	23.2	22.9	6.5	6.4	8.1	7.9
Oxadiagryl 50 g/ha (Pre.) *fb* metsulfuron-methyl 2 g/ha + chlorimuron-ethyl 2 g/ha 20 DAS *fb* 1 HW	24.5	24.2	407.7	401.1	114.7	113.4	22.0	21.7	6.0	5.8	8.3	8.1
Two hand weeding	25.2	24.9	474.4	467.7	131.9	130.6	25.0	24.7	7.2	7.0	8.7	8.5
Weedy	25.0	24.6	315.2	309.9	89.5	88.1	22.2	21.9	2.8	2.6	6.9	6.7
LSD (p=0.05)	0.44	NS	13.54	13.76	3.60	3.84	0.55	0.65	.37	.41	1.1	1.1

*DAS=Days after seeding; HW=hand weeding; CT=Conventional tillage; RT= Reduced tillage

method during both the years. (**Table 3**). Improved performance of growth and yield attributes in paired row planting might have resulted in realization of enhanced rice grain yield. Similar findings were also reported by Mahajan *et al*. (2014). The maximum rice grain yield (7.2 and 7.0 t/ha) was recorded under two hand weeding treatments during 2012 and 2013, respectively. Rice grain yield recorded in this treatment was followed by pendimethalin 1.0 kg/ha *fb* azimsulfuron 17.5 g/ha + bispyribac 25 g/ha 15 DAS *fb* 1 HW treatment (6.5 and 6.4 t/ha). Integration of herbicidal and manual weeding night have weed control and improved resulted in better performance of growth an yield attributes. The minimum rice grain yield (2.8 and 2.6 t/ha) was recorded under weedy treatment during first and second year, respectively. Two hand weeding treatment recorded the maximum straw yield which was at par with oxadiagryl 50 g/ha *fb* metsulfuron-methyl 2 g/ha + chlorimuron-ethyl 2 g/ha 20 DAS *fb* 1 HW and pendimethalin 1 kg/ha *fb* azimsulfuron 17.5 g/ha+ bispyribac 25 g/ha 15 DAS *fb* 1 HW treatment.

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Morphological characterisation of weedy rice morphotypes of Kerala

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ABSTRACT

Weedy rice (*Oryza sativa* f. *spontanea*) has emerged as a major threat to global rice production and has already established in the major rice growing tracts of Kerala, *viz*. Palakkad, Kuttanad and Kole lands. The main objective of the study was to compare the morphological characteristics of weedy rice morphotypes across the state so as to chalk out morphometric relationship between the weedy and cultivated rice at different stages of plant growth. Different morphotypes of weedy rice were collected from the major rice tracts of the state and characterization was done, both for qualitative and quantitative (morphometric) traits. The study revealed similarity in most of the qualitative traits observed for weedy and cultivated rice. The morphometric characters that varied significantly between weedy and cultivated rice during the initial stages of growth included thickness of culm and length of ligule. Most striking difference observed was in the number of tillers/plant with 87 per cent of weedy rice morphotypes recording higher tiller number (ranged from 11 to 20) compared to cultivated rice (10 and 9 for '*Jyothi* (Ptb-39) and '*Uma-MO-16,* respectively). Studies also revealed that weedy rice plants were lanky, taller (105 to 115.67 cm) with more round culm, with or without anthocyanin pigmentation at the nodal region, short ligule, early flowering compared to cultivated rice, more number of tillers per plant and mostly with awned grains. Similarities between weedy and cultivated rice were found to increase after every cultivating season due to the repeated back crossing and gene flow between the two plant types as evident from compact panicles and awnless grains observed among the morphotypes. As weedy rice invasion reduces crop yield substantially (40-70 percent), its management is an urgent need of the hour. Some of the morphological adaptations exhibited by the morphotypes in response to the prevailing ecological situations clearly indicated the possibility of weedy rice becoming a persistent threat to rice cultivation. Morphological characterization could help in identifying the competitive traits of weedy rice morphotypes which can be used in advanced breeding programmes for developing ecofriendly weedy rice management strategies.

INTRODUCTION

The introgressed product of wild and cultivated rice widely known as weedy rice (*Oryza sativa* f. *spontanea*), was first documented in North Carolina, USA as early as in 1846 (Smith 1981). However, reports of weedy rice emerging as a major weed in the direct-seeded rice tracts of South East Asia appeared after more than a century.In direct seeded rice, this noxious weed emerged as a major threat with its huge seed bank in cropped fields favouring persistent invasion. In Asia, weedy rice infestation was first reported from Malaysia in 1988, Philippines in 1990, and Vietnam in 1994 (Saha *et al*. 2014). In India, the first attempt of identifying and characterizing different types of weedy rice in farmer's field was done in Madhya Pradesh (Varshney and Tiwari 2008). In South India, especially Kerala weedy rice infestation and spread has reached an alarming proportion in major rice tracts during 2007-08. The weed then evolved as a major problem in the rice fields reducing the yield from 30 to 60 per cent at an infestation rate ranging from 3 to 10 mature plants per square metre (Abraham *et al*. 2012). Of late, it has infested large rice growing areas across the major rice belts of Kerala, *viz*. Palakkad, Kuttanad and Kole lands with diverse morphotypes. Weedy rice has competitive advantage over cultivated rice as it grows taller and faster, tillers profusely and competes with cultivated rice for nutrients, water, light and space (Abraham and Jose 2015).It flowers much earlier than cultivated rice and produces grains that shatter easily, favouring soil seed bank. Early shattering of the grain and variable seed dormancy are the important weedy traits favouring its invasion (Chauhan 2013). As weedy rice is morphologically similar to cultivated rice at the early growth stages hand weeding becomes ineffective and incomplete as it mimic cultivated rice. Moreover, the genetic and biochemical similarity of weedy rice to cultivated rice makes herbicidal control impossible. Though the marked visual difference between the plants at the time of panicle emergence in weedy rice (55-65 DAS) favour hand weeding it does not favour yield increase; prevents seed shattering. In this backdrop, the present study on characterization of different weedy rice morphotypes was initiated to study the quantitative (morphometric) and qualitative characters of weedy rice in comparison to cultivated rice.

MATERIALS AND METHODS

Morphological characterization of weedy rice morphotypes was done by conducting pot culture experiments at College of Agriculture, Vellayani, Thiruvnanthapuram during October-January, 2015 and 2016. The experimental field is located at 8^0 25'49'' N latitude and 76^0 39' 04'' E longitudes at an altitude of 29 m above the mean sea level. The experiment was laid out in Completely Randomised Design with eight morphotypes of weedy rice along with two cultivated rice varieties, replicated thrice. The weedy rice morphotypes 1 and 2 were collected from the rice fields of Thiruvananthapuram ($8^0 43'$N,$76^0 99'$E) Kuttanad region in the Alleppey district 3 from kuttanad region ($9^0 35'$N,$76^0 40'$E), 4 from Kole lands of Thrissur district ($10^0 30'$N, $75^0 58'$E), 5 and 6 from Palakkad ($10^0 78'$N,$76^0 65'$E), 7 from Kozhikode ($11^0 25'$N, $75^0 78'$E), and 8 from Kaipad lands (Ezhome) of Kannur ($12^0 04'$N,$75^0 29'$E). The experiment consisted of raising weedy rice morphotypes using seeds collected from the major rice belts of Kerala along with the popular short duration rice variety '*Jyothi-Ptb39'* and the popular medium duration rice variety '*Uma-MO-16*'. Weedy rice seeds were allowed to germinate after breaking dormancy. The pre germinated seeds (two seeds per pot) were sown in earthen pots of 50 cm depth and 30 cm diameter and filled with clayey soil collected from non-infested rice fields. Flooded situation was maintained throughout the growth period and all cultural operations including liming, manuring, fertilizer application and irrigation were followed as per KAU (2011). Pots with weedy rice morphotypes and cultivated rice were raised side by side to observe the morphological differences. Morphometric characters like length of ligule, culm thickness, plant height, number of tillers per plant, days to 50% flowering, panicle length and awn length were observed at periodic intervals and measured quantitatively/recorded for both weedy rice and cultivated rice. Alternatively, qualitative characters like attitude of leaf blade, anthocyanin pigmentation, colour of ligule, pigmentation of awns were scored in as per the Descriptors for wild and cultivated rice (*Oryza* spp.) by Bioversity International, IRRI and WARDA (2007). Attitude of leaf blade was measured as the angle of attachment between the leaf blade and the main panicle axis. Various classes included were erect, semi-erect (intermediate), horizontal and descending. Anthocyanin colouration was measured as the presence and distribution of purple colour (anthocyanin) on the outer surface of the nodes on the culm. The data recorded were subjected to Analysis of Variance techniques (ANOVA) as applied to completely randomized design. The treatment *vs*. control comparison is denoted as 'S' when significant and 'NS' when not significant.

RESULTS AND DISCUSSION

Morphometric characters

Among the morphometric characters, plant height of weedy rice morphotypes ranged between 105 to 115.67 cm, while the height of cultivated rice varieties '*Jyothi-Ptb39'* and '*Uma-MO-16'* were 96 and 91 cm, respectively (**Table 1**). Jose *et al.* (2013) reported that weedy rice variants from Kuttand were usually taller (130 to 145 cm) than cultivated rice. As plant height is a competitive trait in plant communities,taller weeds tend to offer more competition reducing the crop yield. Short varieties are more susceptible to weedy rice competition than tall ones (Saha *et al*. 2014). This taller growth habit of weedy rice results in competition between them for above ground growth factors *ie.*, light, space and other growth resources. Taller weedy rice plant shades and lodge over the rice plants reducing photosynthetic ability and yield of rice. However, some dwarf weedy rice morphotypes were also observed by Jose *et al.* (2013), which might be due to the repeated back crossing between weedy rice and cultivated rice or due to the late emergence from soil seedbank. Chauhan (2013) opined that weedy rice morphotypes were more tolerant to shade than cultivated rice.

Other morphological traits which were analyzed quantitatively were ligule length and culm thickness. Significant variation was observed in the length of ligule during initial stages with 75 per cent of weedy rice morphotypes having smaller ligules compared to cultivated rice varieties. During the initial period up to 15 DAS, shorter ligule could be used as a demarcating character between weedy rice and cultivated rice. However, at later stages this difference becomes less significant. Jose *et al*. (2013) reported that ligule length ranged from 2 to 20 mm at 55 DAS for weedy rice collected from Kuttanad region and in the present study ligule length of 3.7 mm to 13.7 mm was recorded for weedy rice and 9.7 and 6.7 mm, respectively, for '*Jyothi-Ptb39*' and '*Uma-MO-16'* (**Table 1**). Culm of weedy rice exhibited distinct cylindrical appearance measured on the basis of length and breadth of cross section of culm compared to cultivated rice, which usually possesses flattened culm in the vegetative phase. Abraham and Jose (2015) also observed more brittle and round culm for weedy rice types of Kerala compared to cultivated rice. Most of the weedy rice morphotypes recorded higher culm thickness ranging from 2.27 to 3.37 cm compared to cultivated rice varieties (1.93 to 2.27 cm) both at initial as well as later growth stages and this character could be used for differentiation of morphotypes from cultivated rice.

Number of tillers per plant varied widely between weedy rice and cultivated rice (**Table 1**). Higher tiller number was observed in weedy rice compared to cultivated rice during initial as well as later stages of growth. About 87 per cent of weedy rice morphotypes had more tiller count (ranged from 11 to 20) compared to cultivated rice (10 and 9) and the only morphotype from Ezhome recorded less tiller count. Hence, high tiller count could be utilized as a trait to differentiate weedy rice from cultivated rice in specific tracts.

Early flowering was observed in weedy rice morphotypes compared to cultivated rice. Fifty percent of weedy rice population flowered in between 49 to 51 DAS, while '*Jyothi-Ptb39*' and '*Uma-MO-16*' flowered at 61 and 82 DAS (**Table 1**). It was observed that the weedy rice plants had very early flowering in the pot culture compared to that it usually had in the cultivated fields of the region (55-60 DAS), which might be due to the stress for various resources. Early flowering resulted in early grain maturing and seed shattering. Shattered seeds added to soil seed bank would intensify the problem in future (Perreto *et al*. 1993). Early flowering in weedy rice is an additional advantage for its survival in rice fields. The results are in confirmation with the findings of Olguin *et al*. (2007) who observed earliness in panicle emergence and asynchronisation of grain maturity in weedy rice compared to cultivated rice.

Weedy rice had short panicles compared to panicles of cultivated rice and morphotype from Palakkad only recorded more length of 22.13 cm (**Table 1**). This might be due to the early invasion of weedy rice in Palakkad region compared to other tracts and repeated back crossing between the weedy lines and cultivated lines might have imparted longer panicle to weedy population, resembling cultivated rice. Rathore *et al.* (2016) reported that there was marked difference in the panicle length and number of panicles in rice and weedy rice.As per morphometric descriptors of IRRI, panicle type of weedy rice can

Table 1. Comparison of morphometric characters of weedy rice morphotypes and rice varieties

Treatment	Length of ligule (mm)		Culm thickness (cm)		Plant height (cm)	No. of tillers/plant at 50% flowering	Days to 50% flowering	Panicle length (cm)	Awn length (cm)
	15 DAS	50% flowering	15 DAS	50% flowering					
Weedy rice morphotype 1	5.70	11.00	2.43	2.57	108.97	15.67	51.43	17.43	4.31
Weedy rice morphotype 2	10.30	14.00	1.57	3.23	115.67	16.67	51.03	17.67	7.41
Weedy rice morphotype 3	6.70	7.30	2.00	3.37	110.20	13.67	50.36	16.83	3.48
Weedy rice morphotype 4	3.70	5.00	2.40	2.43	110.80	16.00	49.63	16.83	4.11
Weedy rice morphotype 5	4.00	5.30	1.73	2.47	113.27	19.67	50.13	17.57	6.69
Weedy rice morphotype 6	6.00	22.30	2.30	2.57	112.77	13.00	50.19	22.13	2.38
Weedy rice morphotype 7	4.00	4.30	2.07	2.27	108.83	11.67	51.13	16.80	7.36
Weedy rice morphotype 8	13.70	14.30	1.57	2.43	105.07	8.33	50.43	18.17	9.23
LSD (p=0.05)	1.90	1.60	0.41	0.22	2.19	2.68	NS	1.51	0.12
Control									
Cultivar–1 (Jyothi)	9.70	10.30	1.87	1.93	96.17	10.33	61.58	23.00	Absent
Cultivar–2 (Uma)	6.70	7.70	2.20	2.27	91.17	9.00	81.88	23.73	Absent
C-1 vs treatments	S	NS	NS	S	S	S	S	S	-
C-2 vs treatments	NS	S	NS	S	S	S	S	S	-

be compact, intermediate or open.The type of panicle varied among the morphotypes with most of them having open or intermediates panicles unlike compact panicles in cultivated varieties. Kuttanad morphotypes recorded an intermediate panicle type in the present study. However, Jose *et al.* (2013) recorded open or compact weedy rice panicles among the weedy rice variants from Kuttanad. Morphotypes from Thiruvananthapuram, Kole and Palakkad recorded compact type of panicle as that of cultivated rice. This clearly indicated that weedy rice morphotypes of these locations are acquiring characters more similar to cultivated rice by repeated back crossing.

Weedy rice and cultivated rice are usually differentiated with the presence of awns. Most of the cultivated rice varieties lack awns except for few traditional varieties which bear very short awns, while most of the weedy rice morphotypes had awns. Awn length of the weedy rice morphotypes exhibited wide variation and it ranged from 2.38 to 9.23 cm (**Table 1**). These findings are in concurrence with the studies of Jose *et al.* (2013), who reported an awn length of 2.5 to 8 cm for the weedy rice variants of Kerala. It was observed that there was no direct correlation between awn colour and anthocyanin pigmentation at the nodal region. In some cases morphotypes with nodal pigmentation exhibited colourless or white awns and this was in confirmation with the findings of Larinde (1979). Some weedy morphotypes from Thiruvananthapuram and Kuttanad were noticed with reduced or no awns, which might be due to the repeated back crossing between weedy rice and cultivated rice resulting in the absence of that particular character.

Qualitative characters

Among the qualitative characters, attitude of leaf blade was found to vary widely among various weedy rice morphotypes. Most of them exhibited semi erect or intermediate attitude, similar to cultivated rice. Marked difference was recorded by the morphotypes collected from Palakkad and Ezhome, while, that from Kozhikode had erect attitude (**Table 2**). The distribution of the culm angle in weedy rice morphotypes ranging from open to erect suggested that the erect growth habit is recessive to that of a spreading or procumbent growth habit (Adair and Jodon 1973). The presence of erect plant types could be due to back-crossing between accessions or with the commercial rice cultivar (Gealy *et al.* 2006). In the present study, variations in the morphology among morphotypes might be due to the variations in the agro-ecological situations in which the morphotype was developed and/or the rice variety cultivated. As weedy rice emerges by natural hybridization between wild rice and cultivated rice, the weedy rice morphotype present in a location will have characters of the most common cultivated rice variety of that location. Variations observed among morphotypes of the same location corroborated the findings of Estorninos *et al.* (2002) and Chauhan (2013) that weedy rice might vary among different variants. It could also be attributed to the variation in the availability of resources, *viz.*, space, light, moisture, nutrients etc., for plant growth and staggered emergence pattern of weedy rice in cropped field.

Anthocyanin pigmentation at the nodes could also be used as a character to differentiate weedy rice and cultivated rice in Ezhome, which exhibits an intense purple pigmentation at the nodal region (**Table 2**). However, morphotypes from Thiruvananthapuram white, Kuttanad and Kozhikode lacked anthocyanin pigmentation at the nodes. Certain rice varieties, *viz. Purple Puttu* and *Violet Sundhari* also possess anthocyanin pigmentation in the plant parts. As weedy rice morphotypes with and without

Table 2. Attitude of leaf blade and anthocyanin pigmentation of nodes in weedy rice morphotypes and rice varieties

Treatment	Attitude of leaf blade				Anthocyanin pigmentation			
	Erect	Semi erect (intermediate)	Horizontal	Descending	Absent	Purple	Light purple	Purple lines
Weedy rice morphotype 1	-		-	-	-	Thiruvananthapuram red		-
Weedy rice morphotype 2	-	Thiruvananthapuram white	-	-	Thiruvananthapuram white	-	-	-
Weedy rice morphotype 3	-	Kuttanad	-	-	Kuttanad	-	-	-
Weedy rice morphotype 4	-	Kole	-	-	-	-	Kole	-
Weedy rice morphotype 5	-	Palakkad red	-	-	-	-	Palakkad red	-
Weedy rice morphotype 6	-	-	-	Palakkad white	-	-	-	Palakkad white
Weedy rice morphotype 7	Kozhikode	-	-	-	Kozhikode	-	-	-
Weedy rice morphotype 8	-	-	-	Ezhome				
Control								
Cultivar - 1	-	-	Jyothi	-				
Cultivar - 2	-	-	Uma	-				

pigmentation in the nodal region were observed, the presence of anthocyanin pigmentation at the nodal region alone could not be considered as a morphological character for differentiation of rice and weedy rice. In heavily infested areas, cultivating pigmented rice can ease the rogueing of non-pigmented weedy rice from the infested fields.

Colour of ligule is another character which could be used for the differentiation of weedy rice and cultivated rice. Ligule colour ranged between whitish to purple among morphotypes (**Table 3**). The morphotypes from Ezhome, Kozhikode and Kole lands could be differentiated from the cultivated rice using the purple shaded ligule pigmentation. Purple pigmentation in the leaf sheath, leaf margin and culm region of weedy rice morphotypes have been reported by Burgos (2005).

Diversity of awn colour in the same field revealed that weedy rice morphotypes were not structured to a geographical region. Morphotypes collected from Thiruvananthapuram and Palakkad exhibited both white and red awn colour. This can be attributed to the seed contamination of cultivated rice and emergence of weedy rice from soil seed bank. Apart from this, wide variation in awn colour was observed ranging from whitish to black. Morphotype from Thiruvananthapuram and Kuttand had straw coloured awns; Kozhikode with whitish awns; Kole had brown awns; Palakkad had light green and Ezhome possessed purple coloured awns (**Table 3**). Larinde (1979) reported about the variation in awns with short awns or without awns, which might be the result of segregation after natural crossing. In the present study, some morphotypes were observed with very short awns or without awns. Colour of pericarp was mostly varying shades of red in all morphotypes. Repeated back crossing between weedy rice and cultivated rice varieties might have imparted the awnless nature of cultivated rice to weedy rice making it very similar to cultivated rice.

In addition, certain demarcating characters were observed in some weedy rice morphotypes like distinct black ring at the nodal region (morphotype from Palakkad and Kole), characteristic bend at the nodal region (morphotype from Kozhikode), presence of adventitious roots (morphotype from Kuttanad), apiculus colouration (for all morphotypes) and presence of very short awns (morphotype from Thiruvananthapuram).Presence of adventitious roots for morphotypes from Kuttanad helped them to thrive under below sea level rice farming situation of the region. These characters might have emerged as an adaptation to the ecological situation in the prevailing tract. Hence, a thorough knowledge of the ecosystem and cultivation practices of a particular area is essential to differentiate and manage weedy rice in cultivated fields. Microscopic analysis of rice and weedy rice grain surface revealed that grain surface of weedy rice is hairy with trichomes which help for easy dispersal. Jose (2015) has also reported the presence of trichomes and long awns on the surface of weedy rice grains favouring its dispersal through fur of animals, machinery and water. Microscopic analysis also exposed the superior size of pollen sacs of weedy rice compared to cultivated rice variety '*Uma-MO-16*'.

The study documented the existing variations among the weedy rice morphotypes of Kerala and

Table 3. Colour of ligule, panicle type and pigmentation of awns in weedy rice morphotypes and rice varieties

Treatment	Colour of ligule						Panicle type	Pigmentation of awns								
	Ab-sent	Whitish	Yellowish green	Purple	Light purple	Purple lines		Ab-sent	Whitish	Straw	Gold	Brown	Light green	Red	Purple	Black
Weedy rice morphotype 1	-	-	TVM red	-	-	-	Compact	-	-	-	-	-	-	TVM red	-	-
Weedy rice morphotype 2	-	TVM white	-	-	-	-	Inter-mediate	-	-	TVM white	-	-	-	-	-	-
Weedy rice morphotype 3	-	Kuttanad	-	-	-	-	Inter-mediate	-	-	Kuttanad	-	-	-	-	-	-
Weedy rice morphotype 4	-	-	-	-	-	Kole	Compact	-	-	-	-	Kole	-	-	-	-
Weedy rice morphotype 5	-	-	PKD red	-	-	-	Compact	-	-	-	-	-	-	PKD red	-	-
Weedy rice morphotype 6	-	PKD white	-	-	-	-	Inter-mediate	-	-	-	-	-	PKD white	-	-	-
Weedy rice morphotype 7	-	-	-	-	Kozhi-kode	-	Open	-	Kozhi-kode	-	-	-	-	-	-	-
Weedy rice morphotype 8	-	-	-	Ezhome	-	-	Open	-	-	-	-	-	-	-	Ezhom e	-
Control																
Cultivar – 1	-	-	Jyothi	-	-	-	Compact	-	-	-	-	-	-	-	-	
Cultivar – 2	-	-	Uma	-	-	-	Compact	-	-	-	-	-	-	-	-	

PKD: Palakkad; TVM: Thiruvananthapuramm

found that weedy rice had many characters very similar to cultivated rice and it was not possible to differentiate between them using a single character. Similarities between weedy and cultivated rice increased year after year due to the repeated back crossing and gene flow between two plant types. The weedy rice morphotype of Kuttanad and Thiruvananthapuram has acquired characters of cultivated rice like compact and awnless panicles making it so difficult to identify even after flowering. However, a combination of morphological traits could be used for the identification of weedy rice from cultivated rice. There existed high phenotypic diversity in weedy rice accessions across different countries, both within and among geographical regions (Song *et al*. 2014). Of the various quantitative traits studied, length of ligule and culm thickness were significantly different for weedy rice during the early growth stages. It was also observed that most of the weedy rice morphotypes studied had short ligule at early stages, tall plants (105 to 115.67 cm), lanky with more round culm and more number of tillers per plant. Among the qualitative characters studied, anthocyanin pigmentation at the nodal region was not distinct among the morphotypes but weedy rice exhibited earliness in flowering (49-51 DAS), more number of adventitious roots under waterlogged condition, characteristic bend at the nodal region with awned grains possessing apiculus pigmentation. The morphological adaptations exhibited by the morphotypes in response to the prevailing ecological situations clearly indicated the possibility of weedy rice becoming a persistent threat to rice cultivation. The morphological diversity unveiled in the present study will help to elucidate the distinguishing traits of weedy rice that could be used for marker assisted selection programmes for developing more competitive varieties of rice.The study revealed the invasive nature of weedy rice and urgent need to strengthen the seed distribution system to prevent the further spread of the noxious weed. The results of the study calls for urgent adoption of integrated weedy rice management strategies.

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Integrated weed management for control of complex weed flora in direct-seeded upland rice under Southern transition zone of Karnataka

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ABSTRACT

A field experiment was conducted during summer 2014 and 2015 at Agriculture and Horticultural Research Station, Kathalagere Davanagere district (Zone-7, Southern Transition Zone, Karnataka), to study the effect of various weed management practices on weed density, weed dry weight, yield and economics of direct seeded rice. The experiment consists of ten treatments replicated thrice in a randomized complete block design. Among the various treatments, three hand weeding (20,40 and 60 DAS) recorded significantly higher rice grain (4.04 t/ha and 3.64 t/ha) and straw (6.3 t/ha and 6.52 t/ha) yields in 2014 and 2015, respectively and it was found at par with pendimethalin 1.0 kg/ha at 2 DAS *fb* bispyribac sodium 25 g/ha *fb* manual weeding (3.87 t/ha, 6.0 t/ha in 2014 and 3.5 t/ha and 6.4 t/ha in 2015, respectively). Higher net returns and benefit: cost ratio of ` 28965 and 2.0 and ` 41402 and 2.4 in 2014 and 2015, respectively were obtained with pendimethalin 1.0 kg/ha *fb* bispyribac sodium 25 g/ha as post-emergence with manual weeding.

INTRODUCTION

Rice (*Oryza sativa* L.) is one of the most important food crops of the world and it is the staple food of about half the world's population. India is the second largest rice producing country in the world with an area of 43.4 Mha and produced 104.3 Mt of rice with a productivity of 2404 kg/ha (Anonoymus 2016) It is one of the most important food crops of India which is evident from the fact that 29.9% of the total calories comes from this crop (Timmer 2010). Of the four ecologies of rice culture in India, irrigated ecology spreading over 26.54 million ha *i.e.* 58.7% of total acreage (FAI, 2011) contributes to over 75% of production. Rice yield growth has slowed considerably in recent years and has failed to keep up with population growth, leading to shortages and higher prices that have adversely affected the poor. This was demonstrated by the food crisis and the rice price spike experienced in 2008. Clearly, food security remains somewhat tenuous despite the rapid economic growth experienced in many parts of the world (Sushil *et al.* 2010).

Transplanted rice cultivation has become uneconomical due to escalating labour costs and non availability of timely labour. To overcome these problems especially that of human labour involved in transplanting, researchers as well as farmers are looking at mechanical transplanting and direct-seeding options that were developed and adopted widely in South-East Asian countries. In direct-seeded rice, seeds are sown manually in rows on well prepared field requires only 1-2 labour/ha. It eliminates the nursery raising, puddling and transplanting operations and thus 25% (250-300 man hours) of total human labour involved in rice cultivation were reduced making rice cultivation more profitable, with no major problems with respect to water management. Success of dry seeding entirely depends on efficient weed management. The yield loss in DSR is as high as 50-60% due to simultaneous germination of both crop and weeds seeds (Pinjari *et al*. 2016). Weed management in direct-seeded rice can be accomplished by mechanical, cultural and chemical methods. Mechanical method of weed control consisting of repeated weeding and hoeing by use of hand hoe is effective, but labour intensive and reduces the benefit: cost ratio. Hence, for direct-seeded rice, the chemical method of weed management is a good option (Sahu and Singh 2011). Weeds in direct-seeded rice emerge almost at the same time as that of the crop and start competing with crop from very beginning, Hence weed management by herbicide is more critical. Therefore, an experiment was conducted with an objective to find the best herbicide combinations to manage weeds effectively in direct seeded rice.

MATERIALS AND METHODS

A field experiment was conducted during summer 2014 and 2015 to know the bio-efficiency of combination of herbicides against complex weed flora, and their effect on growth and yield of direct seeded rice under upland condition. The field study was conducted at the Agricultural Research Station, Kathalagere, Davanagere District (Zone-7, Southern Transition Zone, Karnataka), under the jurisdiction of the University of Agricultural Sciences, Bengaluru. The soil type was sandy clay loam. The treatment combinations tested were bispyribac-sodium 25 g/ha at 20 DAS, pendimethlain 1000 g/ha (2 DAS) *fb* bispyribac-sodium 25 g/ha at 25 DAS, oxadiargyl 100 g/ha at 2 DAS *fb* bispyribac-sodium 25 g/ha at 25 DAS, pyrazosulfuron-ethyl 20 g/ha at 3 DAS *fb* bispyribac-sodium 25 g/ha at 25 DAS, pendimethlain 38.7 CS, 1000 g/ha (2 DAS) *fb* bispyribac 25 g/ha at 25 DAS *fb* manual weeding at 45 DAS, pendimethlain 1000 g/ha (2 DAS) *fb* manual weeding at 30 DAS, at bispyribac-sodium 25 g/ha + chlorimuron-ethyl + metsulfuron-methyl 4 g/ha at 20 DAS, mechanical weeding (conoweeding at 20, 40 and 60 DAS) hand weeding (20, 40 and 60 DAS), unweeded control. These treatment combinations were replicated thrice in randomized complete block design.

Rice variety '*JGL-1798*' was sown at a common spacing of 20 x 10 cm and fertilizer level of 100 kg N, 50 kg P_2O_5 and 50 kg K_2O/ha. The gross and net plot sizes were 3.6 x 3.0 m and 3.0 x 2.6 m, respectively. The herbicides were applied using spray volume of 500 L/ha and 375 L/ha with knapsack sprayer having flood jet nozzle. The data on species wise weed count in a quadrate of 50 x 50 cm were collected on 30, 60 and 90 DAS (days after sowing). From this, density of major weed species/m^2 (sedges, grass and broad-leaf weeds) was worked. In addition, dry weight of weeds' category – sedges, grass and broad-leaf weeds (g/m^2) was also collected at 30, 60 DAS and at harvest. The data on weeds' density and dry weight were analyzed using transformation of square root of $(\sqrt{x+1})$ and log $(\sqrt{x+2})$, depending on the variability. At harvest, the data on rice yield, straw yield and number of panicles/m^2 were collected. In addition, the economics of weed management practices were also calculated based on the prevalent market prices of the inputs used. The data collected on different traits was statistically analyzed using the standard procedure and the results were tested at five per cent level of significance as given by Gomez and Gomez (1984).

RESULTS AND DISCUSSION

Weed flora

Major weed flora observed in the experimental plots were *Cyperus rotundus* (sedge), *Digitaria marginata, Echinolchloa colona* (among grasses); whereas among broad-leaf weeds, *Borreria articularis, Spilanthes acmella, Commelina benghalensis, Ageratum conyzoides, Euphorbia geniculata* and *Euphorbia hirta* were dominant. Among the weed species, the densities of *Cyperus rotundus, Digitaria marginata, Echinolchloa colona, Spilanthes acmella, Euphorbia geniculata* and *Ageratum conyzoides* were more than other weed species indicating their dominance and competitiveness with the direct-seeded rice in both the years.

Weed density and dry weight

Among different category of weeds, density and dry weight of broad-leaf weeds was higher plots in weedy followed by grasses and sedges at 60 after DAS in weedy (**Table 1**). At 60 DAS, hand weeding at 20, 40 and 60 DAS recorded significantly lowest total weed density in both the years and it was found at par with pre-emergence application of pendimethalin 1000 g/ha *fb* bispyribac-sodium 25 g/ha (20 DAS) *fb* manual weeding (45 DAS) as effectively reduced the density and dry-weight of weeds comparable to other treatments. Oxadiargyl 100 g/ha (3 DAS) *fb* bispyribac-sodium 25 g/ha (20 DAS) and perndimethlain 1.0/ha at 2 DAS *fb* manual weeding (30 DAS) also reduced the weed density and dry weight compared to application of bispyribac-sodium 25 g/ha + chlorimuron-ethyl + metsulfuron-methyl 4 g/ha (20 DAS) and bispyribac-sodium 25 g/ha alone since the latter treatments consisted of post-emergence herbicides. However, all these herbicide treatments significantly lowered the weed density as compared to weedy. Effective control of weeds with combination of pendimethalin 1000 g/ha at 3 DAP *fb* bispyribac-sodium 25 g/ha (20 DAS) *fb* manual weeding (45 DAS) and pyrazosulfuron-ethyl 20 g/ha *fb* bispyribac-sodium 25 g/ha (20 DAS) was noticed at 60 DAS as evident from the reduced weed density and dry weight. These findings were in conformity to Sangeetha (2006) and Brar and Bhullar (2012).

Phytotoxicity

None of the herbicides caused phytotoxicity to rice in terms of yellowing, curling, epinasty, hyponasty, and wilting symptoms in both the years.

Table 1. Weeds density (no./m^2) and weeds dry weight (g/m^2) as influenced by weed management practices in direct-seeded rice at 60 DAS during 2014 and 2015

Treatment	Weed density				Weed dry matter			
	Grasses	Sedges	Broad-leaf	Total	Grasses	Sedges	Broad-leaf	Total
2014								
Bispyribac-sodium	3.88(14.3)	2.21(12.9)	1.51(35.9)	1.79(63.1)	2.66(6.2)	2.72(6.5)	1.29(20.9)	1.53(33.5)
Pendimethalin *fb* bispyribac-Na	2.60(6.3)	1.89(19.6)	1.19(13.5)	1.62(39.4)	1.66(1.9)	2.91(7.7)	0.96(7.2)	1.27(16.8)
Oxadiargyl *fb* bispyribac-Na	2.85(7.3)	1.96(14.6)	1.22(15.9)	1.59(37.8)	1.98(3.0)	2.79(6.9)	1.12(12.0)	1.36(21.9)
Pyrazosulfuron *fb* bispyribac-Na	3.50(12.0)	2.11(10.6)	1.18(16.0)	1.58(38.6)	2.13(3.7)	2.24(4.1)	1.00(9.6)	1.25(17.4)
Pendimethalin *fb* bispyribac-Na *fb* manual weeding	2.29(4.3)	1.81(7.0)	1.21(14.9)	1.45(26.2)	1.42(1.0)	1.86(2.5)	0.96(7.5)	1.11(11.1)
Pendimethalin *fb* manual weeding	2.75(6.7)	1.94(13.0)	1.45(27.8)	1.68(47.5)	1.94(2.8)	2.60(6.2)	1.17(13.6)	1.38(22.6)
Bispyribac + (chlorimuron + metsulfuron)	3.55(12.3)	2.12(16.9)	1.36(21.5)	1.71(50.7)	2.36(4.8)	2.97(8.0)	1.24(15.6)	1.47(28.4)
Three cono weeding	2.05(4.0)	1.73(7.0)	1.09(10.5)	1.35(21.5)	1.38(1.0)	1.85(2.5)	0.87(5.5)	1.03(9.0)
Three hand weeding	1.95(3.0)	1.71(5.9)	1.01(9.9)	1.29(18.8)	1.28(0.7)	1.73(2.0)	0.79(4.7)	0.95(7.4)
Weedy	5.11(27.3)	2.45(42.6)	1.77(57.2)	2.11(127)	4.07(16.9)	5.29(27.3)	1.68(47.0)	1.97(91.3)
LSD (p=0.05)	1.66	0.38	0.36	0.25	1.06	0.82	0.33	0.25
2015								
Bispyribac-sodium	3.87(14.3)	2.20(35.7)	1.63(40.7)	1.96(90.6)	2.90(7.6)	4.71(21.8)	5.73(32.5)	1.80(61.9)
Pendimethalin *fb* bispyribac-Na	2.85(7.3)	1.96(17.7)	1.55(34.0)	1.78(59.0)	1.95(2.9)	2.91(7.6)	4.78(22.1)	1.53(32.6)
Oxadiargyl *fb* bispyribac-Na	2.55(5.7)	1.88(16.3)	1.52(32.3)	1.74(54.3)	1.75(2.1)	2.66(6.7)	4.52(20.4)	1.47(29.2)
Pyrazosulfuron *fb* bispyribac-Na	3.03(8.3)	2.00(17.7)	1.60(39.0)	1.83(65.0)	2.09(3.4)	2.98(8.1)	5.14(26.5)	1.59(38.1)
Pendimethalin *fb* bispyribac-Na *fb* manual weeding	2.10(3.7)	1.75(12.0)	1.47(29.3)	1.66(45.0)	1.49(1.3)	2.31(4.4)	4.08(16.1)	1.36(21.9)
Pendimethalin *fb* manual weeding	3.21(9.7)	2.05(20.0)	1.62(41.0)	1.85(70.7)	2.24(4.2)	3.24(9.6)	5.36(28.3)	1.63(42.0)
Bispyribac-Na + (chlorimuron + metsulfuron)	3.44(11.3)	2.10(24.3)	1.68(47.7)	1.91(83.3)	2.58(5.9)	3.76(13.4)	6.01(37.2)	1.73(56.5)
Three cono weeding	2.84(7.7)	1.95(21.3)	1.68(48.3)	1.89(77.3)	2.05(3.5)	3.45(11.1)	5.72(33.8)	1.68(48.4)
Three hand weeding	2.06(3.3)	1.75(9.7)	1.39(23.3)	1.58(36.3)	1.43(1.1)	2.09(3.4)	3.53(12.1)	1.24(16.6)
Weedy	5.41(29.3)	2.52(43.7)	1.95(88.3)	2.21(161)	4.41(19.1)	5.67(31.4)	9.25(86.6)	2.14(137.1)
LSD (p=0.05)	1.27	0.30	0.21	0.10	0.86	0.80	2.07	0.21

Data within the parentheses are original values; Transformed values - - # log $=\sqrt{x+2}$, + = square root of $(\sqrt{x+1})$; DAS = Days after sowing

Table 2. Number of panicles/m^2 at harvest, rice yield, straw yield (t/ha), weed index and economics of direct-seeded rice as influenced by weed management practices during 2014 and 2015

Treatment	No. of panicles/m^2		Rice grain yield t/h		Straw yield t/ha		Weed index (%)		Net returns (x10^3 `/ha)		B:C Ratio	
	2014	2015	2014	2015	2014	2015	2014	2015	2014	2015	2014	2015
Bispyribac-sodium	197	142	2.83	2.07	4.51	3.73	30.1	43.1	16.86	28.63	1.6	2.1
Pendimethalin *fb* bispyribac-Na	240	209	3.33	3.40	5.22	6.15	17.6	6.5	22.33	42.56	1.8	2.5
Oxadiargyl *fb* bispyribac-Na	228	215	3.22	3.42	5.13	6.21	20.3	6.0	21.42	14.65	1.8	1.5
Pyrazosulfuron *fb* bispyribac-Na	250	207	3.55	3.39	5.59	6.05	12.1	6.8	26.71	31.96	2.0	2.2
Pendimethalin *fb* bispyribac-Na *fb* manual weeding	272	224	3.87	3.55	5.99	6.44	4.4	2.4	28.96	41.40	2.0	2.4
Pendimethalin *fb* manual weeding	206	205	3.00	3.13	4.74	6.04	25.7	14.0	19.62	26.28	1.7	2.0
Bispyribac-Na + (chlorimuron + metsulfuron)	219	183	3.12	2.92	4.97	5.46	22.7	19.7	20.44	31.84	1.7	2.2
Three cono weeding	265	196	3.76	3.10	5.89	5.64	6.9	14.8	27.44	26.89	1.9	1.9
Three hand weeding	289	231	4.04	3.64	6.37	6.52	0.0	0.0	28.70	39.20	1.9	2.2
Weedy	51	60	0.44	0.58	0.75	1.45	89.2	84.0	-17.38	-13.42	0.3	0.4
LSD (p=0.05)	34.72	34.7	0.57	0.55	0.82	0.94	-	-	-	-	-	-

NA: Not analysed; Cost of herbicides: Pendimethalin 38.7 EC - ` 450/700 ml; oxadiargyl 80 WP- ` 248/35 g; chlorimuron-ethyl + metsulfuron-methyl 20 WP (almix 20 WP) - ` 350/20 g; pyrazosulfuron-ethyl 10 WP – ` 250/80 g; bispyribac-sodium 10% SC – ` 560/80 ml; herbicide application cost, ` 500/ha

Grain and straw yield

The data pertaining to number of panicles/m^2, rice grain yield, straw yield and weed index were presented (**Table 2**). Three hand weeding (20,40 and 60 DAS) recorded significantly higher rice grain 4.04 t/ha and 3.64 t/ha and straw yield 6.3 t/ha and 6.52 t/ha in 2014 and 2015, respectively as compared to all other treatments, and it was found at par with pendimethalin 1.0 kg/ha at 2 DAS *fb* bispyribac-sodium 25 g/ha at 20 DAS with manual weeding at 45 DAS (3.87 t/ha, 6.0 t/ha in 2014 and 3.5 t/ha and 6.4 t/ha in 2015) and cono weeding at 20, 40 and 60 DAS (3.76 t/ha, 5.9 t/ha and 3.10 t/ha and 5.64 t/ha) resulted in the lowest rice grain and straw yields (0.44 t/ha, 0.76 t/ha and 0.58 t/ha, 1.45 t/ha) during 2014 and 2015, respectively The increase in rice grain yield over weedy check due to different treatments was attributed to the reduced density and biomass of weeds at all stages of crop growth, which resulted in increased dry matter of rice, number of panicles/m^2 .These results were in accordance with Sangeetha (2006) and Singh and Pairka (2014).

Economics

Among different weed management practices, higher net returns of ` 28965/ha and ` 41402/ha was recorded in the pendimethalin 1.0 kg/ha *fb* bispyribac-sodium 25 g/ha with one manual weeding, during 2014 and 2015, respectively, along with higher benefit: cost ratio of 2.0 and 2.4 in summer 2014 and 2015 (**Table 2**). This result was obtained due to effective weed management at critical stages by integration of effective pre- and post-emergence herbicides along with manual weeding, which resulted in higher grain with reduced cost of cultivation. Similar findings have been also reported by Prameela *et al.* 2015.

It was concluded that integrated weed management consisting of pre-emergence application of pendimethalin 1.0 kg/ha *fb* post-emergence application of bispyribac-sodium 25 g/ha with one manual weeding at 45 DAS in direct-seeded rice was found most remunerative under Southern transition zone of Karnataka.

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Penoxsulam influence on weed control and rice yield and its residual effect on microorganisms and succeeding greengram

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ABSTRACT

Field investigations were carried out at wetland farm, Agriculture College and Research Institute, Tamil Nadu Agricultural University, Coimbatore, during rainy seasons (June to October) of 2014 and 2015 to evaluate penoxsulam on weed control and yield of rice and its residual effect on microorganisms and succeeding greengram crop. Two years of field experimentation, revealed that pre-emergence application of penoxsulam at 22.5 g/ha resulted in significantly lower total weed density, weed biomass and higher weed control efficiency at all the stages. Application of new formulation of penoxsulam (21.7% SC) at 22.5 g/ha as pre-emergence herbicide kept the weed density and biomass below the economic threshold level and increased the grain yield as 5.20 and 5.04 t/ha in 2014 and 2015, respectively in rice. Succeeding greengram crop sown immediately after the rice harvest was not affected by the residue of new formulation of penoxsulam at all tested doses.

INTRODUCTION

Rice (*Oryza sativa* L.) is one of the most important food crops in the world and is consumed by more than 3 billion people (Fageria 2007). It is estimated that, by the year 2025, it will be necessary to produce about 60% more rice than currently produced to meet food needs (Fageria 2007,d GRISP 2013).

The transplanted rice is infested with wide range of weed species during early part of growth stage. Grain yield was drastically reduced if rice crop is not weeded out during early growth stages (Pande *et al.* 1994). Weed control in transplanted rice by mechanical and cultural methods is expensive. Normally two manual weeding are done in lowland rice crop, for which 50 women labours are engaged per hectare. The amount incurred for manual weeding in low land rice works out more than 1200 million for single crop per year in Tamil Nadu alone (Tajuddin and Fellow 2009). Manual weeding although effective and most common practice of weed control in transplanted rice, these have several limitations particularly during peak period, which makes it further problematic. At the time of peak period of labour crisis, delayed weeding causes drastic reduction in rice grain yield. In hand weeding, it is difficult to differentiate and remove the mimic weeds like *Echinochloa colonam* and *Echinochola crus-galli* due to phenotypic similarities between weeds and rice seedlings in the early stages (Rao and Moody 1992).

Therefore, evaluation of new herbicides for wide spectrum control of weed flora is imperative. The present study was undertaken to influence of penoxsulam on weed control and yield of rice and its residual effect on succeeding greengram and microorganisms.

MATERIALS AND METHODS

Field experiments were conducted during rainy seasons (2014 and 2015) at wet land farm of Tamil Nadu Agricultural University in Coimbatore, located at western zone of Tamil Nadu. The geographical location of the experiment site is 11^0 N latitude and 77 ^{0} E longitude with an altitude of 426.7 m above the mean sea level. The soil experimental site was well drained clay loam in texture (44.5% clay, 10.2% silt and 45.7% sand) with low available nitrogen, medium in available phosphorus and high in available potassium. The soil analyzed 234, 15.8 and 467 kg/ha of $KMnO_4$-N, Olsens' P and NH_4OAc-K, respectively with EC of 0.29 dS/m, pH of 8.58 and organic carbon of 0.58%. The experiment was laid out in randomized complete block design (RBD) with nine treatments and replicated thrice. The gross plot and net plot size adopted was 20 m^2 (5.0 x 4.0 m) and 15.75 m^2 (4.5 m x 3.5 m). Short duration rice variety *'ADT 43'* maturing in 100-110 days suitable for cultivation in Tamil Nadu was used for the study. Treatments consisted of pre-emergence application penoxsulam, [new formulation of penoxsulam (21.7% SC by Crystal Crop Production Private Ltd)] at penoxsulam 20, 22.5, 25, 27.5 and 50 g/ha and were compared with standard check butachlor 1000 g/ha, pretilachlor 750 g/ha, hand weeding (25 and 45 DAT) and unweeded check. The herbicides were applied as pre-emergence at third day after transplanting followed by a hand weeding on 30 days after transplanting (DAT). Hand operated knapsack sprayer fitted with a flat-fan type nozzle (WFN 40) was used for spraying the herbicide adopting a spray volume of 500 L/ha. The recommended dose of 130:40:40 kg N, P_2O_5, K_2O/ha in the form of urea, single super phosphate and muriate of potash were applied to all plots uniformly. Hundred per cent single super phosphate and fifty per cent of nitrogen and muriate of potash was applied as basal, while, remaining dose was top dressed in tillering and panicle initiation in equal split during the course experiment.

The crop was harvested in first week of October during both the years. After harvesting of the rice crop, each plot was manually prepared for sowing of succeeding crop to know the residual effect of herbicides, without disturbing the layout. Succeeding greengram was sown in each plot in winter season. The germination percentage, plant height, dry weight of plants and yield of greengram crop was recorded and data were used for analysis. Microbial population was counted at initial and harvest stage at different dosage of penoxsulam in rice field.

Weed density and biomass

The weed count was recorded species wise using 0.5 x 0.5 m quadrate from randomly fixed places in each plot and the weeds falling within the frames of the quadrate were counted, recorded and the mean value were expressed in number/m^2. The density of grasses, sedges and broad-leaved weeds and the total weeds were recorded at 30 and 45 days after transplanting and expressed in no./m^2. The weeds falling within the frames of the quadrate were collected, and were shade dried and later dried in hot-air oven at 80^0 C for 72 hrs. The dry weight of grasses, sedges and broad-leaved weeds were recorded separately at 30 and 45 days after transplanting and expressed in kg/ha.

Weed control efficiency

Weed control efficiency (WCE) was calculated as per the procedure (Mani *et al.* 1973).

$$WCE (\%) = \frac{WDC - WDT}{WDC} \times 100$$

Where

WCE- Weed control efficiency (%), WDC - Weed biomass (g/m^2) in control plot,

WDT- Weed biomass (g/m^2) in treated plot.

Weed index

Weed index (WI) was calculated as per the method (Gill and Kumar 1969)

$$WI = \frac{X-Y}{X} \times 100$$

Where, X=yield (kg/ha) from minimum weed competition plot;

Y=yield (kg/ha) from the treatment plot for which WI is to be worked out.

Microbial analysis

Population dynamics of different types of microorganisms was studied from the soil samples of individual treatment plots.

One gram of soil was weighed and transferred to 10 ml sterile water blank and a thorough shaking was given. This gave the dilution of 10^{-1}, from this using a sterile pipette, one ml of the suspension was transferred to 9 ml water blank to get a dilution of 10^{-2}. Subsequent dilution of10^{-3}, 10^{-4}, 10^{-5}, and 10^{-6} were also made accordingly.

The respective media were melted, cooled and poured into the Petri-dishes carrying the respective dilution and the dishes were incubated at 30 °C. After incubation period, the colonies were counted and expressed as colony forming units per gram of soil.

Statistical analysis

The data collected for rice was statistically analysed by following procedure for randomised block design (Gomez and Gomez 2010). The data pertaining to weeds and germination were transformed to square root scale of $\sqrt{x+2}$ and analysed (Snedecor and Cochran 1967). Whenever significant difference existed, critical difference was constructed at 5% probability level.

RESULTS AND DISCUSSION

Effect on weeds

The dominant grassy weed species in the experiment field were *Echinochloa crus-galli* and *Echinochloa colona.* Among the broad-leaved weeds, *Ammania baccifera*, *Eclipta alba* and *Marsilea quadrifolia* were the dominant weeds. *Cyperus rotundus* was the only sedge present in the experimental field.

Pre-emergence application of new formulation of penoxsulam at 20, 22.5, 25, 27.5 and 50 g/ha followed by one hand weeding at 30 DAT resulted in effective control of grassy weeds, broad-leaved weeds and to some extent sedge. Grassy weeds were effectively controlled with the herbicide. Application of penoxsulam at 22.5 g/ha resulted in the weed control of more than 88% of weeds, but the herbicide inhibited the crop growth **(Table 1)**. The efficacy of penoxsulam application at 25 g/ha as pre- and post-emergence 20.0-22.5 g/ha was reported by Yadav *et al.* (2008).

Post-emergence application of penoxsulam was reported to have an edge over pre-emergence application earlier also (Singh *et al.* 2007). Yadav *et al.* (2007) also reported penoxsulam as an effective post-emergence herbicide against mixed weed flora in rice. Dharumarajan *et al.*(2009) envisaged that herbicides applied at different intervals during critical crop growth period recorded higher weed control efficiency in transplanted rice ecosystems.

Effect on crop

In rice, among the weed control treatments, pre-emergence application of penoxsulam at 22.5/g ha recorded higher grain yield of 5.20 and 5.04 t/ha, during 2014 and 2015, respectively due to better control of weeds at critical stages by providing favorable environment for better growth and development leading to enhanced grain yield. It was at par with pre-emergence application of pretilachlor 750 g/ha (5.00 and 5.00 t/ha in 2014 and 2015, respectively). Hand weeding has resulted in grain yield (4.96 and 4.05 t/ha respectively). Rice

Table 1. Effect of different weed management treatments on total weed density in transplanted rice

Treatment	Weed density (no./m^2)			
	2014		2015	
	30 DAT	45 DAT	30 DAT	45 DAT
Penoxsulam 20 g/ha + HW 30 DAT	8.28(67)	8.96(79)	10.03(99)	8.17(65)
Penoxsulam 22.5 g/ha + HW 30 DAT	4.61 (19)	4.70(20)	3.87(13)	3.46(10)
Penoxsulam 25 g/ha + HW 30 DAT	7.92(61)	8.66(74)	4.35(17)	3.99(14)
Penoxsulam 27.5 g/ha + HW 30 DAT	7.42(54)	8.20(65)	9.74(93)	7.93(61)
Penoxsulam 50 g/ha + HW 30 DAT	7.08(48)	7.95(62)	5.38(27)	5.38(27)
Standard check butachlor 1000 g/ha + HW 30 DAT	5.65(30)	5.68(30)	5.74(31)	5.74(31)
Standard check pretilachlor 750 g/ha + HW 30 DAT	5.12(25)	5.16(25)	6.07(35)	6.07(35)
Hand weeding (25 and 45 DAT)	6.12(36)	6.21(37)	7.19(50)	7.12(49)
Unweeded control	14.73(221)	12.69(163)	18.34(335)	15.54(240)
LSD (p=0.05)	1.75	1.54	0.83	0.72

Figures in parentheses are original, transformed to values $\sqrt{x+2}$

Table 2. Effect of weed management methods on weed control efficiency, yield and weed index of rice

Treatment	2014				2015			
	WCE (%)		Grain yield (t/ha)	WI (%)	WCE (%)		Grain yield (t/ha)	WI (%)
	30 DAT	45 DAT			30 DAT	45 DAT		
Penoxsulam 20 g/ha + HW 30 DAT	68.8	51.5	3.89	25.02	69.30	67.64	2.76	45.18
Penoxsulam 22.5 g/ha + HW 30 DAT	90.9	87.5	5.20	00.00	97.00	95.81	5.04	00.00
Penoxsulam 25 g/ha + HW 30 DAT	71.3	54.7	3.90	25.04	95.90	94.28	4.32	14.35
Penoxsulam 27.5g/ha + HW 30 DAT	75.0	59.8	3.95	24.12	71.20	69.63	3.20	36.55
Penoxsulam 50 g/ha + HW 30 DAT	77.4	62.1	4.00	23.16	93.20	88.70	3.97	21.15
Standard check butachlor 1000 g/ha + HW 30 DAT	86.0	81.3	5.05	2.99	92.10	86.97	3.92	22.28
Standard check pretilachlor 750 g/ha + HW 30 DAT	88.5	84.4	5.11	1.84	91.00	85.19	5.00	00.87
Hand weeding (25 and 45 DAT)	83.3	77.0	4.96	4.72	86.30	79.54	4.05	19.58
Unweeded control	0.0	0.0	2.67	48.71	00.00	0.00	1.97	60.82
LSD (p=0.05)	-	-	5.18	-	-	-	5.46	-

WCE- Weed control efficiency, WI- Weed index productivity is mainly decided by the weed control efficiency of weed management methods as earlier observed by Sansa *et al.* (2016) who had noted that, post-emergence herbicides offer the most practical, effective and economical method of weed control for increasing grain yield of rice.

The next best treatment was pretilachlor, which might be due to weed free environment created from the early stage up to harvest, leading to the production of effective tillers, longer panicles, and more number of grains/panicle compared to all other treatments. Ramana *et al.*(2007) concurred with this result that higher grain and straw yield were recorded with weed free check.

Unweeded control accounted for lower grain yield, which was due to higher weed index at 48.7 and 60.82% during 2014 and 2015, respectively due to heavy competition of weeds for nutrients, space and light. Among the weed control methods, the lowest weed index in pre-emergence application of penoxsulamat 22.5 g/ha, which might be due to greater competition stress with prolific weed growth and higher nutrient removal by weeds. The yield reduction was observed in unweeded control to the tune of 48.7 and 60.8% respectively.

Bioassay study

The germination of succeeding greengram at 10 DAS was not significantly affected by residual effect of herbicide applied to transplanted rice. The plant stand of greengram ranged from 84 to 90% under all the treatments at 10 DAS. Further, plant height and dry weight of plants recorded at 20 and 40 DAS were also unaffected due to residual effect of different doses of penoxsulam applied in rice **(Table 3)**. Yield of greengram showed no distinct variation due to different doses of penoxsulam. This result was in line

Table 3. Residual effect of penoxsulam applied in rice on the germination (%), plant height, dry matter production and grain yield of succeeding greengram crop

Treatment	2014						2015					
	Crop establish-ment (%)	Plant height (cm)		DMP (t/ha)		Grain yield (t/ha)	Crop establish -ment (%)	Plant height (cm)		DMP (t/ha)		Grain yield (t/ha)
		20 DAS	40 DAS	20 DAS	40 DAS			20 DAS	40 DAS	20 DAS	40 DAS	
Penoxsulam 20 g/ha + HW 30 DAT	88.2	15.1	32.0	0.62	1.20	0.55	88.2	15.1	32.0	0.61	1.17	0.55
Penoxsulam 22.5 g/ha + HW 30 DAT	87.9	15.9	32.0	0.64	1.21	0.55	87.2	15.7	31.5	0.60	1.20	0.55
Penoxsulam 25 g/ha + HW 30 DAT	87.2	15.1	31.0	0.60	1.21	0.55	86.2	15.4	30.4	0.58	1.15	0.55
Penoxsulam 27.5g/ha + HW 30 DAT	85.1	15.2	31.9	0.62	1.21	0.55	85.1	15.5	31.8	0.57	1.16	0.55
Penoxsulam 50 g/ha + HW 30 DAT	84.1	15.4	32.5	0.62	1.21	0.55	88.3	15.0	32.5	0.61	1.15	0.54
Standard check butachlor 1000 g/ha + HW 30 DAT	89.8	15.7	32.8	0.64	1.21	0.55	87.2	15.7	31.6	0.60	1.21	0.54
Standard check Pretilachlor 750 g/ha + HW 30 DAT	89.7	15.9	35.8	0.65	1.20	0.56	88.2	15.7	33.0	0.60	1.20	0.54
Hand weeding	88.1	15.7	34.5	0.63	1.20	0.56	87.4	15.0	32.8	0.62	1.18	0.54
Unweeded control	88.2	15.1	35.3	0.60	1.20	0.55	75.0	15.1	32.1	0.61	1.16	0.54
LSD (p=0.05)	-	NS	NS	NS	NS	NS	-	NS	NS	NS	NS	NS

NS - Non significant, DMP- Dry matter production

Table 4. Effect of weed management treatments on soil bacteria, fungi and actinomycetes (CFU g^{-1} of soil) in transplanted rice

Treatment	2014						2015					
	Bacteria ($x10^6$ CFU/g)		Fungi ($x10^4$ CFU/g)		Actinomycetes ($x10^2$ CFU/g)		Bacteria ($x10^6$ CFU/g)		Fungi ($x10^4$ CFU/g)		Actinomycetes ($x10^2$ CFU/g)	
	DAT 1st day	H	DAT 1st day	H	DAT 1st day	H	DAT 1st day	H	DAT 1st day	H	DAT 1st day	H
Penoxsulam 20 g/ha + HW 30 DAT	7.91	14.7	4.5	5.2	2.43	4.10	7.30	14.56	4.18	5.18	2.50	4.10
Penoxsulam 22.5 g/ha + HW 30 DAT	7.95	14.7	4.3	5.2	2.42	4.13	7.30	14.21	4.00	5.15	2.40	4.13
Penoxsulam 25 g/ha + HW 30 DAT	7.57	15.0	4.7	5.2	2.40	4.23	7.24	14.56	4.33	5.17	2.29	4.23
Penoxsulam 27.5g/ha + HW 30 DAT	7.67	14.9	4.3	5.2	2.50	4.20	7.16	14.56	4.23	5.16	2.35	4.20
Penoxsulam 50 g/ha + HW 30 DAT	7.64	14.8	4.6	5.2	2.60	4.30	7.10	14.86	4.20	5.19	2.28	4.30
Standard check butachlor 1000 g/ha + HW 30 DAT	7.89	14.9	4.3	5.2	2.47	4.13	7.40	14.06	4.30	5.15	2.48	4.13
Standard check Pretilachlor 750 g/ha + HW 30 DAT	7.45	14.9	4.4	5.2	2.60	4.30	7.50	14.32	4.00	5.16	2.63	4.13
Hand weeding	7.55	14.8	4.4	5.2	2.57	4.37	7.40	14.85	4.54	5.16	2.11	4.31
Unweeded control	7.67	14.9	4.9	5.2	2.42	4.43	7.11	14.12	4.11	5.16	2.33	4.11
LSD (p=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

DAHS- Day after transplanting, H- Harvest with the results of Yadav *et al.* (2008) who reported that pre- and post-emergence application of penoxsulam in rice at different doses did not leave any residue in the soil and there was no toxic effect beyond 60 days.

Effect of herbicide residue on soil microorganisms

The microbial content of the soil was not much affected in the early stage, however penoxsulam when applied at 20, 22.5, 25, 27.5 50 g/ha had significant detrimental effect on soil bacteria, fungi and actinomycetes population with a relatively increased microbial population at harvest. There was no significant effect of the herbicide as crop advanced.

The pre-emergence application of penoxsulam at 22.5 g/ha can keep the weed density and biomass reasonably at lower level and enhance the productivity of transplanted rice. The new formulation of penoxsulam at 20, 22.5 25 and 50 g/ ha, pre-emergence application of pretilachlor 750 g/ha was found to be safe on the succeeding crops and this might be due to detoxification of herbicides in soil, which did not adversely affect the growth and yield of the succeeding crop in terms of plant height, dry matter production and grain yield of the succeeding greengram during both the seasons **(Table 4)**.

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Ready mix of pinoxaden and clodinafop-propargyl for control of *Phalaris minor* in wheat and its residual effects on succeeding rice crop

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ABSTRACT

A field experiment to evaluate the efficacy of a pre-mix herbicide pinoxaden 2.53% + clodinafop 2.53% w/w (Traxos 5% EC) against grassy weed *Phalaris minor* in wheat was conducted during winter season 2011-12 and 2012-13 at CCS Haryana Agricultural University, Regional Research Station, Karnal. Density and dry weight of *P. minor* under pinoxaden + clodinafop 60 g/ha was at par to pinoxaden 50 g/ha but lower than clodinafop 60 g/ha and fenoxaprop 120 g/ha. However, the differences with clodinafop in respect of dry weight of *P. minor* were not significant. Pinoxaden + clodinafop 60 g/ha provided control of *P. minor* as good as weed free check, and resulted in higher number of effective tillers than its lower dose (40 g/ha), fenoxaprop 120 g/ha and weedy check. This ready mix provided grain yield of wheat similar to pinoxaden 50 g/ha, clodinafop 60 g/ha and weed free check but higher than fenoxaprop 120 g/ha during both the years, and there was no phyto-toxicity on wheat. There was also no phyto-toxicity of pinoxaden + clodinafop up to 120 g/ha on succeeding rice crop.

INTRODUCTION

Wheat (*Triticum aestivum*) the most staple food crop in North-Western India is often infested with weeds particularly *Phalaris minor* causing large scale yield reductions (Chhokar *et al*. 2012). *Phalaris minor* evolved resistance first against isoproturon during 1992-93 due to its continuous use for more than 10-15 years coupled with rice-wheat mono-cropping resulting into total crop failure/immature crop harvest as fodder (Malik and Singh 1995). Consequently, the recommendation of isoproturon was displaced with alternate herbicides during 1997-98 and thereafter. But many alternate herbicides including clodinafop-propargyl, fenoxaprop-ethyl, sulfosulfuron and pinoxaden recommended to control this problematic grass weed have also been rendered ineffective due to the evolution of resistance (Brar *et al*. 2002, Dhawan *et al*. 2012, Kaur *et al*. 2016). This further warrants for screening of alternate herbicides alone or in combination as herbicides would stay as the most important tool against resistant *P. minor*.

The availability of new molecules with different mode of action but same level of activity against *P. minor* is limited. Suitable herbicide combinations should reduce selection pressure for resistance development and manage the weeds effectively. Herbicide combinations (ready/pre- mix or tank-mix) have been reported to provide better control of weeds compared to single herbicide (Singh 2015, Singh *et al.* 2015, Yadav *et al.* 2016, Kaur *et al.* 2017, Punia *et al*. 2017) besides delaying herbicide resistance. Similarly, it was hypothesized that pre-mix combination of pinoxaden + clodinafop would provide amicable solution against herbicide resistant *P. minor*. Therefore, to manage resistant *Phalaris minor*, bio-efficacy of a new pre-mix herbicide (pinoxaden 2.53% + clodinafop-propargyl 2.53% w/w) (Traxos 5% EC) was evaluated to optimize its use rate against *P. minor* in wheat. To further make it sure that it is safe to succeeding rice crop, its residual effects were also investigated at 60 and 120 g/ha.

MATERIALS AND METHODS

A field experiment to evaluate the efficacy of a new pre-mix herbicide pinoxaden 2.53% + clodinafop 2.53% w/w (Traxos 5% EC) for *Phalaris minor* control in wheat was conducted during *Rabi* 2011-12 and 2012-13 at CCS Haryana Agricultural University, Regional Research Station, Karnal. The soil of the experimental field was low in organic carbon (0.35 %), medium in available phosphorous (11 kg/ha) and potassium (280 kg/ha) with slightly alkaline in reaction (pH 8.2) The treatments included pinoxaden

+ clodinafop 5% EC 40, 50, 60 and 120 g/ha, in comparison to pinoxaden 5% EC 50 g/ha, clodinafop 15% WP 60 g/ha, fenoxaprop 10% EC 120 g/ha along with weed free and weedy checks. The treatments were laid out in randomized block design (RBD) with three replications. Wheat cultivar '*DPW 621-50*' was sown on 19 November 2011 during 2011-12 and 20 November 2012 during 2012-13 at a row spacing of 20 cm using seed rate of 100 kg/ha. Plot size was 5.4 x 2.2 m. The herbicides were sprayed at 35 days after sowing (DAS) with knapsack sprayer fitted with flat fan nozzle using water volume of 500 l/ha on 24 December 2011 and 25 December 2012. Density and dry weight of weeds was recorded at 75 DAS. Phyto-toxicity of pinoxaden + clodinafop at 60 and 120 g/ha in terms of chlorosis, necrosis and yellowing was recorded at 1, 2, 3, 4, 5 weeks after treatment (WAT). Crop was raised according to package of practices of the state University and harvested on 26 April 2012 and 23 April 2013.

To study the residual effects of pinoxaden + clodinafop at 60 and 120 g/ha compared to untreated check, three additional plots of 5.4 x 4.4 m size replicated thrice were maintained separately in the same experimental field during 2011-12 and 2012-13. Wheat cultivar, sowing time, seed rate, herbicide spraying schedule were similar to the main experiment on bio-efficacy evaluation, as already explained. Similarly, these plots were harvested along with the main experiment. Then the plots were ploughed once in dry field condition (one week before rice transplanting) *fb* irrigation and puddling (1-2 days before transplanting). Transplanting of rice cultivar '*HKR47*' in these plots was done on 11 July 2012 and 7 July 2013 at 20 cm x 15 cm spacing. Rice crop was raised according to package of practices of the state University and harvested on 23 October 2012 and 21 October 2013. Phyto-toxicity in terms of chlorosis, necrosis and yellowing was recorded at 10, 20 and 30 days after transplanting (DAT). Grain yield of rice was also recorded at harvest.

Before statistical analysis, the data on density of weeds were subjected to square root $(\sqrt{x+1})$ to improve the homogeneity of the variance. All the data were subjected to the analysis of variance (ANOVA) separately for each year for better understanding of the results. The significant treatment effect was judged with the help of 'F' test at the 5% level of significance. The 'OPSTAT' software of CCS Haryana Agricultural University, Hisar was used for statistical analysis (Sheoran *et al*. 1998). This software uses type 1 sum of squares in ANOVA for simple RBD, with LSD (least significant difference) being used for multiple comparisons.

RESULTS AND DISCUSSION

Effect on weeds

Phalaris minor was the dominant grass weed in the research plots. Density and dry weight of *Phalaris minor* decreased with increase in dose of the pinoxaden + clodinafop from 40 to 50 and 60 g/ha during both the years (**Table 1**). Density and dry weight of *P. minor* in plots treated with pinoxaden + clodinafop 60 g/ha was similar to the check herbicide pinoxaden 50 g/ha, but lower than clodinafop 60 g/ha (except dry weight) and fenoxaprop 120 g/ha. Pinoxaden + clodinafop 60 g/ha provided control of *P. minor* comparable to weed free check, with weed control efficiency of 99.3 and 98.5% during 2011-12 and 2012-13, respectively. Singh *et al.* (2015) and Kaur *et al.* (2017) have also reported effective control of resistant *P. minor* with post-emergence application of pinoxaden + clodinafop 50-60 g/ha in wheat.

Table 1. Effect of pinoxaden 2.53% + clodinafop-propargyl 2.53% w/w (5% EC) and other herbicidal treatments on density and dry weight of grassy weeds in wheat (2011-12 and 2012-13)

Treatment	Density of *P. minor* (no./m^2)*		Dry weight of grassy weeds (g/m^2)		Weed control efficiency (%)	
	2011-12	2012-13	2011-12	2012-13	2011-12	2012-13
Pinoxaden + clodinafop-propargyl (40 g/ha)	8.21 (66.7)	4.57 (20.0)	15.9	19.8	88.3	86.2
Pinoxaden + clodinafop-propargyl (50 g/ha)	5.19 (26.0)	4.03 (15.3)	7.4	9.9	94.5	93.1
Pinoxaden + clodinafop-propargyl (60 g/ha)	3.68 (12.7)	2.76 (6.7)	0.9	2.2	99.3	98.5
Pinoxaden + clodinafop-propargyl (120 g/ha)	3.26 (10.0)	1.82 (2.7)	0.9	1.9	99.3	98.7
Pinoxaden (50 g/ha)	3.77 (13.3)	2.99 (8.0)	1.7	2.1	98.7	98.5
Clodinafop (60 g/ha)	5.03 (24.7)	4.18 (16.7)	5.8	7.7	95.7	94.6
Fenoxaprop (120 g/ha)	7.16 (50.7)	5.36 (28.0)	14.8	21.3	89.1	85.2
Weed free	1.00 (0.0)	1.00 (0.0)	0.0	0.0	100.0	100.0
Weedy check	13.52 (182.7)	8.83 (77.3)	135.4	143.7	88.3	86.2
LSD (p=0.05)	1.21	1.01	5.0	5.7		

*The original figures in parentheses were subjected to square root transformation $(\sqrt{x+1})$ before statistical analysis

Table 2. Effect of pinoxaden 2.53% + clodinafop-propargyl 2.53% w/w (5% EC) and other herbicidal treatments on yield and yield attributes of wheat (2011-12 and 2012-13)

Treatment	Plant height (cm)		Effective tillers/ mrl		Earhead length (cm)		Grain yield (t/ha)	
	2011-12	2012-13	2011-12	2012-13	2011-12	2012-13	2011-12	2012-13
Pinoxaden + clodinafop-propargyl (40 g/ha)	104.3	96.5	75.0	83.0	11.5	11.5	5.10	5.63
Pinoxaden + clodinafop-propargyl (50 g/ha)	104.9	95.9	79.5	85.2	11.6	11.5	5.31	5.82
Pinoxaden + clodinafop-propargyl (60 g/ha)	105.0	96.1	82.8	88.8	11.7	11.5	5.52	6.05
Pinoxaden + clodinafop-propargyl (120 g/ha)	103.1	95.1	76.3	83.5	11.5	11.4	5.16	5.79
Pinoxaden (50 g/ha)	104.7	96.3	81.5	86.5	11.7	11.6	5.43	5.91
Clodinafop (60 g/ha)	104.3	95.5	80.2	86.8	11.5	11.5	5.40	5.92
Fenoxaprop (120 g/ha)	103.7	95.9	74.0	82.3	11.5	11.5	5.05	5.61
Weed free	104.9	96.9	84.8	90.0	11.8	11.7	5.74	6.08
Weedy check	103.5	94.8	55.0	53.7	10.9	11.3	4.14	3.94
LSD (p=0.05)	NS	NS	5.0	4.1	0.4	NS	0.39	0.17

Abbreviations: mrl- Meter row length, NS- Non-significant

Table 3. Phyto-toxicity (0-10 scale) of pinoxaden 2.53% + clodinafop-propargyl 2.53% w/w (5% EC) on wheat (2011-12 and 2012-13)

Treatment	1 WAT		2 WAT		3 WAT		4 WAT		5 WAT	
	2011-12	2012-13	2011-12	2012-13	2011-12	2012-13	2011-12	2012-13	2011-12	2012-13
Pinoxaden + clodinafop (60 g/ha)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pinoxaden + clodinafop (120 g/ha)	0.0	0.0	1.0	0.7	2.0	1.3	1.7	1.3	1.3	1.0
Untreated check	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Abbreviations: WAT- Weeks after treatment

Table 4. Phyto-toxicity (0-10 scale) of pinoxaden 2.53% + clodinafop-propargyl 2.53% w/w (5% EC) on succeeding rice (2012 and 2013)

Treatment	Phytp-toxicity (0-10 scale)						Grain yield (t/ha)	
	2012			2013			2012	2013
	10 DAT	20 DAT	30 DAT	10 DAT	20 DAT	30 DAT		
Pinoxaden + clodinafop (60 g/ha)	0.0	0.0	0.0	0.0	0.0	0.0	6.94	6.52
Pinoxaden + clodinafop (120 g/ha)	0.0	0.0	0.0	0.0	0.0	0.0	6.88	6.65
Untreated check	0.0	0.0	0.0	0.0	0.0	0.0	6.90	6.58
LSD (p=0.05)							NS	NS

Abbreviations: DAT- Days after transplanting, NS- Non-significant

Effect on crop

Plant height of wheat was not affected by any of the treatments (**Table 2**). Pinoxaden + clodinafop 60 g/ha resulted in a greater number of effective tillers compared to its lower dose (40 g/ha), fenoxaprop 120 g/ha and weedy check; but similar to other check herbicides (pinoxaden 50 g/ha and clodinafop 60 g/ ha), and weed free check. The ear head length of wheat was similar under all the herbicide treatments though smeller ear heads were observed in weedy check plots during 2011-12 growing season.

Grain yield of wheat increased with successive increase in dose of pinoxaden + clodinafop 60 g/ha from 40 to 50 and 60 g/ha, however, the successive differences were significant during 2012-13 only (**Table 2**). During 2011-12, the grain yield under pinoxaden + clodinafop 60 g/ha was similar to 50 g/ha but significantly higher than 40 g/ha. Pinoxaden + clodinafop 60 g/ha resulted in grain yield similar to pinoxaden 50 g/ha, clodinafop 60 g/ha and weed free check but higher than fenoxaprop 120 g/ha during both the years. However, pinoxaden + clodinafop 40-50 g/ha resulted in lower wheat yield compared with the weed free check. Better weed management due to pinoxaden + clodinafop 60 g/ha resulted in to greater number of effective tillers and consequently higher yields. These results are in conformity with earlier findings elsewhere (Singh *et al.* 2015, Kaur *et al.* 2017).

Crop phyto-toxicity

There was no phyto-toxicity (in terms of chlorosis, necrosis and yellowing) of pinoxaden + clodinafop 60 g/ha in wheat. These results were in conformity with the findings of Kaur *et al.* (2017). However, there was phyto-toxicity of 1.3-2.0 (on 0-10 scale) at 120 g/ha on wheat crop at 3 WAT (**Table 3**); which recovered progressively with time.

Residual phyto-toxicity on succeeding rice crop

There was no phyto-toxicity (in terms of chlorosis, necrosis and yellowing) of pinoxaden + clodinafop 60 and 120 g/ha on succeeding rice crop during both the years (**Table 4**). The grain yield of rice in pinoxaden + clodinafop 60 and 120 g/ha treated plots in wheat and untreated check was similar. Kaur *et al*. (2017) also reported no residual phyto-toxicity pinoxaden + clodinafop 60 and 120 g/ ha on succeeding crop of green gram.

Based on present investigation, it may be concluded that pinoxaden 2.53% + clodinafop-propargyl 2.53% w/w (5% EC w/v) 60 g/ha proved very effective against *Phalaris minor* resulting in improved grain yield of wheat, with no phyto-toxicity on the wheat crop. Also there was no phyto-toxicity up to 120 g/ha on succeeding rice crop. These results indicate it as a strong candidate as an alternative herbicide for management of herbicide resistant *Phalaris minor* in present situation.

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Weed dynamics and performance of lentil as affected by weed management practices under rainfed conditions

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ABSTRACT

The field experiment was conducted at research farm of Tirhut College of Agriculture, Dholi of Dr. Rajendra Prasad Central Agricultural University, Pusa, Bihar during winter seasons of 2012-13 and 2013-14 to find out the suitable herbicides and their combinations for controlling weeds and improving yield of rainfed lentil (*Lens culinaris*). Study comprised post-emergence application of quizalofop-ethyl 50 g/ha or imazethapyr 37.5 g/ha, pre-plant application of chlorimuron-ethyl 4 g/ha, pre-emergence (PE) application of pendimethalin 300 g/ha, pendimethalin 154 g/ha + imazethapyr 10.5 g/ha (ready-mix), ready-mix pendimethalin 205 g/ha + imazethapyr 14 g/ha (ready-mix), pendimethalin 300 g/ ha + hand weeding at 40 DAS, hand weeding twice at 20 and 40 DAS and weedy check. Hand weeding twice at 20 and 40 days after sowing caused the highest reduction (84.6%) in weed population (75.9 and 93.3% in monocot and dicot weeds, respectively) and registered the lowest nutrient depletion (13.6 kg/ha) by weeds. The highest seed yield (1.83 t/ha) obtained with hand weeding twice was 117.4% higher as compared to weedy check. The yield obtained under this treatment was at par with the combined application of pendimethalin 300 g/ha + hand weeding at 40 days after sowing (1.73 t/ha). However, the maximum B: C ratio (3.42) was obtained with application of pendimethalin 205 g/ha + imazethapyr 14 g/ha as PE followed by (*fb*) their lower dose (pendimethalin 154 g/ha + imazethapyr 10.5 g/ha as PE). The chemical weed control was found economically better than hand weeding and weedy check.

INTRODUCTION

Among the numerous pulses grown in India, lentil (*Lens culinaris* Medik.) holds a consequential position because of its wider adaptation to a wide range of climate and soil types. In spite of India's large (30%) share in the global production of lentil, the productivity level in the country is substantially low (678 kg/ha). Weed infestation is one of the major causes of low yield of lentil because this crop has a very weak competitive competency due to minuscule and impotent canopy. Weeds reduce the crop yield through competition for space, light, moisture and plant nutrients. Weeds exhaust the soil depriving the crop of nutrients, particularly nitrogen causing a considerable reduction in yield (Upadhyay *et al*. 2013). The yield loss due to weed infestation can be prevented by effective management of weeds in the field. There is critical crop-weed competition period for every crop when the weeds cause maximum harm by competing with the crop plants (Steckel and Sprague 2004).

Different cultural, physical and chemical methods are often employed to manage the weeds in lentil. Of the various methods, hand weeding is often used for controlling weeds in lentil, but it is labour intensive, time demanding and quite expensive. Herbicide based weed management offers cost effective and timely control of weeds and reduces reliance on labour (Gupta 2003). There is little information available regarding herbicide based weed management in lentil. It is, therefore, imperative to find out the suitable herbicides and their combinations for controlling weeds and improving productivity of lentil.

MATERIALS AND METHODS

A field experiment was conducted for two consecutive winter seasons of 2012-13 and 2013-14 at Tirhut College of Agriculture, Dholi, Bihar (52.18 m altitude, 25.98° N and 85.60° E) under rainfed condition. The soil of the experimental plot was sandy loam in texture having pH 8.1, low in organic carbon (0.25%), available N (182.5 kg/ha), available P (16.6 kg/ha) and medium in available K (122.2 kg/ha). The rainfall received during crop season was 31.5 and 27.8 mm in 2012-13 and 2013-14, respectively. The experiment was laid out in a randomized block design with four replications. Nine treatments of the study comprised, *viz.* quizalofop-ethyl 50 g/ha at 30 days after sowing (DAS), imazethapyr 37.5 g/ha at 30 DAS, chlorimuron-ethyl 4 g/ha as pre-plant incorporation, pendimethalin 300 g/ha as PE, ready-mix of pendimethalin 154 g/ha + imazethapyr 10.5 g/ha (as PE, ready-mix pendimethalin 205 g/ha + imazethapyr 14 g/ha) as PE, pendimethalin 300 g/ha as PE + HW at 40 DAS, hand weeding twice at 20 and 40 DAS and weedy check. The lentil variety '*KLS-218*' was sown during first week of November in both the years in rows 30 cm apart using the seed rate of 35 kg/ha. The plant to plant distance of 10 cm was maintained by thinning at two weeks after sowing. The recommended dose of nutrients (20 kg nitrogen, 50 kg phosphorus and 20 kg potassium/ha) was applied at the time of sowing through di-ammonium phosphate and muriate of potash. Spraying of herbicides as per treatments was done using the knapsack sprayer fitted with flat fan nozzle by using a spray volume of 500 liters/ha.

The observation on weed density and biomass were recorded at 60 days after sowing from an area enclosed in the quadrat of 0.25 m^2 randomly selected at two places in each plot. Weed data were subjected to square root transformation before statistical analysis. Weed mortality (%) of treated plots were calculated by using the formula.

$$\text{Weed Moratlity} = \frac{\text{Weed density in control plot - Weed density in treated plot}}{\text{Weed density in control plot}} \times 100$$

Weed growth rate (WGR) was calculated by using the formula and is expressed as gram of dry matter of weed produced per day per square meter.

$$\text{WGR} = \frac{W_2 - W_1}{t_2 - t_1}$$

Where, W_1 and W_2 are dry biomass of plant (g/m^2) at time t_1 and t_2, respectively.

Observations on plant biomass, yield, nutrient uptake and protein content in seeds were recorded at the time of harvesting. The NPK uptake in kg/ha by seed and stover of lentil crop was calculated by multiplying yields of seed or stover with their respective nutrient content, while protein content in seed at maturity was worked out by multiplying nitrogen content of seed at maturity with 6.25 (AOAC, 1960). Economics was computed on the basis of prevailing market rates of produce and agro-inputs. Net returns was calculated by subtracting cost of cultivation from gross returns and benefit: cost ratio was worked by dividing the gross returns by the cost of cultivation.

RESULTS AND DISCUSSION

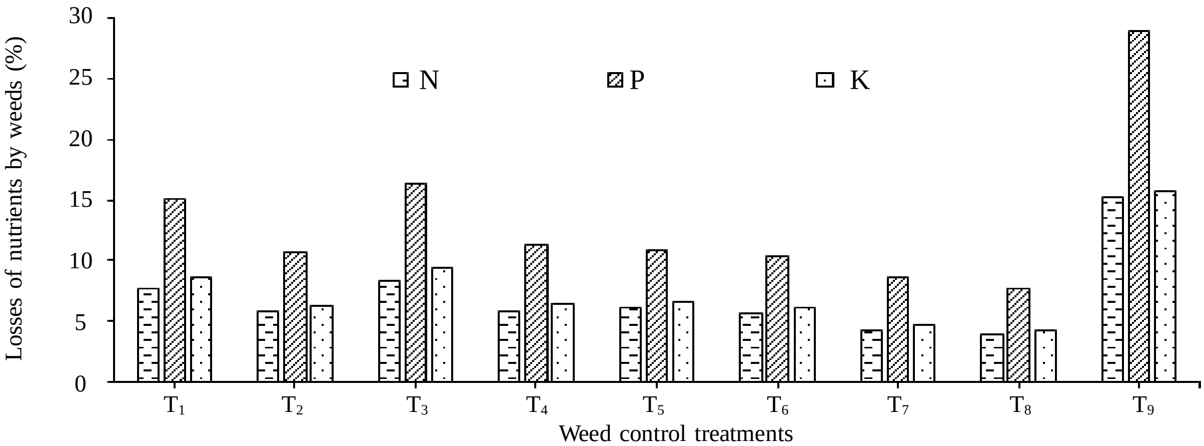
Effect on weeds

Weed flora: The prominent weeds recorded in the experimental field were *Cynodon dactylon* (L.) Pers and *Cyperus rotundus* L. among monocots and *Anagallis arvensis* L., *Cannabis sativa* L., *Chenopodium album* L. and *Parthenium hysterophorus* L. among dicot weeds. Weed species of comparatively less density in the field included *Avena fatua* L., *Argemone mexicana* L., *Cirsium arvense* L., *Convolvulus arvensis* L., *Fumaria parviflora* L., *Lathyrus aphaca* L., *Melilotus indica* L., *Phalaris minor* Retz., *Solanum nigrum* L. and *Vicia sativa* L.

Weed density: The mean density of monocot and dicot weeds at 60 DAS was significantly reduced by the application of herbicides alone as well as by their combination as ready mix and by integration of pendimethalin with HW (**Table 1**). Hand weeding twice at 20 and 40 DAS caused the highest mortality of monocot and dicot weeds (88.8% and 93.2%, respectively) followed by integration of pendimethalin 300 g/ha with hand weeding at 40 DAS (72.4% and 89.3%, respectively). The PE application of ready mix pendimethalin 205 g/ha + imazethapyr 14 g/ha, pendimethalin 154 g/ha + imazethapyr 10.5 g/ha and pendimethalin 300 g/ha alone were less effective in controlling monocot weeds, but were more effective in controlling the dicot weeds (90.2%, 86.6% and 81.8%, respectively) over control. The application of imazethapyr 37.5 g/ha (PoE), quizalofop-ethyl 50 g/ha post-emergence (PoE) and chlorimuron-ethyl 4 g/ha (pre-plant incorporation) alone proved much better for controlling the monocot weeds to the tune of 62.9%, 60.3% and 59.0%, respectively than pre-emergence herbicides. However, these herbicides failed to control the dicot weeds. Earlier, Manjunath *et al.* (2010) reported effective control of broad-leaved weeds like *Chenopodium album*, *Melilotus alba*, *Solanum nigrum*, *etc*. with ready mix pendimethalin + imazethapyr or pendimethalin alone in lentil. Sharma *et al.* (2012) reported excellent weed control in soybean with hand weeding twice followed by the treatment comprising integration of imazethapyr with hand weeding.

Weed dry biomass: Hand weeding, integrated weed control measures and herbicidal treatments significantly reduced the weed dry biomass as compared to weedy check (**Table 1**). Hand weeding twice recorded the lowest weed dry biomass (8.50 g/m^2). Pre-emergence application of ready mix herbicides (pendimethalin 205 g/ha + imazethapyr 14 g/ha, pendimethalin 154 g/ha + imazethapyr 10.5 g/ha) or pendimethalin 300 g/ha alone resulted in lower weed dry biomass (27.3 - 30.5 g/m^2) compared with PoE application of imazethapyr 37.5 g/ha or quizalofop-ethyl 50 g/ha or pre-plant incorporation of chlorimuron-ethyl 4 g/ha (41.7 - 56.3 g/m^2). The lower weed count and weed dry biomass in these treatments might be due to broad-spectrum control of weeds. Kumar *et al.* (2016) also reported reduction in number of weeds, duration of weed growth and lower dry matter of weeds with integrated weed control measures compared to the weedy check in lentil.

Weed growth rate: All the weed control treatments registered significantly lower growth rate of weeds as compared to weedy check (**Table 1**). Pre-emergence application of pendimethalin 300 g/ha + HW at 40 DAS resulted in the lowest weed growth rate (0.150 g/day/m^2) which was at par with HW twice (0.161 g/day/m^2). Among the herbicides, imazethapyr 37.5 g/ha recorded the lowest weed growth rate (0.217 g/day/m^2) which was significantly lower as compared to rest of the herbicide treatments. The reduction in



T_1 – quizalofop-ethyl 50 g/ha at 30 DAS; T_2 – imazethapyr 37.5 g/ha at 30 DAS; T_3 – chlorimuron-ethyl 4 g/ha as pre-plant; T_4 – pendimethalin 300 g/ha as PE; T_5 – pendimethalin 154 g/ha + imazethapyr 10.5 g/ha as PE; T_6 – pendimethalin 205 g/ha + imazethapyr 14 g/ha as pre-em; T_7 – pendimethalin 300 g/ha as PE + HW at 40 DAS; T_8 – two hand weeding at 20 and 40 DAS; T_9 – weedy check.

Figure 1. Major soil nutrients depletion by weeds under different weed control treatments

Table 1. Weed density and weed mortality in lentil as affected by different weed control treatments at 60 days after sowing

Treatment	Weed density (no./m^2)				Weed dry biomass (g/m^2)	Weed growth rate (g/day/m^2)
	Monocots	Mortality (%)	Dicots	Mortality (%)		
Quizalofop-ethyl 50 g/ha at 30 DAS	5.57(30.7)*	60.34	12.42(153.7)	17.68	6.93(47.5)	0.53
Imazethapyr 37.5 g/ha at 30 DAS	5.40 (28.7)	62.93	12.27(150.0)	19.64	6.50(41.7)	0.22
Chlorimuron-ethyl 4 g/ha as pre-plant incorporation	5.67 (31.7)	59.05	12.63(59.0)	68.39	7.54(56.3)	0.88
Pendimethalin 300 g/ha as PE	6.07 (36.3)	53.02	5.87(34.0)	81.79	5.57(30.5)	0.78
Pendimethalin 154 g/ha + imazethapyr 10.5 g/ha as PE	5.93(34.7)	55.17	5.05(25.0)	86.61	5.36(28.2)	0.69
Pendimethalin 205 g/ha + imazethapyr 14 g/ha as PE	5.87(34.0)	56.03	4.34(18.3)	90.18	5.27(27.3)	0.68
Pendimethalin 300 g/ha as PE + HW at 40 DAS	4.67(21.3)	72.42	4.53(20.0)	89.29	3.46(11.5)	0.15
Two HW at 20 and 40 DAS	4.38(8.7)	88.79	3.63(12.7)	93.21	3.00(8.5)	0.16
Weedy check	8.82(77.3)	-	13.68(186.7)	-	8.60(73.5)	1.99
LSD (p=0.05)	0.241	-	0.212	-	0.14	0.32

*Original figures in parentheses were subjected to square-root transformation $\sqrt{x+0.5}$ before statistical analysis. PE - Pre-emergence; HW - Hand-weeding; DAS - Days after sowing rate of weed growth under these treatments might be attributed to lower weed population and weed biomass.

Nutrient depletion by weeds: The average initial value of available N, P and K in soil were 182.5, 16.6 and 122.2 kg/ha, respectively. All the weed control practices reduced the depletion of NPK by weeds over weedy check (**Figure 1**). Hand weeding twice registered the lowest per cent depletion of nutrients by weeds (15.2% N, 28.9% P and 15.7% K) which was *fb* the treatment comprising PE application of pendimethalin 300 g/ha + HW at 40 DAS. Amongst the herbicides, the nutrient losses through weeds was less in ready mix pendimethalin 205 g/ha + imazethapyr 14 g/ha *fb* imazethapyr 37.5 g/ha, ready mix pendimethalin 154 g/ha + imazethapyr 10.5 g/ha and pendimethalin 300 g/ha alone. Better weed control (number and dry matter of weeds) at critical period of crop-weed competition resulted in lesser depletion of nutrients by weeds (Kumar *et al.* 2016, Younesabadi *et al.* 2013).

Effect on crops

Plant biomass: Weed management practices registered significant differences in plant biomass (**Table 2**). Hand weeding twice recorded the highest plant biomass (492 g/m^2) which was significantly more than that obtained with weedy check and at par with all other treatments. The results confirmed the finding of Ram *et al.* (2011).

Seed yield: All the weed control treatments resulted in significantly higher seed yield than the weedy check (**Table 2**). The highest seed yield (1.83 t/ha) obtained with hand weeding twice registered significant increase of 117.4% over weedy check, but was at par with all other treatments. Pendimethalin 300 g/ha + hand weeding at 40 DAS (1.73 t/ha) and ready-mix pendimethalin 205 g/ha + imazethapyr 14 g/ha (1.67 t/ha) or pendimethalin 154 g/ha + imazethapyr 10.5 g/ha (1.60 t/ha) resulted in yield increase of 105.8%, 98.4% and 90.1%, respectively over weedy check. The efficient weed control measures reduced weed density and weed dry biomass resulting in the improvement in yield attributes and ultimately in crop yield. Similar results were obtained by Kumar *et al.* (2016) in lentil and Chander *et al.* (2014) in soybean.

Nutrient uptake by crop: All the weed control treatments significantly differed with weedy check for uptake of NPK by the crop (**Table 3**). The maximum nutrient uptake by the crop was recorded with hand weeding twice (124.1, 17.7 and 59.1 kg/ha of N, P and K, respectively) and was significantly higher than rest of the weed control treatments. The lowest nutrient uptake was registered under weedy check (72.70, 7.72 and 32.20 kg/ha of N, P and K, respectively). Higher plant dry biomass and higher nutrient content in plants contributed to higher uptake of nutrients. Venkateshwarulu (1984) also observed higher nutrient uptake under the conditions of lesser crop-weed competition.

Protein content: Except application of chlorimuron-ethyl 4 g/ha as pre-plant and quizalofop-ethyl 50 g/ha at 30 DAS, all the weed control treatments resulted in significantly higher protein content in seed than weedy check (**Table 3**). The maximum protein content obtained with hand weeding twice (25.2%) was at par with pendimethalin 300 g/ha + hand weeding at 40 DAS (25.0%) and significantly higher over rest of the weed control treatments. Among the herbicides, the pre-emergence herbicidal treatments were statistically at par with each other and significantly superior over post-emergence and pre-plant incorporated herbicides. The higher protein content in these treatments might be due to the higher uptake of nitrogen by plants and their conversion into amino acid under conditions of reduced crop-weed competition (Gronle *et al.* 2015).

Table 2. Effect of different weed control treatments on growth, yield and economics of lentil

Treatment	Plant biomass (g/m^2) at harvest	Yield (t/ha)	Total cost of cultivation (x10^3 `/ha)	Gross returns (x10^3 `/ha)	B:C ratio
Quizalofop-ethyl 50 g/ha at 30 DAS	398	1.45	10.73	32.63	3.04
Imazethapyr 37.5 g/ha at 30 DAS	404	1.50	10.92	35.72	3.27
Chlorimuron-ethyl 4 g/ha as pre-plant incorporation	365	1.37	10.10	30.60	3.03
Pendimethalin 300 g/ha as PE	416	1.46	11.36	37.26	3.28
Pendimethalin 154 g/ha + imazethapyr 10.5 g/ha as PE	420	1.60	11.53	38.63	3.35
Pendimethalin 205 g/ha + imazethapyr 14 g/ha as PE	433	1.67	11.94	40.84	3.42
Pendimethalin 300 g/ha as PE + HW at 40 DAS	443	1.73	12.67	40.17	3.17
Two HW at 20 and 40 DAS	492	1.83	13.40	38.60	2.88
Weedy check	305	0.84	8.23	23.53	2.86
LSD (p=0.05)	168	0.48	-	-	-

PE- Pre-emergence; HW,- Hand-weeding; DAS- Days after sowing

Table 3. Effect of different weed control treatments on nutrient (N, P, K) uptake by seed and stover of lentil

Treatment	Nutrient uptake by crop (kg/ha) N		P		K		Protein content in seed (%)
	Seed	Stover	Seed	Stover	Seed	Stover	
Quizalofop-ethyl 50 g/ha at 30 DAS	56.3	39.2	5.8	5.6	12.8	31.1	24.2
Imazethapyr 37.5 g/ha at 30 DAS	58.5	39.7	6.1	6.1	13.4	31.6	24.4
Chlorimuron-ethyl 4 g/ha as pre-plant	52.6	35.2	5.3	4.3	11.6	27.5	24.1
Pendimethalin 300 g/ha as PE	61.7	40.8	6.9	6.5	14.5	32.5	24.7
Pendimethalin 154 g/ha + imazethapyr 10.5 g/ha as PE	63.2	41.2	7.2	6.8	15.4	33.1	24.8
Pendimethalin 205 g/ha + imazethapyr 14 g/ha as PE	66.2	42.4	7.5	6.9	16.2	34.4	24.8
Pendimethalin 300 g/ha as PE + HW at 40 DAS	69.2	43.5	8.1	7.5	17.1	35.1	25.0
Two HW at 20 and 40 DAS	73.6	50.5	8.8	8.9	18.5	40.6	25.2
Weedy check	43.2	29.5	4.2	3.6	9.3	23.0	24.1
LSD (p=0.05)	6.85	4.91	0.98	1.02	2.04	3.70	0.25

Pre-plant - Pre-plant incorporation; PE- Pre-emergence; HW- Hand-weeding; DAS - Days after sowing

Economics

Hand weeding twice resulted in the highest cost of cultivation (` 13404/ha) *fb* combined use of pendimethalin 300 g/ha + HW at 40 DAS (` 12673/ha). The cost of cultivation in case of herbicidal treatments was low in comparison to manual weed control and integrated approaches.

The influence of all the weed control treatments on gross return and B:C ratio were well marked as they registered significantly higher gross returns and B:C ratio over weedy check (**Table 2**). The maximum gross returns (` 40842/ha) and B:C ratio (3.42) were obtained with the ready-mix pendimethalin 205 g/ha + imazethapyr 14 g/ha, *fb* integrated treatment of pendimethalin 300 g/ha + HW at 40 DAS and ready-mix pendimethalin 154 g/ha + imazethapyr 10.4 g/ha . It may be due to higher seed and stover yield as a result of high weed control efficiency coupled with lesser cost of herbicide under these treatments.

Based on the results of present investigation, it was concluded that PE application of ready-mix pendimethalin 205 g/ha + imazethapyr 14 g/ha offers a cost effective and profitable weed management in lentil under rainfed condition.

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Isolation, screening and selection of efficient native arbuscular mycorrhizal fungi for suppression of *Striga* in sugarcane

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Native AMF consortium

Striga asiatica

Sugarcane

Weed control

ABSTRACT

The control of *Striga* is difficult to achieve because of its high fecundity and asynchronous seed germination. Thus, an attempt was made to control *Striga* in its subterranean stage of development using native arbuscular mycorrhizal fungi (AMF) spp. In this investigation, 16 AMF spp. were isolated, grouped and mass multiplied according to their morphological differences from the *Striga* suppressive soil of sugarcane growing area. Further, these 16 native AMF isolates (coded as UASDAMF), native AMF consortium (including 16 native AMF spp.), standard AMF consortium and uninoculated control- UIC (without AMF spp.) were tested against *Striga* under pot experiment. Significant inhibition of *Striga* emergence was observed with standard AMF consortium, native AMF consortium, UASDAMF-2, UASDAMF-5, UASDAMF-9 and UASDAMF-12. While, the UIC recorded highest number of *Striga* infestation. Chlorophyll content in sugarcane leaves (43.36 and 42.72 at 90 and 120 DAP respectively) were recorded highest with native AMF consortium. The physiological parameters such as photosynthetic rate and stomatal conductivity of sugarcane also recorded highest (18.16 and 0.55 µmol/ m^2/sec respectively) with native AMF consortium. The results indicated that the native AMF can efficiently compensate the negative effect of *Striga* infestation on sugarcane plants. An overall improvement in the biochemical and physiological attributes of the *Striga*-susceptible sugarcane variety CO86032 upon AMF colonization, clearly suggests the biocontrol and growth promotional potential of AMF consortium.

INTRODUCTION

Sugarcane (*Saccharum officinarum*) is an important commercial crop of India occupying around 3.8 million hectares of land with an annual cane production of around 270 million tones (2012-13). In Karnataka, suga rcane is cultivated in 4.4 lakh ha area with a productivity of 90 t/ha during 2015-16 season. The total cane crushed in the state during 2015-16 was 376.65 lakh tones compared to cane crushed during 2014-15 (450.92 lakh tonnes) in Karnataka. The 16.6 % reduction in productivity was caused due to the deficiency of soil fertility, lack of nutrition supply, disease incidence (rust, leaf spot), insect incidence (ex. Shoot borer) and parasitic weed infestation (ex. *Striga*).

Striga, a root parasite of cereals and legumes, has attracted much attention off late, as it is the main cause for serious loss in crop production in the semi-arid tropics. The life cycle of *Striga* is mainly dependent on its host. Approximately 75% of the overall *Striga* damage to the host is made during its subterranean stage of development (Parker and Riches 1993). Rank *et al.* (2004) demonstrated that *Striga* exerts a potent phytotoxicity effect on the host. Managing *Striga* below ground is therefore a crucial task for successful *Striga* management.

The control of *Striga* is difficult to achieve because of its high fecundity and asynchronous seed germination. Therefore, management of *Striga* infestation needs an integrated approach including host plant resistance, cultural practices, and chemical and biological treatments. Among all the components of this integrated *Striga* management, biological control gives a demonstrable crop-yield benefit within one growing season (Ahonsi *et al.* 2002). Thus, in order to prevent the weed menace as well as to prevent the environmental pollution by herbicides, the biotic interaction is required for effective and sustainable management of weed infestation and which will be a boon to sorghum and sugarcane growing farming community of northern Karnataka wherein devastating losses of yield due to *Striga* infestations are recorded in recent times. In this regard, an attempt was made to use the beneficial microbial community for the control of *Striga* weed in the sugarcane crop.

The germination stimulant for *Striga* seeds is a chemical exuded by the host roots known as strigolactones (SLs). However, the same chemical SL functions as a signal for recruitment of AM fungi in the host roots in P-deficient soils and is also known to induce hyphal branching.

Several species of mycorrhizal fungi have also been shown to increase plant biomass and compensate for damage by *S. asiatica* and their metabolites either stimulate or inhibit weed germination in sugarcane variety CO86032. Recent studies have shown that AM fungal colonization is likely to induce resistance to plant parasitism by converting strigolactones into mycorradicin, which is accumulated in mycorrhized roots and thereby reducing availability of strigolactones for *Striga* to germinate. The previous reports (Jones *et al.* 2014 and Sagarkar *et al.* 2017) also demonstrated the effectiveness of AM fungi against *Striga* emergence in sugarcane and sorghum. The present study envisaged the useful biotic interaction of AM fungi with plant roots for effective and sustainable integrated management of *S. asiatica* infestation for the resource-poor farming situations.

MATERIALS AND METHODS

Soil samples were collected from *Striga* infested site located at 16.01.01.03 N latitude; 074.58.1903 E longitude, and at an altitude of 643 m above mean sea level; and *Striga* suppressive sites located at 16.01.00.93 N latitude; 074.58.18.63 E longitude, and at an altitude of 642 m above mean sea level at Yergatti village of Belgaum district. The soil samples recovered from *Striga* infested soil was used to carry out the pot experiment while native AMF isolates were isolated from *Striga* suppressive soils. All the experiments were conducted at weed control scheme, MARS and Department of Agricultural Microbiology, University of Agricultural Sciences, Dharwad during the year 2014-15. There were nineteen treatments with five replications. The treatment details are as follows: UASDAMF1 to UASDAMF16; consortium AMF (standard) containing *Glomus macrocarpum, Gigaspora margarita, Acaulospora laevis;* consortium AMF (native) containing all 16 native isolates; and uninoculated control. AM spores were identified as described by Rodrigues and Muthukumar (2009). The pots were filled with *Striga* infested soil prior to the planting equal sized sugarcane sets (CO-86032). AMF inoculum at 150 g/pot was mixed thoroughly with the top 10 to 15 cm of the soil. The data were subjected to analysis following Completely Randomized Design (CRD) as defined by Gomez and Gomez (1984)

The number of *Striga* emerged was recorded in each pot. The shoot and root portions of uprooted *Striga* plants were separated and oven dried at 60°C to constant weight. The dry weights (n=5) were then recorded separately for shoots and roots.

The sugarcane leaf chlorophyll content was determined using a single photoelectric analyzing diode (SPAD) meter (SPAD-502 KONICA-Japan).

Measurement of photosynthetic rate, stomatal conductance, rate of transpiration and leaf temperature were made on the top fully expanded leaf of sugarcane at different locations by using a portable photosynthesis system (LI-6400 LICOR, Nebraska, Lincoln USA). The chlamydospores in rhizosphere of sugarcane were determined by wet sieving and decantation method as outlined by Gerdemann and Nicholson (1963). Spores counts were taken under a stereo zoom microscope.

Mycorrhizal root colonization was determined as per the procedure proposed by Philips and Hayman (1970). The percentage of roots colonized by mycorrhizae was calculated by the formula

$$\% \text{ root colonization} = \frac{\text{Root bits positive for colonization}}{\text{Total number of root bits}} \times 100$$

RESULTS AND DISCUSSION

The structural and morphological features of native AMF spores is as outlined in **Table 1** and microphotographs shown in **Figure 1**. *Glomus* was the predominant genus followed by *Acaulospora*.

No emergence of *Striga* was recorded in treatments received AMF consortium (STD), AMF consortium (native) and native AMF isolates UASDAMF2, UASDAMF5, UASDAMF9 and UASDAMF12. The shoot and root dry weight of *Striga* was found to be higher in UIC compared to all other isolates (18.02 and 2.60 g/plant respectively) at 120 DAP (**Table 2**). The suppression of *Striga* by AM fungi is chiefly known to be due to depletion of Strigolactones by them in the rhizosphere of the host

Table 1. Identification of native AM fungal morpho-types from *Striga* suppressive soils

Isolate code no.	Shape	Colour	Spore mean size (µm)	Spore wall size mean (µm)	Spore surface	Size of hyphae mean (µm)	Species
UASD AMF1	Oval	Dark brown	104.83	5.60	Smooth	9.1	*Glomus ambisporum*
UASD AMF2	Oval	Dark brown	96.62	10.50	Smooth	12.3	*Glomus etunicatum*
UASD AMF3	Ellipsoid	Brown	137.60	11.90	Rough	-	*Glomus mossae*
UASD AMF4	Oval	Light yellow	104.60	9.40	Smooth	63.6	*Glomus spp.*
UASD AMF5	Oval	Light yellow	120.80	5.52	Smooth	71.8	*Acaulospora maarowe*
UASD AMF6	Oval	Brown	165.52	10.8	Granular	47.8	*Glomus deserticola*
UASD AMF7	Oval	Yellow	179.32	10.60	Laminated	53.3	*Glomus phansihalos*
UASD AMF8	Oval	Yellow	118.9	13.00	Smooth	-	*Acaulospora spinosa*
UASD AMF9	Round	Light brown	107.8	7.60	Smooth	-	*Glomus leptotichum*
UASD AMF10	Oval	Brown	78.58	7.90	Smooth	12.6	*Glomus aggregatum*
UASD AMF11	Ellipsoid	Dark yellow	149.56	12.75	Granular	-	*Glomus lacteum*
UASD AMF12	Oval	Dark yellow	73.7	11.9	Granular	51.4	*Glomus fasciculatm*
UASD AMF13	Ellipsoid	Yellow	111.27	8.90	Smooth	-	*Glomus radiata*
UASD AMF14	Oval	Brown	105.72	7.50	Rough	-	*Glomus retuculatum*
UASD AMF15	Oval	Dark yellow	121.65	5.40	Smooth	-	*Acaulospora bisporus*
UASD AMF16	Oval	Brown	131.45	10.02	Granular	-	*Acaulospora lacunosa*

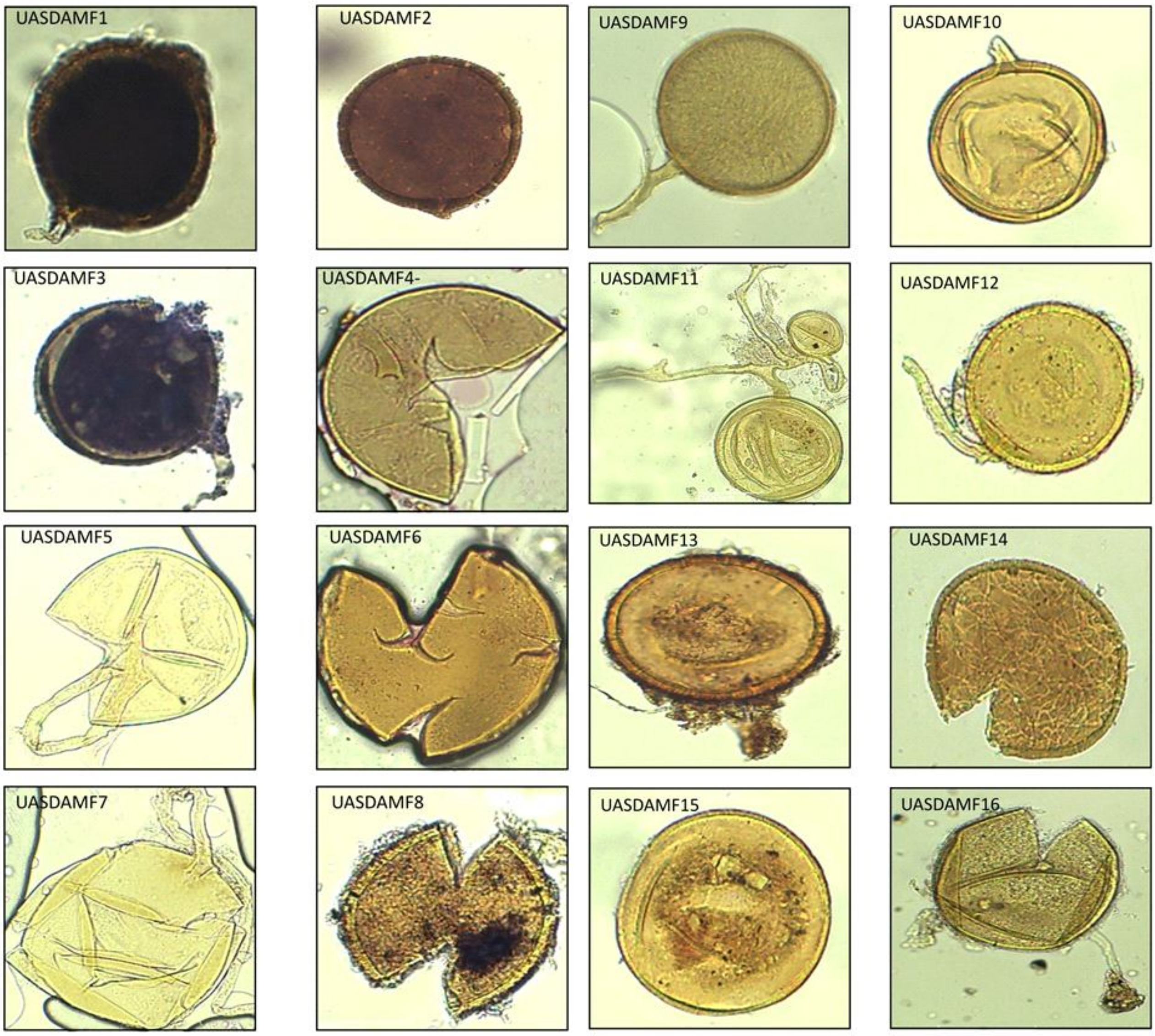

Figure 1. Microphotographs of chlamydospores of native AM fungi

Table 2. Influence of AM fungal isolates on *Striga* parameters

Treatment	No. of *Striga* per pot	Shoot dry matter (g)	Root dry matter (g)	Total dry matter (g)
UASD AMF1	40	12.2	1.53	13.9
UASD AMF2	0	0	0	0
UASD AMF3	41	13.5	1.71	15.2
UASD AMF4	39	15.2	1.65	16.8
UASD AMF5	0	0	0	0
UASD AMF6	42	13.2	1.53	14.7
UASD AMF7	42	12.2	1.62	14.0
UASD AMF8	43	13.5	1.50	15.0
UASD AMF9	0	0	0	0
UASD AMF10	40	14.7	1.53	16.2
UASD AMF11	44	15.9	1.71	17.3
UASD AMF12	0	0	0	0
UASD AMF13	47	15.3	1.92	17.5
UASD AMF14	41	11.5	1.41	12.9
UASD AMF15	41	13.4	1.54	14.9
UASD AMF16	45	17.6	1.72	19.1
AMF consortium (STD)	0	0	0	0
AMF consortium (native)	0	0	0	0
UIC	51	18.0	2.6	20.6
LSD (p=0.05)		0.62	0.07	0.65

Table 3. Sugarcane chlorophyll content as influenced by native AM fungal isolates in *Striga* infested soil

Treatment	Chlorophyll content of sugarcane plants			
	30 DAP	60 DAP	90 DAP	120 DAP
UASD AMF1	34.9	42.2	39.0	37.7
UASD AMF2	40.0	44.1	42.1	40.5
UASD AMF3	35.5	40.7	35.4	34.1
UASD AMF4	34.9	40.5	34.8	35.2
UASD AMF5	42.9	45.9	43.1	41.8
UASD AMF6	35.5	39.6	37.6	40.7
UASD AMF7	34.9	37.6	35.2	40.5
UASD AMF8	35.4	41.5	40.8	39.8
UASD AMF9	43.1	46.0	43.3	42.7
UASD AMF10	36.4	40.4	35.9	35.5
UASD AMF11	34.1	40.3	35.1	34.5
UASD AMF12	41.0	44.9	42.9	41.8
UASD AMF13	32.7	36.9	34.4	34.1
UASD AMF14	35.4	41.0	35.5	34.6
UASD AMF15	33.9	38.1	36.9	37.3
UASD AMF16	32.6	36.1	33.9	32.5
AMF consortium (STD)	46.7	49.8	46.3	45.8
AMF consortium (native)	43.4	46.5	43.4	42.7
UIC	29.8	35.4	32.0	25.3
LSD (p=0.05)	1.34	2.34	2.29	2.30

plants. Interestingly, AM fungi and parasitic weeds respond to strigolactones for their germination. Mycorrhizal colonization induces mycorrhizosphere effects that negatively impact on *Striga* germination (Lendzemo *et al.* 2007).When plants are subjected to a shortage in the available phosphate the production and release of strigolactones into the rhizosphere are increased. AM fungi perceive this signal and respond with extensive hyphal branching. This process increases the chance of encountering the roots of the host plant and hence assists in establishing the symbiosis. The *Striga*, *Orobanche* and *Phelipanche* spp. have likely evolved a mechanism to hijack this communication signal and turn it into a germination inducing signal to respond in the presence of a suitable host.

Field experiments have shown that AM symbiosis delayed the emergence and reduced the number of *Striga* parasites on sorghum (Lendzemo *et al.* 2007). In tomato, the decrease in parasitism by *Phelipanche ramosa* upon AM colonization also correlated with a lower induction of germination of seeds of this parasite by the root exudates. Subsequent LC-MS analysis showed that the root exudates of colonized plants indeed contained lower amounts of strigolactones (Lopez-Raez *et al.* 2011). These results suggest that AM fungal colonization likely induces resistance to plant parasitism by reducing the exudation of strigolactones.

The AMF consortium (STD), AMF consortium (native), and single native AMF isolates UASDAMF9, UASDAMF5, UASDAMF12 and UASDAMF2 significantly improved the chlorophyll content compared to the uninoculated plants as outlined in **Table 3**. AMF induced increase in chlorophyll content was also observed by Franco and Garza (2006).

Table 4. The influence of AMF on physiological parameters of sugarcane plants

Treatment	PR (µmol/ m^2/ sec)	SC (µmol/ m^2/ sec)	TR (µmol/ m^2/sec)	LT (C^o)
UASD AMF1	14.54	0.51	4.99	29.5
UASD AMF2	16.75	0.52	4.51	29.3
UASD AMF3	14.02	0.51	4.74	30.1
UASD AMF4	15.35	0.50	5.53	29.9
UASD AMF5	17.29	0.53	4.46	29.1
UASD AMF6	15.36	0.51	4.54	29.3
UASD AMF7	15.58	0.49	4.94	29.9
UASD AMF8	14.21	0.47	5.28	29.3
UASD AMF9	17.91	0.54	4.40	28.3
UASD AMF10	14.57	0.45	4.50	30.2
UASD AMF11	15.20	0.48	4.80	29.9
UASD AMF12	17.10	0.52	4.50	29.3
UASD AMF13	14.46	0.50	5.26	30.7
UASD AMF14	14.15	0.50	4.86	31.1
UASD AMF15	16.35	0.49	5.12	28.7
UASD AMF16	15.15	0.47	5.40	29.0
AMF consortium (STD)	18.91	0.58	4.16	28.0
AMF consortium (native)	18.16	0.55	4.36	28.0
UIC	13.59	0.45	5.54	31.7
LSD (p=0.05)	0.99	0.04	0.39	2.44

PR = Photosynthestic rate; SC = Stomatal conductance; TR = Transpiration rate; LT = Leaf temperature

Table 5. Mycorrhizal spore count in sugarcane rhizosphere and Mycorrhizal root colonization as influenced by AM fungal isolates

Treatment	Mycorrhizal spore count (no. of spores/50 g)				Per cent root colonization (%)
	30 DAP	60 DAP	90 DAP	120 DAP	
UASD AMF1	156.5	210.0	281.5	540.0	51.0
UASD AMF2	220.5	271.5	310.5	615.0	66.0
UASD AMF3	162.5	220.5	273.5	564.5	47.0
UASD AMF4	183.0	227.5	288.5	594.0	51.5
UASD AMF5	230.0	282.5	366.5	625.5	67.5
UASD AMF6	193.5	238.0	283.5	572.0	47.5
UASD AMF7	219.5	233.0	271.5	584.5	53.5
UASD AMF8	164.5	195.0	268.0	528.5	52.0
UASD AMF9	238.5	292.0	373.0	641.5	68.0
UASD AMF10	150.5	209.0	288.5	592.5	58.0
UASD AMF11	154.0	194.0	267.5	527.0	51.0
UASD AMF12	226.0	277.5	349.5	623.5	67.5
UASD AMF13	141.5	191.5	254.0	497.5	50.5
UASD AMF14	155.0	199.0	274.5	556.0	51.0
UASD AMF15	158.5	206.5	285.0	551.5	52.5
UASD AMF16	139.5	191.5	234.0	454.5	40.5
AMF consortium (STD)	255.0	305.0	384.5	687.5	72.5
AMF consortium (native)	227.0	300.0	379.0	668.0	70.0
UIC	137.0	146.5	167.0	211.0	25.5
LSD (p=0.05)	17.18	18.81	13.24	30.33	3.64

The physiological parameters such as photosynthetic rate and stomatal conductivity of sugarcane in the present study showed maximum values where AMF was inoculated in comparison with UIC (**Table 4**); this is in agreement with the reports of Selvaraj and Chellapan (2006), who also reported an increased photosynthetic activity in the leaves of *Prosopis julifera* inoculated with *G. fasciculatum*.

The highest mycorrhizal spore load was recorded with AMF consortium (STD) (687.5/50 g soil) followed by AMF consortium (native) (668/50 g soil) at 30, 60, 90 and 120 DAP. Least number of spore load was recorded with non mycorrhized sugarcane plants, UIC (211/50 g soil). Percentage root colonization by native AMF in the presence of *Striga* is given in **Table 5**.

Devika *et al*. (2013) reported AM fungal colonization in the roots of sugarcane may be due to fungal preference by the host and due to the factors influencing the mycotrophy of sugarcane. AM fungi can colonize many host plants. But it has a preferred host which exhibits maximum symbiotic response when colonized by that particular AM fungal species.

Thus, the native AM fungal species isolated in the present study could form an efficient and inexpensive *Striga* control agent, which should be integrated with other *Striga* management strategies to help sugarcane farmers of north Karnataka.

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Surfactant influence on efficacy of herbicides in barley

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ABSTRACT

Field experiment was conducted at Agricultural Research Farm, Banaras Hindu University during winter seasons of 2014-15 and 2015-16 to evaluate the effect of herbicides alone or as mixture with or without nonionic surfactant on broad-leaf weeds in barley (*Hordeum vulgare* L.). Post-emergence application of premix formulation of metsulfuron-methyl + carfentrazone-ethyl at 25 g/ha + surfactant at 0.2% proved most effective against *Anagalis arvensis* L., *Chenopodium album* L., *Melilotus alba* L., *Solanum nigrum* L. and *Rumex dentatus* L. Maximum reduction in population and dry weight of weeds, and higher weed control efficiency (63.2%), yield attributes and yield (3.5 t/ha) of barley were recorded in metsulfuron-methyl + carfentrazone-ethyl at 25 g/ha + surfactant at 0.2% applied as post-emergence.

INTRODUCTION

Barley (*Hordeum vulgare* L.) is an ancient cereal grain, which can grow in a wide range of environments than any other cereal, including extremes of latitude, longitude, and high altitude. In India, during 2014-15,barley occupied nearly 0.67 million hectare area producing nearly 1.63 million tons grain, with a productivity of 2.4 t/ha (Anonymous 2015). Presently, 25-30% of total barley produced is used in the manufacturing of malt extract, which is further utilized for brewing, distillation, baby foods, coca-malt drinks, and medicinal syrups. Amongst the factors, limiting barley production, weeds are an important biotic stress affecting crop productivity. Lack of effective weed control measures and basic knowledge of weed management in barley have emerged as the limiting factor in barley production (Duwayri *et al*.1988). Phenoxy herbicides, such as 2,4-D is a widely used chemical for control of broad-leaf weeds in barley but prolonged use of 2,4-D for several years leads to reduced efficacy of 2,4-D especially against hard to control broad-leaf weeds such as *Rumex dentatus* L., *Rumex spinosus* L., and *Malva parviflora.* Recently, *Rumex dentatus* has evolved resistance against metsulfuron, pyroxsulum and mesosulfuron + iodosulfuron in wheat. Proactive approach using herbicide mixture with different mode of action can be an effective way to prevent evolution of resistance biotypes in predominant weeds. Metsulfuron-methyl is a sulfonylurea herbicide and has both, pre- and post-emergence activity for control of broad-leaf weeds and can suppress some annuals. Studies indicated that barley can metabolize metsulfuron-methyl (Anderson *et al.* 1989), thus may be helpful to reducing the phyotoxicity on plant. Carfentrazone-ethyl has slight edge over metsulfuron-methyl for the control of *Convolvulus arvensis*, *Rumex dentatus* and *Malva parviflora*, but its efficacy was lower on *C. album*, *A. tenuifolius*, *L. aphaca* and *M. indica* compared to metsulfuron-methyl (Walia *et al.* 2010). Use of activator adjuvant is widely accepted to improve efficacy of post-emergence herbicides, which may allow herbicide dosage to be reduced and nonionic surfactant when added as a tank mixture increased the efficacy of post-emergence herbicides (Hosseini *et al.* 2011). Since, no single herbicide controls all broad-leaved weeds, the present study was conducted to evaluate the effect of alone and tank mix application of different herbicide with or without surfactant on weed growth and yield of barley.

MATERIALS AND METODS

The efficacy of alone and tank mix application of different herbicides in reducing weed biomass and effect on crop yield were evaluated during the winter seasons of 2014-15 and 2015-16 at the Agricultural Research Farm, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi (Uttar Pradesh). The soil of the experimental field was sandy loam in texture, neutral in reaction, low in organic carbon (0.4%) and available nitrogen (196.4 kg/ha), high in available phosphorus (25.6 kg/ha) and medium in available potassium (170.1 kg/ha). The experiment was laid out in a randomized complete block design with 3 replications and 16 treatments. The treatments consisted of 3 rates (15, 20 and 25 g/ha), of metsulfuron-methyl 10% + carfentrazone-ethyl 40% and 2,4-D Na salt at 500 g/ha without and with 0.2% non-ionic surfactant (NIS), alone application of metsulfuron-methyl, carfentrazone-ethyl, isoproturon 1000 g/ha, mixture of isoproturon + 2,4-D sodium salt (1000 + 500 g/ha),weedy check and weed free. Barley variety '*RD2552*' was sown with recommended package and practices except treatments. Herbicides were applied with knapsack sprayer fitted with flat-fan nozzle. The quantity of spray volume was calculated by test run basis. Data on weed density and dry weight was recorded on 60 DAS, and was subjected to square root transfor-mation. Data on weed control efficiency (WCE) was calculated at 60 DAS. The yield attributes were recorded at harvest and yield of barley was recorded after threshing adjusted to 14% moisture content.

RESULTS AND DISCUSSION

Effect on weeds

The major weeds found to infest experimental field were *Anagalis arvensis*, *Chenopodium album*, *Melilotus alba*, *Solanum nigrum* and *Rumex dentatus* among the broad-leaf weeds. Crop was also infested with perennial grass *Cynodon dactylon* L. and sedge, *Cyperus rotundus* L. All the weed control treatments significantly reduced the weed density as compared to the untreated control. Metsulfuron-methyl + carfentrazone-ethyl at 25 g/ha with 0.2% non ionic surfactant (NIS) was most effective and had significantly minimum density of broad-leaf weed species than other treatments, except metsulfuron-methyl + carfentrazone-ethyl at 20 g/ha with surfactant. Alone application of carfentrazone-ethyl at 40 g/ha and metsulfuron-methyl at 4 g/ha with 0.2% NIS were significantly superior to their application without surfactant and also to 2,4-D at 500 g/ha, either applied alone or with NIS. These treatments remained at par with metsulfuron-methyl + carfentrazone-ethyl at 15 and 20 g/ha without NIS. Isoproturon at 1000 g/ha was ineffective in controlling broad-leaf weeds and thus had significantly higher density of weeds. However, when mixed with 2,4-D, it controlled broad-leaf weeds similar to metsulfuron-methyl + carfentrazone-ethyl at 15 and 20 g/ha without NIS (**Table 1)**. The application of 2,4-D + isoproturon was most effective in controlling broad-leaved weeds at all stages except 30 DAS. These results obtained mainly due to the fact that most of the herbicides when applied alone controlled few broad leaf weeds or grassy weeds.

The dry matter accumulation by weeds envisages that it varied in different herbicide treatments. This might be due to the variable density of weeds under different treatments. The maximum reduction in weed dry matter was observed in the treatment metsulfuron-methyl + carfentrazone-ethyl at 25 g/ha + 0.2% NIS and minimum in weedy check. Similar results were obtained by Singh *et al.* (2011)

Table 1. Effect of different herbicides on weeds population at 60 days after sowing (two years mean)

Treatment	Weeds population/m^2						
	Anagalis arvensis	*Chenopodium album*	*Melilotus alba*	*Solanum nigrum*	*Rumex dentatus*	*Cyperus rotundus*	Total weed
Metsulfuron-methyl + carfentrazone-ethyl (15 g/ha)	2.24(4.5)	1.8(3.0)	1.7(2.7)	2.9(8.0)	2.3(5.2)	3.19(9.7)	6.83(46.2)
Metsulfuron-methyl + carfentrazone-ethyl (20 g/ha)	2.04(3.6)	1.7(2.5)	1.6(2.3)	2.8(7.5)	2.2(4.5)	3.03(8.7)	6.52(42.0)
Metsulfuron-methyl + carfentrazone-ethyl (25 g/ha)	1.69(2.3)	1.4(1.5)	1.4(1.7)	2.7(7.0)	2.2(4.3)	2.92(8.0)	6.14(37.2)
Metsulfuron-methyl + carfentrazone-ethyl + nonionic surfactant (15 g/ha + 0.2%)	1.91(3.1)	1.5(1.9)	1.5(2.0)	2.7(7.2)	2.1(4.2)	2.97(8.3)	6.31(39.4)
Metsulfuron-methyl + carfentrazone-ethyl + nonionic surfactant (20 g/ha + 0.2%)	1.53(1.8)	1.3(1.3)	1.3(1.3)	2.6(6.7)	2.0(3.7)	2.86(7.7)	5.93(34.7)
Metsulfuron-methyl + carfentrazone-ethyl + nonionic surfactant (25 g/ha + 0.2%)	1.08(0.6)	1.0(0.7)	1.2(1.0)	2.5(6.2)	1.9(3.2)	2.80(7.3)	5.60(30.4)
Metsulfuron-methyl (4 g/ha)	2.83(7.5)	2.7(7.0)	2.5(6.0)	3.2(9.9)	2.8(7.3)	2.45(5.5)	7.33(53.2)
Carfentrazone-ethyl (20 g/ha)	2.68(6.6)	2.6(6.3)	2.4(5.3)	3.1(9.5)	2.7(6.9)	2.62(6.4)	7.22(51.7)
2,4-D-Na (500 g/ha)	3.03(8.6)	2.9(8.0)	2.7(7.2)	3.2(10.3)	2.9(8.0)	2.27(4.7)	7.55(56.5)
Metsulfuron-methyl + nonionic surfactant (4 g/ha + 0.2%)	2.52(5.8)	2.3(5.0)	2.0(3.7)	3.1(9.2)	2.6(6.3)	2.24(4.5)	6.63(43.5)
Carfentrazone-ethyl + nonionic surfactant (20 g/ha + 0.2%)	2.42(5.3)	2.2(4.7)	1.9(3.3)	3.1(8.9)	2.5(5.9)	2.20(4.3)	6.52(42.0)
2,4-D-Na + nonionic surfactant (500 g/ha + 0.2%)	2.94(8.1)	2.8(7.5)	2.6(6.5)	3.2(10.0)	2.8(7.7)	2.00(3.5)	7.15(50.7)
Isoproturon (1000 g/ha)	3.16(9.5)	3.0(8.50)	2.8(7.83)	3.3(10.8)	3.0(8.5)	2.12(4.0)	7.59(57.2)
Isoproturon + 2,4-D-Na (1000 + 500 g/ha)	2.31(4.8)	2.1(4.0)	1.8(3.0)	3.0(8.5)	2.4(5.5)	1.78(2.7)	5.92(34.5)
Weedy check	3.49(11.6)	3.2(10.0)	3.0(9.0)	3.6(12.5)	3.1(9.5)	3.8(14.2)	9.06(81.7)
Weed free	0.71(0.0)	0.7(0.0)	0.7(0.0)	0.7(0.0)	0.7(0.0)	0.71(0.0)	0.71(0.0)
LSD (p=0.05)	0.50	0.40	0.51	0.23	0.28	0.37	0.44

Table 2. Effect of herbicide on weed dry weight, weed control efficiency, yield attributes, and yield of barley (two years mean)

Treatment	Weeds weight (g/m^2)	WCE (%)	Ear heads/m^2	Grains (no./ear)	Test weight (g)	Grain yield (t/ha)
Metsulfuron-methyl + carfentrazone-ethyl (15 g/ha)	12.6	51.2	332	39	31.1	2.9
Metsulfuron-methyl + carfentrazone-ethyl (20 g/ha)	11.9	53.8	341	40	32.2	3.1
Metsulfuron-methyl + carfentrazone-ethyl (25 g/ha)	11.2	56.5	348	41	32.8	3.2
Metsulfuron-methyl + carfentrazone-ethyl + nonionic surfactant (15 g/ha + 0.2%)	11.8	56.6	352	42	31.6	3.0
Metsulfuron-methyl + carfentrazone-ethyl + nonionic surfactant (20g/ha + 0.2%)	10.1	60.1	356	46	32.6	3.3
Metsulfuron-methyl + carfentrazone-ethyl + nonionic surfactant (25g/ha + 0.2%)	9.5	63.2	358	45	33.8	3.5
Metsulfuron-methyl (4 g/ha)	15.4	39.2	333	37	30.5	2.9
Carfentrazone-ethyl (20 g/ha)	14.3	44.5	336	38	31.2	2.8
2,4-D-Na (500 g/ha)	16.4	36.4	330	35	29.9	2.7
Metsulfuron-methyl + nonionic surfactant (4 g/ha + 0.2%)	14.1	45.3	337	38	31.0	3.2
Carfentrazone-ethyl + nonionic surfactant (20 g/ha + 0.2%)	13.4	48.1	340	44	31.7	3.0
2,4-D-Na + nonionic surfactant (500 g/ha + 0.2%)	14.6	43.4	290	36	30.2	2.9
Isoproturon (1000 g/ha)	22.1	14.4	284	34	29.4	2.7
Isoproturon+2,4-D-Na (1000 + 500 g/ha)	15.0	41.9	300	37	30.9	2.8
Weedy check	25.8	0.0	271	33	28.6	2.4
Weed free	0.00	100	349	45	34.8	3.7
LSD (p=0.05)	0.25	2.7	8.6	1.2	1.6	0.01

WCE-Weed control efficiency

who found that the use of tank mix application of metsulfuron-methyl + carfentrazone-ethyl at 25 g/ha with surfactant reduced the weed dry weight. The lower doses of application of herbicide at 15, 20 g/ha with surfactant proved similarly to its mixture at higher rates that is at 20 and 25 g/ha without surfactant, respectively. It indicates that use of non-ionic surfactant was effective in improving herbicide efficacy and reducing rate of herbicide mixtures (Rashed *et al.* 2011). Weed dry weight was significantly reduced under herbicide treatments due to decrease in weed population (Punia *et al.* 2011). The highest weed dry matter was recorded with the application of isoproturon which might be due to dominance of broad-leaf weeds in experimental crop.

Weed control efficiency (WCE) reflects the relative efficiency of weed control practices in reducing weed growth over weedy check. Among various weed control treatments, application of metsulfuron-methyl + carfentrazone-ethyl at 25 g/ha + 0.2% NIS recorded higher WCE than other weed control treatments. The results were in conformity with Ram *et al.* (2009) who reported that the higher WCE might be due to better weed control, which was associated with reduction in weed density and weed dry weight. The lowest WCE was found with the application of isoproturon owing to its poor efficacy against broa-leaf weeds.

Effect on crop

All the weed control practices significantly influenced the yield attributes as compared to weedy check and sole application of isoproturon. Application of metsulfuron-methyl and carfentrazone-ethyl at 25 g/ha recorded maximum ear heads/m^2, number of grains/ear head, test weight and ultimately the yield. Application of herbicide mixture at higher rates at 20 and 25 g/ha without surfactant remained at par with lower rates at 15g and 20g/ha with surfactant (**Table 2**).This could be due to higher WCE in these treatments, which showed minimum competition from weeds resulting in higher crop dry matter production and yield attributing characters. Consequently, the grain yield also improved with increase in yield attributes under the treatment.

This study confirmed the role of herbicide mixture in managing complex weed flora in barley and also the role of surfactant in reducing rate of herbicides. Thus, pre-mix formulation of metsulfuron-methyl + carfentrazone-ethyl at dose of 20 g/ha or 25 g/ha + 0.2% NIS is an alternate to their individual use for managing weeds in barley.

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Appearance of new weeds in Punjab

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ABSTRACT

Weed monitoring and survey was conducted to detect appearance of new weed species. Ten new weed species namely *Galium spurium* Linn. (family Rubiaceae), *Geranium nepalense* Sweet (family Geraniaceae), *Lamium amplexicaule* Linn. (family Lamiaceae), *Evolvulus nummularius* (family Convolvulaceae), *Euphorbia thymifolia* Linn.(family Euphorbiaceae), *Oenothera laciniata* Hill (family Onagraceae), *Soliva anthemifolia* (Juss.) R. Brown (family Asteraceae), *Verbesina encelioides* (Cav.) Benth. and Hook. f. ex A. Gray (family Asteraceae), *Nicotiana plumbaginifolia* Viv. (family Solanaceae) and *Portulaca oleracea* L. (family Portulacaceae) have been recorded in the last decade from different places of Punjab State. Out of these, weed species namely, *O. laciniata*, *L. amplexicaule*, *S. anthemifolia* and *G. nepalense* were mainly observed inhabiting the crop fields. Three weed species namely, *G. spurium*, *N. plumbaginifolia* and *V. encelioides* were observed growing along roadsides, wastelands, canal banks and uncultivated areas. *P. oleracea* and *E. thymifolia* were observed growing on bunds of agricultural fields. *E. nummularius* is a serious weed of lawns and landscapes. These weeds have now domesticated in the studied ecological niche and may potentially harm the biodiversity of those areas.

INTRODUCTION

Punjab is a state in North-West region of India at latitude of 28°17' to 32°17' N and longitude of 74°04' to 77°06' E covering 50,362 square kilometer of area with 22 districts. Most of the Punjab lies in a fertile, alluvial plain with many rivers and an extensive irrigation canal system. Agriculture is the largest industry forms the backbone of the state economy. It is the leading producer of wheat (19.5%) and rice (11%), thereby contributing to the national food security (GOI 2017). It has earned the sobriquet of “Granary of India” or “India’s bread-basket”.

Weeds are more harmful pests of field crops as compared to other crop pests (insects, fungi, rodents, storage pests etc.) as far as their losses to crop produce are concerned. Weeds compete with the crop for limited resources and may also serve as alternate hosts for various insect and disease pests. Weeds are classified into annuals, biennials and perennials based on life cycle, and into grasses, sedges and broadleaved weeds based on their leaf morphology. The weed species found in the field generally reflect the history of agricultural activities in that field. Weeds are genetically diverse and can readily take advantage of the variety of conditions created by any crop production system. Weedy and invasive species can easily adapt to changes in production practices in order to take advantage of the available niches as invasive weeds have phenotypic plasticity to suit the changing weather conditions. These plants have all the characteristics of the ‘pioneer plants’, the first to inhabit any new place. Invasive weeds are inclined to occupy the habitats with much rapidity in areas where same ecological demands are being fulfilled. Eventually, invasive weeds may displace the local flora to gain the foothold in local landscape ecology.

Invasive alien weeds are those plant species that are intentionally or unintentionally introduced to a location, area, or region where it does not occur naturally, and has established and spread or has the potential to do so, and which then threatens ecosystems, habitats and/or other species, potentially causing economic and/or environmental damage, or harm to human health. In the treaty of Convention of Biological Diversity, invasive alien weeds have been identified as the second worst threat (CBD 1992). Surveys help in predicting areas potentially subject to weed invasion, understanding the biology of the invasion process and determining means by which weeds spread and to develop, implement and evaluate weed management plans, assess the economic impact of weed invasion and increase public awareness, education and weed management efforts. Weed monitoring provides information to tailor weed management efforts that reduce the impact of the weeds with greatest potential impact. In Punjab, this survey and surveillance study was planned to see the extent of distribution of new invasive alien weeds during decade of 2008-2017.

MATERIALS AND METHODS

The primary objective of weed surveying and mapping was to accurately identify and delineate land with populations of undesired plants. Weed monitoring involves repetitive surveys to track weed populations over time and appearance of new weed to that area is reported. A standardized system of weed surveying and mapping is followed to provide consistently reliable information that can be compared from year to year (McIntosh 1962). These surveys were conducted over the span of ten years in both, winterand rainyseasons to check for any new weed infesting the crop fields, waste lands, canal banks and roadside areas. Stoppage was made at 10 km and the caution was taken that survey spot was not near to any building or permanent structure. Invasion of new weed species, new emerging weed problem, shift in weed flora and reduced efficacy of used herbicide was specifically noted. The observation about growing habit and life cycle of weed was noted and possible source of entry was also looked into. Weed survey was made every season for appearance of any new weed(s) and surveillance was done after five year of its first appearance at the designated GPS locations, and in this study, occurrence of new weeds has been reported.

RESULTS AND DISCUSSION

This is the first report of ten new broadleaf weed species (**Table 1**) recorded in the last decade from different places of Punjab State. Out of these, two species belonged to the advance dicotyledonous family, Asteraceae, and rests belonged to Rubiaceae, Geraniaceae, Lamiaceae, Portulacaceae, Convolvu-laceae, Solanaceae, Euphorbiaceae and Onagraceae. All these weeds are potential invader in different parts of the world, hence, their introduction and subsequent naturalization in Punjab soil is found to be of great concern. The salient characteristics, distribution and control measures of these new weeds are as under:

***Galium spurium* Linn. (Rubiaceae):** It was observed for the first time in and around wheat fields of Ludhiana and Shaheed Bhagat Singh Nagar districts during winter season of 2014-15. Its common names include ‘False Cleavers’ and ‘Sticky Willy’. It is an annual procumbent herb, 30-50 cm high and with quadrangular stem. Leaves are narrowly oblong-lanceolate, up to 4 cm long, arranged in whorls of 4-8, subsessile. Flowers are minute, 1-3 mm in diameter, yellowish green or

Table 1. Characteristics of new weeds observed in Punjab state in last decade

Weed species, Family	GPS Location of first observation	Occurrence	Season	Name of the domesticated location at present
Galium spurium Linn. RUBIACEAE	30°55'-30°57' N & 75°54'-76°32' E	Wheat fields and uncultivated areas	Winter Annual	Ludhiana and Shaheed Bhagat Singh Nagar districts
Geranium nepalense Sweet GERANIACEAE	30°55' N & 75°54' E	*Rabi* crop fields	Perennial	Ludhiana
Lamium amplexicaule Linn. LAMIACEAE	32°17' N & 75°42' E	Wheat fields	Winter Annual	Pathankot submontane areas
Oenothera laciniata Hill ONAGRACEAE	30°55' N & 75°54' E	Crop fields and wastelands	Annual or short-lived perennial	PAU, Ludhiana
Soliva anthemifolia (Juss.) R. Brown ASTERACEAE	30°55' N & 75°54' E	Wheat fields and lawns	Winter Annual	PAU, Ludhiana
Verbesina encelioides (Cav.) Benth. & Hook.f. ex A.Gray ASTERACEAE	30°55' - 31°12' N & 74°04' -77°06' E	Uncultivated areas, canal banks, roadsides	Annual	South-west Punjab
Euphorbia thymifolia EUPHORBIACEAE	31°23'N & 75°25' E	Paddy and vegetable fields	Annuals	Whole Punjab state
Evolvulus nummularius CONVOLVULACEAE	30°55'N & 75°54' E	Lawns	Annuals	PAU, Ludhiana
Nicotiana plumbaginifolia SOLANACEAE	30°55'N & 75°54' E	Uncultivated areas, canal banks, roadsides	Annuals	PAU, Ludhiana
Portulaca oleracea L. PORTULACACEAE	31°23'N & 75°25' E	Paddy and vegetable fields	Summer Annual	Whole Punjab state

white, arranged in terminal or axillary cymes. Fruits are capsular, hairy or glabrous, broadly reniform, and 1-3mm in diameter.

This plant is known to be cultivated at higher altitudes as ornamental herb in India; however, it has started naturalization at Ludhiana during last 3-4 years, indicating its transformation to a probable invasive weed in near future starting from the land of Punjab. It is a serious weed in western Canada, where 20% reduction in canola crop yield was reported by 100 plants/m^2 (Zhang and Bailey 2000). In addition, some populations of false cleavers have shown high resistance to imazethapyr (resistance factors greater than 100) and florasulam, both ALS inhibitors, but these populations were found to be susceptible to fluroxypyr, a synthetic auxin (Beckie *et al.* 2012).

Geranium nepalense **Sweet (Geraniaceae):** It is an erect and branched herb and was observed since winter 2008-09 at Ludhiana. A native of Himalayas distributed from Nepal and Bhutan to Sikkim, Arunachal Pradesh and Meghalaya towards North East, and Kashmir towards western India; however, in Nilgiris and Wstern Ghat, the species is cultivated. Beyond India, its distribution is extended to Afghanistan, Pakistan, China, Myanmar, Thailand, Indonesia and Sri Lanka. The usual distribution range of 'Nepal Geranium' is in between 1500 to 2900m altitudes. This species of *Gernium* is a perennial herb with vertical rootstocks, diffusely decumbent-ascending herb, 30-70 cm high, sometimes rotting at nodes. Leaves are palmately cleft into 5-7 lobes, opposite, petiolate and stipulate; segments are further cut into 6-12 lobes. The flowering occurred from April to September. Flowers are small, white with 5 spreading petals and have violet lines towards the base.

Lamium amplexicaule **Linn. (Lamiaceae):** It was observed for the first time in and around rainfed wheat fields during winter season 2014-15 in sub-montaneous area of Pathankot. It is commonly known as 'Henbit Dead-nettle', 'Common Henbit', or 'Greater Henbit' and is a winter annual, herbaceous and broadleaved weed with quadrangular stem, usually hairy throughout, about 30cm high. It possesses opposite, rounded leaves with lobed margins which grasp the stem, however, its lower leaves are petioled and not associated with the flower. Flowers are bilabiate, purple or purple-red. Broadleaf herbicides namely metsulfuron at 4 g/ha, carfentrazone at 20 g/ha, premix of carfentrazone plus metsulfuron at 25g/ha gave excellent control of this weed in wheat fields (personal experience). A native of Europe and Temperate Asia, and taxonomically a variable taxon (Mennema 1989); introduced in to USA, Canada and South Africa as invasive weed, especially in the croplands. In India the plant is known to occur in Sikkim at 2740 to 4270 m altituide (SMPB 2017) to Jammu & Kashmir.

Oenothera laciniata **Hill (Onagraceae):** This weed was observed in wheat, spring maize, vegetables and *Brassica* fields in Research farm of Punjab Agricultural University, Ludhiana during late winters since 2008. Recently, it has started appearing in both cultivated and uncultivated lands starting from November-December and is one of the major summer weeds. It set small, dark-brown seeds abundant in early summer (April-May). This weed was found associating with some other rosette forming species *viz. Tribulus terrestris* and *Coronopus didymus* and few other weeds such as *Amaranthus viridis*, *Chenopodium album*, *Heliotropium eichwaldii* etc. in loose-textured sandy-clayey soil. Ploughing leads to elimination of plants unlike most other co-occurring weeds. This weed warrants attention for its potential for further spread as a weed of *rabi* and spring crops in the Indian region. The outbreak of Onagracean species belonging to *Ludwigia* genus as serious weed in India is also very recent (Barua 2010, Barua *et al.* 2017). It is an important alien invasive species whose occurrence (Khan *et al.* 1984, Sasidharan 2004) and spread must be monitored within the Indian region, taking into consideration, its wide global distribution and potential for spread as a crop contaminant, persistence in the soil seed bank and the high genetic diversity reported in the species (Ellstrand and Levin 1982).

O. laciniata is an erect or semi-erect annual or short-lived perennial, commonly known as "Ragged Evening Primrose" or "Cutleaf Eveningprimrose", a native of Northern America. The distribution range of the species included the islands of Hawaii to Japan, Taiwan and coastal China and Korea across the Pacific Ocean and Libya, France, Greece and some other regions of Europe and Africa around the Mediterranean Sea extending to Iran. In India the plant was first reported from Bijnor district of Uttar Pradesh by Khan *et al.* (1984), in Idukki district of Kerala by Sasidharan (2004) and during 2008 to 2010, it spread to the Agricultural fields of Delhi and Ludhiana (Nayar *et al.* 2012). In many parts of the world it is known for its invasiveness and potentially harmful nature, especially in cotton fields of USA (Culpepper *et al.* 2005) and pastures, as it is resistance to Glyphosate and responsible for deterioration of habitat quality (Montgomery *et al.* 2012).

Soliva anthemifolia **(Juss.) R. Brown (Asteraceae):** It was observed for the first time in and around wheat fields during winter season 2008-

09 at Ludhiana. In Punjab, the species appeared as a winter annual infesting low growing thin lawns as well as wheat fields. *S. anthemifolia,* commonly known as 'Lawn Burweed', is an annual low herb, but stoloniferous, and with spreading stolons, it develops dense tufts. The diameter of the tufts varied from 10 to 30 cm. It has opposite, sparsely hairy leaves that are twice divided into narrow segments or lobes. It remains small and inconspicuous during the cold winter months and in the early spring, it undergos rapid vegetative growth. Interestingly there is no pappus in this Asteracean species in the cypsela; instead the collar region possesses numerous white hairs. However, the persistent spinescent style helped the 2.8-3.0 mm long wingless cypsela to catch in footwear and cloths as well as puncture the skin.

In India, *Soliva anthemifolia* was first reported from Northern district of Uttar Pradesh in 1963 (Bhattacharya 1963), then spread to Delhi (1973) via Dehra Dun (1966), Jammu (1981), Himachal Pradesh (2009), Eastern India (2011), Maharashtra ((2016) and Chattishgarh (Shukla, 2017). The present report is the first record of this species in Punjab.

***Verbesina encelioides* (Cav.) Benth. and Hook.f. ex A. Gray (Asteraceae):** This plant is commonly known as 'Golden Crownbeard' or 'Wild Sunflower', and is believed to be a native of United States and Mexico. It is a 30-60 cm tall broadleaved herb, minutely hairy throughout and produces flower heads of 2-5 cm diameter on long peduncles with golden yellow ray and orange yellow disc florets. It is often cultivated as garden plant in some places of India. Golden crownbeard was observed escaped in and around Rajasthan (India Biodiversity 2017) and believed to be migrated to Punjab or introduced from Rajasthan state along with land-fill and sand meant for road constructions. In Punjab climate, it is naturalized, found growing along roadsides, canal banks and vacant places and started replacing the resident plant species. The survey was conducted at different places of Punjab since August 2015 to study the occurrence of this weed and this weed was found profusely growing in South-west Punjab (Ferozepur, Fazilka, Bathinda, Barnala and Sangrur districts) and it was not recorded in Pathankot, Hoshiarpur, Jalandhar and Kapurthala districts till reporting of this study. Golden Crownbeard was found infested with mealy bug and yellow mosaic virus at few locations. Studies also revealed that *V. encelioides* possessed a toxic compound Galegine, which caused poisoning in livestock from ingestion of this plant including dullness and anorexia (Jain *et al.* 2008)

Kaul and Mangal (1987) studied the phenology and ecology of this weed and found that this weed exhibits rapid seedling, vegetative and reproductive growth. Seed germination found to be occurred in varying soils except in gravel and significantly suppressed under drought and waterlogged conditions. Seedling emergence was the highest from surface-sown seeds and least in those sown at 2.5-cm soil depth, beyond which no emergence occurred. High phenotypic plasticity, ecological variability, phenological diversity, seed germination in varied soils and under diverse moisture regimes, quick seedling growth and subsequent establishment, coupled with versatile breeding system, contribute to the successful growth, propagation, and spread of this species in India. The species responds strongly to disturbances on suitable sites and retards the development of other local species. Research has identified its allelopathic effect on radishes (Inderjit *et al.* 1999) which may explain its ability to dominate other species in some locations. Bentazon and 2,4-DB alone provided e" 90% control of *Verbesina encelioides* while acifluorfen at 0.42 kg/ha and pyridate resulted in e" 80% control in groundnut at Texas (Grichar and Sestak 1998). Study conducted at Punjab also revealed that glyphosate at 1%, paraquat at 0.5% and 2,4-D ethyl ester at 0.25% gave excellent control of this weed in non-cropped areas (personal experience).

***Evolvulus nummularius*:** It is an invasive alien weed, native of tropical America. It was first observed and identified in 2009, growing profusely in poorly maintained lawns of Punjab Agricultural University, Ludhiana. The growth starts in spring season and remains green up to November-December. It is a perennial, low growing, slender broadleaved weed. Its methanol extract has been found to have antibacterial and antioxidant activity (Pavithra *et al.* 2009).

***Nicotiana plumbaginifolia*:** It was observed for the first time in and around wheat fields during *Rabi* 2014-15 at Punjab Agricultural University, Ludhiana. It is a species of tobacco plant and the species epithet, "*plumbaginifolia*", is from the leaves which bear similarity to those of the genus *Plumbago.* It is a flowering annual herb and can grow up to 1 meter tall. The species has small, white, 5-petal flowers that are tube-like in shape with the tube ranging from 3 to 4 cm in length and 1 to 1.5 cm wide (Khan 2008).

***Euphorbia thymifolia*:** It was observed for the first time in 2008 and look like *Euphorbia microphylla* except stem colour. Its stem is slender, smooth and green in colour and profusely branched resulting into a mat like growth. This is mainly found on bunds, in waste lands, along roadsides and wall sides under humid conditions in rainy season of whole Punjab state. It is a small plant containing milky latex in it, belonging to the family Euphorbiaceae. Delicate, thin adventitious roots come out from nodes. It is widely used in ayurveda and possesses antibacterial, antiviral and antioxidant properties (Lin *et al*. 2002)

Portulaca oleracea: It ia an invasive alien weed, native of tropical South America. It was found growing along the bunds of paddy fields and in the well-fed vegetable farms of whole Punjab state. *P. oleracea* thrives well on nutrient-rich soils with high clay content. It has spreading-type growth and forms a thick mat over the soil surface. Its growth is very fast and produces large number of seeds. The control of this weed in the vegetable fields is very difficult and can limit summer vegetable production. Various broadleaf herbicides are effective for controlling this weed and directed spray of non-selective herbicides in widely spaced crops may provide effective control of this weed (personal experience).

Early recognition of invasive weed populations and adoption of appropriate management strategies at their lag phases are highly essential to stop their further horizontal expansion, failing of which will cause great threat to the resident biodiversity of both cropland and non-cropland situations as well as great economic loss in restoration of edaphic, climatic and social land use systems. Interestingly, all these six weed species are still in their lag phases of population expansion, and hence, it is the high time to think for their effective control, including their already developed soil seed banks.

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Herbicide mixtures effect on weed seed bank in direct-seeded rice

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ABSTRACT

To study the effect of post-emergence applied herbicide mixtures, *viz.* bispyribac-sodium + metamifop and penoxsulam + cyhalofop-butyl on soil weed seed bank, weed seed bank assay were carried out at College of Agriculture Vellayani, Thiruvananthapuram during rainy season 2014 and winter season 2014-15. Weed seed bank assay results revealed a significant reduction in the emergence of sedges, broad-leaved weeds (BLW) and grasses from the soil treated with herbicide mixtures compared to individual application of bispyribac-sodium at 25 g/ha and penoxsulam at 22.5 g/ha. The results also revealed that penoxsulam + cyhalofop-butyl was more effective in reducing the weed seed bank than bispyribac sodium + metamifop. The higher doses of penoxsulam + cyhalofop-butyl (135, 130 and 125 g/ha) were found to be more effective than its lower dose of 120 g/ha. Among the tested doses of bipyribac-sodium + metamifop, its higher doses (90 and 80 g/ha) performed better than lower doses (60 and 70 g/ha) in reducing the soil weed seed bank. Hence, post-emergence application of penoxsulam + cyhalofop-butyl either at 125 or 130 or 135 g/ha or bispyribac-sodium + metamifop at 80 or 90 g/ha at 15 DAS (days after sowing) can be recommended for the effective management of weed seed bank in wet direct-seeded rice.

INTRODUCTION

Weed seed bank is the reserve of viable weed seeds present in the soil surface and scattered in the soil profile. Weed seed bank is the main reason for the continued presence of weeds in the agricultural field (Cousens and Mortimer 1995) and it is an indicator of weed population in soil (Dhawan 2007). Annual fluctuations of climatic factors significantly influence the weed seed bank (Harbuck *et al.* 2009). Steinmann and Klingebiel (2004) opined that weed seed bank has impact on the distribution of annual and perennial weeds over the years and it affects the spread of weed community. Weed seed characteristics such as high output, efficient dispersal, longevity and seed dormancy, produce large seed banks in the soil (Pereira *et al.* 2013). Understanding the dynamics of soil seed bank can help in the development of integrated weed management programmes and also help to predict the degree to which the crop-weed competition affects the crop yield and quality (Menalled 2008). Accurate forecast of potential weed seedling density would allow the farmers to implement control measures more effectively thus avoiding inappropriate and over use of herbicides (Mobli and Hassannejad 2013).

Weed seed bank can be manipulated by altering seedling recruitment, seedling mortality, seed viability and fecundity. Manual weeding and herbicidal use reduce the weed population by increasing seedling mortality (Pandey and Pingali1996). Barberi *et al.* (1998) reported that herbicides reduced the weed density and number of weed seeds entering the seed bank. Buhler *et al.* (2001) pointed out that when weeds were controlled by cultivation only, the seed bank was approximately 25 times greater than where herbicides in conjunction with cultivation practices were adopted for weed control. Jain *et al.* (2006) reported that continuous use of clodinafop *fb* 2,4-D and isoproturon + 2,4-D for control of weeds in wheat field significantly reduced the number of weed seeds in the seed bank over weedy check. Walia and Brar (2006) also reported that herbicide treatments significantly reduced the seed bank of *Phalaris minor* in wheat field. According to Islam (2012), herbicide application influenced the seed number and species composition of the seed bank.

The main objective of any weed management programme should be to deplete the weed seed bank and enable the rice crop to be competitive either by delaying the weed emergence or suppressing the weed emergence and growth. With this background the present study was formulated to find out the effect of herbicide mixtures, *viz*. bispyribac-sodium + metamifop and penoxsulam + cyhalofop-butyl on soil weed seed bank.

MATERIALS AND METHODS

Field experiments were conducted during the first (rainy season 2014) and second (winter 2014-15) crop seasons at Upaniyoor padashekaram, in Kalliyoor Panchayat, Nemom block, Thiruvananthapuram district, Kerala, India. The experimental site was situated at 8° 26.762' N latitude and 77° 0.136' E longitude and 29 m above mean sea level (MSL) with humid tropical climate. The soil was sandy clay loam, acidic in reaction, high in organic carbon and medium in N, P and K status. The average annual rainfall received during the period of experimentation was 875.5 mm during first crop season and 203.4 mm during second crop season. The mean maximum and minimum temperature recorded during first and second crop seasons were 30.1 ºC and 24.4 ºC and 30.8 ºC and 22.6 ºC, respectively.

For the first and second crop, the field was ploughed thrice with a power tiller and uniformly levelled. The experiment was laid out in a randomized block design with twelve treatments and three replications. Raised bunds of 20 cm height and channels of 30 cm width were taken around each plot and 60 cm wide channels were taken along the length of each block between the replications. The treatments were bispyribac-sodium + metamifop at 60 g/ha, bispyribac-sodium + metamifop at 70 g/ha, bispyribac-sodium + metamifop at 80 g/ha, bispyribac-sodium + metamifop at 90 g/ha, penoxsulam + cyhalofop-butyl at 120 g/ha, penoxsulam + cyhalofop-butyl at 125 g/ha, penoxsulam + cyhalofop-butyl at 130 g/ha, penoxsulam + cyhalofop-butyl at 135 g/ha, bispyribac-sodium applied alone 25 g/ha, penoxsulam applied alone 22.5 g/ha, hand weeding twice and weedy check. The herbicides were applied at 15 DAS using knapsack sprayer fitted with flat-fan nozzle. The spray fluid used for the study was 500 L/ha. The rice variety '*Kanchana*', a short duration variety released from Regional Agricultural Research Station, Pattambi, Kerala Agricultural University was used under the study. The crop was fertilized with 70:35:35 kg/ha N, P and K, with one third N and K and half P applied on 15 DAS (days after sowing), one third N and K and half P on 35^{th} day and remaining one third N and K on 55^{th} day of sowing.

Weed seed bank in the soil was estimated before and after the first and second crop by the seedling emergence method suggested by Luschei (2003) in a completely randomized block design with twelve treatments in with three replications. Weed seed bank assay was conducted under net house condition at College of Agriculture Vellayani.

Composite soil samples were collected from each plot before the crop and after the harvest of first and second crop using a soil auger at a depth of 15 cm. From the composite samples one kg soil was weighed accurately and transferred and spread evenly in plastic trays under net house condition. The soil was kept at adequate moisture level. The emerging weeds were counted up to 70 days at fortnightly interval and categorized into sedges, broad-leaved weeds and grasses. The data generated were statistically analyzed using analysis of variance technique (ANOVA) and difference between the treatments means were compared at 5% probability level.

RESULTS AND DISCUSSION

Weed flora composition

Weed seed bank assay results revealed that three major groups of weeds, *viz*. sedges, broad-leaved weeds (BLW) and grasses were present in the experimental field. Among the three, BLW were the predominant weed flora followed by sedges and grasses (**Table 1** and **2**).

Effect of herbicides mixtures on the emergence of sedges

Weed seed bank assay carried out before the first and second crop season revealed that there was no significant difference among the treatments in the number of sedges emerged from the soil.

Weed control treatments registered a significant reduction in the emergence of sedges from the soil seed bank after the first and second crop season (**Table 1** and **2**). Among the herbicide mixtures, penoxsulam + cyhalofop-butyl was found to be better than bispyribac-sodium + metamifop in reducing the weed seed bank of sedges. In both the experiments, penoxsulam + cyhalofop-butyl 135 g/ha recorded the lowest count of sedges emerged from the soil.Weed seed bank observations indicated that, compared to weedy check, population of sedges was reduced by 60.40 and 88.70%, respectively after the first and second crop season; however, compared to hand weeding, the percentage reduction was 45.44 and 67.60%, respectively. Compared to penoxsulam applied alone at 22.5 g/ha, the percentage reduction in the count of sedges by the application of penoxsulam + cyhalofop-butyl at 135 g/ha was 34.44 and 63.24, respectively and compared to bispyribac-sodium applied alone at 25 g/ha the percentage reduction was 36.46 and 70.94, respectively after the first and second crop seasons. Raj and Syriac (2015) reported that post-emergence application of penoxsulam + cyhalofop-butyl 135 g/ha significantly reduced the density of sedges. This might be the plausible reason for the reduction in the weed seed bank of sedges in this treatment. Singh *et al*. (2012) reported that the main source of weed seeds in the seed bank is the local matured weeds that set seed.

Effect of herbicides mixtures on the emergence of broad-leaved weeds

Weed seed bank assay carried out before the first and second crop season revealed that there was no significant difference among the treatments in the number of BLW emerged from the soil (**Table 1** and **2**).

As compared to weedy check there was significant reduction in the emergence of BLW from the soil seed bank in all the herbicide treatments and hand weeding treatment. Penoxsulam + cyhalofop-butyl 135 g/ha recorded the lowest population of BLW after the first crop season. However, penoxsulam + cyhalofop-butyl 125 g/ha recorded the lowest population after the second crop season and was on par with its higher dose of 135 g/ha. (**Table 2**). Both these treatments were statistically on par with bispyribac-sodium + metamifop 80 and 90 g/ha. It has been observed that, as compared to hand weeding, the treatments bispyribac-sodium + metamifop 80 and 90 g/ha reduced the emergence of BLW by 42.25 and 39.05% and 72.80 and 86.22%, respectively after the first and second crop seasons. Compared to penoxsulam applied alone at 22.5 g/ha, bispyribac-sodium + metamifop 80 and 90 g/ha recorded a reduction in the emergence of BLW by 30.82 and 26.98 and 13.23 and 56.03%, respectively. Compared to bispyribac-sodium applied alone at 22.5 g/ha, these treatments reduced the emergence of BLW by 29.53 and 25.62% and 68.61 and 38.06%, respectively after first and second crop seasons.

As compared to hand weeding, penoxsualm + cyhalofop-butyl 125 and 135 g/ha reduced the emergence of BLW by 23.40 and 48.36% and 91.87 and 85.0%, respectively after the first and second crop season. Compared to penoxsulam 22.5 g/ha, the percentage reduction of BLW was 8.23 and 38.13 and 74.04 and 52.14, respectively and compared to bispyribac-sodium 25 g/ha the percentage reduction was 6.52 and 36.98 and 81.47 and 65.83, respectively. Higher population of BLW in the weedy check might have enhanced the seed rain from mature weeds, as the weeds were not controlled and allowed to grow throughout the season. Roberts (1982) reported that weedy field may contain large amount of viable weed seeds; similarly, Sheibani and Ghadiri (2012) reported that weedy plots had the highest number of weed seeds in 0-15 cm depth.

Effect of herbicide mixtures on the emergence of grasses

Similar to sedges and BLW, a significant reduction in the emergence of grasses was also observed in the herbicide treated pots and hand weeding treatment as compared to weedy check (**Table 1** and **2**). Weed seed bank assay carried out after the first and second crop season indicated that penoxsulam + cyhalofop-butyl 125 g/ha recorded the lowest emergence of grasses among the treatments. After the first and second crop seasons, penoxsulam + cyhalofop-butyl 125 g/ha reduced the grass

Table 1. Emergence of broad leaf weeds, grasses and sedges (no./kg soil in 70 days) as influenced by weed management treatments before and after the first crop

Treatment	BLW		Grasses		Sedges	
	Before the first crop	After the first crop	Before the first crop	After the first crop	Before the first crop	After the first crop
Bispyripac-sodium + metamifop 60 g/ha	237.0(15.0)	215.3(14.7)	19.3(4.32)	15.3(3.97)	107.0(10.3)	68.3(8.28)
Bispyripac-sodium + metamifop 70 g/ha	315.3(17.6)	195.0(14.0)	14.0(3.78)	9.7(3.15)	177.3(13.3)	73.7(8.58)
Bispyripac-sodium + metamifop 80 g/ha	246.0(15.7)	151.3(12.3)	25.3(5.05)	18.0(4.22)	145.0(12.0)	63.7(7.99)
Bispyripac-sodium + metamifop 90 g/ha	257.7(16.0)	159.7(12.6)	30.7(5.54)	13.3(3.64)	160.0(12.6)	51.3(7.18)
Penoxsulam + cyhalofop-butyl 120 g/ha	190.0(13.7)	215.0(14.7)	18.0(4.14)	12.0(3.45)	93.0(9.6)	45.3(6.76)
Penoxsulam + cyhalofop-butyl 125 g/ha	301.0(17.3)	200.7(14.2)	13.3(3.70)	4.3(2.11)	180.7(13.4)	57.3(7.60)
Penoxsulam + cyhalofop-butyl 130 g/ha	310.0(17.6)	199.0(14.1)	22.0(4.65)	9.3(3.08)	160.0(12.6)	52.7(7.28)
Penoxsulam + cyhalofop-butyl 135 g/ha	229.7(14.8)	135.3(11.6)	28.7(5.36)	9.7(3.18)	175.7(13.1)	41.3(6.46)
Bispyribac-sodium 25 g/ha	236.3(17.2)	214.7(14.7)	16.7(4.14)	20.3(4.54)	146.7(12.0)	65.0(8.09)
Penoxsulam 22.5 g/ha	255.3(15.9)	218.7(14.7)	9.7(3.16)	12.0(3.53)	151.7(12.2)	63.0(7.92)
Hand weeding twice at 20 and 40 DAS	294.7(17.2)	262.0(16.2)	15.7(4.02)	9.7(3.19)	169.3(13.0)	75.7(8.69)
Weedy check	320.0(17.9)	314.0(17.8)	22.0(4.63)	33.0(5.69)	159.7(12.6)	104.3(10.23)
LSD (p=0.05)	NS	1.279	NS	1.250	NS	1.188

Values in parentheses are transformed values $\sqrt{x+0.5}$, NS- non-significant

Table 2. Emergence of broad leaf weeds, grasses and sedges (no./kg soil in 70 days) as influenced by weed management treatments before and after the second crop

Treatment	BLW		Grasses		Sedges	
	Before the second crop	After the second crop	Before the second crop	After the second crop	Before the second crop	After the second crop
Bispyripac-sodium+ metamifop 60 g/ha	231.0(14.8)	48.0(6.94)	22.3(4.54)	13.0(3.54)	73.3(8.58)	29.0(5.29)
Bispyripac-sodium+ metamifop 70 g/ha	254.3(15.9)	42.7(6.18)	27.7(5.28)	10.0(3.22)	117.3(10.8)	20.3(4.49)
Bispyripac-sodium + metamifop 80 g/ha	181.0(13.4)	22.3(3.43)	22.7(4.73)	13.3(3.70)	82.0(8.91)	17.0(4.02)
Bispyripac-sodium + metamifop 90 g/ha	191.7(13.5)	27.3(4.65)	28.3(5.35)	17.0(4.13)	71.3(8.25)	17 .0(4.12)
Penoxsulam + cyhalofop-butyl 120 g/ha	210.3(14.4)	27.3(4.65)	15.3(3.80)	12.0(3.10)	63.7(7.97)	11.3(3.42)
Penoxsulam + cyhalofop-butyl 125 g/ha	349.7(18.6)	6.67(2.62)	8.7(2.88)	5.0(2.23)	101.3(10.1)	14.0(3.80)
Penoxsulam + cyhalofop -butyl 130 g/ha	327.0(18.0)	21.0(4.54)	12.7(3.56)	10.3(3.2)	92.7(9.62)	14.3(3.84)
Penoxsulam + cyhalofop-butyl 135 g/ha	267.0(15.9)	12.3(2.75)	19.3(4.44)	14.7(3.85)	86.7(9.24)	9.3(3.09)
Bispyribac-sodium 25 g/ha	305.3(17.5)	36.0(6.02)	29.3(5.30)	32.3(5.72)	69.3(8.33)	32.0(5.68)
Penoxsulam 22.5 g/ha	294.7(17.2)	25.7(5.11)	10.0(3.20)	17.3(4.21)	86.3(9.24)	25.3(4.84)
Hand weeding twice at 20 and 40 DAS	353.7(18.7)	82.0(9.07)	14.3(3.83)	14.7(3.88)	81.0(8.97)	28.7(5.31)
Weedy check	295.7(17.1)	136.0(11.6)	19.7(4.39)	52.0(7.25)	91.0(9.55)	82.3(9.09)
LSD (p=0.05)	NS	2.907	NS	1.616	NS	1.710

Values in parentheses are transformed values $\sqrt{x+0.5}$, NS- non-significant

population by 55.67 and 65.99%, respectively as compared to hand weeding. While compared to bispyribac-sodium applied alone at 25 g/ha, the percentage reduction in the grass population was 78.82 and 84.52, respectively and compared to penoxsulam applied alone at 22.5 g/ha, the percentage reduction was 64.17 and 71.10, respectively. Sheibani and Ghadiri (2012) opined that herbicide application indirectly affects the weed seed bank by reducing the number of seed producing plants.

Effect on total weed population

Data on the total weed population after the first and second crop season revealed that non-herbicide treatments, *viz*. weedy check and hand weeding recorded the highest emergence of weeds and were significantly inferior in reducing the size of the weed seed bank. Buhler *et al.* (2001) pointed out that when weeds were controlled by cultivation only, the seed bank was approximately 25 times greater than where herbicides in conjunction with cultivation practices were adopted for weed control. Many researchers have the opinion that absence of herbicides has resulted in increased weed seed bank (Hyvonen and Salonen 2002). Among the treatments, penoxsulam + cyhalofop-butyl 135 g/ha recorded the lowest weed seed bank after the first crop season. Compared to weedy check, the percentage reduction was 58.69 and compared to hand weeding, the percentage reduction was 46.36. Compared to individual application of penoxsulam 22.5 g/ha and bispyribac-sodium 25 g/ha, the percentage reduction was 36.57 and 37.90, respectively (**Table 3**).

Weed seed bank assay after the second crop season revealed that penoxsulam + cyhalofop- butyl 125 g/ha recorded the lowest weed population and was at par with its higher doses of 135 and 130 g/ha. These treatments reduced the weed seed bank by 94.41, 90.28 and 89.43%, respectively. The reduction in the emergence of weeds in treatments penoxsulam + cyhalofop-butyl 125 and 135 g/ha as compared to hand weeding were 79.48 and 71.03%, respectively. Compared to bispyribac-sodium 25 g/ha the percentage reduction was 74.38 and 63.81%, respectively and compared to penoxsulam 22.5 g/ha, the reduction was 62.37 and 46.85%, respectively. Voll *et al*. (1996) reported that application of herbicides can lead to exhaustion of the weed seed bank and similarly Carmona (1992) observed that application of certain chemicals contributed to an accelerated decay rate of seeds in the soil. Among the different doses of bispyribac-sodium + metamifop tested, its highest dose (90 g/ha) was better than other three doses in reducing the weed seed bank. This was mainly because of the better efficacy in controlling the sedges, BLW and grasses, the major group of weeds present in the soil as reported by Raj and Syriac (2016). Schweizer and Zimdahl (1984) reported that the number of weed seeds in continuous corn dropped by approximately 70% after three years of herbicide application and inter row cultivation. Several researchers (Walia and Brar 2006, Konstantinovic and Blagojevic 2014) have reported that herbicide use reduced the weed seed bank considerably.

It can be concluded that the application of herbicide mixtures, *viz*. penoxsulam + cyhalofop-butyl and bispyribac-sodium + metamifop were more effective in depleting the weed seed bank, than the individual application of bispyribac-sodium and penoxsulam. The results also revealed that penoxsulam + cyhalofop-butyl was better than bispyribac-sodium + metamifop in depleting the weed seed bank in direct-seeded rice.

Table 3. Effect of herbicide mixtures on the emergence of total number of weeds (no./kg soil in 70 days) from the soil seed bank during the first and second crop season

Treatment	Total no. of weeds		Total no. of weeds	
	Before the first crop	After the first crop	Before the second crop	After the second crop
Bispyripac-sodium + metamifop 60 g/ha	363.7(18.92)	299.0(17.30)	326.7(17.98)	91.3 (9.57)
Bispyripac-sodium + metamifop 70 g/ha	506.7(22.35)	278.3(16.70)	399.3(19.96)	73.0(8.38)
Bispyripac-sodium + metamifop 80 g/ha	416.3(20.40)	233.0(15.28)	285.7(16.86)	52.7(7.22)
Bispyripac-sodium + metamifop 90 g/ha	448.3(21.18)	224.3(14.99)	291.3(16.68)	45.3(6.76)
Penoxsulam + cyhalofop butyl 120 g/ha	301.0(17.31)	272.3(16.52)	289.3(16.94)	50.7(6.70)
Penoxsulam + cyhalofop-butyl 125 g/ha	495.0(22.22)	262.3(16.21)	459.7(21.40)	25.7(5.10)
Penoxsulam + cyhalofop-butyl 130 g/ha	492.0(22.17)	261.0(16.17)	432.3(20.73)	45.7(6.72)
Penoxsulam + cyhalofop-butyl 135 g/ha	434.0(20.57)	186.3(13.67)	373.3(18.94)	36.3(5.82)
Bispyribac-sodium 25 g/ha	399.7(19.74)	300.0(17.33)	404.0(20.10)	100.3(10.3)
Penoxsulam 22.5 g/ha	416.7(20.35)	293.7(17.13)	391.0(19.78)	68.3(8.21)
Hand weeding twice at 20 and 40 DAS	479.7(21.91)	347.3(18.63)	449.0(21.06)	125.3(11.18)
Weedy check	501.7(22.40)	451.0(21.26)	406.3(20.11)	270.3(16.44)
LSD (p=0.05)	NS	1.133	NS	2.507

Values in parentheses are transformed values $\sqrt{x+0.5}$, NS- non-significant

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Adoption of integrated weed management practices correlates with farmers profile characteristics

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ABSTRACT

This study explored the adoption level towards integrated weed management (IWM) practices and the associated relationship with various profile characteristics of 108 farmers from 12 villages of 6 blocks of Jabalpur district of Madhya Pradesh with an ex-facto sampling design. A list of various IWM practices in major crops suited to the study area and recommended by ICAR-Directorate of Weed Research, Jabalpur, was prepared after consultation with experts in the area. It was found that majority of the respondents had medium extent of adoption of IWM practices with reference to rice (56%), soybean (49%), greengram (50%) and wheat (55%). A positive and significant correlation between level of adoption of respondents on overall IWM practices with other variables *viz*. age, education, farm size, training, extension contact, mass media exposure, input availability and innovativeness were noticed.

INTRODUCTION

Agriculture plays an important role in economic growth, enhancing food security, poverty alleviation and rural livelihood development. It is main source of income for about 60% of people in India. Presently in India, foodgrains production is about 252 million tonnes (GOI 2016). However, still there exist a wide gap between the production potential and the actual production realized by the farmers. The lower yields are due to heavy infestation of pest in general, and weeds in particular. To minimize these losses, different methods of weed management practices have been developed in different crops and cropping systems. However, adoption of weed management practice at farmers' fields varies as per the resource availability. Various reasons such as lack of knowledge and skill, non availability of herbicides, spray equipments, technical know-how, climatic and social-economic conditions, poor extension mechanism *etc*. are hindrance on adoption. Non-adoption of weed management practices leads to cause heavy yield penalty.

The knowledge level of the farmer has significant role on adoption of integrated weed management (IWM). Knowledge level improves with education, farming experience, training, accessible to farm machineries, extension contacts and innovativeness (Rajashekar *et al.* 2017). Age has both negative as well as positive effect on adoption of IWM as aged persons has more farming experience but majority are late adopter of new technologies. In contrary to this, lower age persons are fond of new technologies and ready to take risk to obtain higher profit although they have less farming experiences. Similarly, education level play crucial role and has positive effect on adoption level of the IWM practices. The adoption level of IWM also depends on farming experience, as knowledge increase over the years. Experience also influences the adoption level of IWM at different stages of crop. Capacity building through training, on-farm demonstration, farm visits *etc*. may also increases the knowledge level of farmers.

Considering the diversity of weed problem and agro-ecosystems, no single method of weed control could reach the desired level of efficiency under all situations (Singh 2010). Thus, IWM has been suggested as a sustainable and long-term management technique. Several studies have been conducted on adoption and impact of new technologies, but few are accomplished especially on adoption and the impact of IWM on farmer's fields. It is therefore, important to find out the existing level of knowledge and extent of adoption of IWM practices by the farmers, and also to identify the constraints faced by them in adoption of IWM practices. Thus, efforts were made to study the adoption level of IWM and factors affecting it at farmers' level in different farming situations.

MATERIALS AND METHODS

An ex-post facto sampling design was used in the present investigation. Field survey based study was conducted at randomly selected six blocks of Jabalpur district of Madhya Pradesh during 2014-15 and 2015-16. For the selected blocks, a list of villages containing farmers practicing IWM practices was obtained from the Department of Agriculture, Madhya Pradesh. A random sampling method was employed to select two villages from each block and thus making total of 12 villages. In the study area, rice, soybean, greengram and wheat were the major crops. Nine IWM practicing respondents from each village were selected using random sampling method. The final sample size consisted of 108 respondents. For measuring respondents' knowledge on IWM practices, a knowledge test was developed. Data were collected using developed interview schedule and based on obtained scores, the respondents were grouped into low, medium and high extent of adoption categories according to equal interval method. Collected data were analyzed using appropriate statistical tools like frequency and percentage, class interval, arithmetic mean, standard deviation and correlation coefficient.

RESULTS AND DISCUSSION

Majority of the respondents irrespective of the crop had medium level of adoption (**Table 1)**. Among all the respondents, medium level of adoption were noticed to the tune of 56, 49, 50 and 55% in rice, soybean, greengram and wheat growers, respectively. Correspondingly, high level of adoption of IWM practices was observed in 27.5, 19.3, 26.3 and 25.0% farmers associated with rice, soybean, greengram and wheat crops, respectively.

Adoption level of integrated weed management practices

Adoption level of various integrated weed management practices varied irrespective of crops and locations (**Table 2**). Application of post-emergence herbicides was the most popular among farmers to the tune of 52.7%, followed by application of pre-emergence herbicides with one hand weeding (HW). The adoption level of only one HW and application of pre-emergence herbicide only were the next most popular adopted weed management practices adopted by the farmers irrespective of crops. However, use of wheel hoe followed by (*fb*) 1 HW was the least preferred (12.5%) weed management practice.

Table 1. Classification of the respondents based on their extent of adoption of IWM practices

Extent of adoption	Class interval	Frequency	Percentage
Rice (n=36)			
Low	12-14	6	16.5
Medium	14-16	20	56.0
High	16-18	10	27.5
Soybean (n=41)			
Low	07-10	13	31.7
Medium	10-13	20	49.0
High	13-16	8	19.3
Greengram(n=38)			
Low	08-10	9	23.7
Medium	10-12	19	50.0
High	12-14	10	26.3
Wheat (n=40)			
Low	11-13	8	20.0
Medium	13-15	22	55.0
High	15-17	10	25.0

Table 2. Extent of adoption of the recommended integrated weed management practices (n=108)

Integrated weed management practices	Adoption level (%)
Application of pre-emergence herbicides *fb* 1 HW	46.2
Application of herbicide (pre *fb* post)	37.4
Application of post-emergence herbicide *fb* 1 HW	31.8
Application of pre and post-emergence herbicide *fb* 1 HW	15.5
Application of pre-emergence herbicide only	40.6
Application of post-emergence herbicide only	52.7
Use of wheel hoe *fb* 1 HW	12.5
Two hand weeding only	30.4
One hand weeding only	41.3

n - number of respondents

Relationship between profile characteristics of respondents and adoption level of IWM practices

While studying the relationship between profile characteristics and adoption level of IWM practices in rice (**Table 3**). It was found that farming experience, extension contact and input availability influenced the adoption level significantly at 5% level of significance, whereas, training in IWM and innovativeness affected significantly at 1% level of significance. However, age, education, farm size, mass media exposure, information seeking behaviour, farm mechanization status, risk orientation and labour availability had no impact on adoption.

In case of soybean, all the independent factors influenced the adoption level at 1% level of significance except farm size, risk orientation and labour availability. Similarly, in case of greengram, age, farm size and extension contact influenced the adoption significantly at 5% level of significance and

Table 3. Relationship between profile characteristics and extent of adoption of IWM practices (n=108)

Characteristics	Correlation coefficient (r)			
	Rice	Soybean	Greengram	Wheat
Age	0.127^NS	0.713**	0.391*	0.443**
Education	0.278^NS	0.458**	0.610**	0.439**
Farm size	0.083^NS	0.258^NS	0.350*	0.431**
Farming experience	0.336*	0.616**	-0.158^NS	0.290^NS
Training in IWM	0.502**	0.533**	0.455**	0.164^NS
Extension contact	0.371*	0.637**	0.453*	0.316*
Mass media exposure	0.143^NS	0.455**	0.115^NS	0.401**
Information seeking behaviour	-0.129^NS	0.608**	0.522**	0.477**
Farm mechanization status	0.321^NS	0.549**	0.158^NS	-0.127^NS
Risk orientation	0.206^NS	0.272^NS	0.252^NS	0.393*
Innovativeness	0.535**	0.710**	0.687**	0.684**
Input availability	0.359*	0.682**	0.029^NS	0.592**
Labour availability	0.098^NS	-0.134^NS	0.088^NS	0.221^NS

n= number of respondents; *significant at 5% level of significance; ** significant at 1% level of significance; NS - Non-significant

education, training in IWM, information seeking behaviour and innovativeness at 1% level of significance influenced the adoption level of respondents with reference to IWM practices. However, farming experience, mass media exposure, farm mechanization status, risk orientation, input availability and labour availability had no effect on adoption. In case of wheat, extension contact and risk orientation affected the adoption level at 5% level of significance and age, education, farm size, mass media exposure, information seeking behaviour, innovativeness and input availability influenced the adoption level at 1% level of significance. On the other hand, farming experience, training in IWM, farm mechanization status and labour availability had no impact on adoption.

Venkattakumar (2012) reported while studying the adoption of IPM technologies in rice and/or greengram that half of the proportion (50.67%) of the respondents had medium level of adoption followed by 38% who had low level of adoption. Desale *et al.* (2012) reported that three-fourth of the hybrid rice growers in Kheda district of Gujarat had medium to high level of adoption of recommended hybrid rice production technology. Similar observation was also made by Perera (2008) and Nirmala (2012) in rice cultivation.

It may be concluded that innovations and extension contact were the major factors which had significant impact on adoption level of IWM practices. Further, farmers should be provided with more practical training on IWM technologies that will accelerate the rate of adoption of technologies for improving the productivity of crops. The present study also highlighted that the socio-economic factors of farmers were important in deciding the adoption of recommended IWM technologies. Hence, for the introduction of new IWM technologies in different crops, the farmers' characteristics and conditions must also be considered apart from the technical factors.

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Pathogenicity of *Rhizoctonia solani* AG 1-IB on common weeds in Meghalaya

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ABSTRACT

Rhizoctonia solani Kuhn is a soil borne fungal plant pathogen, infecting several crops. Many weeds act as collateral hosts of this pathogen and help in spreading this. Pathogenicity of *R. solani* AG 1-IB isolate was tested on 47 common weeds of Meghalaya. Incubation period on all the common weeds was 2-3 days except 6 days on *Cyperus iria* with *R. solani* AG 1-IB isolate. Minimum days for sclerotia formation was 4 days on *Crassocephalum crepidioides, Galinsoga parviflora* and *Tridax procembens*. Maximum sclerotia production (16 nos.) was observed on *Lantana camara*. The weed *Emilia sonchifolia* was most susceptible to isolate *R. solani* AG 1-IB based on area under disease progress curve criteria. Highly susceptible weeds identified in this study should be avoided for mulching purpose since this will increase the inoculum load of this pathogen

INTRODUCTION

The pathogen *Rhizoctonia solani* Kuhn is a soil borne fungal plant pathogen that attacks various cereals, vegetables, legumes, forest trees, ornamentals and turf grasses, causing significant losses (Lakshman *et al.* 2016). It causes various plant diseases like collar rot, root rot, damping off, sheath blight, banded leaf and sheath blight, stem canker, web blight, and wire stem in different plant species throughout the world (Debbarma and Dutta 2015). The pathogen forms sclerotia under unfavourable conditions and it survives in the soil for around two years. The fungus *R. solani* also survives as mycelium by colonizing soil organic matter as a saprophyte. Sclerotia or mycelium present in soil and on plant tissue germinate to produce vegetative threads (hyphae) of the fungus that can attack a wide range of crops. The fungus *R. solani* has been classified into different anastamosis groups (AGs) on the basis of hyphal anastomosis reactions. These groups are considered to be genetically isolated (Carling 1996). Till date, *R. solani* contains 13 AG groups and AG IB (Carling *et al.* 2002).

Several weeds and cultivated plant species are known to act as alternate and collateral hosts of *R. solani* in different agro-climatic regions of India (Chahal *et al.* 2003 and Saveinai *et al.* 2017). Information related to pathogencity of *R. solani* on different weeds is scarce. Hence, this study was carried out to explore to find out the susceptible weed species to plan a better management of crops and weeds.

MATERIALS AND METHODS

Experiments related to "Pathogenicity of *R. solani* AG 1-IB on common weeds in Meghalaya" were conducted at ICAR Research Complex for NEH Region, Umiam, Meghalaya. Infected soybean samples exhibiting web blight symptoms were collected from experimental plots of ICAR, Umiam and isolation was done following the method as described in Saveinai (2016) with minor modifications. Isolates (pure cultures) were designated as PPJ1, PPJ2, PPJ3, PPJ4 and PPJ5. Microscopic observations were performed on soybean isolates for confirmation of the fungus as *Rhizoctonia* spp. based on hyphal characters using Olympus BX 53 microscope.

PCR was used for amplification of extracted DNA with specific primers for AG 1-IA and IB (Matsumoto 2002 and Sayler and Yang 2007). Both positive and negative controls were also used.The DNA extraction, PCR (with minor modifications), gel documentation and identification was done following the procedure described by Mahendra *et al.* (2016).One isolate (PPJ3) was also amplified and sequenced by using universal primers for ITS region (ITS 5 and 4) (White *et al.* 1990) and the sequence was deposited in Genbank. Similarity search was also performed using BLASTn. Sequences of other AGs were downloaded from NCBI and included in the phylogenetic analysis using Maximum parsimony method in MEGA 6 (using Subtree pruning and regrafting algorithm) (Tamura *et al.* 2013). Nodal support was calculated using one thousand bootstrap replicates (Felsenstein 1985).

Initial pathogenicity was done by inoculation of *R. solani* AG 1-IB isolates PPJ1, PPJ2, PPJ3, PPJ4 and PPJ5 on soybean by using detached leaf method (Rahayu 2014). Same method was used for testing pathogenicity of PPJ3 isolate on common weeds. The area under disease progress curve (AUDPC) was calculated and analysis was done as mentioned in Saveinai *et al.* (2017).

RESULTS AND DISCUSSION

Molecular identification of *Rhizoctonia solani* AG 1-IB

Five isolates collected were identified by using specific primers. Based on amplification with specific primers and band size (~300 bp) the isolates were identified as AG 1-IB. The ITS region of one isolate (PPJ3) was obtained using universal primers and the resulting sequence has been deposited in Genbank (KY172991). Similarity searches using BLASTn showed 99% similarity with AG 1-IB sequences (KF907717, JQ692292). Phylogenetic analysis using maximum parsimony also clustered the isolate with AG 1-IB with 81% bootstrap support (**Figure 1**). Baiswar *et al.* (2012) have also identified AG 1-IB on soybean and marigold using the primers developed by Matsumoto (2002) and Saylor and Yang (2007).

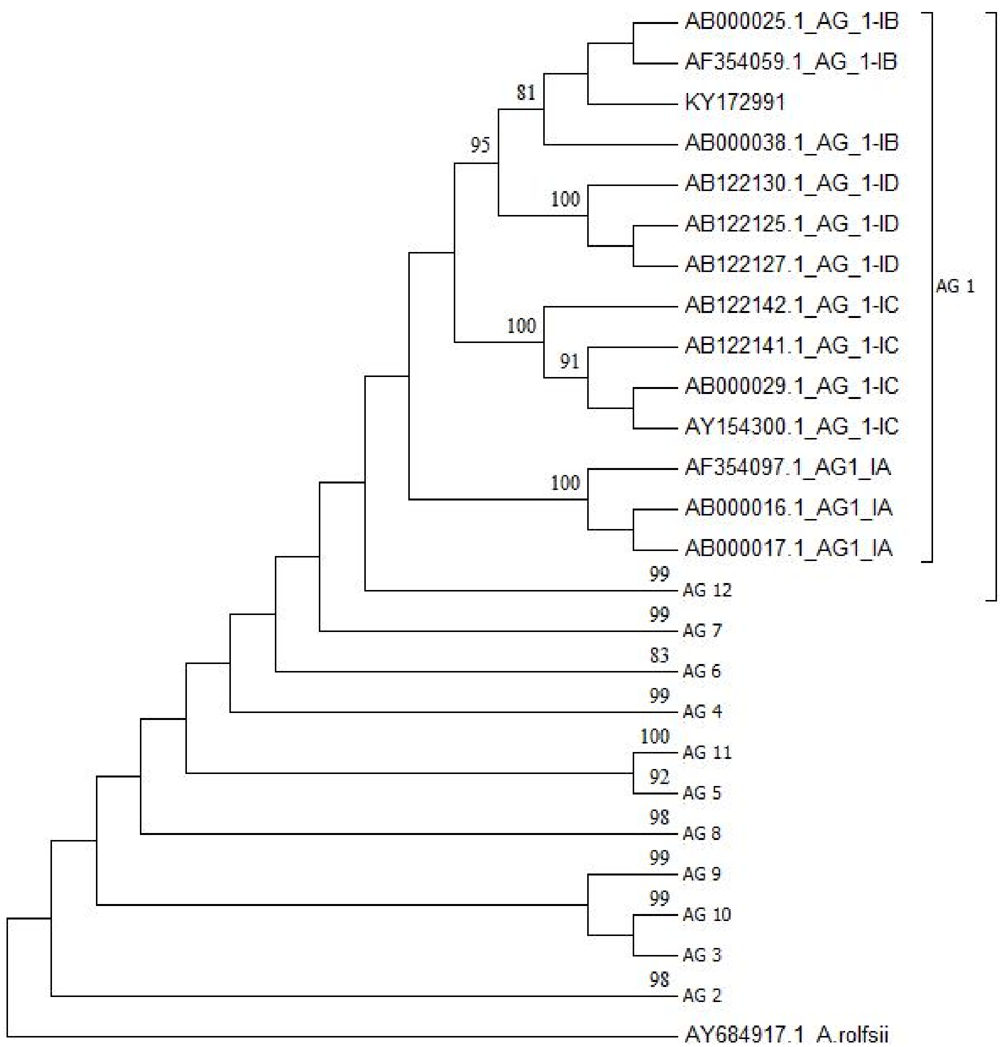

Figure 1. Phylogenetic analysis of *Rhizoctonia solani* isolate PPJ3. The ITS sequence of *Athelia rolfsii* (AY684917) was used as root. All the nodes except AG 1 have been collapsed to improve the clarity. The sequence IDs of collapsed AGs are mentioned in Saveinai *et al.* (2017)

Phylogenetic approach utilizing ITS region has also been used by several workers for accurate identification (Baiswar 2012; Mahendra *et al.* 2016 and Savenai *et al.* 2017).

Pathogenicity of *Rhizoctonia solani* AG 1-IB on common weeds

Initial pathogenicity was done by inoculation of *R. solani* AG 1-IB isolates PPJ1, PPJ2, PPJ3, PPJ4 and PPJ5 on soybean by using detached leaf method. All the isolates were found to be virulent and isolate PPJ3 was used for further pathogenicity test on common weeds.

Rhizoctonia solani AG 1-IB isolate PPJ3 was pathogenic on all the 47 common weeds (**Table 1**). Kannaiyan and Prasad (1979) have also reported that *R. solani* occured on 21 weed hosts and it was severe on weeds like *Eriochloa procera, Andropogon asper, Cynodon dactylon* and *Ischaemum indicum*. Saveinai *et al*. (2017) did similar kind of work on pathogeniticity of *R. solani* AG 1-IA on weeds and results showed that isolate SRS (isolated from rice) was pathogenic on all the weeds and isolate RSM2 (isolated from maize) was found to be pathogenic on all weeds except *Cyperus difformis, C. haspans*, *C. odoratus, S. sagittifolia, Celosia argentea, Commelina diffusa* and *F. miliacea.* In our findings, *R. solani* AG 1-IB (isolated from soybean) was pathogenic on all the weeds. This clearly demonstrates that different AG subgroups and even different isolates of same AG subgroup differ in there pathogenicity against different weeds.

Incubation period, minimum days taken for sclerotia formation and maximum number of sclerotia on common weeds with *Rhizoctonia solani* AG 1-IB isolate

Incubation period on all the common weeds varied from 2-6 days (**Table 1**) *i.e.* two days on *Ageratum houstonianum, Alternanthera sessilis, Amaranthus viridis, Ambrosia artemisiifolia, Arundinella mutica, Bidens pilosa, Borreria latifolia, , Celosia argentea, Commelina benghalensis, Crassocephalum crepidioides, Crotalaria striata, Cuphea balsamona, Cynodon dactylon, Cyperus rotundus, Digitaria adscendens, Echinochloa colona, Eleucine indica, Emilia sonchifolia, Erigeron bonariensis, Eupatorium adenophorum, Euphorbia hirta, Fagopyrum esculantum, Galinsoga parviflora, Ipomoea* sp., *I. indica, Lantana camara, Mikania micrantha, Rotala indica, Sida carpinifolia, Sida rhombifolia, Spermacoce latifolia, Spilanthes paniculata, Stachytarpheta indica, Tridax procumbens* and *Urena lobata* three days on *A. philoxeroides, A. bengalensis, Cyrtoccum accrescens, E. crusgalli, E. unioloides, Fimbristylis miliacea, P. dilatatum, P. scrobiculatum, Scirpus juncoides* and *Setaria glauca.* Incubation period of four days on *I. rugosum* and six days was observed on *C. iria* with *R. solani* AG 1-IB isolate.

Table 1. Pathogenicity, incubation period, minimum days taken for Sclerotia formation and maximum number of sclerotia on common weeds with *Rhizoctonia solani* AG 1-IB isolate

Weed	Pathog -enicity	Incuba -tion period (days)	Sclerotia formation (minumu m days taken)	Maximum no. of sclerotia
Ageratum houstonianum	+	2	11	4
Alternanthera philoxeroides	+	3	-	-
Alternanthera sessilis	+	2	15	9
Amaranthus viridis	+	2	8	2
Ambrosia artemisiifolia	+	2	8	7
Arundinella bengalensis	+	3	12	3
Arundinella mutica	+	2	12	4
Bidens pilosa	+	2	5	8
Borreria latifolia	+	2	5	13
Celosia argentea	+	2	8	7
Commelina benghalensis	+	2	11	2
Crassocephalum crepidioides	+	2	4	12
Crotalaria striata	+	2	7	4
Cuphea balsamona	+	2	7	3
Cynodon dactylon	+	2	10	3
Cyperus iria	+	6	10	2
Cyperus rotundus	+	2	10	3
Cyrtoccum accrescens	+	3	12	2
Digitaria adscendens	+	2	9	9
Echinochloa colona	+	2	10	2
Echinochloa crusgalli	+	3	10	8
Eleucine indica	+	2	7	6
Emilia sonchifolia	+	2	8	4
Eragrostis unioloides	+	3	12	3
Erigeron bonariensis	+	2	12	3
Eupatorium adenophorum	+	2	12	3
Euphorbia hirta	+	2	5	5
Fagopyrum esculantum	+	2	8	3
Fimbristylis miliacea	+	3	12	7
Galinsoga parviflora	+	2	4	6
Ipomoea indica	+	2	-	-
Ipomoea sp.	+	2	12	7
Ischaemum rugosum	+	4	9	4
Lantana camara	+	2	9	16
Mikania micrantha	+	2	8	8
Paspalum dilatatum	+	3	9	7
Paspalum scrobiculatum	+	3	10	5
Rotala indica	+	2	10	1
Scirpus juncoides	+	3	10	1
Setaria glauca	+	3	9	2
Sida carpinifolia	+	2	8	6
Sida rhombifolia	+	2	8	4
Spermacoce latifolia	+	2	7	4
Spilanthes paniculata	+	2	10	3
Stachytarpheta indica	+	2	-	-
Tridax procumbens	+	2	4	12
Urena lobata	+	2	8	6

Minimum days taken for sclerotia formation on common weeds with *R. solani* AG 1-IB isolate showed great variation, these ranged from 4 to 15 days after inoculation (**Table 1**. Minimum days taken for sclerotia formation was observed on weeds *C. crepidioides*, *G. parviflora* and *T. procumbens,* which took 4 days. Three weeds *B. pilosa*, *B. latifolia* and *E. hirta* took 5 days for sclerotia formation. Four weeds *C. striata*, *C. balsamona*, *E. indica* and *S. latifolia* took 7 days. Weeds, *A. viridis,A. artemisiifolia*, *C. argentea*, *E. sonchifolia*, *F. esculantum*, *M. micrantha*, *S. carpinifolia*, *S. rhombifolia* and *U. lobata* took 8 days. Five weeds *D. adscendens, I. rugosum, L. camara, P. dilatatum* and *S. glauca* took 9 days. Nine weeds took 10 days (*C. dactylon, C. iria, C. rotundus, E. colona, E. crusgalli, P. scrobiculatum, R. indica, S. juncoides* and *S. paniculata*). Two weeds *A. houstonianum* and *C. benghalensis* took 11 days. Weeds, *A. bengalensis, A. mutica, C. accrescens, E. unioloides, E. bonariensis, E. adenophorum, F. miliacea* and *Ipomoea* sp. took 12 days for sclerotia formation. Maximum days taken for sclerotia formation (15 days) was observed on weed *A. sessilis*. Rajput and Harlapur (2016) observed great diversity for time taken for initiation of sclerotia formation ranging from 8 to 15 days with *R. solani* isolates.

Number of sclerotia production using *R. solani* AG 1-IB isolate ranged from 1 to 16 (**Table 1**). Maximum sclerotia production (16 nos.) was observed on weed *L. camara*. Sclerotia were produced on almost all the weeds, *viz. B. latifolia* (13 nos.), *C. crepidioides* and *T. procumbens* (12 nos.), *A. sessilis* and *D. adscendens* (9 nos.), *B. pilosa, E. crusgalli* and *M. micrantha* (8 nos.), *A. artemisiifolia, C. argentea, F. miliacea, Ipomoea* sp. and *P. dilatatum* (7 nos.), *E. indica, G. parviflora, S. carpinifolia* and *U. lobata* (6 nos.), *E. hirta* and *P. scrobiculatum* (5 nos.), *A. houstonianum, A. mutica, C. striata, E. sonchifolia, I. rugosum, S. rhombifolia* and *S. latifolia* (4 nos.), *A. bengalensis, C. balsamona, C. dactylon, C. rotundus, E. unioloides, E. bonariensis, E. adenophorum, F. esculantum* and *S. paniculata* (3 nos.), *A. viridis, C. benghalensis, C. iria, C. accrescens, E. colona* and *S. glauca* (2 nos.). Minimum sclerotia production (1 no.) was observed on weeds *R. indica*, and *S. juncoides*. No sclerotia production was observed on weeds *A. philoxeroides, I. indica* and *S. indica*.

AUDPC (Area under the disease progress curve) used for susceptibility analysis of common weeds with *Rhizoctonia solani* AG 1-IB isolate

The weed *E. sonchifolia* (195.1) was most susceptible to isolate *R. solani* AG 1-IB followed by *C. argentea* (187.1), *T. procumbens* (180.0), *G. parviflora* (174.1) and *C. crepidioides* (172.7) were statistically at par (**Figure 2**), followed by *M. micrantha* (159.0), *A. viridis* (157.7), *S. rhombifolia* (148.2) and *A. artemisiifolia* (128.4). The weeds *S. carpinifolia* (118.5) and *R. indica* (113.4) were statistically at par followed by *U. lobata* (105.1). The AUDPC in case of weeds *C. striata*, *S. latifolia* and *B. pilosa* was 101.3, 100.8 and 100.2, respectively

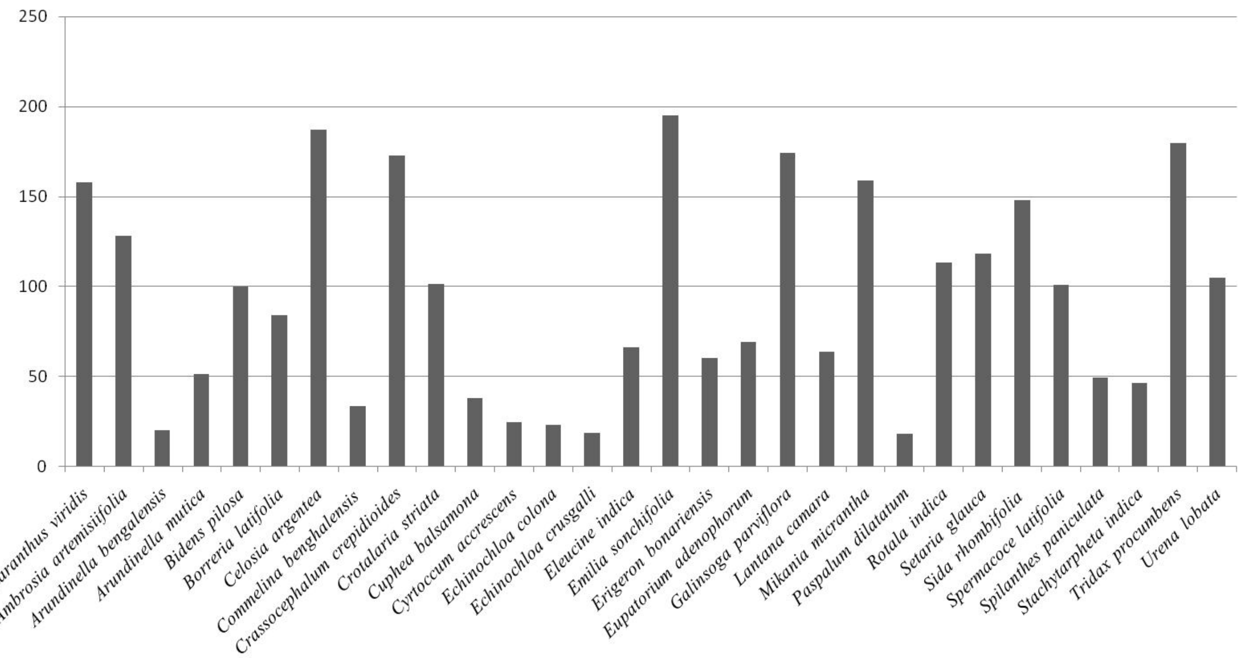

Figure 2. AUDPC used for susceptibility analysis on common weeds with *Rhizoctonia solani* AG 1-IB isolate

and all were statistically at par followed by *B. latifolia* (84.0), *E. adenophorum* (69.4), *E. indica* (66.2), *L. camara* (64.0) and *E. bonariensis* (60.7). The weeds *A. mutica* (51.4), *S. paniculata* (49.7) and *S. indica* (46.7) were statistically at par followed by *C. balsamona* (38.0) and *C. benghalensis* (33.7) which were also statistically at par followed by *C. accrescens* (24.8). The weeds *P. dilatatum* (18.1) *E. crusgalli* (18.6) and *A. bengalensis* (20.1) were least susceptible and statistically at par followed by *E. colona* (23.4). Saveinai *et al.* (2017) have conducted the susceptibility analysis of *R. solani* AG 1-IA on weeds by using AUDPC criteria. They also observed great variation in susceptibility of weeds to *R. solani* AG 1-IA using this criteria.

Most of common weeds in Meghalaya are susceptible to *R. solani* AG 1-IB, but few are highly susceptible. Highly susceptible weeds should not be used as a mulch because this practise will help in spreading this pathogen.

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Weed management in wheat grown at Doon valley of Uttarakhand

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ABSTRACT

Sulfosulfuron + metsufuron-methyl 30 + 2 g/ha application as post-emergence recorded significantly less weed biomass and higher weed control efficiency followed by clodinafop 60 g/ha compared to the rest of the herbicidal treatments. The highest (65.8 g/m^2) weed biomass was recorded with weedy check conditions. Post-emergence application of sulfosulfuron + metsulfuron-methyl 30 + 2 g/ha recorded significantly less weed biomass and higher weed control efficiency, number of effective tillers, grain yield which were at par with weed free check and clodinafop 60 g/ha.

Wheat (*Triticum aestivum* L.) is an important cereal crop for a large number of countries in the world. In India, wheat stands second next to rice in area and production, but first in productivity among all the cereals. In Uttarakhand, area under wheat is about 3.4 lakh ha with total production of 6.6 lakh tonne with 1.92 t/ha productivity (Anonymous 2016). Weeds are the prominent constraint in achieving the potential yield of wheat. Wheat suffers with mixed weeds flora. The losses caused by weeds vary depending on the weed species, their abundance, crop management practices and other environmental factors. Herbicides are one of the major groups of pesticides, which contribute to the increased and economical production of crop and reduction in the drudgery in agricultural production. In this context, the continuous use of a particular herbicide for many years resulted in development of resistance against some weeds, which happened in case of isoproturon (Malik and Singh 1995). Keeping these in view, present study was conducted to assess the efficacy of different herbicides in managing weeds in wheat qrown under Doon valley of Uttarakhand.

A field experiment was conducted during winter season 2015-16 at research farm of Doon P.G. College of Agriculture Science & Technology, Selaqui, Dehradun, Uttarakhand. The experimental soil was sandy loam in texture, medium in available P (21.6 kg/ha) and K (167.2 kg/ha) and low in OC (0.4%) with pH 6.4. The treatments consisted eight weed control practices, *viz.* isoproturon 750 g/ha, sulfosulfuron + metsulfuron-methyl 30 + 2 g/ha, clodinafop 60 g/ha, metribuzin 200 g/ha, 2,4-D 1000 g/ha, metsulfuron-methyl 4 g/ha, weedy check and weed free check were laid out in randomized complete block design with three replications. In experimental field, wheat variety *'WH-1105'* was sown manually by drilling at 4-5 cm deep in 1st fortnight of December using seed rate of 125 kg/ha with rows 20 cm apart. Herbicides were applied as post-emergence at 35 days after seeding (DAS) with the help of manually operated knapsack sprayer using 600 L water/ha. The crop were fertilized with N:P_2O_5:K_2O of 120:60:40 kg/ha through urea, single super phosphate and murate of potash, respectively. The recommended packages of practices were adopted to raise the healthy crop. Observations of weeds and crop were taken as per standard procedures followed and being statistically analyzed data on weeds was subjected to square root transformation to normalize the distribution.

Weed flora

The most dominant weed species at experimental field were *Phalaris minor*, *Avena fatua, Cynodon dactylon* in grassy, *Melilotus alba, Chenopodium album, Anagallis arvensis, Convolvulus arvensis* and *Fumaria indica* under broad-leaved whereas *Cyperus rotundus* in sedges group.

Table 1. Effect of weed control treatments on weed biomass, weed control efficiency, yield and yield attributes of wheat

Treatment	Dose (g/ha)	Weed biomass (g/m^2)	Weed control efficiency (%)	Effective tillers/m^2	Grain yield (t/ha)	Straw yield (t/ha)	Weed index (%)	Test weight (g)
Isoproturon	750	4.54 (21.7)	67.0	218.3	2.82	4.48	16.1	37.2
Sulfosulfuron + metsulfuron- methyl	30 + 2	2.14 (10.3)	84.3	234.8	3.29	4.44	2.1	35.8
Clodinafop	60	2.56 (14.6)	77.8	229.3	3.20	4.39	4.8	38.6
Metribuzin	200	3.85 (18.4)	72.0	221.2	2.82	3.88	16.1	37.7
2,4-D	1000	4.35 (20.7)	68.5	226.9	2.76	4.53	17.9	36.2
Metsulfuron-methyl	05	3.12 (16.6)	73.3	229.4	2.81	4.73	16.4	38.8
Weedy check	-	8.68 (65.8)	-	183.8	2.43	3.65	27.7	38.2
Weed free	-	0.71 (0.0)	100	240.5	3.36	4.53	-	41.2
LSD (p=0.05)	-	0.87	8.6	9.8	0.22	0.27	-	NS

*Data in parentheses are original values

Effect on weeds

The weed biomass and weed control efficiency were affected significantly due to weed management treatments (**Table 1**). Sulfosulfuron + metsufuron-methyl 30 + 2 g/ha application as post-emergence recorded significantly less weed biomass and higher weed control efficiency followed by clodinafop 60 g/ha compared to the rest of the herbicidal treatments. The highest (65.8 g/m^2) weed biomass was recorded with weedy check conditions. The effectiveness under combined application of sulfosulfuron + metsufuron-methyl and clodinafop might be due to its killing selectivity to both of the grassy and broad-leaved weeds in the field. The results are in conformity with the findings of Chhokar *et al.* 2007. Other herbicidal treatments efficacy managing either grassy or broad-leaved weeds was lesser than that of sulfosulfuron + metsufuron-methyl.

Effect on crop

All the herbicide treatments registered significantly higher crop yield over weedy check **(Table 1)**. Presence of weeds throughout the crop season reduced wheat grain yield by 27.8% as compared to crop under weed free situation. The higher wheat yield of 3.29 t/ha recorded with the application of sulfosulfuron + metsufuron-methyl 30 + 2 g/ha which was at par with clodinafop (3.20 t/ha) and weed free check (3.36 t/ha) and significantly superior to rest of the treatments **(Table 1)**. The higher yield might be attributed to more effective tillers produced with sulfosulfuron + metsufuron-methyl 30 + 2 g/ha and clodinafop 60 g/ha as post-emergence due to their knockdown effect on grassy and broad-leaved weeds which resulted in increased yield attributes and wheat yield. Similar results were also obtained by Brar and Walia 2007 and Jain *et al.* 2007.

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Integrated weed management in maize-based intercropping systems

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ABSTRACT

Field experiments were conducted to study the effect of intercropping and integrated weed management practices on weeds experiment was conducted at Agricultural College and Research Institute, Madurai (Tamil Nadu) during winter 2013. The experiment was laid out in a split plot design and replicated thrice. The main plots were assigned with three cropping systems, *viz.* maize, maize + blackgram, maize + cowpea and six weed management practices, Application of pendimethalin at 0.75 kg/ha followed by one rotary hoeing on 35 DAS recorded the highest weed control efficiency (85.9) and reduced weed populations and weed dry matter production at 60 DAS. The maize + cowpea system resulted increased plant height, LAI and dry matter production of maize at 30, 60 and 90 DAS respectively. Application of pendimethalin at 0.75 kg/ha followed by one rotary hoeing on 35 DAS resulted in the highest grain and straw yield of maize 6.05 and 18.15 t/ha, respectively.

Maize (*Zea mays* L.) is an important cereal in many developed and developing countries of the world and provides maximum share of human food. Since it is a versatile crop allowing it to grow across a wide range of agro ecological zones, there is no cereal crop on the earth that has so much yield potential and hence it is popularly called “queen of cereals”. Low productivity of maize in India as compared to world productivity can be attributed to several limiting factors and all but the most important amongst these has been the poor weed management, which poses a major threat to crop productivity. The wider row spacing in maize can be used to grow short duration legumes which not only will act as smother crop, but will give additional yield. In intercropping system, manual and mechanical means of weeding may be difficult due to unavailability of labourers and it is costly too. Chemical weed control helps to alleviate the weed problem in maize, but it is difficult to find suitable broad spectrum herbicides as the herbicides are often crop specific. Weed control approach involving intercropping, herbicides and non- chemical method in maize and maize based intercropping system is very important to provide effective and acceptable weed control for realizing high production (Shah *et al*. 2011). The present study was undertaken to address these issues to develop an integrated weed management strategy for controlling weeds and improving productivity of irrigated maize.

Field experiment was conducted at Agricultural College and Research Institute, Madurai, Tamil Nadu to evaluate suitable weed management practices for maize based intercropping system during winter season of 2013. The soil of the experimental field was well drained clay loam of Madukur series. The soil was low, medium and high in available status of N, P_2O_5 and K_2O respectively. The recommended fertilizer schedule of 250:75:75 NPK kg/ha was applied in maize crop. Investigation was carried out in split plot design with three replications. The treatments consisted of three cropping systems, *viz.* maize, maize + blackgram, maize + cowpea were assigned to main plots and six weed control practices *viz.* pre-emergence application of pendimethalin at 0.75 kg/ha, alachlor at 1.0 kg/ha, oxyfluorfen at 0.2 kg/ha and in combination with one rotary hoeing on 35 DAS. In addition to this, rotary hoeing twice at 15 and 35 DAS, hand weeding on 15, 35 DAS and unweeded check were assigned to sub plot. Test crops were maize hybrid, blackgram and cowpea with varieties of ‘*COHM 6*’, ‘*VBN (Bg) 4*’ and ‘*VBN1*’, respectively. The weed count was recorded group-wise, *viz.* grasses, sedges and broad-leaved weed using 0.25 m^2 quadrat from four randomly selected fixed places in each plot at 5 plants and expressed in no./m^2 as suggested by Burnside and Wicks (1965). Weeds found within two 0.50/m^2 quadrat were removed, sun dried and then oven dried at 70 ^{0}C for 72 hours. The dry weight of the weeds were assessed and expressed in kg/ha. The weed control efficiency was worked out to evaluate the efficiency of integrated weed management practices in maize based intercropping system.

Effect on weeds

Broad-leaved weeds dominated among weed flora followed by grasses and sedge in herbicide treated plots whereas in unweeded plots grasses dominated over others. *Echinochloa colona*, *Eleusine indica* and *Dactyloctenium aegyptium* among the grasses; *Cyperus rotundus* in sedges and *Trianthema portulacastrum*, *Boerhaavia diffusa* and *Digera arvensis* among broad-leaved weeds were dominant species.

The grasses, sedges and broad-leaved weeds density were lesser under intercropping system than sole crop. Maize + cowpea intercropping system suppress the weed density to a greater degree followed by maize + blackgram. Weed management practices through herbicide application reduced the weed density significantly. These were lesser at 60 DAS by application of pendimethalin at 0.75 kg/ha, which was followed by alachlor at 1.0 kg/ha along with rotary hoeing on 35 DAS (**Table 1**). The reduction of weed density in intercropping systems was attributed due to shading effect and competition stress created by the canopy of more crops in a unit area having suppressive effect on associated weeds, thus preventing the weeds to attain full growth (Pandey *et al.* 2003). Several workers also found that the intercropping maize and legumes considerably reduced the weed density compared with the mono cropping maize by decrease in available light for weeds compared to mono crops.

The weed dry matter production was lower in the intercropping system. Maize + cowpea intercropping recorded lower weed dry matter production of 189.0 kg/ha whereas sole maize registered the highest dry matter production of 255.4 kg/ha at 60 DAS. The lowest dry matter production in intercropping system might be attributed to shading effect and competition stress created by the canopy of more number of crops in a unit area. The highest weed dry matter production was observed under unweeded check. Pendimethalin at 0.75 kg/ha + one rotary hoeing at 35 DAS registered the lowest weed dry matter production of 51.23 kg/ha (**Table 1**). All the herbicide applied treatments in combination with one rotary hoeing on 35 DAS registered significantly lower weed dry matter production as compared to other treatments. It showed that the integrated approach was more beneficial in controlling weeds than the hand weeding or chemical approach alone (Chalka and Nepalia 2006).

All the weed management practices resulted in increased weed control efficiency (WCE) over unweeded check. The highest WCE was observed under pre-emergence application of pendimethalin at 0.75 kg/ha + one rotary hoeing on 35 DAS (**Table 1**). It might be due to low persistence of pre-emergence herbicides in soil which control the weeds for a shorter period and lead to lower weed density and dry matter production (Pandey and Prakash 2002).

Effect on growth, yield and yield parameters of maize

The growth characters of maize at 30, 60 and 90 DAS, *viz.* plant height, LAI and DMP were significantly influenced by the cropping system and

Table 1. Influence of integrated weed management practices on weed density, weed dry matter production and weed control efficiency at 60 DAS in maize based intercropping system

Treatment	Weed density (no./m^2)			Weed dry weight (kg/ha)	Weed control efficiency (%)
	Grasses	Sedges	BLW		
Cropping system					
Maize alone	5.57(31.06)	5.36 29.39)	(35.17)5.84	(255.43)14.96	65.4
Maize + blackgram	5.01(25.14)	(27.11)5.13	(26.94)5.10	(194.51)12.83	68.1
Maize + cowpea	4.60(21.17)	(19.15)4.27	(21.44)4.55	(189.04)12.61	68.4
LSD (p=0.05)	1.59	0.18	0.24	0.67	-
Weed control					
PE pendimethalin + one rotary hoeing	(14.67)3.78	(13.30)3.62	(14.44)3.78	(92.62)9.52	85.9
PE alachlor + one rotary hoeing	(17.11)4.09	(18.67)4.28	(21.11)4.55	(103.57)10.08	84.1
PE oxyfluorfen + one rotary hoeing	(19.67)4.42	(23.89)4.83	(27.33)5.17	(120.67)10.90	81.6
Rotary hoeing twice (15 and 35 DAS)	(28.56)5.34	(26.78)5.14	(32.22)5.63	(148.39)12.13	77.2
Hand weeding twice (15 and 35 DAS)	(23.17)4.80	(29.78)5.43	(25.89)5.07	(164.00)12.72	74.9
Unweeded check	(51.56)7.18	(38.89)6.23	(46.11)6.76	(648.70)25.44	-
LSD (p=0.05)	3.15	0.23	0.27	0.77	-

*Original values are given in parentheses

Table 2. Influence of integrated weed management practices on plant height, leaf area index, dry matter, yield parameters, grain yield and stover yield production of maize

Treatment	Plant height (cm)			Leaf area index			Dry matter production (t/ha)			Cob length (cm)	Cob girth (cm)	No. of grains/ cob	Grain yield (t/ha)	Stover yield (t/ha)
	30 DAS	60 DAS	90 DAS	30 DAS	60 DAS	90 DAS	30 DAS	60 DAS	90 DAS					
Cropping system														
Maize alone	106.1	206.9	231.8	4.08	5.64	6.35	2.95	5.13	18.66	13.75	12.77	442	3.31	9.94
Maize + blackgram	95.2	198.1	226.6	3.58	5.73	6.66	3.03	5.02	18.90	15.53	13.11	463	3.92	11.77
Maize + cowpea	100.7	180.3	238.4	4.31	6.07	6.96	3.13	5.18	20.12	16.83	14.47	490	4.94	14.82
LSD (p=0.05)	3.1	5.2	5.7	0.31	0.34	0.44	0.07	0.09	0.46	1.38	1.35	35	0.37	1.11
Weed control														
PE pendimethalin + one rotary hoeing	106.1	217.9	258.9	5.10	7.46	8.16	3.49	5.76	21.52	19.11	15.72	558	6.05	18.15
PE alachlor + one rotary hoeing	101.6	170.6	244.6	4.83	6.82	7.68	3.42	5.71	21.11	17.17	14.22	530	5.23	15.67
PE oxyfluorfen + one rotary hoeing	98.4	196.0	230.2	4.51	5.75	6.50	3.32	5.55	20.63	16.00	13.78	506	4.36	13.08
Rotary hoeing twice (15 and 35 DAS)	109.2	210.0	241.1	3.97	5.15	6.18	3.21	5.27	20.35	15.06	12.39	481	3.43	10.28
Hand weeding twice (15 and 35 DAS)	99.0	195.3	215.0	3.66	4.98	6.01	3.07	5.06	20.27	13.00	13.37	401	3.09	9.27
Unweeded check	89.1	181.0	204.0	1.86	4.72	5.40	1.70	3.32	11.46	11.89	11.23	315	2.19	6.58
LSD (p=0.05)	2.3	4.0	6.1	0.68	0.63	0.56	0.07	0.09	0.51	1.43	1.31	29	0.52	1.57

weed management practices. The plant height was significantly higher with sole maize at 30 and 60 DAS whereas at 90 DAS, maize + cowpea system increased the plant height significantly. In all the three stages of observation, higher value of LAI and DMP were recorded under maize + cowpea over sole maize. In herbicide application, value of all the three growth parameters, *viz.* plant height, LAI and DMP was significantly higher with pre-emergence application of pendimethalin at 0.75 kg/ha along with one rotary hoeing at 35 DAS (**Table 2**).

Cropping systems and weed management practices significantly influenced the yield parameters of maize. Maize + cowpea system significantly registered higher value of cob length (16.83 cm), cob girth (14.47 cm) and number of grains per cob (490.7). Pre-emergence application of pendimethalin at 0.75 kg/ha + one rotary hoeing on 35 DAS recorded the higher cob length (19.11 cm), cob girth (15.72 cm) and number of grains per cob (558) (**Table 3**) than other treatments. Higher WCE and low depletion of nutrients by weeds promoted the yield components of maize (Sen *et al.* 2000).

All the weed management practices influenced the grain and stover yield significantly over sole maize. Weed management practices through herbicide application along with one rotary hoeing at 35 DAS recorded significantly higher grain and stover yields over unweeded check. The higher grain (6.05 t/ha) and stover (18.15 t/ha) yields were registered with the application of pendimethalin at 0.75 kg/ha as pre-emergence followed by one rotary hoeing at 35 DAS (**Table 3**). It was followed by pre-emergence application of alachlor at 1.0 kg/ha with one rotary hoeing at 35 DAS. This might be due to better control of all categories of weeds. In addition to that, lower nutrient depletion and lesser dry matter production of weeds and thereby increasing the nutrient uptake by crop influenced the growth and yield attributes which favoured grain and stover yields of maize. Similar findings were also repoted by Walia *et al*. (2007). Grain and stover yields were the highest with maize + cowpea (4.94 t/ha and 14.81 t/ha, respectively), followed by maize + blackgram (**Table 2**). This might be due to mutual association between legume and non legume crops.

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Weed management through early post-emergence herbicides to improve productivity and nutrient uptake in greengram

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ABSTRACT

A field experiment was conducted at College of Agriculture, PJTSAU, Rajendranagar, Hyderabad (Telangana) during rainy season 2015-16 on sandy loam soil to study the weed growth, yield and nutrient uptake in greengram under different early post-emergence herbicide treatments. Lower density and dry matter of weeds was recorded with hand weeding at 20 and 40 DAS followed by haloxyfop-p-methyl 135 g/ha + imazethapyr 75 g/ha at 12-15 DAS as early post-emergence, which remained at par with quizalofop-ethyl 50 g/ha + imazethapyr 75 g/ha at 12-15 DAS. Hand weeding twice at 20 and 40 DAS showed the highest uptake of N, P and K, which was comparable with haloxyfop-p-methyl 135 g/ha + imazethapyr 75 g/ha at 12-15 DAS and quizalofop-ethyl 50 g/ha + imazethapyr 75 g/ha at 12-15 DAS. Significantly higher seed yield was observed with hand weeding at 20 and 40 DAS (1.09 t/ha) which remained at par with haloxyfop-p-methyl 135 g/ha + imazethapyr 75 g/ha at 12-15 DAS (1.03 t/ha) and quizalofop-ethyl 50 g/ha + imazethapyr 75 g/ha at 12-15 DAS (1.01 t/ha).

Greengram is the third important pulse crop of India in terms of area (3.55 million ha) and production (1.82 million tonnes). It serves as vital source of vegetable protein (19.1-28.3%) and vitamins (Singh *et al*. 2015). Being a short-statured crop, it faces heavy weed competition right from the early crop growth stages. In greengram, hand weeding is effective in controlling the weeds but cost, unavailability of labour and continuous rainfall in rainy season does not permit it to operate timely. Therefore, chemical weed control forms an excellent alternative and provide weed-free environment up to 30–35 days after sowing (Dungarwal *et al*. 2003). Pendimethalin is the most commonly used pre-emergence herbicide in greengram which control weeds during early growth stage, but it does not control newly germinated weeds. Hence, this warrants the use of early post-emergence herbicides for good weed control and thereby increasing the crop yield. Keeping these facts in view, the present investigation was carried out to study weed growth, yield and nutrient uptake in greengram through various early post-emergence herbicide combinations.

The present experiment was carried out during rainy season 2015-16 at research farm of College of Agriculture, PJTSAU, Rajendranagar, Hyderabad (Telangana) with eleven early post-emergence weed management treatments in a randomized block design and replicated thrice **(Table 1)**. The plant and weed samples collected for dry matter production were utilized for chemical analysis. The dried samples were grounded in willey mill. The powdered material collected was used for chemical analysis of N, P and K content as suggested by Subbiah and Asija (1956) for N, Olsen *et al.* (1954) for P and Jackson (1973) for K. Total N, P and K uptake was calculated for each treatment separately by multiplying per cent content in the tissue with their respective dry matter values and expressed as kg/ha.

Weed flora

The field was infested with complex weed flora comprising grasses, sedges and broad-leaved weeds. The predominant weeds observed in the experimental field during crop growth period were: *Cynodon dactylon, Dactyloctenium aegyptium, Digitaria sanguinalis, Dinebra retroflexa, Echinochloa crus-galli, Panicum repens* and *Rottboellia exaltata* among the grasses. *Cyperus rotundus* was the dominant sedge. *Amaranthus viridis, Celosia* *argentia, Commelina benghalensis, Digera arvensis, Euphorbia hirta, Parthenium hysterophorus, Trianthema portulacastrum, Tribulus terrestris* and *Trichodesma indicum* were the major broad-leaved weeds.

Weed density, dry matter, yield and nutrient uptake

Significantly lower density 5.44 no./m^2 and dry matter 1.97 g/m^2 of weeds were recorded with pendimethalin 1.0 kg/ha as pre-emergence, which was on a par with pendimethalin at 1.0 kg/ha as pre-emergence + imazethapyr at 75 g/ha as post-emergence (5.45 no./m^2 and 1.97 g/m^2) whereas significantly higher weed density 8.16 no./m^2 and dry matter 2.76 g/m^2 were recorded with unweeded control. The varying weed control treatments showed significant effect on weed density and dry matter at 30 DAS (**Table 1**). Significantly lowest weed density 3.31 no./m^2 and dry matter 3.20 g/m^2 of weeds were recorded with hand weeding at 20 and 40 DAS which was at par with haloxyfop-p-methyl 135 g/ha + imazethapyr 75 g/ha at 12-15 DAS for weed density 3.44 no./m^2 and dry matter 3.33 g/m^2 and quizalofop-ethyl 50 g/ha + imazethapyr 75 g/ha at 12-15 DAS (3.55 no./m^2 and 3.49 g/m^2, respectively) and were significantly superior over rest of the treatments. Significantly higher weed density 10.38 no./m^2 and dry matter 10.41 g/m^2 were recorded in unweeded control compared to other treatments at 30 DAS. From the findings, it can be stated that the combination of early post-emergence herbicides showed effective weed control same as hand weeding at early stages. At 45 DAS, significantly lower weed density 1.84 no./m^2 and dry matter 1.48 g/m^2 of weeds were recorded in hand weeding at 20 and 40 days after sowing followed by haloxyfop-p-methyl 135 g/ha + imazethapyr 75 g/ha at 12-15 DAS (4.56 no./m^2 and 5.55 g/m^2), which remained at par with quizalofop-ethyl 50 g/ha + imazethapyr 75 g/ha at 12-15 DAS (4.58 no./m^2 and 5.59 g/m^2 for weed density and dry matter, respectively) than other treatments. Significantly higher density and dry matter of weeds were recorded with unweeded control (9.46 no./m^2 and 11.52 g/m^2 for weed density and dry matter, respectively). Similar trend was observed at harvest stage also (**Table 1**). This clearly indicated that the excellent performance of two hand weedings at 20 and 40 DAS was due to better control of weeds. Herbicides showed significant reduction in weed growth thereby facilitated vigourous crop growth, increased photosynthesis and biomass accumulation and ultimately helped to smother weeds resulted in higher WCE (Naidu *et al.* 2012).

Hand weeding at 20 and 40 DAS showed significantly higher uptake of nitrogen, phosphorus and potassium (79.19, 7.58 and 63.90 kg/ha, respectively) which was at par with haloxyfop-p-methyl 135 g/ha + imazethapyr 10% SL 75 g/ha (76.98, 7.37 and 62.12 kg/ha, respectively) and quizalofop-ethyl 50 g/ha + imazethapyr 75 g/ha (75.65, 7.24 and 61.05 kg/ha, respectively) (**Table 2**). The higher uptake of N, P and K in these treatments were due to vigorous growth with adequate supply of these nutrients resulting in higher biological yield coupled with their effective transfer to the ultimate sink *i.e.* grains (Kaur *et al*. 2009). Significantly lower removal of nitrogen, phosphorus and potassium by weeds was observed with hand weeding at 20 and 40 DAS (0.64, 0.26 and 0.60 kg/ha, respectively) followed by haloxyfop-p-methyl 135 g/ha + imazethapyr 75 g/ha (8.96, 1.29 and 6.33 kg/ha, respectively) and quizalofop-ethyl 50 g/ha + imazethapyr 75 g/ha (9.12, 1.31 and 6.45, respectively) whereas significantly the highest

Table 1. Effect of weed management practices on weed density and dry matter of weeds

Treatment	Weed density (no./m^2)				Weed dry matter (g/m^2)			
	15 DAS	30 DAS	45 DAS	At harvest	15 DAS	30 DAS	45 DAS	At harvest
Pendimethalin (1000 g/ha) at 2-3 DAS	5.4(28.6)	6.6(43.5)	7.4(54.1)	8.1(64.4)	1.97(2.9)	6.7(44.3)	9.3(85.3)	10.1(102)
Pendimethalin *fb* imazethapyr (1000 *fb* 75 g/ha) at 2-3 *fb* 12-15 DAS	5.4(28.7)	4.6(20.4)	5.3(27.3)	6.3(38.5)	1.97(2.9)	4.6(20.5)	6.6(42.4)	7.8(61.0)
Imazethapyr (75 g/ha) at 12-15 DAS	8.1(65.3)	6.5(41.8)	6.2(37.2)	7.1(49.0)	2.76(6.7)	6.6(43.2)	7.7(57.8)	8.9(77.8)
Chlorimuron-ethyl (9 g/ha) at 12-15 DAS	8.0(62.8)	8.8(77.9)	7.5(54.7)	8.1(65.0)	2.75(6.7)	8.4(70.6)	9.3(86.5)	10.2(103)
Quizalofop-ethyl + imazethapyr (50+75 g/ha) at 12-15 DAS	7.9(61.2)	3.5(11.7)	4.6(20.2)	5.5(29.5)	2.75(6.7)	3.5(11.4)	5.6(30.6)	6.9(46.5)
Imazethapyr + imazamox (70 g/ha) at 12-15	8.0(62.5)	4.7(21.1)	5.4(27.9)	6.3(38.7)	2.76(6.7)	4.6(21.0)	6.6(42.9)	7.7(61.4)
Propaquizafop + imazethapyr (50 + 75 g/ha) at 12-15 DAS	7.8(60.8)	4.5(19.8)	5.3(27.0)	6.2(38.2)	2.75(6.6)	4.5(20.0)	6.5(41.8)	7.8(60.5)
Haloxyfop-p-methyl + imazethapyr (135+75 g/ha) at 12-15 DAS	8.1(65.5)	3.4(11.0)	4.6(19.8)	5.5(29.0)	2.75(6.7)	3.3(10.4)	5.5(30.2)	6.8(45.7)
Cycloxydim + imazethapyr (80 + 75 g/ha) at 12-15 DAS	8.0(62.8)	6.6(42.6)	6.2(37.8)	7.1(49.5)	2.75(6.7)	6.7(43.7)	7.7(58.5)	8.9(78.7)
Hand weeding at 20 and 40 DAS	8.1(65.0)	3.3(10.1)	1.8(2.4)	2.3(4.4)	2.76(6.6)	3.2(9.6)	1.5(1.2)	2.0(3.2)
Unweeded control	8.2(66.0)	10.0(107)	9.5(88.6)	9.9(96.7)	2.76(6.7)	10.4(108)	11.5(132)	12.5(156)
LSD (p=0.05)	0.70	0.52	0.55	0.60	0.27	0.59	0.52	0.57

Original values are given in parentheses which were transformed to $\sqrt{x+0.5}$

Table 2. Effect of weed management practices on WCE, seed yield and nutrient uptake by crop and weeds

Treatment	WCE (%)	Seed yield (t/ha)	Nutrient uptake (kg/ha)					
			Crop			Weeds		
			N	P	K	N	P	K
Pendimethalin (1000 g/ha) at 2-3 DAS	34.47	0.43	37.16	2.67	24.08	0.16	0.11	0.15
Pendimethalin *fb* imazethapyr (1000 *fb* 75 g/ha) at 2-3 *fb* 12-15 DAS	60.89	0.91	66.73	6.23	52.13	0.16	0.11	0.15
Imazethapyr (75 g/ha) at 12-15 DAS	50.12	0.74	57.88	4.49	43.41	0.37	0.19	0.32
Chlorimuron-ethyl (9 g/ha) at 12-15 DAS	33.75	0.22	28.99	2.20	17.36	0.37	0.19	0.33
Quizalofop-ethyl + imazethapyr (50+75 g/ha) at 12-15 DAS	70.15	1.01	75.65	7.24	61.05	0.37	0.19	0.32
Imazethapyr + imazamox (70 g/ha) at 12-15	60.62	0.90	64.92	6.06	50.72	0.37	0.16	0.33
Propaquizafop + imazethapyr (50 + 75 g/ha) at 12-15 DAS	61.18	0.92	67.33	6.28	52.61	0.37	0.19	0.33
Haloxyfop-p-methyl + imazethapyr (135+75 g/ha) at 12-15 DAS	70.69	1.03	76.98	7.37	62.12	0.37	0.19	0.32
Cycloxydim + imazethapyr (80 + 75 g/ha) at 12-15 DAS	49.51	0.74	57.88	4.49	43.41	0.36	0.16	0.33
Hand weeding at 20 and 40 DAS	97.92	1.09	79.19	7.58	63.90	0.36	0.16	0.33
Unweeded control	0.00	0.42	36.46	2.62	23.44	0.37	0.16	0.33
LSD (p=0.05)		0.08	6.55	0.58	5.22	0.12	0.03	0.03

removal of nitrogen, phosphorus and potassium by weeds was recorded with unweeded control (31.87, 4.40 and 26.52 kg/ha, respectively) at harvest. Because in hand weeding treatment one manual weeding was done at 40 DAS that contributed very less weed population and reduced the nutrient removal by weeds. This could be attributed to higher weed control efficiency of haloxyfop-p-methyl 135 g/ha + imazethapyr 75 g/ha and quizalofop-ethyl 50 g/ha + imazethapyr 75 g/ha resulting in more favourable environment for growth and development of crop apparently due to the lesser weed competition up to harvest. Similar results were reported by Chhodavadia *et al.* (2013).

Significantly higher seed yield was observed with hand weeding at 20 and 40 DAS (1.09 t/ha) which remained at par with haloxyfop-p-methyl 135 g/ha + imazethapyr 75 g/ha at 12-15 DAS (1.03 t/ha) and quizalofop-ethyl 50 g/ha + imazethapyr 75 g/ha at 12-15 DAS (1.01 t/ha) (**Table 2**). The combination of early post-emergence herbicides resulted in superior control of weeds over other treatments leading to higher seed yield. Significantly the lowest seed yield (0.22 t/ha) was obtained with the application of chlorimuron-ethyl 9 g/ha at 12-15 DAS since it showed high phyto- toxicity and plant did not recover even at later stages also which in turn led to poor weed control during entire crop growth period. Thus, it can be summarized that combinations of haloxyfop-p-methyl 135 g/ha + imazethapyr 75 g/ha and quizalofop-ethyl 50 g/ha + imazethapyr 75 g/ha at 12-15 DAS as early post-emergence can be recommended for Southern Zone of Telangana in greengram.

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Weed management in chickpea under irrigated conditions

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Weed Density

ABSTRACT

In a study on chickpea at Uttar Pradesh, two hand weeding done in weedy check and weed free plot results indicated that weed control treatments significantly reduced the density of weeds. Maximum weed control efficiency (100%) was recorded with weed free plot. Among herbicides, maximum WCE (95.0%) was recorded in pre-emergence of pendimethalin1000 g/ha followed by combined PoE application of imazethapyr 75 g + quizalofop-ethyl 60 g/ha at 35 DAS and lowest WCE was recorded in weedy check. Among herbicides, the lowest number of plants (20.7/m^2), plant height (33.4 cm) and number of pods/ plant (22.4) at harvest stage of chickpea were recorded in PE application of pendimethalin 750 g/ha followed by combined PoE application of quizalofop-ethyl 60 g + oxyfluorfen 200 g/ha at 30 DAS. Maximum net monetary returns ` 53588/ha was recorded with pre-emergence application of pendimethalin 1000 g and PoE application of clodinafop 60 g/ha at 35 DAS.

In Uttar Pradesh, chickpea is cultivated in an area of 0.62 million hectares with a production and productivity of 0.51 million tonnes and 824 kg/ha, respectively (DES 2011). Weed infestation in chickpea offer serious competition and cause yield reduction to the extent of 75% (Chaudhary *et al.* 2005). The initial 60 days period is considered to be the critical for weed crop competition in chickpea (Singh and Singh 1992). With the increase in labour cost and scarcity of labour, manual weed control has become a difficult task. Suitable herbicide for effective control of mixed weed flora is required for better adoption in this crop by farmers. Hence, present investigation was carried out to study the efficacy of different herbicides on mixed weed flora and their effect on growth and yield of chickpea.

The field experiment was conducted during winter season of 2011 at N.D. University of Agriculture and Technology, Narendra Nagar (Kumarganj), Faizabad (U.P.) India. The soil of the experimental field was clay-loam, low in organic carbon, available nitrogen and phosphorus, medium in available potassium and alkaline in reaction (pH 8.1). Chickpea variety "*PG-186*" was sown on 19 November, 2011 in rows, at 40 cm apart at 4-5 cm deep. The experiment was laid out in a randomized block design with fourteen treatments (**Table 1**). Pre-plant incorporation and pre-emergence herbicides were applied one day before and after sowing, respectively using a knapsack sprayer fitted with flatfan nozzle with a spray volume of 600 litres of water per hectare. Hand weeding was done as and when required. Weed dry weight was recorded by placing a quadrate of 0.25 m at three random places in each plot and then weighed for all weeds separately after oven drying at 45 days after sowing and harvesting. Weed control efficiency was calculated on the basis of dry weight of weeds as per the formula of Patil and Patil (1983). The weed index was calculated as per formula suggested by Gill and Kumar (1969).

Effect on weeds

Both monocot and dicot weeds were observed in the experimental fields. Among dicot weeds *Chenopodium album* (51.9%) and *Anagallis arvensis* (17.9%), while grassy weed *Phalaris minor* (11.2%) and *Cynodon dactylon* (1.7%) at harvest were predominant in the weedy check plot. All the treatments receiving weed control measures effectively controlled both grassy and dicot weeds over weedy check (**Table 1**). Among the herbicides, pre-emergence application of pendimethalin 1000 g/ ha followed by combined post-emergence application of imazethapyr 75 g + quizalofop 60 g/ha at 35 days after sowing (DAS) recorded significantly lower weed density of both grassy and dicot weeds at each growth stages as compared to other treatments (**Table 2**).

Table 1. Effect of weed control treatments on density of different weed species at 30 and 60 DAS of chickpea

Treatment	Weed density (no./m^2) at 30 DAS						Weed density (no./m^2) at 60 DAS					
	C. album	*P. minor*	*A. arvensis*	*C. dactylon*	Other weeds	Total	*C. album*	*P. minor*	*A. arvensis*	*C. dactylon*	Other weeds	Total
Pendimethalin1000 g/ha PE	2.54	2.38	2.14	1.12	3.44	5.30	3.93	2.94	2.53	1.72	3.96	6.86
	(6.00)	(5.15)	(4.10)	(1.15)	(11.37)	(27.77)	(15.00)	(8.15)	(5.90)	(2.46)	(15.17)	(46.68)
Pendimethalin 1000 g PE *fb* quizalofop	2.91	2.33	2.09	1.39	3.27	5.38	3.66	1.83	2.31	1.80	2.59	5.48
60 g/ha PoE	(8.00)	(4.95)	(3.90)	(1.45)	(10.26)	(28.56)	(13.00)	(2.85)	(4.85)	(2.75)	(6.24)	(29.69)
Pendimethalin 1000 g PE *fb* clodinafop	2.73	2.31	2.13	1.46	3.14	5.23	3.39	1.63	2.29	1.65	2.39	5.08
60 g/ha PoE	(7.00)	(4.85)	(4.08)	(1.65)	(9.45)	(27.03)	(11.00)	(2.15)	(4.75)	(2.22)	(5.24)	(25.36)
Pendimethalin750 g PE *fb* quizalafop	2.91	2.40	2.16	1.32	3.26	5.41	1.87	1.91	1.83	1.80	1.90	3.92
60 g + oxyfluorfen 200 g/ha PoE	(8.00)	(5.25)	(4.15)	(1.25)	(10.16)	(28.81)	(3.00)	(3.15)	(2.85)	(2.76)	(3.12)	(14.88)
Oxyfluorfen 200 g/ha PE	3.07	2.78	2.69	1.46	3.80	6.26	4.18	3.32	2.79	1.83	3.95	7.30
	(9.00)	(7.25)	(6.75)	(1.65)	(14.25)	(38.90)	(17.00)	(10.56)	(7.30)	(2.85)	(15.15)	(52.86)
Oxyfluorfen 200 g PE *fb* quizalofop	3.23	2.57	2.59	1.39	3.80	6.18	3.93	2.18	2.40	1.66	3.02	5.99
60 g/ha PoE	(10.00)	(6.15)	(6.25)	(1.45)	(14.00)	(37.85)	(15.00)	(4.28)	(5.30)	(2.25)	(8.65)	(35.48)
Oxyfluorfen 200 g PE *fb* clodinafop	3.07	2.96	2.70	1.35	3.89	6.36	3.67	2.06	2.37	1.72	2.82	5.68
60 g/ha PoE	(9.00)	(8.25)	(6.85)	(1.34)	(14.75)	(40.19)	(13.00)	(3.76)	(5.15)	(5.15)	(7.45)	(29.91)
Oxyfluorfen 200 g + quizalofop	8.84	5.16	4.46	1.40	4.60	12.08	2.82	3.12	1.98	1.77	2.42	5.35
60 g/ha PoE	(78.00)	(26.23)	(19.45)	(1.45)	(20.71)	(145.84)	(7.50)	(9.26)	(3.45)	(2.65)	(5.35)	(28.21)
Oxyfluorfen 200 g + *fb* clodinafop	8.79	5.06	4.37	1.35	4.52	11.93	3.13	3.30	2.27	1.81	2.63	5.83
60 g/ha PoE	(77.00)	(25.23)	(18.68)	(1.33)	(20.00)	(142.24)	(9.30)	(10.45)	(4.65)	(2.78)	(6.45)	(33.63)
Imazethapyr 75 g/ha PoE	9.08	5.27	4.55	1.47	4.86	12.44	4.30	5.29	2.95	1.74	2.63	7.97
	(82.00)	(27.23)	(20.22)	(1.65)	(23.16)	(154.26)	(18.00)	(27.45)	(8.21)	(2.54)	(6.78)	(62.98)
Pendimethalin 1000 g PE *fb* imazethapyr	2.91	2.37	2.09	1.28	3.21	5.33	2.10	3.12	1.66	1.63	2.22	4.74
75 g/ha PoE	(8.00)	(5.11)	(3.89)	(1.14)	(9.87)	(28.01)	(3.90)	(9.26)	(2.26)	(2.15)	(4.42)	(21.99)
Pendimethalin 1000 g PE *fb* imazethapyr	2.72	2.15	2.16	1.49	3.26	5.25	1.44	1.41	1.28	1.82	2.08	3.36
75 g + quizalofop 60 g/ha PoE	(7.00)	(4.15)	(4.20)	(1.75)	(10.27)	(27.37)	(1.58)	(1.50)	(1.15)	(2.85)	(3.85)	(10.93)
Weed free	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Weedy check	9.25	5.34	4.65	1.56	4.55	12.52	9.67	5.77	4.94	1.90	5.13	13.38
	(86.00)	(28.37)	(21.34)	(1.95)	(20.45)	(158.11)	(94.00)	(33.15)	(24.19)	(3.15)	(26.15)	(180.64)
LSD (p=0.05)	0.78	0.45	0.44	NS	0.55	1.16	0.64	0.41	0.34	0.19	0.39	0.95

Table 2. Effect of weed control treatments on density of different weed species

Treatment	Weed density (no./m^2) at 90 DAS						Weed density (no./m^2) at harvest					
	C. album	*P. minor*	*A. arvensis*	*C. dactylon*	Other weeds	Total	*C. album*	*P. minor*	*A. arvensis*	*C. dactylon*	Other weeds	Total
Pendimethalin1000 g/ha PE	4.23	3.19	2.78	2.09	4.26	7.51	4.10	3.63	2.62	2.09	3.84	6.91
	(17.4)	(9.76)	(7.26)	(3.87)	(17.77)	(56.11)	(16.40)	(6.45)	(6.35)	(3.87)	(14.25)	(47.32)
Pendimethalin 1000 g PE *fb*	4.01	1.99	2.61	2.09	3.15	6.26	3.81	1.81	2.22	2.09	2.63	5.66
quizalofop 60 g/ha PoE	(15.6)	(3.46)	(6.35)	(3.90)	(9.46)	(38.82)	(14.10)	(2.80)	(4.45)	(3.90)	(6.44)	(31.69)
Pendimethalin 1000 g PE *fb*	3.70	1.83	2.58	1.98	2.77	5.77	3.52	1.58	2.15	1.98	2.39	5.21
clodinafop 60 g/ha PoE	(13.2)	(2.85)	(6.15)	(3.44)	(7.24)	(32.93)	(11.95)	(2.00)	(4.15)	(3.44)	(5.24)	(26.78)
Pendimethalin750 g PE *fb* quizalafop	2.85	2.11	2.16	2.06	2.39	5.02	2.57	1.86	1.94	2.06	2.16	4.55
60 g + oxyfluorfen 200 g/ha PoE	(7.6)	(3.95)	(4.15)	(3.15)	(5.22)	(24.72)	(6.10)	(2.95)	(3.25)	(3.75)	(4.15)	(20.20)
Oxyfluorfen 200 g/ha PE	4.49	3.55	3.08	2.06	4.29	7.93	4.14	3.15	2.78	2.06	3.97	7.27
	(19.8)	(12.15)	(9.00)	(3.76)	(18.00)	(62.67)	(16.76)	(9.45)	(7.26)	(3.76)	(15.25)	(52.48)
Oxyfluorfen 200 g PE *fb* quizalofop	4.29	2.57	2.79	2.03	3.33	6.75	3.99	2.39	2.60	2.03	2.59	6.10
60 g/ha PoE	(18.0)	(6.15)	(7.30)	(3.65)	(10.65)	(45.75)	(15.45)	(5.21)	(6.30)	(3.65)	(6.25)	(36.86)
Oxyfluorfen 200 g PE *fb* clodinafop	3.95	2.31	2.60	2.10	3.14	6.32	3.74	1.91	2.38	2.11	2.37	5.60
60 g/ha PoE	(15.2)	(4.85)	(6.25)	(3.95)	(9.45)	(39.75)	(13.00)	(3.16)	(5.17)	(3.95)	(5.15)	(30.99)
Oxyfluorfen 200 g + quizalofop	3.08	3.29	2.34	2.12	2.96	6.09	2.76	2.95	2.08	2.12	2.36	5.36
60 g/ha PoE	(9.0)	(10.35)	(5.00)	(4.01)	(8.30)	(36.66)	(7.15)	(8.22)	(3.85)	(4.01)	(5.10)	(28.33)
Oxyfluorfen 200 g + *fb* clodinafop	3.36	3.51	2.38	1.94	3.13	6.39	3.05	3.05	2.14	1.94	2.41	5.55
60 g/ha PoE	(10.8)	(11.88)	(5.19)	(3.26)	(9.35)	(40.53)	(8.85)	(8.85)	(4.08)	(3.26)	(5.33)	(30.37)
Imazethapyr 75 g/ha PoE	4.79	5.45	2.95	2.17	3.06	8.57	4.58	4.96	2.64	2.17	2.35	7.79
	(22.4)	(29.19)	(8.21)	(4.22)	(8.85)	(72.92)	(20.45)	(24.11)	(6.46)	(4.22)	(5.00)	(60.24)
Pendimethalin 1000 g PE *fb*	2.22	3.38	1.66	1.93	1.69	5.30	1.87	3.04	1.63	1.94	2.14	4.66
imazethapyr 75 g/ha PoE	(4.4)	(10.98)	(2.26)	(3.26)	(6.76)	(27.71)	(3.00)	(8.78)	(2.15)	(3.26)	(4.10)	(21.29)
Pendimethalin 1000 g PE *fb* imazeth-	1.62	1.65	1.28	2.01	2.46	3.88	1.56	1.53	1.22	2.01	2.09	3.55
apyr 75 g + quizalofop 60 g/ha PoE	(2.1)	(2.26)	(2.15)	(3.58)	(5.60)	(14.74)	(1.95)	(1.85)	(1.00)	(3.58)	(3.90)	(12.28)
Weed free	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71
	(0.0)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Weedy check	9.82	5.98	4.94	2.37	5.51	13.81	9.67	5.61	4.49	2.37	5.12	13.24
	(97.0)	(35.70)	(24.19)	(5.15)	(30.20)	(192.24)	(94.00)	(31.76)	(19.87)	(5.15)	(26.00)	(176.78)
LSD (p=0.05)	0.72	0.49	0.36	0.28	0.52	1.12	0.24	0.42	0.32	0.24	0.38	0.98

Fig. in parenthesis are the original value, x = $\sqrt{x+0.5}$ transformation

Table 3.Effect of weed control practices on yield attributes, yield, weed index and economics

Treatment	Weed control efficiency (%)	Weed index (%)	No. of plants (m^2) at harvest	Plant height (cm) at harvest	No. of pods/ plant	Grain yield (t/ha)	Net return ($x10^3$ `/ha)
Pendimethalin1000 g/ha PE	75.6	18.3	22.5	41.0	34.5	1.40	42.31
Pendimethalin 1000 g PE *fb* quizalofop 60 g/ha PoE	83.1	5.5	23.2	46.9	39.8	1.62	50.45
Pendimethalin 1000 g PE *fb* clodinafop 60 g/ha PoE	86.8	3.0	24.0	47.3	40.3	1.67	53.59
Pendimethalin750 g PE *fb* quizalafop 60 g + oxyfluorfen 200 g/ha PoE	92.2	72.2	6.5	29.7	24.9	0.48	-3.88
Oxyfluorfen 200 g/ha PE	73.5	23.0	24.2	36.3	29.6	1.32	37.99
Oxyfluorfen 200 g PE *fb* quizalofop 60 g/ha PoE	81.1	10.2	24.0	42.3	35.4	1.54	46.06
Oxyfluorfen 200 g PE *fb* clodinafop 60 g/ha PoE	84.8	7.8	24.4	44.3	36.2	1.58	48.38
Oxyfluorfen200 g + quizalofop 60 g/ha PoE	89.7	71.8	6.6	30.2	27.0	0.48	-2.41
Oxyfluorfen 200 g + *fb* clodinafop 60 g/ha PoE	88.6	69.5	7.2	30.6	27.4	0.52	0.00
Imazethapyr 75 g/ha PoE	74.7	27.3	21.9	33.6	30.3	1.25	35.86
Pendimethalin 1000 g PE *fb* imazethapyr 75 g/ha PoE	90.5	14.2	22.0	34.1	34.9	1.47	44.83
Pendimethalin 1000 g PE *fb* imazethapyr 75 g + quizalofop 60 g/ha PoE	95.0	40.0	14.3	31.4	28.7	1.03	22.62
Weed free	100.0	0.0	24.0	48.8	41.5	1.72	48.99
Weedy check	0.0	46.4	20.7	33.4	22.4	0.92	22.05
LSD (p=0.05)	-	-	3.26	5.84	5.45	0.21	-

Maximum weed control efficiency (100%) was recorded with weed free plot. Among herbicides, maximum WCE (94.99%) was recorded in pre-emergence of pendimethalin1000 g/ha followed by combined PoE application of imazethapyr 75 g + quizalofop-ethyl 60 g/ha at 35 DAS. The lowest WCE was recorded in weedy check. Among herbicides pre-emergence application of oxyfluorfen 200 g/ha recorded the lowest WCE (73.5%). Sharma (2009) and Ratnam *et al.* (2011) also reported the maximum WCE in pre-plant and incorporation of fluchloralin at 1.0 kg/ha and the lowest in oxyfluorfen at 0.15 kg/ha.

Effect on crop

All the weed-control measures had significantly positive impact on yield attributes and seed yield of chickpea over weedy check (**Table 3**). Significantly the lowest values of number of plants ($20.7/m^2$), plant height (33.4cm) and number of pods/plant (22.4) at harvest stage of chickpea were recorded under weedy check. Among herbicides, lowest number of plants ($20.7/m^2$), plant height (33.4cm) and number of pods/plant(22.4) at harvest stage of chickpea were recorded in PE application of pendimethalin750 g followed by combined PoE application of quizalofop-ethyl 60 g + oxyfluorfen 200 g/ha at 30 DAS. These results were in agreement with the findings of Dungerwal *et al.* (2002). Maximum reduction in seed yield was recorded in PE application of pendimethalin750 g followed with tank mix PoE application of quizalofop-ethyl 60 g+ oxyfluorfen 200 g/ha (0.47 t/ha) at 35 DAS over weedy check (0.92 t/ha)

Maximum net monetary returns ` 53588/ha was recorded with pre-emergence application of pendimethalin 1000 g and PoE application of clodinafop 60 g/ha at 35 DAS. By registering net monetary returns of ` 50448/ha, pre-emergence application of pendimethalin 1000 g PE and PoE application of quizalofop-ethyl 60 g/ha at 35 DAS found to be the next best treatment. Pre-emergence application of pendimethalin 750 g followed by tank mix PoE application of quizalofop-ethyl 60 g + oxyfluorfen 200 g/ha at 35 DAS and PoE application of oxyfluorfen 200 g + quizalofop-ethyl 60 g/ha at 35 DAS gave negative returns because of high cost of cultivation (Pedde *et al.* 2013).

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Efficacy of herbicides for control of weeds in mothbean

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ABSTRACT

A field experiment was conducted at College of Agriculture, S K Rajasthan Agricultural University, Bikaner during rainy season 2015 to find out the efficacy of herbicides for control of weeds in mothbean (*Vigna aconitifolia)*. The experiment comprised of 16 treatment combinations. Application of imazethapyr + imazamox 50 g/ha (20 DAS) + hand weeding at 35 DAS were significantly superior in reducing weed density and dry weight of both broad-leaved and grassy weeds. Weed free, pendimethalin 0.75 kg/ha + hand weeding at 25 DAS and pendimethalin 0.75 kg/ha PE alone, imazethapyr + imazamox 50 g/ha + hand weeding at 35 DAS and imazethapyr + imazamox 30 g/ha + hand weeding at 35 DAS registered 844, 827, 805, 801 and 781 kg/ha seed yield, respectively as against the seed yield of 427 kg/ha in weedy check. Among the weed control treatments, maximum net returns of ` 50529/ha was recorded under weed free treatment while highest B:C ratio was recorded with pendimethalin 0.75 kg/ha (2.48) closely followed by imazethapyr + imazamox 50 g/ha + hand weeding at 35 DAS (2.47).

Mothbean [*Vigna aconitifolia* (Jacq.) Marechal] is a short-day and most drought tolerant rainy season legume crop, grown extensively in arid and semi-arid regions of India for grain, green fodder and green manuring purposes. Investigations revealed a loss of 30-50% in the seed yield of mothbean due to weed infestation depending upon the intensity and type of weed flora (Shekhawat *et al.* 2003). Hand weeding is a traditional and effective method of weed control. But untimely rains, unavailability of labour at peak time and increasing labour cost are the main limitations of manual weeding. Under such situations, the only alternative that needs to be explored is the use of suitable herbicides which may be effective and economically viable.

In view of paucity of information on weed management especially the application of post-emergence herbicides in mothbean, an attempt has been made to test imazethapyr and imazethapyr + imazamox as a post-emergence herbicides, as these have shown encouraging results in other leguminous crops.

A field study was conducted during rainy season 2015 at Agronomy Farm, College of Agriculture, Swami Keshwanand Rajasthan Agricultural University, Bikaner, Rajasthan. The experiment comprises of 16 treatment combinations (**Table 1**). The soil of experimental site was loamy sand having 0.08% organic carbon, 8.22 pH, 78, 22 and 210 kg/ha available N, P and K, respectively. Mothbean '*RMO-423*' was sown on 17 July 2015 at 30 cm row to row spacing using seed rate of 16 kg/ha and was harvested on 28 September 2015. Recommended dose of fertilizers (20 kg N + 40 kg P + 40 kg K/ha) was applied as basal dose. Pendimethalin was applied after the sowing of crop while imazethapyr and imazethapyr + imazamox were applied 20 days after sowing at 3-4 leaf stage. These herbicides were sprayed with knapsack sprayer using 500 litres of water per hectare. In the weed free plots, two hoeing were done at 15 and 30 DAS. In pendimethalin + one hand weeding treated plots, the hoeing was done at 25 DAS as well as in imazethapyr + one hand weeding and imazethapyr + imazamox + one hand weeding treated plots, the hoeing was done at 35 DAS. Weed density was recorded by using quadrate of 0.25 m^2 at 20 DAS and at harvest in all the treatments and then converted into number of weeds/m^2. The weeds were dried in oven till a constant weight was observed and then transformed into g/m^2 by using the appropriate formula. The data on total weed count and weed dry matter were subjected to square root transformation to normalize their distribution (Gomez and Gomez 1984).

Effect on weeds

The experimental field was infested with *Amaranthus spinosus*, *Digera arvensis*, *Aristida depressa*, *Portulaca oleracea*, *Cenchrus biflorus*, *Tribulus terrestris*, *Digiteria* spp. and *Dactyloctenium* *aegyptium*.The density and dry weight of broad-leaf and grassy weeds as well as total weeds were significantly reduced by pendimethalin 1.0 kg/ha in controlling weeds at 20 DAS (**Table 1**). On the other hand, pre-emergence application of pendimethalin 0.75 kg/ha alone and pendimethalin 0.75 kg/ha + hand weeding at 25 DAS were superior over imazethapyr 50, 40 or 30 g/ha alone and integrated with hand weeding and imazethapyr + imazamox 50 or 30 g/ha alone and along with hand weeding and these treatments statistically at par each other. This might be due to effective control of weeds either by manual weeding or herbicides or integrated approach. Moreover, dense crop canopy might have smothering effect on weeds. At 20 DAS, more reduction in both density and dry weight of grassy and broad-leaved weeds with application of pendimethalin. Application of imazethapyr + imazamox 50 or 30 g/ha at at 20 DAS + one hand weeding at 35 DAS, pendimethalin 1.0 kg/ha and imazethapyr 30 g/ha + one hand weeding at 35 DAS was found at par with each other and significantly superior over pendimethalin 0.75 kg/ha alone and integrated with hand weeding and imazethapyr 50 or 40 g/ha + one hand weeding at 35 DAS. Hand weeding 20 DAS and imazethapyr + imazamox 50 g/ha significantly decreased weed density compared to imazethapyr 50, 40 or 30 g/ha alone and imazethapyr + imazamox 30 g/ha alone. On other hand the lowest dry weight found in imazethapyr + imazamox 50 g/ha + one hand weeding at 35 DAS, which remained at par with imazethapyr + imazamox 30 g/ha + one hand weeding at 35 DAS and pendimethalin 1.0 kg/ha. Performance of herbicidal (all levels of imazethapyr and pendimethalin) treatments along with one hand weeding were found superior over application of herbicide alone with respect to both density and dry weight of broad-leaved, grassy and total weeds. In case of application

Tables 1. Effect of weed control measure on density and dry weight of weed at harvest

Treatment	Weed density (no./m^2)						Weed dry weight (g/m^2)					
	Broad-leaved		Grassy		Total		Broad-leaved		Grassy		Total	
	20 DAS	At harvest	20 DAS	At harvest	20 DAS	At harvest	20 DAS	At harvest	20 DAS	At harvest	20 DAS	At harvest
Pendimethalin 0.75 kg/ha as PE	1.53 (1.8)	1.42 (1.5)	0.71 (0)	1.58 (2.1)	1.53* (1.8)$^{\#}$	2.02 (3.58)	4.11 (16)	3.63 (13)	0.71 (0)	1.44 (1.6)	16.4	14.2
Pendimethalin 1 kg/ha as PE	0.71 (0)	0.99 (0.5)	0.71 (0)	1.26 (1.1)	0.71 (0.0)	1.44 (1.57)	0.71 (0)	3.15 (9.4)	0.71 (0)	1.26 (1.1)	0	10.5
Pendimethalin 0.75 kg/ha as PE + 1 HW at 25 DAS	1.53 (1.8)	1.40 (1.5)	0.71 (0)	1.25 (1.1)	1.53 (1.8)	1.74 (2.53)	4.11 (16)	3.61 (12)	0.71 (0)	1.25 (1.1)	16.4	13.6
Imazethapyr 30 g/ha at 20 DAS	7.72 (59)	2.71 (6.8)	5.13 (26)	3.13 (9.3)	9.24 (85)	4.08 (16.2)	8.66 (74)	4.78 (22)	2.92 (8.0)	2.10 (3.9)	82.6	26.2
Imazethapyr 40 g/ha at 20 DAS	7.60 (57)	2.64 (7.1)	5.15 (29)	3.03 (8.7)	9.25 (85)	4.01 (15.6)	8.52 (73)	4.68 (22)	2.91 (8.1)	2.05 (3.7)	81.5	25.5
Imazethapyr 50 g/ha at 20 DAS	7.66 (58)	2.48 (5.8)	5.11 (26)	2.74 (7.0)	9.18 (84)	3.63 (12.6)	8.63 (74)	4.59 (21)	2.92 (8.0)	1.95 (3.3)	82.0	23.9
Imazethapyr 30 g/ha at 20 DAS + 1 HW at 35 DAS	7.77 (60)	1.37 (1.4)	5.07 (25)	1.05 (0.6)	9.25 (85)	1.58 (2.0)	8.69 (75)	3.57 (12)	2.91 (8.0)	1.15 (0.8)	83.0	13.1
Imazethapyr 40 g/ha at 20 DAS + 1 HW at 35 DAS	7.70 (59)	1.37 (1.4)	5.18 (26)	1.32 (1.2)	9.25 (85)	1.76 (2.6)	8.65 (74)	3.57 (12)	2.94 (8.1)	1.30 (1.2)	82.5	13.4
Imazethapyr 40 g/ha at 20 DAS + 1 HW at 35 DAS	7.83 (61)	1.35 (1.3)	5.20 (26)	1.40 (1.4)	9.37 (87)	1.81 (2.8)	8.72 (76)	3.55 (12)	2.94 (8.1)	1.34 (1.3)	83.7	13.4
Imazethapyr + imazamox 30 g/ha at 20 DAS	7.70 (61)	2.78 (7.2)	5.16 (26)	2.94 (8.5)	9.28 (85)	4.00 (15)	8.65 (74)	4.83 (23)	2.93 (8.0)	2.03 (3.6)	82.4	26.5
Imazethapyr + imazamox 50 g/ha at 20 DAS	7.65 (58)	2.35 (5.0)	5.18 (26)	2.11 (4.0)	9.21 (84)	3.08 (9.0)	8.63 (74)	4.49 (20)	2.94 (8.1)	1.69 (2.4)	82.0	22.0
Imazethapyr + imazamox 30 g/ha at 20 DAS + 1 HW at 35 DAS	7.74 (60)	1.00 (0.5)	5.18 (26)	1.26 (1.1)	9.30 (85)	1.44 (1.6)	8.67 (75)	3.16 (9.5)	2.94 (8.1)	1.26 (1.1)	82.9	10.6
Imazethapyr + imazamox 50 g/ha at 20 DAS + 1 HW at 35 DAS	7.63 (58)	0.84 (0.2)	5.19 (26)	1.00 (0.5)	9.20 (84)	1.10 (0.7)	8.62 (74)	2.96 (8.3)	2.94 (8.1)	1.10 (0.7)	81.9	9.0
Hand weeding 20 DAS	7.66 (58)	1.64 (2.2)	5.10 (25)	2.14 (4.2)	9.18 (84)	2.61 (6.3)	8.59 (73)	3.85 (14)	2.92 (8.0)	1.71 (2.4)	81.3	16.7
Weedy check	7.80 (60)	9.35 (86)	5.10 (25)	6.64 (44)	9.30 (85)	11.4 (130)	8.71 (75)	8.52 (72)	2.92 (8.0)	3.11 (9.2)	83.4	81.2
Weed free	0.71 (0)	0.71 (0)	0.71 (0)	0.71 (0)	0.71 (0)	0.71 (0)	0.71 (0)	0.71 (0)	0.71 (0)	0.71 (0)	0	0
LSD (p=0.05)	0.96	0.83	0.83	0.47	1.0	0.49	0.61	0.51	0.35	0.47	9.1	3.8

HW= Hand weeding DAS=Day after sowing *: Figures in parenthesis are original, #: Weed density transformed to “n+0.

Tables 2. Effect of weed control measure on weed control efficiency, weed index, yield and economics in mothbean

Treatment	Weed control efficiency (%)	Weed index (%)	Seed yield (t/ha)	Straw yield (t/ha)	Net returns (x10^3 `/ha)	B:C ratio
Pendimethalin 0.75 kg/ha as PE	96.04	4.69	0.80	1.61	48.75	2.48
Pendimethalin 1 kg/ha as PE	98.26	13.11	0.73	1.48	42.36	2.11
Pendimethalin 0.75 kg/ha as PE + 1 HW at 25 DAS	97.23	2.04	0.83	1.62	47.22	2.05
Imazethapyr 30 g/ha at 20 DAS	82.39	12.95	0.73	1.48	43.49	2.29
Imazethapyr 40 g/ha at 20 DAS	83.49	12.45	0.74	1.48	43.69	2.28
Imazethapyr 50 g/ha at 20 DAS	86.10	12.15	0.74	1.49	43.76	2.26
Imazethapyr 30 g/ha at 20 DAS + 1 HW at 35 DAS	97.77	9.76	0.76	1.54	45.67	2.39
Imazethapyr 40 g/ha at 20 DAS + 1 HW at 35 DAS	97.13	9.02	0.77	155	46.01	2.38
Imazethapyr 40 g/ha at 20 DAS + 1 HW at 35 DAS	96.98	8.49	0.77	1.57	46.23	2.37
Imazethapyr + imazamox 30 g/ha at 20 DAS	82.99	10.81	0.75	1.49	44.90	2.35
Imazethapyr + imazamox 50 g/ha at 20 DAS	90.23	10.59	0.75	1.47	44.59	2.29
Imazethapyr + imazamox 30 g/ha at 20 DAS + 1 HW at 35 DAS	98.27	7.50	0.78	1.59	47.25	2.46
Imazethapyr + imazamox 50 g/ha at 20 DAS + 1 HW at 35 DAS	99.23	5.14	0.80	1.61	48.49	2.47
Hand weeding 20 DAS	93.05	9.99	0.76	1.53	44.84	2.27
Weedy check	0.00	49.41	0.43	0.95	18.07	0.98
Weed free	100.0	0.00	0.84	1.64	50.53	2.39
LSD (p=0.05)	-	-	0.10	0.23	-	-

of imazethapyr + imazamox integrated with hand weeding showed superior effect on reducing weed density and weed dry weight with or without hand weeding. At harvest more reduction in both density and dry weight of grassy weeds with application of imazethapyr + imazamox was might be due to the more effectiveness of imazamox against grassy weeds. The results also corroborated with the finding of Singh *et al.* (2015), and Reddy *et al.* (2016). Saltoni *et al.* (2004) have suggested that imazethapyr and imazethapyr + imazamox are imidazolinones herbicide, which are absorbed both by the roots and the shoots. These can effectively control a broad spectrum of weeds. Imazethapyr + imazamox 50 or 30 g/ha at 20 DAS + hand weeding 35 DAS, pendimethalin 1.0 kg/ha as PE and imazethapyr 50 g/ha + one hand weeding at 35 DAS recorded higher weed control efficiency (**Table 2**). The lowest weed index was recorded under pendimethalin 0.75 kg/ha as PE + one hand weeding at 25 DAS (0.87%) followed by pendimethalin 0.75 kg/ha as PE (3.54%) and imazethapyr + imazamox 50 g/ha at 20 DAS + one hand weeding at 35 DAS (4.0%). This might be due to elimination of weeds by manual weeding and interculturing or by herbicides.

Effect on mothbean

Among different treatments, significant superiority of weed free treatment over all weed control methods significantly enhanced yield components with concomitant increased in seed and straw yield (**Table 2**). The extents of increase in seed and straw yield of mothbean were by 97.65 and 73.07 per cent under weed free treatment, respectively compared to weedy check. Similar results were also reported by Upadhayay *et al.* (2013). Maximum net returns of ` 50529/ha was realized under the weed free treatment and it was closely followed by pendimethalin 0.75 kg/ha alone and imazethapyr + imazamox 50 g/ha at 20 DAS as PoE which recorded net return of ` 48753 and ` 48492/ha, respectively. The higher seed yield recorded with this treatment might be responsible for higher net returns. The maximum B:C ratio (2.48) was accrued under treatment pendimethalin at 0.75 kg/ha as PE followed by imazethapyr + imazamox 50 g/ha + one hand weeding 35 DAS and imazethapyr + imazamox 30 g/ha + one hand weeding 35 DAS values 2.47 and 2.46.

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Weed control in sesame with pre-emergence herbicides

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ABSTRACT

Pendimethalin, imazethapyr, metribuzin, oxyfluorfen, imezemox were evaluated as pre-emergence herbicides in sesame during summer season of 2013 and 2014 at ICAR-Directorate of Weed Research, Jabalpur. All the herbicides reduced the weed population significantly as compared with weedy check but delayed the germination of sesame and caused sesame injury. Among all the herbicides, pendimethalin alone and in combination with lower dose of imazethapyr caused less injury to the sesame and produced higher sesame yield. None of the herbicides surpassed the yield what was achieved with 2 HW.

Sesame (*Sesamum indicum* L.) is one of the oldest crops known to humans. There are archeological remnants of sesame dating to 5500 BC in the Harappa Valley in the Indian subcontinent (Bedigian and Harlan 1986). India ranks first in area and second in sesame production by contributing 23.2% and 18.5% of the world area and production, respectively. In India, it is cultivated in an area on 1.86 m ha with a production of 0.81 m t (Anonymous 2007). Its average productivity (437 kg/ha) is far below then that of world average (489 kg/ha) (FAO 2004). Being a slow growing crop during seedling stage weeds affect the growth of sesame and reduce the yield. Yield reduction due to weeds was observed to the tune of 55 to 65% (Punia *et al.* 2001). The period from 15 to 30 days after sowing (DAS) is the most critical period of crop-weed competition in sesame (Venkatakrishnan and Gnanamurthy 1998). Though the conventional methods of weed control are very much effective, but due to high wages and non- availability of labour during critical weeding season, use of herbicides could be more time saving, economical and efficient to check early crop-weed competition. With weak seedling vigor, limited competitive ability, the use of pre-emergence herbicides is essential for sesame production. Therefore, the present investigation is planned to find out the suitable pre-emergence herbicide for weed control during early growth stages of sesame.

A field experiment was conducted at experimental farm of ICAR-Directorate of Weed Research, Jabalpur, (23°132 N, 79°582 E, and 390 m above mean sea level) Madhya Pradesh, India during summer seasons of 2013 and 2014. The soil of experimental field was clay loam in texture, neutral (7.2) in reaction, medium in organic carbon (0.79%), available nitrogen (312 kg N /ha) and phosphorus (18 kg P_2O_5/ha) but high in available potassium (291 kg K_2O/ha). The experiment was laid out in randomized block design, replicated thrice, comprised 8 treatments with different groups and herbicides, *viz.* pendimethalin 750 g/ha (dinitroaniline), oxyfluorfen 150 g/ha (diphenyethers), imazethapyr 60 g/ha (imidazolinone), metribuzin 200 g/h (triazines), pendimethalin 750 g/ha + imazethapyr 50 g/ha, imazethapyr 35 g/ha + imazemox 35 g/ha (imidazolinone), two hand weeding (15 and 30 DAS) and weedy check. Sesame variety '*TKG-22*' was sown with recommended package of practices. Fertilizers were applied through urea, di-ammonium phosphate and muriate of potash @ 60 kg N, 40 kg P_2O_5 and 20 kg K_2O/ha. All the pre-emergence herbicides were applied with manually operated 'ASPEE' knapsack sprayer fitted with flat-fan nozzle at spray volume of 500 L/ha. Weed density and dry matter were recorded at 45 DAS with the help of 1 x 1 m quadrate by throwing randomly at three places in each plot. Weeds were removed and counted species wise. Plant height was measured by gentle stretching the main stem of the plant to its full length and measuring the height in centimeters. Sesame injury was evaluated based on scale of 0 (no stunting) to 100 (complete plant death). Observations were recorded for different characters and mean values were subjected to pooled analysis. The combined analysis of 2 years revealed that the year effect was non-significant, and the mean data of 2 years were analyzed. The statistical analysis of data was done using SAS Windows Version 9.3.

Weed flora

The most dominant broad-leaved weeds were *Alternanthra philoxeroides, Cichorium intybus, Euphorbia geniculata,* and grassy weeds were *Digitaria sanguinalis, Dinebra retroflexa, Echinocloa colona.*

Effect of herbicides

The pre-emergence herbicides have varied response over broad-leaved and narrow-leaved weeds. Among the pre-emergence, pendimethalin + imazethapyr showed better control over *Alternanthra philoxeroides* (**Table 1**) and was at par with pendimethalin alone and other herbicides, except imazethapyr + imazemox, which showed that lower dose of imazethapyr had no impact on *Alternanthra philoxeroides*. Metribuzin controlled *Cichorium intybus* effectively and was at par to oxyfluorfen. Pendimethalin could control approximately 50% whereas imazethapyr had negligible effect on this weed. Emergence of *Euphorbia geniculata* was checked by imazethapyr + imazemox followed by oxyfluorfen and imazethapyr. Pendimethalin was less effective against *Euphorbia geniculata.* The population of *Digitaria sanguinalis* was significantly reduced with the application of imazethapyr and oxyfluorfen. All the herbicides reduced the population of *Dinebra retroflexa,* but the difference was not upto the level of significance. *Echinocloa colona,* the major narrow-leaf weed was effectively controlled by pendimethalin + imazethapyr and by metribuzin and pendimethalin alone. Among pre-emergence treatments minimum dry weight of weed was recorded with the application of pendimethalin + imazethapyr followed by pendimethalin alone (**Table 1**). Byrd and York (1987) also reported that grasses and small-seeded dicot weed species can be controlled with the pre-emergence application of

Table 1. Effect of pre-emergence herbicides on density (no. /m^2) and dry matter (g/m^2) of broad and narrow leaf weeds of summer sesame

Treatment	Broad-leaved weeds			Narrow-leaved weeds (no/m^2)			Total weed dry matter (g/m^2)
	Alternanthra philoxeroides	*Cichorium intybus*	*Euphorbia geniculata*	*Digitaria sanguinalis*	*Dinebra retroflexa*	*Echinocloa colona*	
Pendimethalin 750 g/ha	2.0^{C}	13.1^{B}	9.03^{A}	2.8^{ABC}	1.3^{A}	5.1^{CD}	28.7^{BC}
Oxyfluorfen 150 g/ha	3.4^{C}	5.8^{C}	1.7^{AB}	1.2^{D}	4.3^{A}	11.4^{AB}	33.6^{B}
Imazethapyr 60 g/ha	3.7^{BC}	18.7^{AB}	3.4^{AB}	1.7^{D}	1.6^{A}	7.0^{BC}	33.7^{B}
Metribuzin 200 g/ha	5.3^{ABC}	3.6^{C}	6.6^{AB}	2.9^{AB}	4.0^{A}	4.5^{CD}	24.1^{B}
Pendimethalin 750 + imazethapyr 50 g/ha	1.7^{C}	16.2^{B}	4.6^{AB}	2.2^{BCD}	1.3^{A}	4.1^{CD}	23^{CD}
Imazethapyr 35 g/ha + imazemox 35 g/ha	9.3^{A}	20.4^{AB}	1.2^{B}	1.8^{CD}	1.3^{A}	7.1^{BC}	26.1^{CD}
Two hand weeding	3.6^{BC}	4.6^{C}	1.3^{B}	1.6^{D}	1.0^{A}	1.7^{D}	16.2^{D}
Weedy check	8.6^{AB}	25.7^{A}	6.4^{AB}	3.84^{A}	4.3^{A}	12.9^{A}	75.4^{A}
LSD (p=0.05)							

In a column, means followed by common letter are not significantly different at 5 % level by DMRT

Table 2. Effect of pre-emergence herbicides on seed yield and yield attributing characters of sesame

Treatment	Days to 50% germination	Plant height (cm)	No. of branches/plant	No. of capsules /plant	Test wt (g)	Sesame stunting (%)	Seed yield (kg/ha)
Pendimethalin 750 g/ha	12.0^{B}	105.9^{AB}	5.65^{AB}	55.1^{AB}	3.12	16.3^{C}	546.3^{B}
Oxyfluorfen 150 g/ha	13.3^{B}	80.0^{C}	3.63^{CD}	31.3^{CD}	3.14	36.6^{A}	373.5^{CDE}
Imazethapyr 60 g/ha	13.6^{B}	92.1^{ABC}	3.81^{CD}	41.8^{BCD}	3.08	32.0^{AB}	411.4^{CD}
Metribuzin 200 g/ha	20.6^{A}	98.5^{ABC}	4.66^{BCD}	45.8^{BC}	3.09	26.6^{B}	459.6^{BC}
Pendimethalin 750 + imazethapyr 50 g/ha	13.6^{B}	104.3^{AB}	5.12^{BC}	52.4^{AB}	3.06	17.3^{C}	531.7^{B}
Imazethapyr 35 g/ha + imazemox 35 g/ha	13.0^{B}	82.8^{BC}	3.35^{D}	31.7^{CD}	3.09	30.3^{AB}	342.1^{DE}
Two hand weeding	7.0^{C}	109.8^{A}	7.10^{A}	66.7^{A}	3.08	0.00^{D}	682.0^{A}
Weedy check	7.3^{C}	107.5^{A}	3.27^{D}	29.1^{D}	3.12	0.00^{D}	271.33^{E}
LSD (p=0.05)							

In a column, means followed by common letter are not significantly different at 5% level by DMRT pendimethalin. All the broad-leaved and narrow-leaved weeds were effectively controlled by two hand weeding (2 HW) and the lowest population of all the weeds (broad and narrow leaved) was observed with this treatment except *Alternanthra philoxeroides*. Significantly higher populations of grassy as well as broad-leaved weeds were recorded in weedy check. Bhadauria *et al.* (2012) also observed similar findings in their studies.

Significantly higher plant height, no. of branches per plant, no of capsules and yield was recorded with 2 HW, while weedy check yielded lowest (**Table 2**). All the pre-emergence herbicide reduce the plant height of sesame but significantly lower plant height was observed with oxyfluorfen and imazethapyr + imazemox when compared with 2 HW and untreated check. During initial stages of plant growth, the stunting was observed with all the pre-emergence herbicide tried. Significantly higher stunting was observed with oxyfuorfen whereas pendimethalin alone and in combination with lower dose of imazethapyr caused least injury to the sesame. Due to suppressive effect on initial crop growth and subsequently on yield attributes, in spite of good weed control, seed yield was poor in plots treated with pre-emergence herbicide. This was in confirmation with findings of Punia *et al.* (2001) and Grichar *et al.* (2009). Among pre-emergence herbicide tried, the maximum plant height, no. of branches per plant and yield and less stunting was observed with pendimethalin alone followed by pendimethalin + imazethapyr (**Table 2**). It showed that dinitroanilines were much safer to sesame as compared to imidazolinone, triazines and diphenyethers (Bhadauria *et al.* 2012). Rao and Rao (1965) also reported significantly higher yield of sesame with the application of pendimethalin.

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Weeds phytosociology in *Jatropha* plantation of *Terai* region in West Bengal

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ABSTRACT

Phytosociological association of the weeds in the plantation of *Jatropha curcas* L. was studied in pre-monsoon and monsoon season at Uttar Banga Krishi Viswavidyalaya, Pundibari, Cooch Behar, West Bengal. In pre-monsoon and monsoon period, 15 and 31 weed species were found, respectively. In both the seasons, the dominant family was Poaceae followed by Compositae, Araceae and Cyperaceae. Among the life forms, herbs were found to be dominant followed by grasses, shrubs and climbers. *Digitaria violascens* (54.32) and *Torenia thouarsii* (3.29) had the highest and lowest IVI, respectively, in pre–monsoon period, while *Oplismenus burmani* (68.63) and *Cyperus rotundus* (1.49) recorded maximum and minimum IVI, respectively, in monsoon period. Highest and lowest abundance frequency (A/F) ratio was found with *Ludwigia octavolvis* (0.75) and *Kyllinga bulbosa*, respectively, in pre–monsoon period and *Cyperus rotundus* (0.03); and *Axonopus compressus* (1.05) and *Mikania micrantha* (0.05), respectively, in monsoon period.

The energy scenario of India is based on the both renewable and non-renewable sources of energy *etc*. As per Bharat Petroleum Statistical Review of world Energy (2008), the coal is the highest (51%) contributor of the energy in India followed by oil (32%). To prevent the bad effects of oil imports in relation to economic growth, biofuels are gaining momentum for development (Subramanian *et al.* 2005) due to their economic and social benefits through rural employment and increase in per capita income (Goswami *et al.* 2011). However, the shortage of raw material with high proportion of oil content is one of the major concerns for production of biodiesel (Wani *et al.* 2006). In this context, *Jatropha* as renewable source of production of biofuel hold immense potential for fulfilling the demand of India's future energy needs.

Weeds interfere with the growth of desirable plants which are harmful and persistent hence they are regarded as undesirable. The present study was done to see the association and phytosociological study of weed species that grows in the Jatropha (*Jatropha curcas*) plantation site. *Jatropha* commonly known as 'Physic nut', is a bio-fuel which is of great concern these days as it can meet the increasing demand of energy. Among many factors, weeds too can limit the yield of this biofuel. This crop is highly sensitive to competition with weed species (Concenco *et al.* 2014). It is usually a monocrop and its interrows are usually kept clear during the growing season and this leads to higher weed infestation. This study was aimed at identifying the species that have greater infestation in *Jatropha* plantation, which will help to manage the weeds.

The study was carried out at the *Jatropha* plantation at Uttar Banga Krishi Viswavidyalaya located at Pundibari, Cooch Behar, West Bengal situated between N26^{0}24'16.9" latitudes and E 89^{0}23'11.9" longitudes and at the elevation of 34 msl. The field study was conducted in pre-monsoon and monsoon period of 2013-2014. The climate of the area is sub-topical humid in nature. There was a considerable variation in the seasonal and diurnal temperature of the experimental site. The average minimum and maximum temperature varied from 7.32 ^{0}C during winter (January) to 33.23 ^{0}C during summer (August). Annual rainfall varied from 2000 – 2500 mm, bulk of which being received during the pre-monsoon and monsoon *i.e*. May to September. Relative humidity of the experimental site varied from 56% to 92%.

The size and number of quadrates were determined by species area curve method (Misra 1968). Total 15 quadrates of size 1 x 1 m for each season were laid randomly in the field. The weed species were then collected from each quadrate for further study. After the collection of weeds from the field, the specimens were identified from Flora of British India (Hooker, 1875 -1897), online data base

Table 1. Family and habit of the weed species in *Jatropha* plantation

Plant Species	Family	Habit
Colocasia esculenta (L.) Schott	Araceae	Herb
Cynodon dactylon (L.) Pers.	Poaceae	Grass
Typhonium trilobatum Schott	Araceae	Herb
Eleutheranthera rudielis (Sw.) Sch.Bip.	Compositae	Herb
Kyllinga bulbosa P.Beauv.	Cyperaceae	Herb
Digitaria violascens Link	Poaceae	Grass
Commelina benghalensis L.	Commelinaceae	Herb
Mimosa pudica L.	Leguminosae	Herb
Ludwigia octavolvis (Jacq.) P.H.Raven	Onagraceae	Herb
Ageratum conyzoides (L.) L.	Compositae	Herb
Oplismenus burmani (Retz.) P.Beauv.	Poaceae	Grass
Mikania micrantha Kunth	Compositae	Climber
Axonopus compressus (Sw.) P.Beauv.	Poaceae	Grass
Sida acuta Burm.f.	Malvaceae	Herb
Ceratopteris thalictriodes (L.) Brongn.	Pteridaceae	Herb
Cyperus rotundus L.	Cyperaceae	Herb
Eragrostis tenella (L.) P.Beauv. ex Roem. & Schult.	Poaceae	Grass
Clerodendrum viscosum Vent.	Lamiaceae	Shrub
Pouzolzia indica Gaudich.	Urticaceae	Herb
Acmella calva (DC.) R.K.Jansen	Compositae	Herb
Pupalia atropurpurea (Lam.) Moq.	Amaranthaceae	Herb
Eleusine indica (L.) Gaertn.	Poaceae	Grass
Euphorbia hirta L.	Euphorbiaceae	Herb
Polycarpon prostatum (Forssk.) Asch. & Schweinf.	Caryophyllaceae	Herb
Phyllanthus urinaria L.	Phyllanthaceae	Herb
Eragrostis unioloides (Retz.)	Poaceae	Grass
Dactyloctenium aegyptium (L.) Willd.	Poaceae	Grass
Torenia thouarsii (Cham. & Schltdl.) Kuntze	Linderniaceae	Herb
Setaria viridis (L.) P.Beauv.	Poaceae	Grass
Urena lobata L.	Malvaceae	Herb
Oxalis corniculata L.	Oxalidaceae	Herb

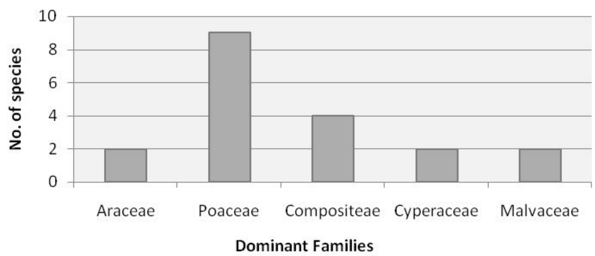

Figure 1. Dominant families among the weed species in the jatropha plantation site

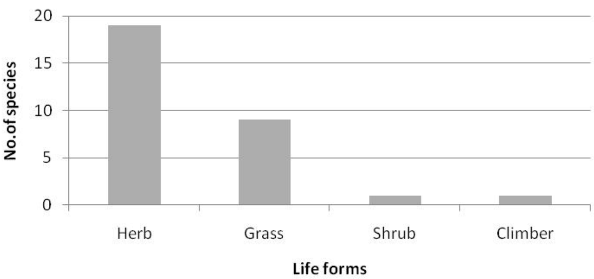

Figure 2. Life forms of the weed species in the jatropha plantation site

www.theplantlist.org on from university. Importance value index (IVI), relative frequency (RF), relative density (RD) and relative abundance (RA) of plant species were calculated according to the formula given by Curtis and McIntosh (1950). The spatial distribution of weed species was determined as per the method outlined by Whitford (1949).

Phytosociological analysis of weeds

Total 31 species occurred in monsoon and 15 species occurred in pre-monsoon season and 31 in monsoon season (**Table 1** and **3**). Large numbers of species were grasses belonging to the family Poaceae (9) followed by Compositae (4), Araceae (2), Cyperaceae (2) and Malvaceae (2) (**Figure 1**). Among the life forms, herbs were more in number followed by grasses, shrubs and climbers (**Figure 2**). Climbers and shrubs were not found in the pre-monsoon period.

The phytosociological survey showed that out of the total plant species, only four species, *viz. Digitaria violascens*, *Cynodon dactylon*, *Oplismenus burmani* and *Ageratum conyzoides* were most dominant species. Dominant species based on importance value (IV) during pre–monsoon was *Digitaria violascens* (54.32) followed by *Oplismenus burmani* (52.91) whereas *Torenia thouarsii* (3.29) showed lower dominance (**Table 2**). During the monsoon period the highest dominance was observed in *Oplismenus burmani* (68.63) followed by *Ageratum conyzoides* (42.54) and the lowest in *Cyperus rotundus* (1.49) (**Table 3**). High importance value (IV) of a species indicates its dominance and ecological success with the power of regeneration, tolerance ability and survivability. It varied with season. It is observed that maximum species grow together in both seasons because similar environment (light, temperature, water and nutrients) requirement for their adaptability. Similar observations were made by Shameem *et al*. (2010). High IVI value was observed by few species because of the most

Table 2. Phytosociological analysis of weeds occurrence during pre- monsoon in the *Jatropha* plantation

Species	RF	RD	RA	IVI	A/F ratio
Typhonium trilobatum Schott	10.53	3.55	3.39	17.47	0.08
Digitaria violascens Link	10.53	22.40	21.39	54.32	0.51
Axonopus compressus (Sw.) P.Beauv	10.53	2.73	2.61	15.87	0.06
Kyllinga bulbosa P.Beauv.	5.26	0.27	0.52	6.06	0.03
Oplismenus burmani (Retz.) P.Beauv	13.16	22.54	17.21	52.91	0.33
Cynodon dactylon (L.) Pers.	13.16	13.11	10.02	36.29	0.19
Ludwigia octavolvis (Jacq.) P.H.Raven	2.63	2.05	7.82	12.51	0.75
Eleusine indica (L.) Gaertn.	7.89	6.69	8.52	23.11	0.27
Cyperus rotundus L.	5.26	0.27	0.52	6.06	0.03
Commelina benghalensis L.	7.89	1.50	1.91	11.31	0.06
Acmella calva (DC.) R.K.Jansen	2.63	0.27	1.04	3.95	0.10
Torenia thouarsii (Cham. & Schltdl.) Kuntze	2.63	0.14	0.52	3.29	0.05
Oxalis corniculata L.	2.63	0.41	1.56	4.61	0.15
Ageratum conyzoides (L.) L.	2.63	0.41	1.56	4.61	0.15
Setaria viridis (L.) P.Beauv.	2.63	1.09	4.17	7.90	0.40

Table 3. Phytosociological analysis of weeds occurrence during monsoon in the *Jatropha* plantation

Species	RF	RD	RA	IVI	A/F ratio
Colocasia esculenta (L.) Schott	1.81	0.56	1.19	3.57	0.19
Cynodon dactylon (L.) Pers.	4.53	13.79	11.62	29.93	0.73
Typhonium trilobatum Schott	1.81	0.45	0.95	3.22	0.15
Eleutheranthera rudielis (Sw.) Sch.Bip.	3.62	0.90	0.95	5.48	0.08
Kyllinga bulbosa P.Beauv.	8.15	8.47	3.97	20.59	0.14
Digitaria violascens Link	11.77	13.22	4.29	29.28	0.10
Commelina benghalensis L.	9.05	11.19	4.71	24.95	0.15
Mimosa pudica L.	2.72	1.02	1.43	5.16	0.15
Ludwigia octavolvis (Jacq.) P.H.Raven	3.62	3.95	4.17	11.74	0.33
Ageratum conyzoides (L.) L.	6.34	22.60	13.61	42.54	0.61
Oplismenus burmani (Retz.) P.Beauv.	11.77	42.94	13.92	68.63	0.34
Mikania micrantha Kunth	4.53	0.90	0.76	6.19	0.05
Axonopus compressus (Sw.) P.Beauv.	1.81	3.16	6.67	11.64	1.05
Sida acuta Burm.f.	2.72	0.45	0.63	3.80	0.07
Ceratopteris thalictriodes (L.) Brongn.	2.72	1.36	1.90	5.98	0.20
Cyperus rotundus L.	0.91	0.11	0.48	1.49	0.15
Eragrostis tenella (L.) P.Beauv. ex Roem. & Schult.	1.81	0.56	1.19	3.57	0.19
Clerodendrum viscosum Vent.	0.91	0.23	0.95	2.08	0.30
Pouzolzia indica Gaudich.	3.62	1.02	1.07	5.71	0.08
Acmella calva (DC.) R.K.Jansen	3.62	1.69	1.79	7.10	0.14
Pupalia atropurpurea (Lam.) Moq.	0.91	0.11	0.48	1.49	0.15
Eleusine indica (L.) Gaertn.	1.81	0.45	0.95	3.22	0.15
Euphorbia hirta L.	3.62	0.90	0.95	5.48	0.08
Polycarpon prostatum (Forssk.) Asch. & Schweinf.	0.91	0.68	2.86	4.44	0.90
Phyllanthus urinaria L.	0.91	0.11	0.48	1.49	0.15
Eragrostis unioloides (Retz.)	1.81	0.45	0.95	3.22	0.15
Dactyloctenium aegyptium (L.) Willd.	0.91	0.23	0.95	2.08	0.30
Torenia thouarsii (Cham. & Schltdl.) Kuntze	2.72	1.58	2.22	6.52	0.23
Setaria viridis (L.) P.Beauv.	1.81	0.34	0.71	2.86	0.11
Urena lobata L.	3.62	0.90	0.95	5.48	0.08
Oxalis corniculata L.	1.81	0.56	1.19	3.57	0.19

RF- Relative frequency, RD- Relative density, RA- Relative abundance, IVI- Importance value index, A/F-ratio of abundance and frequency

available resources utilized by that species and left over are being trapped by the other species as competitors or as associates. This might be due to the sprouting of root stock or seed stock is diminished due to the adverse climatic factors. It is generally argued that each individual species require some set of other species for their existence and they have co-evolved in the ecosystem on which they depend (Paine 1966).

Highest abundance frequency (A/F) ratio in pre–monsoon period was found with *Ludwigia octavolvis* (0.75) and lowest was recorded by both *Kyllinga bulbosa* and *Cyperus rotundus* (0.03) (**Table 2**). In monsoon period, the abundance frequency ratio was highest and lowest with *Axonopus compressus* (1.05) and *Mikania micrantha* (0.05), respectively (Table 3). A seasonal picture of the most of species showed contagious pattern of distribution as the abundance frequency (A/F) ratio of each weed species was > 0.05, except *Kyllinga bulbosa* and *Cyperus rotundus* which showed random pattern of distribution in pre-monsoon season. The pattern of distribution depend both on physic-chemical natures of the environment as well as on the biological characters of the organisms. The contagious pattern of distribution of species indicates natural vegetation (Venna *et al.* 1999). It was evidenced that the area was with natural vegetation in which most seedlings were adapted to grow close to the mother plant as also observed by Njoh *et al.* (2013), Generally weed competition causes low productivity of crops and therefore it become pertinent to protect the crops from the weed infestation. The results of present investigation have significance in effective weed management in *Jatropha* plantation.

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Polarity nature of seed germination stimulants present in root extract of host plants of *Orobanche* spp.

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ABSTRACT

The seed germination of *Orobanche* is initiated by the stimulants present in the root exudates of host plants. Therefore, in order to find out the polarity nature of germination stimulants, root extract of tomato, tobacco and brinjal plants were assayed through different organic solvents of varying polarity by the flow chart method. Hexane and ethyl acetate fractions of root extract of tobacco, tomato and brinjal induced better germination than any other solvent tested. Tobacco root extract fractions isolated in ethyl acetate induced the highest germination compared to hexane. Tomato root extract fractions in different solvents also produced similar results. The performance of root extract of brinjal was more or less similar to that of tobacco and tomato root extracts except that the percentage of germination in both the solvents was greater than in other two host plants. The polarity of one form of stimulants matches with that of hexane (1.89) and polarity of another form with that of ethyl acetate (6.02).

Orobanche spp. (Broomrapes) are holoparasites that acquire all nutrition and water from their host through root connection. The seeds of *Orobanche* germinates in the soil only when they come in contact with chemical stimulants exuded by its specific host. It has been reported that the roots of host plants of *Orobanche* possess one or more types of chemicals that stimulate seed germination in the field condition.Three different types of compounds (dihydroquinones, sesquiterpene and strigolactone) have been identified as germination stimulants for parasitic plants (Bouwmeester *et al.* 2003). Different germination stimulants such as strigol, strigyl acetate, sogolactone, alectrol and orobanchol were isolated from root exudate of host and non-host plants. These compounds belong to strigolactones groups and are potent stimulants of both *Striga* and *Orobanche* (Bouwmeester *et al.* 2003). Other germination stimulants such as peapolyphenols A-C (Evidente *et al.* 2010), dehydrocostus lactone (Joel *et al.* 2011), or isothyocynates (Auger *et al.* 2012) have been identified. The sitmulant is required at optimum concentration, which if exceeded causes reduced germination (Brown *et al.*1951). The first germination stimulant from sunflower root exudate was identified as dehydrocostus lactone, a sesquiterpene lactone (Frank *et al.* 2013). Besides dehydrocostus lactone, costunolide, tomentosin, and 8-expixanthatin were purified and identified spectroscopically.

It is a general practice of using host root extract or exudation in laboratory study of *Orobanche* seed germination. Very few reports are available regarding the specific work on polarity nature of germination stimulant exuded by host root. Whitney (1979) has reported that the stimulant is soluble in die-ethyl ether but Chabrolin (1938) found that the stimulant is insoluble in organic solvents. Therefore, understanding polarity nature of stimulating chemicals could be a step towards the identification of stimulating chemicals present in the host plants. In this context, root extract of tomato, tobacco and brinjal, which are usual hosts of *O. solmsii*, were prepared by flow-chart method in different solvents of increasing polarity and were, tested in *invitro* germination of seeds of the parasitic species.

Method of preparation of root extract

Root extracts of tomato and brinjal plants were prepared in different solvents in order of hexane®ethylacetate®butanol® water (**Figure 1**).

Similarly, tobacco root extracts were prepared by the same method but using two different orders of

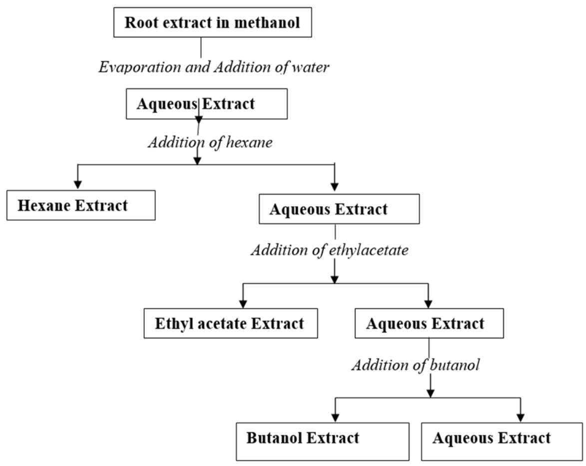


Figure 1. Flow chart showing the method used in the separation of germination stimulants present in the host root extract by different solvents

solvents.

(a) Hexane® benzene ® carbon-tetrachloride ®etylacetate

(b) Ethylacetate® benzene ®carbon-tetrachloride® hexane

Fresh roots of host plants (flowering stages) were taken out from the soil carefully so as to obtain maximum root parts and washed thoroughly with tap water and then with distilled water. Roots were cut into pieces and dried under laminar flow. Root extract was prepared by blending the dried roots with methanol at 1:30 ratio (1g root/30 ml methanol) at 20 ^{0}C. The whole blended mass was shaken for few minutes in a vertical shaker and supernatant methanol fraction was removed. The extract was evaporated to dryness at 20 ^{0}C with the help of aerator. The residue was taken out in 52.5 ml water to get aqueous extract, which was further extracted in different solvent in order of increasing polarities by solvent extraction method as shown in **Figure 1**.

Treatment of *Orobanche* seeds with root extract in different solvents

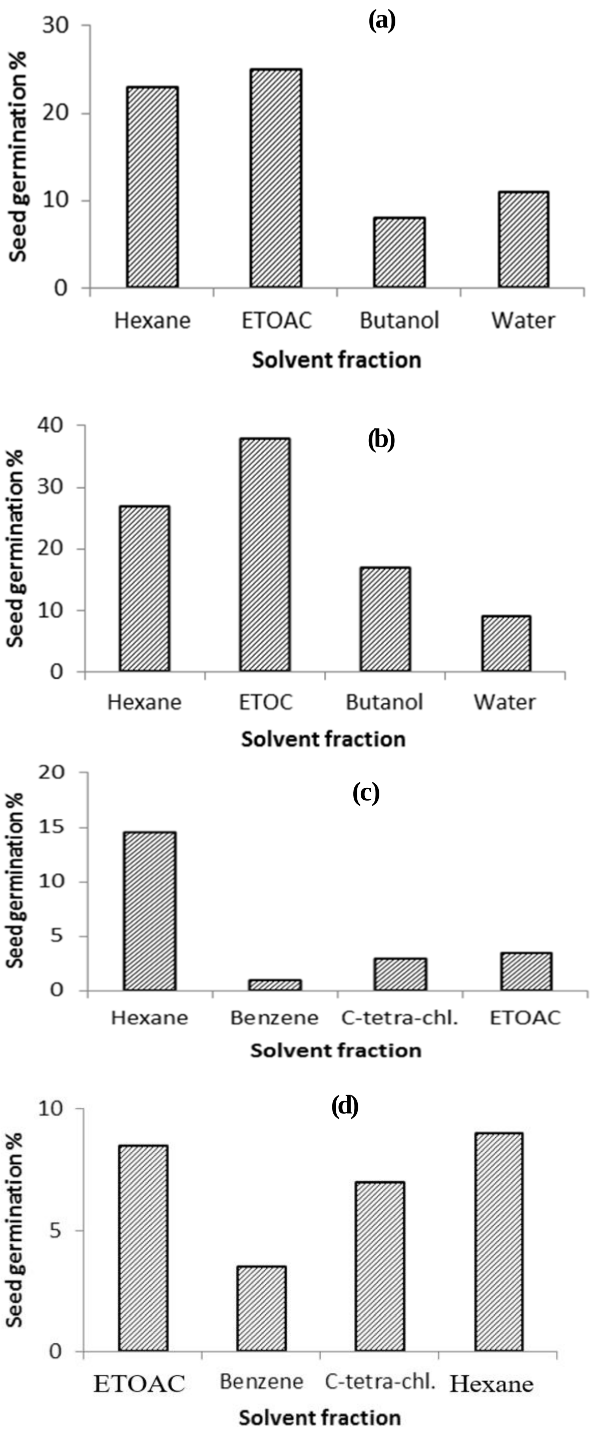
Before preconditioning, the *Orobanche* seeds were sterilized with 1% sodium hypochlorite solution for 5 minutes followed by washing with distilled water and then incubated at 22 ^{0}C for 10 days. Preconditioning was done in small vial and distilled water in the vial was changed regularly at an interval of three days. After preconditioning period, the seeds were post-conditioned with different solvent extract prepared above. The concentration (amount) of the root extract used were 10, 20, 40, 80 µl and control (solvent). Solvent part of the extract was allowed to evaporate completely from GFFP disks before preconditioned seeds were put on the solvent treated disks. Each GFFP disks contained about 40 seeds and moistened with distilled water. All the treatments were replicated five times. The incubation was done at room temperature (25-27 ^{0}C) for 10 days and germinated seeds were counted under binocular microscope.

In the present study, fractions of root extract of tomato in ethyl acetate at 80 µl (24.28%) and hexane at 10 µl (22%) stimulated the highest percentage of seed germination than the fractions in other solvents (**Figure 2a**). It can be inferred that there was a greater amount of ethyl acetate soluble stimulatory chemicals than the hexane soluble stimulatory chemicals in tomato root extract. The different solvent concentrations did not produce marked difference in the percentage of seed germination. In hexane fraction, there was a progressive decrease in percentage of germination with the increase of concentration. The result indicated that lower concentration of hexane fraction contains more stimulatory chemicals than the higher concentration.

In case of brinjal root extract, ethyl acetate induced better germination (38%) at 40 µl and hexane 27% at 80 µl (**Figure2b**). The result supports the former experiment where ethyl acetate gave the highest percentage of seed germination in tomato root extract. The performance of root extract of brinjal was found to be more or less similar to that of tobacco and tomato except that percentages of germination in hexane and ethyl acetate fractions were greater than in the other two host plants. This indicated that brinjal plants contain more stimulatory chemicals per unit root mass.

When tobacco root extract was essayed through different solvents in order of hexane, benzene, carbon tetra chloride and ethyl acetate, root extract in ethyl acetate stimulated higher seed germination than in hexane (**Figure 2c)**. Unlike previous order of solvents, fractions essayed in order of ethyl acetate, benzene, carbon tetra chloride and hexane, it was only ethyl acetate that produced better percentage (14%) of seed germination at 80 µl (**Figure 2d**). This indicated that a solvent of greater polarity, like ethyl acetate could dissolve stimulatory chemicals of lower polarity and, on the other hand, solvent of lower polarity, like hexane could not dissolve stimulatory chemicals of higher polarity. Furthermore, fraction in ethyl acetate induced germination better than the fraction in hexane. It indicated that the root stimulant(s) of tobacco plant is more soluble in ethyl acetate than in hexane and in, another words, ethyl acetate soluble form of stimulant is greater in amount than the hexane soluble form.

Low percentage of *Orobanche* seed germination in root extract fractions of other solvents like,



(The bars in the figure represent mean value of percentage germination in different concentration (µl) of each-solvent tested; ETOAC= ethyl acetate, C-tetra.chl= carbon tetrachloride)

Figure 2. Germination of *O. solmsii* seeds in different solvent fractions of the root extract of (a) tomato (b) brinjal (c) tobacco prepared by using the order hexane-benzene-carbon-tetrachloride-etylacetate (d) tobacco prepared by using the order ethylacetate-benzene-carbon-tetrachloride-hexane

benzene, carbon tetrachloride, di-ethylether, butanol and water was in contrasts with the findings of Sunderland (1960) and Whitney (1979) who found that the stimulants are soluble either in water or in ether.

In the present study, hexane and ethyl acetate fractions of root extracts of tobacco, tomato and brinjal induced germination better than any other solvents tested. This suggests that the stimulatory chemicals exist in more than one form in the host plants and possibly, in two main forms. On this basis, it can be said that the polarity of one form of stimulants matches with that of hexane (1.89) and polarity of another form with that of ethyl acetate (6.02).

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Host plant preference of army worm (*Spodoptera litura*) on crops and weeds

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ABSTRACT

A study was conducted to determine the preference and host range of a polyphagous lepidopteron, *Spodoptera litura*, collected during a search for biocontrol agent of *Trianthema portulacastrum* L. Culture of *S. litura* was maintained on *T. portulacastrum* leaves at 26 ±2 ^{0}C and 70 ±5% RH. The experiment was done using 10 days old larvae of *S. litura* obtained from the laboratory reared nuclears culture. Forty five plant species of crops and weeds belonging to 21 families were used for host preference study. In each replication, 10 larvae were placed on bouquet of various crop and weed plants in well aerated large size containers (2x3x2 ft). Out of the 45 crop and weed plants tested, larvae of *S. litura* showed high, moderate, low and nil preference for 15, 12, 7 and 9 plant species, respectively. Among the crop plants, maximum preference was observed on *Lycopersicon esculentum* Mill., *Spinacea oleracea* L., *Brassica oleracea* L. var. *capitata* and *Trifolium alexandrium* L. Among the 25 weed plants tested, high feeding preference was observed on *Alternanthera philoxeroides* Mart., *Euphorbia hirta* L., *Eichhornia crassipes* Mart., *Trianthema portulacastrum* L., *Parthenium hysterophorus* L., *Cichorium intybus* L., *Rumex obtusifolius* L. *Chenopodium album* L., and *Ipomoea fistulosa* Mart.

Army worm (*Spodoptera litura* Fabricius Lepidoptera: Noctuidae) is a notorious leaf feeding insect of more than one hundred plants around the Asia-Pacific region. It is considered as one of the most destructive insect pests in the region because of its high reproductive rate and heavy losses to crops. Larvae feed gregariously on plant leaves and later eat almost every plant part. The behavior of moving like army from one field to another gave its local name as armyworm in Indo-Pak region (Ahmad *et al*. 2007). Large host range has been considered significant for better chance to survive (Lee *et al*. 2003). Host selection may be associated with primary as well as secondary metabolites present in the plants, which help them to choose preferred hosts due to nutritional variation. Difference in quality or quantity of a satisfactory diet can have a intense effect on insect development (Awmack and Leather 2002). The acceptance of plant species by any insect depends on the specific interaction between host and insect, which includes feeding, digestion and efficiency of conversion of plant biomass into insect biomass. Such quantitative aspect of insect nutrition has been studied by several authors to understand host preference of several insects. Reese (1979) stated that those insects species feeding on less quality food face nutritional hurdles in obtaining sufficient energy. Several authors have studied growth, development and host range of *S. litura* on crop plants (Sharma 1994). However, there are many weed species which act as alternate host to number of insect pests. *Trianthema portulacastrum* is one such a weed on which *S. litura* has been found to feed vigorously. Not much work has been done on weed hosts of this insect. Therefore, a study was undertaken to determine host preference of *S. litura* on weeds along with its crop hosts.

The present study was undertaken during the rainy season of 2008-2009 at ICAR-Directorate of Weed Research, Jabalpur, Madhya Pradesh. A culture of *S. litura* was maintained on *T. portulacastrum* leaves at 26 ±2 ^{0}C temperature and 70 ± 5% relative humidity. The adults were reared in well aerated plastic jars and were provided with *T. portulacastrum* twigs in form of bouquet for egg laying. Cotton swabs soaked in 10% sucrose solution was kept for adult feeding in each jars. The experiment was done using larvae of *S. litura* obtained after the egg laying from the adults in the rearing jars. Forty five plant species of crop and weed species belonging to 21 families were used for host preference study. Ten larvae were placed on each host plants in well aerated containers. All the experiments were replicated thrice. Fresh food material was provided daily until pupation of larvae. The uneaten food along with the fecal matter was removed regularly. The feeding preference was visually monitored and scores were assigned as no feeding (-), low feeding (+), moderate feeding (++) and high feeding (+++).

Weed preference

Among 45 plant species of crops and weeds studied, *S. litura* fed on all the plants except *Oryza sativa* L., *Centrella asiatica* L., *Caesulia axillaris* L., *Sonchus arvensis* L., *Convolvulus arvensis* L., *Cyperus iria* L., *Cynodon dactylon* L., *Sida acuta* Burm. F. and *Lantana camara* L. (**Table 1**). Among the crop plants, maximum feeding was observed on *Lycopersicon esculentum* Mill., *Spinacea oleracea* L., *Chenopodium album* L., *Brassica oleracea* L. var. *capitata* and *Trifolium alexandrium* L. Among the 25

Table 1. Feeding preference of *S. litura* on crop and weed hosts

Common name	Vernacular name in Hindi	Botanical name in English	Family	Plant status	Feeding preference*
Alligator weed	Pani-khutura	*Alternanthera philoxeroides* (Mart.) Griseb.	Amaranthaceae	Weed	+++
Sessile joyweed	Kantewali santhi	*Alternanthera sessilis* L.	Amaranthaceae	Weed	++
Amaranth	Chaulai	*Amaranthus viridis* L.	Amaranthaceae	Cultivated	++
Cauliflower	Phool gobhi	*B. oleracea* L. *var. botrytis*	Brassicaceae	Cultivated	+++
Cabbage	Bandha gobhi	*B. oleracea* L. *var. capitata*	Brassicaceae	Cultivated	+++
False oxtongue	Kukurbanda	*Blumea lacera* DC	Asteraceae	Weed	++
Para grass	-	*Brachiaria mutica* (Forsk.) Stapf.	Gramineae	Weed	++
Rai	Sarson	*Brassica campestris* L. *var sarson*	Brassicaceae	Cultivated	+
Ghrilla	Balonda	*Caesulia axillaris* Robx.	Asteraceae	Weed	-
Pigeon Pea	Arhar	*Cajanus cajan* L.	Fabaceae	Cultivated	+++
Asian pennywort	Brahmi	*Centella asiatica* L.	Apiaceae	Medicinal	-
Goosefoot	Bathua	*Chenopodium album* L.	Chenopodiaceae	Cultivated	+++
Gram	Chana	*Cicer arietinum* L.	Fabaceae	Cultivated	++
Chickory	Kasani	*Cichorium intybus* L.	Asteraceae	Weed	+++
Tropical Spiderwort	Kanteri	*Commelina benghalensis* L.	Commelinaceae	Weed	++
Bindweed	Hiran chara	*Convolvulus arvensis* L.	Convolvulaceae	Weed	-
Podrush	Bagnatho	*Corchorus aestuans* L.	Tiliaceae	Weed	+
Bermuda grass	Dubh	*Cynodon dactylon* L.	Gramineae	Weed	-
Rice foot sedge	Galmotha	*Cyperus iria* L.	Cyperaceae	Weed	-
Waterhyacinth	Jal kumbhi	*Eichhornia crassipes* (Mart.) Solms	Pontederiaceae	Weed	+++
Asthma weed	Dudhi	*Euphorbia hirta* L.	Euphorbiaceae	Weed	+++
Soybean	Soyabean	*Glycine max* L.	Fabaceae	Cultivated	++
Pignut	Wilayati tulsi	*Hyptis suaveolens* L. Point.	Lamiaceae	Weed	+
Morning Glory	Beshram	*Ipomoea fistulosa* Mart.	Convolvulaceae	Weed	+++
Lantana	Makoiya	*Lantana camara* L.	Verbenaceae	Weed	-
Lentil	Masoor	*Lens esculenta* Moench	Fabaceae	Cultivated	++
Linseed	Alsi	*Linum usitatissimum* L.	Linaceae	Cultivated	+
Tomato	Tamaatar	*Lycopersicon esculentum* Mill.	Solanaceae	Cultivated	+++
Medick	-	*Medicago polymorpha* L.	Fabaceae	Weed	+
Paddy	Dhan	*Oryza sativa* L.	Gramineae	Cultivated	-
Carrot grass	Gajar ghas	*Parthenium hysterophorus* L.	Asteraceae	Weed	+++
Wild gooseberry	Pachkotta	*Physalis minima* L.	Solanaceae	Weed	++
Water lettuce	-	*Pistia stratiotes* L.	Araceae	Weed	++
Pea	Matar	*Pisum sativum* L.	Fabaceae	Cultivated	+
Broad-leaved dock	Jungli palak	*Rumex obtusifolius* L.	Polygonaceae	Weed	+++
Common wire weed	Kareta	*Sida acuta* Burm. f.	Malvaceae	Weed	-
Perennial sowthistle	Bhatkataiya	*Sonchus arvensis* L.	Asteraceae	Weed	-
Spinach	Palak	*Spinacia oleracea* L.	Chenopodiaceae	Cultivated	+++
Marigold	Genda	*Tagetes erecta* L.	Asteraceae	Ornamental	+
Horse-purslane	Patharchata	*Trianthema portulacastrum* L.	Aizoaceae	Weed	+++
Coat buttons	Phulani	*Tridax procumbens* L.	Asteraceae	Weed	++
Egyptian clove	Barseem	*Trifolium alexandrium* L.	Fabaceae	fodder	+++
Wheat	Gehoon	*Triticum aestivum* L.	Gramineae	Cultivated	++
Mung bean	Moong	*Vigna radiata* L.	Fabaceae	Cultivated	+
Maize, Corn	Bhutta	*Zea mays* L.	Gramineae	Cultivated	++

*Feeding preference: no feeding (-), low feeding (+), moderate feeding (++), high feeding (+++).

weed plants tested, high feeding was observed on *Alternanthera philoxeroides* Mart., *Euphorbia hirta* L., *Eichhornia crassipes* Mart., *Trianthema portulacastrum* L., *Parthenium hysterophorus* L., *Cichorium intybus* L., *Rumex obtusifolius* L. and *Ipomoea fistulosa* Mart (**Table 1**).

S. litura showed preference towards wide range of hosts plants from no feeding to high voracious feeding. Mandal and Mandal (2000) also reported feeding preference and life cycle of *S. litura* on different crop and weed plant species. They reported good feeding of *S. litura* on *Ricinus communis*, *Solanum nigrum*, *Ipomoea aquatica*, *Amaranthus viridis*, tomato, tobacco, mulberry, brinjal and cabbage. In our experiment, *S. litura* did not feed on *Cynadon dactylon* while Jamjanya and Quinsenberry (1988) reported feeding of *S. litura* on some genotypes of *C. dactylon*. Sushilkumar and Ray (2007) reported high consumption of leaves of eight weed species out of 24 weed plants, among which *Triaanthema portulasactrum, Rumex obtusifolius* and *Cichorium intybus* emerged the best food plant for fast development of *S. litura*. Though the insect is a major crop pest, yet it plays an important role in natural biological control of several noxious weeds. Ahmad *et al.* (2013) during their survey in the cotton belt in Pakistan revealed 27 plant species as host plants of *S. litura* belonging to 25 genera of 14 families including cultivated crops, vegetables, weeds, fruits and ornamental plants. Major host plants on which it thrived for maximum period were *Gossypium hirsutum Ricinus communis, Brassica oleracea* var. *botrytis, Colocasia esculenta, Trianthema portulacastrum* and *Sesbania sesban*.

Survival and feeding of *S. litura* on major weed and crop species necessitates its regular monitoring for its population build-up and for early warning for its management on commercial crops. Preference of this insect pest towards different weed species reflects that though weeds act as alternate hosts for the insects and give chances of their enhanced survival, yet they play important role in suppression of weeds naturally in the field.

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