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Recent advances in mitigation methods for herbicide residues in the soil

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ABSTRACT

In modern agriculture, with more emphasis on high input systems and the widespread application of herbicides has indubitably improved the crop production but has also resulted in inadvertent harm to the ecosystem. The increased awareness towards the adverse effects of herbicide residues on human health and environment resulted in a significant shift towards the mitigation strategies of herbicide residues in the soil as well as in the plants. Several approaches have been found to be utilized for mitigation of herbicide residues in the soil. The hazards from herbicide residues in the soil can be reduced by using low dosage chemicals, tillage operations, crop rotation, using proper nozzle and spraying technique and by using granular, foam, gel and encapsulated materials. Site specific application using variable rate applicator, enhancement of herbicide degradation through bio-stimulation, use of non-phytotoxic oil, adjuvants, surfactants, adsorbents, protectants, antidotes, safeners, biochar, *etc*. are various other effective ways for mitigation of herbicide residues in the soil. Biochar as an amendment to agricultural soils has been found to increase the bioavailable water, builds soil organic matter, enhances nutrient cycling, lowers bulk density, and can provide shelter for beneficial soil microorganisms. Biochar prevents the mobilization of herbicide residues in soil due to its sorption property and hence helps the crop to escape toxicity. Carbon based nano-absorbents such as carbon nanotubes (CNTs) represents a new class of nanomaterial and has been shown to have good potential in removal of various types of herbicide residues in the soil. Graphene is another carbon nanomaterial that has tremendous potential in water purification as well as in various fields due to its unique physical and chemical properties. Nanocrystalline metal oxides such as ferric oxides, manganese oxides, aluminium oxides, titanium oxides, magnesium oxides and cerium oxides are highly effective adsorbents for a broad range of herbicides. These nanocrystalline metal oxides do not only adsorb but also actually annihilate many chemical hazards by converting them to much safer by-products. The amalgamation of bio-augmentation and bio-stimulation along with organic matter addition might be a promising technology for biodegradation of herbicides in soil.

INTRODUCTION

In the modern agriculture, herbicide usage becomes inexorable to obtain large harvests and minimize the yield losses due to weeds. The availability of herbicides as a cheaper option and a rally in farm good prices has led to a sharp increase in herbicide demand within the farming community (Mukherjee 2011). Usage of herbicides occupy 44% of the total agrochemicals globally and 15% in India (Sondhia 2014). The astute use of herbicides provides selective and economical weed control; however, recurrent and non-judicial use may lead to soil residues, phytotoxicity and adverse consequence on subsequent crops, non-targets organisms and environment eventually leading to human peril (Janaki *et al.* 2015). The continuous use of herbicides leads to the problem of soil persistency that causes far reaching environmental consequences. The longer persistence of herbicide in soil poses a hazard to subsequent land use, which is undesirable. The increased awareness towards the adverse effects of herbicide residues on human health and environment caused a significant shift towards the adoption of mitigation strategies of herbicide residues in soil as well as in plants.

Several approaches have been utilized for mitigation of herbicide residues in the soil. The hazards from herbicide residues in the soil can be reduced by using low dosage chemicals. Residue levels exceeding the maximum residue limit (MRL), due to unnecessary high application rates or short pre-harvest intervals (PHIs) are contrary to the concept of good agricultural practices (GAP) and necessitating use of mitigation measures. Tillage operations, soil decontamination, crop rotation, site specific application using variable rate applicator, enhancement of herbicide degradation through bio-stimulation, use of non-phytotoxic oil, adjuvants, surfactants, adsorbents, protectants, antidotes, safeners, biochars, *etc*. are various effective ways for mitigation of herbicide residues in the soil. Biochar as an amendment to agricultural soils has been found to increase the bioavailable water, builds soil organic matter, enhances nutrient cycling, lowers bulk density, and can provide shelter for beneficial soil microorganisms. Carbon based nano-absorbents such as carbon nanotubes (CNTs), graphene, nanocrystalline metal oxides represents a new class of material and have shown good potential in removal of various types of herbicide residues in the soil (Firozjaee *et al.* 2018). The amalgamation of bio-augmentation and bio-stimulation along with organic matter addition are also promising technology for biodegradation of herbicides in soil. Despite these traditional means of herbicide residue mitigation methods, there appears need of more modern cost effective, farmer's friendly and modern approaches of soil residue mitigation strategies. Here, in this review, we discussed the different approaches and methods used for the mitigation of herbicidal residues in the soil.

Management of herbicide residues in soil

An ideal soil applied herbicide should persist long enough to give an acceptable period of weed control but not so long that soil residues after crop harvest limit the nature of subsequent crops (Wagh 2017). Despite the presence of several cultural and mechanical management practices, management of herbicide residues in the soil remains a challenging task. Management techniques, which can help and are in use to minimise the residue hazards in soil are discussed briefly in this review.

Use of optimum dose of herbicide

Expected hazards from herbicide residues can be minimized by the application of herbicide in their lowest effective dose by which the desired weed control is achieved. Application of herbicides in bands will also reduce the total amount of herbicide to be applied. This can be practiced in line-sown crops or crops raised along ridges, such as cotton, sugarcane, sorghum, maize, *etc.* Application of atrazine at the rate of 2.0 kg/ha exhibited more than 90% atrazine degradation on 90th day in the sugarcane grown soil, whereas, the same was achieved in 180 days when the atrazine application rate was 5.0 kg/ha (Shanmugasundram *et al.* 2005). Increase in residue and persistence of herbicides in soil with increase in quantity of application have also been reported for various herbicides (Sondhia 2013, Janaki *et al.* 2015).

Application of farmyard manure

Adsorption of the herbicide molecules in the colloidal fractions of farmyard manure makes (FYM) them unavailable for crops and weed. It is also a well-known effective way to mitigate the residual toxicity of herbicides. FYM enhances the microbial activity, which in turn degrades the herbicide at a faster rate. Reduction in atrazine residue has been observed on application of FYM application (12.5 t/ha) followed by application of compost (12.5 t/ha) and phosphoric acid (50 ppm) (Meena *et al.* 2007). Decrease in residual toxicity of atrazine in soybean on application of farmyard manure at 12.5 t/ha or compost 12.5 t/ha or charcoal 5.0 kg/ha along the seed line has also been reported (Chinnusamy *et al.* 2008).

Ploughing/cultivating the land

Tillage operations help in bringing deep present herbicide residues to the soil surface, which would aid in decontamination by volatilization (Janaki *et al.* 2015, Sondhia *et al.* 2015). Use of disc plough or inter-cultivators reduces the herbicide toxicity, as the applied herbicide is mixed to a large volume of soil and gets diluted. In case of deep ploughing, the herbicide layer is inverted and buried in deeper layers and thereby the residual toxicity got reduced. The comparative study on the effect of conventional tillage and no-tillage exhibited faster herbicide degradation on the surface layers in conventional tillage (Gaston and Locke 2000). Study on atrazine behavior in soil exhibited faster herbicide degradation in deeper soils than surface layers (Hang *et al.* 2010).

Crop rotation

Crop rotation is among another herbicide residue management practices that spreads the planting and herbicide application season, reducing the risk of encountering widespread herbicide runoff during a single runoff event. Ragi–cotton–sorghum is the common example of crop rotation under irrigated field conditions. Fluchloralin 0.9 kg or butachlor 0.75

kg/ha + hand weeding at 35 DAT for ragi + sunflower (border crop), pendimethalin 1.0 kg/ha + hand weeding on 35 DAS for cotton intercropped with onion and two manual weeding at 15 and 35 DAS for sorghum inter cropped with cowpea is the recommended weed control practice (Wagh 2017). Rape seed and sugar beet being sensitive to imidazolinones (imazamox + imazethapyr) must be avoided in rotation as a succeeding crop when the previous crop was applied with these herbicides, however, maize, winter wheat and barley can be used for crop rotation (Suzer and Byuk 2010). Maize and millets can be used for crop rotation in the soils containing triazine residues, whereas crops like, methi, turnip, berseem and gobhi-sarson can be grown in the soil having sulfosulfuron residue (Singh and Walia 2005).

Use of activated carbon

Activated carbon has a high adsorptive capacity because of its tremendous surface area which vary from 600–1200 m^2/g. Incorporation of 50 kg/ha of activated charcoal is found to inactivate chlorsulfuron when applied at 1.25 and 2.50 kg/ha and did not affect the yield of maize when compared to untreated control. A study conducted on charcoal application at 5.0 kg/ha along the seed line have shown reduced residual toxicity of atrazine in the soybean crop (Wagh 2017).

Light irrigation after application

Continuous moist soils often result in a more rapid degradation of herbicides due to creation of favorable conditions for microbial activity. However, controlled irrigations enhance all modes of deactivation, heavy irrigations leach herbicides out of the root zone of the crop. Leaching of the herbicides by frequent irrigation is possible especially in case of water-soluble herbicides. In this case, the herbicides are leached down to lower layers *i.e.,* beyond the reach of the crop roots. Studies have shown that dissipation of metolachlor and formation of soil bound residues are favoured in saturated soils (Rice *et al.* 2002). Lovell *et al.* (2002) reported faster isoxaflutole degradation in soil maintained at -100 or -1500 kPa as compared to that in air-dry soil.

Modern approaches for mitigation of soil herbicide residue

Biostimulation

Biostimulation involves the modification of the environment to stimulate existing bacteria capable of bioremediation. This can be done by addition of various forms of limiting nutrients and electron acceptors, such as phosphorus, nitrogen, oxygen, or carbon (Scow and Hicks 2005). Biostimulation can be perceived by addition of adequate amounts of water, nutrients and oxygen into the soil, in order to enhance the activity of indigenous microbial degraders (Couto *et al.* 2010) or to promote cometabolism (Lorenzo 2008). Biostimulation requires modification of a contaminated soil to provide a natural microbial population with a favorable environment that will allow them to destroy the target contaminant. Biostimulation is mostly preferred due to its stimulation and growth of natural microbes, which are already used to the subsurface environment.

The concept of biostimulation is to boost the inherent degradation potential of a polluted matrix through the accumulation of amendments, nutrients, or other limiting factors and has been used for a wide variety of xenobiotics (**Table 1**). Even though the diversity of natural microbial populations apparently displays the potential for contaminant remediation at polluted sites, factors such as lack of electron acceptors or donors, low nitrogen or phosphorus

Table 1. Use of various amendments for the enhanced degradation of herbicides

Amendment	Target herbicide	Reference
Animal manure and sewage sludge	Atrazine and alachlor	Guo *et al.* (1991)
Activated sludge	Atrazine and simazine	Leoni *et al.* (1992)
Sewage sludge and corn meal	Alachlor and trifluralin	Dzantor *et al.* (1993)
Maize straw	Methabenzthiazuron	Printz *et al.* (1995)
Dairy manure	Atrazine	Gan *et al.* (1996)
Cornmeal, rye grass, and poultry litter	Cyanazine and fluometuron	Wagner and Zablotowicz (1997)
Plant residues, ground seed, or commercial meal	Alachlor, metolachlor, atrazine and trifluralin	Felsot and Dzantor (1997)
Cellulose, straw, and compost	Atrazine	Abdelhafid *et al.* (2000)
Compost, corn stalks, corn fermentation by-product, peat, manure, and sawdust	Atrazine, trifluralin, and metolachlor	Moorman *et al.* (2001)
Raw olive cake	Chlorsulfuron, prosulfuron, and bensulfuron	Delgado-Moreno and Peña (2007)
Biogas slurry, mushroom spent compost, and farm yard manure	Atrazine	Kadian *et al.* (2008)
Rice straw, farm yard manure, saw dust, and charcoal	Atrazine	Mukherjee (2009)

availability, or a lack of stimulation of the metabolic pathways responsible for degradation can inhibit or delay the remediation process. In these cases, accumulation of exogenous nutrients can enhance the degradation of the toxic materials (Kadian *et al.* 2008).

The biostimulation of herbicide degradation in the soil was conceptualized by "land farming techniques," which involves dilution of contaminated soil with uncontaminated soil leading to stimulation of the biodegradation due to the increased activity of soil dehydrogenases (Felsot and Dzantor 1997). Biostimulation requires modification of a contaminated soil to provide a natural microbial population with a favourable environment that will allow them to destroy the target contaminant. Biostimulation is mostly preferred due to its stimulation and growth of natural microbes which are already used to the subsurface environment. The lack of adequate organic matter in the soil generally lead to low microbial population and hence lower decomposition of herbicides (Felsot and Dzantor 1990) leaving the herbicides recalcitrant in the soil for years without degradation.

The addition of organic matter, bioprocessed materials or compost naturally initiates the microbial activity in the soil and could be utilized to treat contaminated soils (Buyuksonmez *et al.* 1999). Fresh bioprocessed materials serve as rich nutrient source and provide an optimum condition for flourishing the microbial growth (Kadian *et al.* 2008). Additions of inorganic nutrients have been reported to facilitate the breakdown of atrazine in the soil (Hance 1973). The addition of inorganic salts like ammonium nitrate, potassium nitrate, and ammonium phosphate have been found to significantly decrease the half-life of herbicides in the soil. Inorganic nitrogen starvation has also found to be more effective in promoting degradation of atrazine and other heterocyclic compounds (Sims 2006). This can potentially be accomplished by supplying excess carbon to make nitrogen limiting.

Bioaugmentation

Bioaugmentation is the process of introduction of specific microorganisms aiming to accelerate the biodegradation of target compound or serving as donors of the catabolic genes. Usually this goes in pair with the biostimulation (Kanissery and Sims 2011). If appropriate biodegrading microorganisms are not present in the soil, or if microbial populations have been reduced because of contaminant toxicity, specific microorganisms can be added as "introduced organisms" to enhance the existing populations. Microorganisms help in degradation of the herbicide compounds in the soil by utilizing them as a supply of nutrients and energy. Hence, increasing the population of herbicide degrading, pure culture bacteria by artificial means may be helpful in enhancement of herbicides in the soil. Mixture of pure cultures of microbial population have been found to be effective in enhanced metabolism of atrazine (Mandelbaum *et al.* 1993) with the repeated transfer of the mixed cultures even at the elevated concentrations. *Rhizopus oryzea* is a potential fungal isolate and can be used for the bioremediation of alachlor from soil and the half-life values in sterile and non-sterile soil incubated with *Rhizopus oryzea* were found to be 7.2 and 8.6 days, respectively (Jaya *et al.* 2014).

Use of biochar

Adsorption using commercially available activated charcoal can reduce organic pollutants in soils (Rhodes *et al.* 2008) but is an expensive means due to the use of non-renewable and relatively expensive starting material, such as coal. This resulted in increased interest in using biochar as a soil amendment to sequester carbon to mitigate the herbicide residues in the soil. However, the insinuations of adding biochar to the agricultural soil for the environmental fate of pesticides remain unclear. Experimental evidences reveal that application of biochar as an amendment to agricultural soils increases bioavailable water, builds soil organic matter, enhances nutrient cycling, lowers bulk density, and can provide refugia for beneficial soil microorganisms, such us bacteria and mycorrhizal fungi (Atkinson *et al.* 2010). Application of biochar temporarily immobilizes the herbicide residues in the soil and allows the crop to escape from toxicity. The source of material used for biochar production also affects the sorption of herbicide residues in the soil. Cabrera and Spokas (2011) demonstrated that biochar additions, even in small quantity, increased diuron sorption. Thus, the presence of carbonaceous material, even in small amounts, can dominate sorption of organic compounds in the soils (Cornelissen *et al.* 2005). Soils amended with 1% and 2% biochar showed enhanced sorption, slower desorption, and reduced biodegradation of isoproturon (Sopeña *et al.* 2012).

Nanotechnological interventions

Nowadays, the entry of residues in the food chain has raised serious concerns related to health issues. Nanotechnology offers many potential benefits to improve existing environmental technologies using new materials with effective performance that resulting to less consumption of energy and materials. Due to its beneficial effects, researchers and industrial communities also gained much interest in nanotechnology**.** Nanotechnology intervention utilizes the structures and devices with a size range from 1 nm (molecular scale) to about 100 nm (Riu *et al.* 2006). A number of nanotechnological interventions such as carbon-based nanotubes (CNT's), graphene, nanocrystalline metal oxides *etc.* are becoming popular in terms of herbicide residue mitigation (Iavicoli *et al.* 2017).

Carbon nanotubes (CNTs)

Carbon nanotubes represent a novel class of nanomaterials. They are generally composed of graphite carbons arranged in one or several concentric tubules. CNT's may be single walled nanotubes (SWNTs) as well as multi-walled nanotubes (MWNTs) and possess one dimensional structure, thermal stability and unique chemical properties (Firozjaee *et al.* 2018) and have shown tremendous potential in removal of several types of herbicides. The adsorption capacity of herbicides by CNTs is mainly determined by the pore structure and the existence of a broad spectrum of surface functional groups that can be achieved by chemical or thermal modifications to improve the optimal performance for a particular purpose (Yunus *et al.* 2012). The adsorption of organic chemicals on CNTs may involve several mechanisms, such as hydrophobic interactions, covalent bonding, $\pi - \pi$ interactions, hydrogen bonding and electrostatic interactions. Organic molecules containing double bonds or benzene rings such as polycyclic aromatic hydrocarbons (PAHs) and polar aromatic compounds adsorb on CNT through $\pi - \pi$ interaction (Smith and Rodrigues 2015). Adsorption process may also involve hydrogen bonding between functional groups such as –carboxyl, hydroxyl, amino group and organic molecules (Yang *et al*. 2008). Electrostatic attraction is one of the adsorption mechanisms that causes the adsorption of some organic chemicals such as antibiotics and dyes at suitable pH on the functionalized- CNTs. Functional groups increases the hydrophilicity of the CNTs surfaces and make them suitable for sorption of relatively low molecular weight and polar compounds. Multiwalled nanotubules have been investigated for the adsorption of diuron and dichlobenil (Chen *et al.* 2011) and the results indicated an increased absorption of diuron and dichlobenil with an increase in surface area and total pore volume of MWNTs.

The values of adsorbed amount and surface coverage of diuron were larger than those of dichlobenil, while the surface area, molecular volume, and water solubility of dichlobenil were smaller. The adsorption of atrazine by surfactant-dispersed SWNTs and MWNTs demonstrated that surfactant treatment inhibited atrazine adsorption (Shi *et al.* 2010). The hydrophilic fraction of the surfactant micelles faces in water cause the modified-CNTs to become more hydrophilic, which reduced the adsorption of atrazine significantly. Oxidation treatment on MWCNTs increases the surface area and pore volume of the tubes and subsequently and increase in diuron adsorption in spontaneous and exothermic manner (Deng *et al.* 2012). SWCNTs have been reported to have a higher adsorption capacity for 4-chloro-2-methylphenoxyacetic acid (MCPA), a phenoxy acid herbicide (De Martino *et al.* 2012).

Graphene

Graphene is a carbon nanomaterial that has attracted remarkable attention due to its unique physico- chemical properties and its vital use in water purification. The effective interaction between graphene and pesticides is mediated by polar nature of water (Maliyekkal *et al.* 2012). Graphene has great adsorption capacities for pesticides (ranging from 600 to 2000 mg/g). Graphene has also been used for removal of persistent halocarbon pesticides from water (Sengupta *et al.* 2015). Graphene and related carbon-based nanomaterials can adsorb contaminants with aromatic rings through $\pi - \pi$ interactions (Smith and Rodrigues 2015). Graphene can combine with other materials to improve pesticide adsorption capacity (Zhang *et al.* 2015). Graphene-coated silica (GCS) as a highly efficient sorbent has also been used for removal of residual organophosphorus pesticides from water (Zhang *et al.* 2015).

Nanocrystalline metal oxides

Nanocrystalline metal oxides are highly effective adsorbents for a broad range of herbicides. Metal oxides such as ferric oxides, manganese oxides, aluminium oxides, titanium oxides, magnesium oxides and cerium oxides are effective and low-cost adsorbents. These metal oxides are used for removal of a broad range of pesticides due to their higher adsorption capacity, faster kinetics, shorter intra-particle diffusion distance and larger number of surface reaction sites (Armaghan and Amini 2012, Moradi Dehaghi *et al.* 2014). Nanocrystalline metal oxides not only adsorb but also degrade the chemical hazards by converting them to much safer by-products under a broad range of temperatures. Their large surface areas and high remedial activities are caused by the size quantization effect. Studies on the removal of organophosphorus pesticides by nano metal oxides revealed that although nano sized metal oxides are effective destructive absorbents for organophosphorus pesticides, production of high-quality fine oxide powders is a relatively difficult task and can be costly.

Herbicide removal using magnetic nanoparticles revealed that the surface modified magnetic core–shell nanoparticles exhibit high adsorption efficiency and high rate of removal of contaminants (Kaur *et al.* 2014). C_{18} fabricated Fe_3O_4 core–shell nanoparticle is the most commonly used magnetic nanoparticle for removal of pesticides. They are suitable for extraction of nonpolar and moderately polar compounds due to their suitable separation ability, excellent stability, and convenient operation. C_{18}-silane modification of Fe_3O_4-C_{18} magnetic particles resulted in hydroxylation as well as adsorption of C_{18} groups on the surface of the magnetite because of adsorption of both hydrophilic and hydrophobic compounds. Organophosphorus pesticides were absorbed by Fe_3O_4-C18 by a magnetic field (Shen *et al.* 2007). Nanocrystalline alumina particles have been used for effective adsorption of organophosphate in a short period of time. The faster adsorption may be attributed to high surface area and the concentration of hydroxyl groups on the surface of nanocrystalline alumina. A list of nanocrystalline metal oxides with their adsorption parameters for pesticide removal is summarized in **Table 2**.

Nanofiltration

The nanofiltration (NF) membrane is a type of pressure-driven membrane with properties between reverse osmosis and ultrafiltration membranes and is considered the most effective recent technique of membrane filtration. It is a promising technology to remove hazardous organic micro-pollutants, such as pesticides, dyes, and many other synthesized products. Specific nanofiltration membranes of specific pore size can be used for different molecules based on their molecular weight. The adsorption characteristics of organic matter on membrane surfaces are governed by the physical and chemical properties of the membrane, pesticides properties, feed water composition and filtration system operating parameters. The physical and chemical properties of the membrane selected are an important factor for the removal of herbicides. NF70, NF45, UTC-20 and UTC-60 are some nanofiltration membranes used for herbicide/pesticide rejection (Bruggen *et al.* 2001). The major parameters that affect the filtration capacity of membrane are molecular weight cut-off (MWCO), desalting degree, porosity and the membrane material. The molecular weight cut-off (MWCO) of 90% is commonly used by most membrane manufacturers as a measure of the retention properties of NF membranes (Singh 2005). The rejection of uncharged herbicide molecules was positively correlated with membrane porosity parameters.

Photocatalysis

Photocatalysis is an environmentally friendly process used for elimination of a number of organic pollutants and is quite suitable pre-treatment for hazardous and non-biodegradable contaminants to enhance their biodegradability. Photocatalysis can also be used as a polishing step to treat recalcitrant organic compounds (De Lasa and Serrano-Rosales 2009). In a photocatalysis process, photoexcitation of semiconductor solid surfaces happens by irradiation, either by near UV or solar light. As a result, mobile electrons and positive surface charges are generated. These excited sites and electrons accelerate oxidation and reduction of pollutants. Through the development of nanotechnology, semiconductor photocatalysts have been modified in terms of reactivity and selectivity. Based on this principle, a wide range of pesticides has been treated by photocatalytic degradation (**Table 3**).

Table 2. Nanocrystalline metal oxides commonly used for adsorption of different pesticides

Nanocrystalline metal oxides	Modifier	Target pesticide class or pesticide	Reference
Fe_3O_4	Polystyrene	Organochlorine	Cheng 2013
Fe_3O_4	C18	Organophosphorus	Shen *et al.* 2007
Fe_3O_4	Hexagonal Mesoporous silica (HMS)	DDT	Tian *et al.* 2009
Al_2O_3 and MgO	Activated carbon	Diazinon	Behnam *et al.* 2013
Al_2O_3	Cerium Oxide	Dimethyl methyl phosphonate	Mitchell *et al.* 2004
Al_2O_3	—	Diazinon and Fenitrothion	Armaghan and Amini (2012)
LFCOs NPs	—	Vitavax	Tavakkoli and Yazdanbakhsh (2013)
Zinc oxide	Chitosan	Permethrin	Moradi Dehaghi *et al.* 2014

Table 3. Degradation of pesticides by photocatalysts

Photocatalyst	Modifier	Target pesticide	Reference
ZnO	$Na_2S_2O_8$	Azoxystrobin, kresoxim-methyl, hexaconazole, tebuconazole, triadimenol, and pyrimethanil (fungicides), primicarb (insecticide), and propyzamide (herbicide)	Navarro *et al.* (2009)
TiO_2	Ag	Organochlorine pesticides (α-hexachlorobenzene (BHC) and dicofol)	Guo *et al.* (2009)
TiO_2	C, N and S	Isoproturon	Police *et al.* (2010)
TiO_2	N	Lindane	Senthilnathan and Philip (2010)
TiO_2	Au–Pd	Malathion	Yu *et al.* (2010)
TiO_2	V, Mo, Th	Chlorpyrifos	Gomathi *et al.* (2011)
TiO_2	$CdSO_4$	Methomyl	Barakat *et al.* (2013)

Conclusion

Extensive use of herbicides poses far-reaching consequences and there is an essential need for efficient technologies for mitigation of residues. Integration of the mechanical and cultural management practices with herbicides for managing weeds is the most viable option. The combination of bioaugmentation and biostimulation along with organic matter addition might be a promising technology to accelerate the biodegradation of herbicides in the soil. Present researches have shown significant potential for pesticides removal using the different processes of nanotechnology. Although it needs to be studied further on large-scale application of nanotechnology process to eliminate pesticide and other pollutants associated with the investigation on potential risks of nanomaterials for environmental and human health.

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Chemical and non-chemical weed management effects on weed spectrum, yield and economics of direct-seeded rice in North-Western zone of Tamil Nadu

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Bispyribac-sodium, Cono-weeder, Direct-seeded rice, Mechanical weeding, Weed control efficiency

ABSTRACT

Field experiments were conducted to study the chemical and non-chemical weed management on weed spectrum, yield and economics of direct-seeded rice (DSR) under lowland irrigated condition at Regional Research Station, Tamil Nadu Agricultural University, Paiyur, Tamil Nadu, India in wet and dry seasons of 2013-14 and 2014-15. The results revealed that application of pyrazosulfuron-ethyl 10% WP at 20 g/ha at 3 DAS *fb* mechanical weeding with cono-weeder at 25 DAS recorded higher weed control efficiency (WCE) of 94% and higher grain yield of 6.45 t/ha, gross income of ₹ 82669/-, net income of ₹ 48767/- with the benefit : cost ratio of 2.45. It recorded 56% higher grain yield over weedy check and 14% higher yield over pyrazosulfuron-ethyl. Hence, pre-emergence application (3 DAS) of pyrazosulfuron-ethyl 10% WP at 20 g/ha followed by mechanical (cono-weeder) at 25 DAS was effective for weed management in DSR.

INTRODUCTION

Weeds have been reported to reduce the yield by 50-60% in direct-seeded rice (Naresh *et al.* 2011). DSR is an eco-friendly water and energy (labour) saving technology under the present resources scarcity scenario (Mallikarjun *et al.* 2014 and Choudhary and Dixit 2018). To overcome the problems of human labours involved in nursery preparation and transplanting operations, researchers as well as farmers are looking at direct-wet seeding options for rice establishments. Direct-wet seeding of rice (WSR) through drum seeder offers the advantages of eliminates the nursery raising and transplanting operations, faster and easier planting, reduces labour requirement, hastens crop maturity and increase water use efficiency, thus 25% (250-300 man hours) of total human labour involved in rice cultivation were reduced making rice cultivation more profitable (Kachro and Bazaya 2011).

Rice crop sown through drum seeding technique by using sprouted seeds on puddled soil is associated with the problem of profuse growth heterogeneous weed flora. It becomes the biggest biological constraint because uncontrolled weeds in direct-seeded rice can reduce yields to the tune of 53% (Naresh *et al.* 2011) and losses were reported even up to 90% (Bhat *et al.* 2011). The yield loss due to weeds varied from 40 to 100% in direct-seeded rice (Choubey *et al.* 2001). The weed flora of WSR is entirely different from that of transplanted crop due to maintenance of saturation moisture at sowing and shallow depths of water up to 3 weeks after sowing. As weeds emerge almost at the same time as that of the crop in WSR and weed competition with rice crop is greater, hence weed management by herbicide is more crucial (Singh and Singh 2010). Hence, present investigation was carried out to study the chemical and non-chemical weed management to manage the weeds in direct WSR.

MATERIALS AND METHODS

Field experiments were conducted to study the effect of chemical and non- chemical weed control in direct (drum)-seeded rice under lowland irrigated condition at Regional Research Station, Tamil Nadu Agricultural University, Paiyur Tamil Nadu India in wet and dry seasons of 2013-14 and 2014-15, respectively in a randomized block design with three replications. The treatments constituted pre- and post-emergence application of pyrazosulfuron-ethyl 10% WP at 20 g/ha on 3 DAS and bispyribac sodium

10% EC 25 g/ha on 20 DAS, respectively and in combination with mechanical weeding (cono-weeder) at 10 and 25 DAS. Hand weeding at 15 and 30 DAS and in combination with mechanical weeding at 10 and 30 DAS along with weedy check. The eight row drum seeder (20 cm line spacing) was used.

The soil was sandy loam in texture with pH 8.1. The available N, P and K were 175, 25 and 235 kg/ha with organic carbon of 0.5%. The recommended fertilizer at 150: 50: 50 kg N, P and K/ha were applied as urea (46% N), single super phosphate (16% P) and muriate of potash (60% K). The full dose of phosphorus was applied as basal at the time of sowing. Nitrogen and potassium was applied in four equal splits, *viz*. basal, active tillering, panicle initiation and flowering stages. Pre-germinated seed of rice variety '*ADT 39*' at 25 k g/ha was used for direct seeding of rice. Pre- and post-emergence herbicides were applied with the help of a sand mixture and hand-operated knapsack sprayer fitted with flat-fan nozzle respectively and water as a carrier at 600 liters/ha for post-emergent herbicide application. Observations on weed population and weed dry matter were recorded with the help of a quadrate 1 × 1 m placed randomly at two spots in each plot at 30 and 60 DAS and expressed in number per meter square (no./m^2) and gram per meter square (g/m^2), respectively. The data was subjected to square root transformation ($\sqrt{x+1}$) to normalize their distribution and statistical analysis was done. Weed control efficiency (WCE) was calculated. Yield parameter like panicle (no./m^2), panicle length (cm), grains (no./panicle) and unfilled grains (no./panicle) were calculated from the individual plots and converted to kg per hectare.

RESULTS AND DISCUSSION

Weed flora of the experimental field

The dominant weed flora of the experimental fields are *Echinochola colona* (L.) among the grasses, *Cyperus difformis* (L.) among the sedges and *Ammannia baccifera* (L.), *Bergia capensis* (L.), *Marsilia quadrifolia* (L.), *Eclipta alba* (L.) Hassk. among the broad-leaved weeds.

The total weed count was recorded at 30 and 60 DAS. The weed samples were dried and dry weight was recorded for individual treatments. Based on dry weight the WCE was worked out for all treatments **(Table 1)**.

Among the treatments, application of pyrazosulfuron-ethyl 10% WP at 20 g/ha at 3 DAS *fb* cono-weeding at 25 DAS recorded the lowest weed number of 113.3/m^2 to 168.6/m^2 and 101/ m^2 to 86/m^2 at 30 and 60 DAS during 2014 and 2015, respectively, which was significantly lower than the other treatments. This was followed by the cono-weeding on 10 and 25 DAS, which recorded the total weed count of 380.3 to 169.6/m^2 and 111 to 100/m^2 at 30 and 60 DAS during 2014 and 2015, respectively. The higher weed counts of 2169.6 and 1266 /m^2 and 1808 and 1049/m^2 at 30 and 60 DAS were recorded during 2014 and 2015, respectively in weedy check. Application of pyrazosulfuron-ethyl 10% WP at 20 g/ha on 3 DAS *fb* cono-weeding on 25 DAS recorded higher WCE of 85.8 to 70.7% and 94 to 96.5% at 30 and 60 DAS during 2014 and 2015, respectively. Application of bispyribac-sodium 10% EC 25 g/ha recorded lower WCE of 53.8 to 8.7% and 64% at 30 and 60 DAS during 2014 and 2015, respectively. The weed density and weed dry weight data indicated the application of pyrazosulfuron-ethyl 10% WP 20 g/ha at3 DAS *fb* cono-weeding at 25 DAS effectively controlled the grasses and broad-leaved weeds and suppressed the sedges followed by cono-weeding. The cono-weeding incorporates the weeds in puddle soil and enriches the nutrient content of soil and supply the nutrient to the crop plants. This finding was also supported by Pal *et al.* (2012). Chopra and Chopra (2003) also found that pyrazosulfuron-ethyl at 20 and 25 g/ha significantly reduced weed density and total weed biomass of *Cyperus iria* (L.), *Echinochloa colona* (L.).

Among the weed control treatments, application of pyrazosulfuron-ethyl 10% WP 20 g/ha at 3 DAS *fb* cono-weeding at 25 DAS recorded the lowest weed dry weight of 9.03 to 29.49 g/m^2 and 4.2 to 12.5 g/m^2 at 30 and 60 DAS during 2014 and 2015, respectively, which was significantly superior over other treatments. This was followed by the cono-weeding on 10 and 25 DAS, which recorded the total weed dry weight of 13.74 to 38.34 g/m^2 and 9.4 to 19.9 g/m^2 at 30 and 60 DAS during 2014 and 2015, respectively. The higher weed dry weight of 63.93 to 100.76 g/m^2 and 61.2 to 360.7 g/m^2 at 30 and 60 DAS during 2014 and 2015, respectively were recorded in weedy check followed by application of bispyribac sodium 10% EC 25 g/ha at 20 DAS recorded higher weed dry weight of 29.49 to 91.91 and 32.1 to 74.6 g/m^2 at 30 and 60 DAS during 2014 and 2015, respectively. Application of pyrazosulfuron-ethyl at 15 g/ha was effective to lower the weed density and weed biomass and not having any phyto-toxicity to the rice plant (Angirs and Kumar 2005, Acharya and Bhattachrya 2013). Choudhary and Dixit (2018) indicated that adoption of pyrazosulfuron *fb* pretilachlor have effective control of wide spectrum weeds.

Growth characteristics

Application of pyrazosulfuron-ethyl 10% WP at 20 g/ha at 3 DAS *fb* cono-weeding on 25 DAS recorded the higher plant height of 48.8 to 92.2 cm during 2014 and 2015, respectively. This was followed cono-weeding at 10 and 25 DAS, it recorded the plant height of 48.4 to 91.9 cm during 2014 and 2015, respectively. The lower plant heights of 46.7 to 87.7 cm were recorded in weedy check. This treatment also recorded the higher panicle length of 25.8 cm. The lower panicle length of 23.3 cm was recorded in weedy check **(Table 2)**.

Yield and yield attributes

Application of pyrazosulfuron-ethyl 10% WP at 20 g/ha on 3 DAS *fb* cono-weeding at 25 DAS recorded the higher panicles (440.6 and 493.7 no./m^2), grains (167.2 and 183.1 no./panicle) and 1000 grain weight (16.2 and 16.9 g) during 2014 and 2015, respectively. This was followed by cono-weeding at 10 and 25 DAS and it recorded the panicle (410.3 and 477 no./m^2), grains (166.3 and 177 no./panicle) and 1000 grain weight (15.6 and 16.7 g) during 2014 and 2015, respectively. The minimum number of panicle (260.8 and 272 no./m^2), grains (120.5 and 146 no./panicle) and 1000 grain weight (14.9 and 15.9 g) during 2014 and 2015, respectively were recorded in weedy check (**Table 3**).

Application of pyrazosulfuron-ethyl at 20 g/ha at 3 DAS *fb* cono- weeding on 25 DAS recorded the higher grain yield of 6.25 and 6.38 t/ha during 2014 and 2015, respectively. This treatment recorded 69% higher grain yield over weedy check and 11% higher yield over pyrazosulfuron-ethyl at 20 g/ha. The cono-weeding at 10 and 25 DAS recorded the grain yield of 6.10 and 6.29 t/ha during 2014 and 2015,

Table 1. Effect of different weed control treatments on no. of weeds, weed dry weight and WCE in direct-seeded rice

Treatment	30 DAS						60 DAS					
	Total weed (no./m^2)		Total weed dry weight (g/m^2)		WCE (%)		Total weed (no./m^2)		Total weed dry weight (g/m^2)		WCE (%)	
	2014	2015	2014	2015	2014	2015	2014	2015	2014	2015	2014	2015
Pyrazosulfuron-ethyl 10% WP at 20 g/ha	26.2	25.1	4.7	4.5	66.2	64.3	26.7	18.0	9.4	7.6	12.9	83.0
	(688)	(644)	(216)	(19.2)			(715)	(365)	(87.7)	(59.6)		
Bispyribac-sodium 10% EC 25 g/ha	26.4	25.4	5.5	5.7	53.8	64.3	27.2	17.9	9.6	7.5	8.7	79.3
	(698)	(644)	(29.5)	(31.2)			(737)	(412)	(91.9)	(74.6)		
Cono-weeder on 10 and 25 DAS	19.5	10.6	3.8	3.2	78.5	93.8	13.1	10.0	6.3	4.4	61.9	94.5
	(380)	(111)	(13.7)	(9.4)			(170)	(101)	(38.3)	(19.9)		
Pyrazosulfuron-ethyl 20 g/ha *fb*	20.0	11.0	3.9	3.7	77.4	91.6	15.2	11.4	6.8	5.2	54.4	92.3
bispyribac sodium 25 g/ha at 20 DAS	(400)	(120)	(14.4)	(12.5)			(230)	(129)	(45.9)	(27.5)		
Pyrazosulfuron-ethyl at 20 g /ha *fb* Cono-	10.7	10.1	3.2	2.3	85.8	94.3	13.0	9.2	5.5	3.5	70.7	96.5
weeder on 25 DAS	(113)	(102)	(9.0)	(4.2)			(169)	(86)	(29.5)	(12.5)		
Cono-weeder on 10 DAS *fb* bispyribac-	21.4	11.6	4.1	3.8	74.5	92.6	20.1	10.9	7.6	4.2	43.8	94.7
sodium 25 g/ha at 20 DAS	(457)	(133)	(16.3)	(13.7)			(402)	(127)	(56.6)	(19.1)		
Hand weeding on 15 and 30 DAS	20.2	11.1	4.0	3.6	76.0	93.3	18.1	11.5	7.3	4.4	47.5	94.4
	(408)	(121)	(15.3)	(12.1)			(328)	(132)	(52.9)	(19.9)		
Hand weeding on 15 DAS *fb* cono-weeder	22.5	13.3	4.6	4.2	68.8	90.3	23.7	11.4	9.1	5.5	16.9	90.9
on 25 DAS	(503)	(175)	(19.9)	(16.9)			(561)	(131)	(83.7)	(32.6)		
Cono-weeder on 10 DAS *fb* hand weeding	21.6	12.3	4.3	3.8	72.4	91.6	20.3	11.7	9.1	5.6	17.7	89.9
on 30 DAS	(466)	(150)	(17.6)	(13.7)			(412)	(136)	(82.9)	(36.4)		
Weedy check	46.6	42.5	8.0	7.8	-	-	35.6	32.3	10.1	18.9	-	-
	(2170)	(1808)	(63.9)	(61.2)			(1266)	(1049)	(100)	(361)		
LSD (p=0.05)	3.59	3.5	0.66	0.59	-	-	2.55	7.2	1.13	2.7	-	-

Figures in parentheses are original values (analysis by $(\sqrt{x+1})$ transformations)

Table 2. Effect of different weed control treatments on growth characters of direct-seeded rice

Treatment	Plant height (cm)						Panicle length (cm)		Unfilled grain (no./panicle)	
	60 DAS		90 DAS		At harvest					
	2014	2015	2014	2015	2014	2015	2014	2015	2014	2015
Pyrazosulfuron-ethyl at 20 g/ha	49.9	46.8	73.5	64.9	75.9	89.9	21.4	23.9	21.0	33.7
Bispyribac-sodium 25 g/ha	48.6	46.7	73.5	65.5	75.0	90.3	21.3	23.9	22.8	35.2
Cono-weeder on 10 and 25 DAS	53.3	48.4	77.2	69.3	78.3	91.9	22.4	24.7	16.1	23.9
Pyrazosulfuron-ethyl 20 g/ha *fb* bispyribac-sodium 25 g/ha at 20 DAS	51.2	47.2	77.3	67.2	73.8	91.5	21.4	23.4	16.0	28.2
Pyrazosulfuron-ethyl at 20 g/ha *fb* Cono-weeder on 25 DAS	54.1	48.8	78.3	70.9	79.3	92.2	22.6	25.8	16.6	22.7
Cono weeder on 10 DAS *fb* bispyribac-sodium 25 g/ha at 20 DAS	51.7	47.3	71.6	70.3	73.5	89.1	21.5	23.8	22.2	32.8
Hand weeding on 15 and 30 DAS	51.7	48.2	71.7	68.8	72.0	91.8	22.4	24.6	24.4	32.3
Hand weeding on 15 DAS *fb* cono-weeder on 25 DAS	50.2	47.1	73.8	69.2	75.6	89.6	22.1	23.7	18.8	33.4
Cono-weeder on 10 DAS *fb* hand weeding on 30 DAS	50.7	46.9	75.0	67.8	78.2	89.1	22.2	24.3	20.3	33.9
Weedy check	48.5	46.7	70.9	63.0	73.5	87.7	21.2	23.3	23.1	37.5
LSD(p=0.05)	4.0	2.3	5.5	6.6	5.4	3.2	1.1	1.9	5.9	9.2

Table 3. Effect of different weed control treatments on yield characters in direct-seeded rice

Treatment	Panicle (no./m^2)		Grain (no./panicle)		Test weight (g)		Grain yield (t/ha)		Straw yield (t/ha)	
	2014	2015	2014	2015	2014	2015	2014	2015	2014	2015
Pyrazosulfuron-ethyl at 20 g/ha	359.6	432.2	145.6	157.2	15.7	16.5	5.58	5.76	6.32	6.44
Bispyribac-sodium 25 g/ha	300.5	454.7	133.2	155.1	15.5	16.5	5.57	5.64	6.31	6.53
Cono-weeder on 10 and 25 DAS	410.3	477.3	166.3	177.4	15.6	16.7	6.10	6.29	6.91	7.31
Pyrazosulfuron-ethyl 20 g/ha *fb* bispyribac-sodium 25 g/ha at 20 DAS	398.1	457.3	163.2	166.0	15.8	16.6	5.94	5.89	6.74	6.71
Pyrazosulfuron-ethyl at 20 g/ha *fb* Cono-weeder on 25 DAS	440.6	493.7	167.2	183.1	16.2	16.9	6.25	6.38	7.28	7.48
Cono weeder on 10 DAS *fb* bispyribac-sodium 25 g/ha at 20 DAS	384.6	470.7	151.1	153.7	14.9	15.9	5.83	5.68	6.61	6.97
Hand weeding on 15 and 30 DAS	391.8	469.3	155.7	170.6	15.4	16.4	5.94	5.90	6.64	7.03
Hand weeding on 15 DAS *fb* cono-weeder on 25 DAS	376.3	424.2	147.3	165.1	15.8	16.7	5.75	5.81	6.53	6.58
Cono-weeder on 10 DAS *fb* hand weeding on 30 DAS	392.0	467.3	148.7	172.7	15.0	16.0	5.81	5.79	6.59	6.82
Weedy check	260.8	272.3	120.5	146.7	14.9	15.9	4.49	3.79	5.10	4.98
LSD(p=0.05)	59.54	46.6	21.70	25.8	0.9	1.0	0.34	0.37	0.38	0.46

Table 4. Effect of different weed control treatments on yield and economics of direct-seeded rice

Treatment	Grain yield (t/ha)			Straw yield (t/ha)			Gross income (x10^3 ₹/ha)			Net income (x10^3 ₹/ha)			B:C ratio		
	2014	2015	Pooled	2014	2015	Pooled	2014	2015	Pooled	2014	2015	Pooled	2014	2015	Pooled
Pyrazosulfuron-ethyl at 20 g/ha	5.58	5.76	5.67	6.32	6.44	6.37	72.49	75.49	73.99	40.46	43.46	41.96	2.26	2.36	2.31
Bispyribac-sodium 25 g/ha	5.57	5.64	5.60	6.32	6.53	6.42	72.40	74.21	73.30	39.44	41.26	40.35	2.19	2.25	2.23
Cono-weeder on 10 and 25 DAS	6.10	6.29	6.20	6.92	7.31	7.12	79.30	82.79	81.05	44.52	48.01	46.26	2.28	2.38	2.33
Pyrazosulfuron-ethyl 20 g/ha *fb* bispyribac-sodium 25 g/ha at 20 DAS	5.94	5.89	5.92	6.74	6.71	6.73	77.27	77.40	77.33	43.14	43.82	43.48	2.29	2.31	2.30
Pyrazosulfuron-ethyl at 20 g/ha *fb* Cono-weeder on 25 DAS	6.41	6.48	6.45	7.28	7.48	7.39	81.24	84.10	82.67	47.34	50.19	48.77	2.40	2.49	2.45
Cono-weeder on 10 DAS *fb* bispyribac-sodium 25 g/ha at 20 DAS	5.83	5.68	5.76	6.61	6.97	6.79	75.82	75.10	75.46	41.00	40.27	40.64	2.17	2.16	2.17
Hand weeding (HW) on 15 and 30 DAS	5.94	5.90	5.92	6.64	7.03	6.79	77.16	77.80	77.48	38.93	39.57	39.25	2.01	2.04	2.03
HW on 15 DAS *fb* cono-weeder on 25 DAS	5.75	5.81	5.78	6.53	6.58	6.57	74.78	76.30	75.54	38.28	39.79	39.03	2.04	2.09	2.07
Cono weeder on 10 DAS *fb* HW on 30 DAS	5.81	5.79	5.80	6.59	6.82	6.71	73.51	76.33	74.92	37.00	39.82	38.41	2.01	2.09	2.05
Weedy check	4489	3.79	4.14	5.10	4.99	5.04	58.36	50.41	54.39	27.33	19.30	23.32	1.87	1.62	1.75
LSD(p=0.05)	0.34	0.37	0.33	0.39	0.46	0.29	-	-	-	-	-	-	-	-	-

respectively. The lower grain and straw yield of 4.49 t/ha and 3.79 t/ha during 2014 and 2015, respectively was recorded in weedy check (**Table 3**).

Application of pyrazosulfuron-ethyl 10% WP at 20 g/ha on 3 DAS *fb* cono-weeding on 25 DAS recorded the higher gross income of ₹ 82669/ ha, net income of ₹ 48767/ha with the B:C ratio of 2.45. This was followed by the cono-weeding on 10 and 25 DAS, which recorded the gross income of ₹ 81046/ ha, net income of ₹ 46264/ha with the B:C ratio of 2.33. The lower gross income of ₹ 54387/ha, net income of ₹ 23316/ha with the B:C ratio of 1.75 were recorded in weedy check **(Table 4)**.

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Herbicide combinations and nitrogen scheduling for weed management and yield improvement in transplanted rice

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ABSTRACT

Field experiment was conducted during rainy seasons of 2018 and 2019 to evaluate the efficacy of herbicide mixtures and nitrogen application scheduling to control grasses, sedges and broad-leaved weeds in transplanted rice. Post-emergence application of triafamone 20% + ethoxysulfuron 10% (ready-mix) 67.5 g/ha at 20 days after transplanting (DAT) was found comparable with two rounds of hand weeding at 20 and 40 DAT in controlling all categories of weeds. Among different nitrogen application schedules, application of 25% N at 10 DAT + 50% N at active tillering (AT) + 25% N at panicle initiation (PI) recorded higher weed control efficiency (73.4%) and grain yield (6.3 t/ha) of rice as compared to the recommended schedule of 25% N as basal + 50% N at AT + 25% N at PI (WCE of 66.9% and grain yield of 5.7 t/ha). Triafamone 20% + ethoxysulfuron 10% (ready-mix) 67.5 g/ha at 20 DAT recorded 81.7% WCE, improved crop growth and yield attributes and consequently increased grain yield (6.0 t/ha) as well as net return (69360 ₹/ha) as compared to fenoxaprop-p-ethyl 9 EC 56.2 g/ha + ethoxysulfuron 15 WDG 18.7 g/ha (tank-mix) at 20 DAT. Tank-mix application of fenoxaprop-p-ethyl + ethoxysulfuron caused yellowing of rice leaves although it disappeared within 20 days after application, whereas no such phytotoxicity was recorded under ready-mix application of triafamone + ethoxysulfuron.

INTRODUCTION

Rice (*Oryza sativa* L.) occupies prime position among food crops in India. It is cultivated in an area of 43.79 million hectares with production of 112.91 million tonnes (mt) and productivity of 2.58 t/ha in 2017-18 (Agristat 2018). Weeds are the major pests that affect the rice yields up to 57% in puddled transplanted rice and 82% in direct-seeded rice (Mahajan *et al.* 2009). Transplanted rice is infested with both grassy and broad-leaved weeds at initial stages of crop growth. Fenoxaprop-p-ethyl is most widely used herbicide for management of grassy weeds although ineffective against broad-leaved weeds in rice. Exclusive reliance on herbicides with single mode of action is not advisable as they contribute to rapid evolution of multiple herbicide resistance, which is again becoming a threat to weed control in rice. Metsulfuron-methyl + chlorimuron-ethyl and penoxsulam + cyhalofop-butyl are certain ready-mix combinations introduced as post-emergence application against complex weed flora in transplanted rice (Tripathy and Mohapatra 2017). Likewise, tank-mix application of azimsulfuron 27.5 g/ha + metsulfuron-methyl 2.0 g/ha was also found effective to control grassy and broad-leaved weeds in transplanted rice (Jayadev *et al.* 2010). Still there is a need to identify suitable herbicide combinations for improving weed control efficiency without any adverse effect on crop.

Nutrient management is an important component of integrated weed management systems that influences crop yield and reduces weed infestation over time (Blackshaw *et al.* 2004). Soil nutrients, especially nitrogen, are known to promote seed germination in some weed species (Hendrics and Taylorson 1972). Selective placement or delayed application of nitrogen may avoid flushes of weeds to come up at initial period of crop growth (Tripathy and Mohapatra 2007). There is often a significant interaction between herbicide and nitrogen, where increased level of nitrogen is found to enhance the performance of herbicide as well as nitrogen. Scheduling of nitrogen application not only influences the crop growth, but also affects the weed growth at large (Kim *et al.* 2006). However, precise information in this regard is meagre under rice-rice cropping system in Hirakud command areas of West Central Table Land Zone of Odisha. Hence, an attempt was made to study the effect of newer herbicide combinations and nitrogen application scheduling on weeds and yield of transplanted rice.

MATERIALS AND METHODS

A field experiment was conducted at Regional Research and Technology Transfer Station, Chiplima, Odisha during rainy seasons of 2018 and 2019. The soil of the experimental field was sandy clay loam with pH 6.6 and fertility status with low in organic carbon (0.43%), low (268 kg/ha) in available N ($KMnO_4$ method), medium (13.4 kg/ha) in available P (Olsen's method) and medium (132 kg/ha) in available K (NH_4OHC method). The experiment was laid out in a split plot design with three replications. The treatments included four weed management methods, *viz.* triafamone 20% +ethoxysulfuron 10% (ready-mix) 30 WG 67.5 g/ha at 20 days after transplanting (DAT), fenoxaprop-p-ethyl 9 EC 56.2 g/ha + ethoxysulfuron 15 WDG 18.7 g/ha (tank-mix) at 20 DAT, hand weeding at 20 and 40 DAT and weedy in main plots and three different schedules of nitrogen application, *viz.* 25% at 10 DAT + 50% at active tillering (AT) + 25% at panicle initiation (PI), 25% as basal + 50% at AT + 25% at PI and 50% as basal + 25% at AT + 25% at PIin sub-plots. The field was prepared with two ploughings, each followed by planking with the help of a tractor-drawn cultivator. The puddling was done at the time of transplanting. The crop variety '*MTU 1001*'was transplanted in July and harvested in November during both the years. A common fertilizer dose of 80-40-40 kg N-P-K/ha was applied, giving full doses of P and K as basal and N fertilizers as per treatment schedule. Two rice seedlings per hill were transplanted at 20 × 15 cm spacing in experimental field. Plant protection measures and irrigation were provided as and when required. The required quantity of herbicides was applied with manually operated knapsack sprayer fitted with flood jet nozzle, using a spray volume of 500 L of water/ha. A thin film of water was maintained in the field at the time of herbicide application.

Weed count (no./m^2) and weed dry weight (g/m^2) were recorded after random sampling at two spots with the help of 0.25 m^2 quadrat at 50 DAT. For the assessment of weed dry weight, weed samples were kept at 85^0C in hot air oven for 16 h (Klingman 1971). Weeds were separated into three broad categories (grass, sedge and broad-leaved) before drying. Weed data were analysed after subjecting them to square root transformation. Phytotoxicity of herbicides at different nitrogen application scheduling were recorded at 5 and 20 days after application (DAA) of herbicides using visual scoring scale of 0 to 10, where 0: no injury and 10: complete mortality (Rao 2001). Data were recorded on crop growth (plant height at harvest, number of tillers/hill at 50 DAT and leaf area index at flowering), whereas yield attributes (panicle length, number of filled grains/ panicle and test weight) along with yields (grain and straw) were recorded at crop harvest. Weed control efficiency (%) was also calculated on the basis of dry matter production of weeds.

$$\text{Weed control efficiency (WCE)} = \frac{(\text{WDc} - \text{WDt})}{\text{WDc}} \times 100$$

Where, WDc was the weed dry weight in weedy check plots and WDt was the weed dry weight in treated plots.

Economics were computed using the prevailing market price of inputs and outputs such as rice grain (₹ 17.5 x10^3/t), rice straw (₹ 0.7 x10^3/t) and manual labour (₹ 0.28 x10^3/day). All data were subjected to analysis of variance as described by Gomez and Gomez (1984).

RESULTS AND DISCUSSION

Effect on weeds

The major weed flora in the experimental field comprised of grasses, *viz. Digitaria sanguinalis* L. Scop., *Echinochloa crus-galli* L., *Echinochloa colona* L. Link, *Panicum repens* L.; sedges, *viz. Cyperus difformis* L., *Cyperus iria* L., *Fimbristylis miliacea* L. Vahal; and broad-leaved weeds (BLW) viz. *Ammania baccifera* L., *Ludwigia parviflora* L., *Eclipta prostrata* L., *Eclipta alba* L., *Lippia nodiflora* Nich, *Marsilea quadrifolia* L., *Sphenoclea zeylanica* Gaertn., *Commelina benghalensis* L., and *Leptochloa chinensis* L.. Similar weed flora was reported earlier by Mohapatra *et al.* (2017). The proportionate composition of grasses, sedges and broad-leaved weeds in weedy check plots was 45.4, 29.1 and 25.4%, respectively. Emergence of grasses was noticed earlier as compared to broad-leaved weeds.

Hand weeding twice manually resulted in 100% weed control. But among the herbicides, triafamone 20% + ethoxysulfuron 10% (ready-mix) 67.5 g/ha proved to be the most effective herbicide against grasses and broad-leaved weeds, and recorded significantly lower density (4.2, 6.5) and biomass (1.8, 5.3 g/m^2) of these weeds than the tank-mixed application of fenoxaprop–p-ethyl 9 EC 56.2 g/ha + ethoxysulfuron 15 WDG at 18.7 g/ha (**Table 2**). Weed density and biomass of grass, sedge and broad-leaved weeds were made in the year 2018 as compared to 2019 in weedy check plot (**Table 1**). The highest weed control efficiency (81.7%) was recorded under triafamone 20% + ethoxysulfuron 10% (ready-mix) 67.5 g/ha than tank-mixed application of fenoxaprop-p-ethyl 9 EC 56.2 g/ha + ethoxysulfuron 15 WDG at 18.7 g/ha. Compared with fenoxaprop-p-ethyl 9 EC 56.2 g/ha + ethoxysulfuron 15 WDG 18.7 g/ha, higher efficacy of triafamone 20% +ethoxysulfuron 10% (ready-mix) 67.5 g/ha was attributed to complete control of grassy and broad-leaved weeds throughout the crop growth period. Again tank-mix application of fenoxaprop-p-ethyl + ethoxysulfuron caused yellowing of rice leaves which disappeared within 20 days after application, whereas no such phytotoxicity was found under ready-mix application of triafamone + ethoxysulfuron.

Split application of nitrogen as 25% at 10 DAT + 50% at AT + 25% at PI showed lower density and biomass of weeds, being at par with 25% N as basal + 50% N at AT + 25% N at PI, but it was significantly superior to 50% N as basal + 25% N at AT + 25% N at PI. This might be due to improved crop growth, which caused a smothering effect on weed growth. These findings were in conformity with those of Sahu *et al.* (2015).

Crop phytotoxicity

Crop phytotoxicity (injury) was observed with application of fenoxaprop-p-ethyl 9 EC 56.2 g/ha + ethoxysulfuron 15 WDG (tank-mix) 18.7 g/ha at 5 days after application (DAA) of herbicide (**Table 3**). Such phytotoxicity was primarily expressed as yellowing of flag leaves and reduced plant growth although it was automatically reversed at 20 DAA. The crop recovered quickly from the herbicidal phytotoxicity with the application of 25% N at 10 DAT +50% N at AT + 25% N at PI than that of 50% N as basal + 25% N at AT + 25% N at PI.

Table 1. Effect of herbicides and time of nitrogen application on weed density and biomass of rice at 50 DAT

Treatment	Weed density (no./m^2)						Weed biomass (g/m^2)					
	Grass		Sedge		Broad-leaved		Grass		Sedge		Broad-leaved	
	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019
Weed management												
Fenoxaprop-p-ethyl + ethoxysulfuron	2.9(10)	3.2(10)	3.3(10)	3.2(9)	4.4(19)	3.9(15)	2.1(4)	2.3(4)	3.0(8)	2.9(8)	4.1(16)	4.3(19)
Triafamone 20% + ethoxysulfuron 10%	2.2(5)	2.7(7)	2.2(4)	2.9(6)	2.9(8)	3.1(9)	1.7(2)	2.0(3)	2.1(3)	2.6(6)	3.2(9)	3.4(11)
Two hand weeding	1.0(0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)
Weedy	8.9(8)	6.8(5)	5.3(3)	4.4(2)	7.5(6)	5.9(35)	6.0(38)	4.6(21)	4.6(20)	3.8(14)	5.9(34)	6.9(49)
LSD(p=0.05)	0.12	0.26	0.20	0.27	0.29	0.34	0.09	0.11	0.10	0.08	0.08	0.06
Nitrogen application schedule												
25% N at 10 DAT + 50% N at AT + 25% N at PI	2.7(12)	2.8 (9)	2.9(10)	2.7(8)	3.5(16)	3.2(12)	2.0(5)	2.1(4)	2.7(8)	2.6(7)	3.5(14)	3.6(16)
25% N at basal + 50% N at AT + 25% N at PI	3.0(15)	3.1(12)	2.9(10)	2.8(8)	3.3(13)	3.1(11)	2.2(7)	2.2(5)	2.5(7.)	2.5(6)	3.5(14)	3.3(12)
50% N at basal + 25% N atAT + 25% N at PI	5.6(48)	4.4(27)	3.0(11)	2.9(9)	5.1(36)	4.2(22)	3.8(21)	3.1(12)	2.8(9)	2.6(7)	3.6(16)	4.9(31)
LSD (p=0.05)	0.10	0.22	0.17	NS	0.25	0.29	0.09	0.09	0.08	0.07	0.07	0.05

Figures within parentheses were original values, and those without parentheses were values transformed to square root of $(\sqrt{x+1})$ before statistical analyses; DAT: Days after transplanting; AT: Active tillering; PI: Particle initiation

Table 2. Effect of herbicides and time of nitrogen application on weed density, biomass and weed control efficiency of rice at 50 DAT (pooled data of 2 years)

Treatment	Weed density (no./m^2)				Weed biomass (g/m^2)				
	Grasses	Sedges	Broad-leaved	Total	Grasses	Sedges	Broad-leaved	Total	WCE (%)
Weed management									
Fenoxaprop-p-ethyl + ethoxysulfuron	2.6(6)	2.7(6)	3.4(11)	4.9(24)	1.8(3)	2.5(5)	3.1(9)	4.1(17)	68.5
Triafamone 20% + ethoxysulfuron 10%	2.1(4)	2.1(4)	2.6(6)	3.8(14)	1.6(2)	1.9(3)	2.4(5)	3.2(10)	81.7
Two hand weeding	1.0(0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)	1.0(0)	100
Weedy	6.5(44)	3.9(15)	5.5(31)	9.2(91)	4.4(20)	3.5(11)	4.9(24)	7.3(55)	0
LSD (p=0.05)	1.84	0.05	0.53	2.2	1.18	0.11	1.09	1.4	
Nitrogen application schedule									
25% N at 10 DAT + 50% N at AT + 25% N at PI	2.8(12)	2.0(4)	2.7(10)	3.9(19)	2.1(5)	1.8(3)	2.5(8)	3.4(15)	73.4
25% N at basal + 50% N at AT + 25% N at PI	2.8(13)	2.5(6)	3.1(12)	5.0(27)	2.1(6)	2.2(5)	2.8(9)	3.6(18)	66.9
50% N at basal + 25% N at AT + 25% N at PI	3.5(16)	2.8(9)	3.5(15)	5.2(41)	2.4(7)	2.6(7)	3.2(12)	4.6(29)	47.3
LSD (p=0.05)	0.21	0.04	0.45	1.03	0.11	0.01	0.06	0.6	-

Figures within parentheses were original values, and those without parentheses were values transformed to square root of $(\sqrt{x+1})$ before statistical analyses; DAT: Days after transplanting; WCE: Weed control efficiency

Effect on crop

Higher leaf area index (4.1) at flowering was found in the ready-mix application of triafamone 20% +ethoxysulfuron 10% at 67.5 g/ha, followed by tank-mix application of fenoxaprop-p-ethyl 9 EC 56.2 g/ha + ethoxysulfuron 15 WDG 18.7 g/ha as compared to weedy check (**Table 3**). This might be due to effective control of weeds which, in turn, significantly increased the number of tillers/hill (9.1), number of grains/panicle (163) and 1,000-grain weight (20.6 g), thereby improving grain and straw yield. Control of grass, sedge and broad-leaved weeds by ready-mix application of triafamone 20% +ethoxysulfuron 10% at 67.5 g/ha resulted in lower competition for growth resources throughout the crop growth period and influenced the crop plants to grow and develop in a better way as evidenced from higher values of yield attributes. Similar findings were also observed by Ramachandra *et al.* (2012).

Application of nitrogen as 25% at 10 DAT +50% at AT + 25% at PI registered significantly higher LAI (4.7), plant height (114.9 cm), panicle length (24.8 cm) and 1,000-grain weight (21.2 g) (**Table 3**). Initial reduction in dose and delayed application of nitrogen resulted in significant improvement in panicle length, grains/panicle and grain yield in comparison to conventional scheduling of recommended nitrogen application. Higher values of yield attributes and grain yield were ascribed to more utilization and uptake of nitrogen at active growth stages, *viz.* AT and PI. Similar findings were also reported by Gill and Walia (2013).

The grain (6.8 t/ha) and straw (8.4 t/ha) yields were the highest in the weed free plot and the lowest (4.7 t/ha) in weedy plot (**Table 4**). The reduction in grain and straw yield in weedy plot were 30.9 and 30.5%, respectively due to weeds. Triafamone 20% + ethoxysulfuron 10% (ready-mix) at 67.5 g/ha recorded higher grain and straw yield (6.0 and 7.7 t/ha) than fenoxaprop-p-ethyl 9 EC 56.2 g/ha + ethoxysulfuron 15 WDG 18.7 g/ha. (tank-mix). Similar findings on rice grain yield by application of triafamone + ethoxysulfuron was also reported by Hossain and Mallik (2017).

Nitrogen scheduling as 25% at 10 DAT + 50% at AT + 25% at PI recorded higher grain (6.3 t/ha) and straw (8.0 t/ha) yield followed by 25% at basal + 50% at AT + 25% at PI. The traditional practice of higher basal dose of N (50-25-25% split) recorded the lowest grain (5.5 t/ha) and straw (6.8 t/ha) yield. The scheduling of N with split amounts increased the grain and straw yield by 12.7% and 15%, respectively over traditional approach.

Economics

The cost of cultivation was lower in all the treatments involving herbicide use. It was the lowest with ready-mix combination of triafamone 20% +ethoxysulfuron 10% (₹ 35.64 x10^3/ha), closely followed by fenoxaprop-p-ethyl + ethoxysulfuron (₹ 35.71 x10^3/ha). Although two hand weeding at 20 and 40 DAT resulted in the highest yield (6.8 t/ha), it involved the highest cost of cultivation (₹ 55.71 x10^3/ha), resulting in less net return (₹ 64.46 x10^3/ha) and reduced return per rupee invested (1.2) as compared to chemical weed management (1.8-1.9). As reported by Warde *et al.* (2006), manual hand weeding was very effective in controlling weeds although it was cumbersome, labour-intensive, cost-prohibitive and time-consuming. B:C ratio was the highest (1.9) with application of triafamone 20% + ethoxysulfuron 10%, fetching higher economic return.

Table 3. Growth and yield parameters of rice as influenced by herbicides and time of nitrogen application (pooled data of 2 years)

Treatment	Plant height (cm)	tillers/ hill	LAI at flowering	Panicle length (cm)	Filled grains/ panicle	1000 grain weight (g)	Crop phytotoxicity Initial (5 DAA)	Crop phytotoxicity 20 DAA of herbicide
Weed management								
Fenoxaprop-p-ethyl + ethoxysulfuron	111.7	9.0	3.9	23.9	160.0	20.2	4.0	1.4
Triafamone 20% + ethoxysulfuron 10%	114.4	9.1	4.1	24.4	163.0	20.6	1.0	1.0
Two hand weeding	115.7	11.0	4.7	25.2	164.0	21.5	1.0	1.0
Weedy	102.5	7.0	3.8	22.6	141.0	18.9	1.0	1.0
LSD (p=0.05)	2.97	1.29	0.33	0.89	3.02	0.92	-	-
Nitrogen fertilizer schedule								
25% N at 10 DAT + 50% N at AT + 25% N at PI	114.9	10.0	4.7	24.8	161.0	21.2	1.8	1.0
25% N at basal + 50% N at AT + 25% N at PI	110.6	9.0	3.8	23.8	157.0	20.1	1.8	1.1
50% N at basal + 25% N at AT + 25% N at PI	107.7	9.0	3.9	23.4	153.0	19.6	1.8	1.2
LSD (p=0.05)	2.56	NS	0.27	0.77	2.61	0.79	-	-

DAT: Days after transplanting; DAA: Days after application; NS: Not significant

Table 4. Yield and economics of rice as influenced by herbicide mixture and nitrogen application (pooled data of 2 years)

Treatment	Grain yield (t/ha)			Straw yield (t/ha)			Cost of cultivation	Net returns	B:C
	2018	2019	Pooled	2018	2019	Pooled	(x10^3 ₹/ha)	(x10^3 ₹/ha)	ratio
Weed management									
Fenoxaprop-p-ethyl + ethoxysulfuron	6.2	5.5	5.8	7.6	6.9	7.2	35.71	66.92	1.8
Triafamone 20% + ethoxysulfuron 10%	6.0	6.1	6.0	7.8	7.6	7.7	35.64	69.36	1.9
Two hand weeding	7.2	6.7	6.8	8.9	8.2	8.5	55.71	64.46	1.2
Weedy	4.6	4.7	4.7	6.0	5.8	5.9	34.03	47.83	1.4
LSD (p=0.05)	0.28	0.01	0.59	0.47	0.03	0.22	-	10.4	0.29
Nitrogen fertilizer schedule									
25% N at 10 DAT + 50% N at AT + 25% N at PI	6.6	6.2	6.3	8.2	7.8	8.0	39.27	71.07	1.8
25% N at basal + 50% N at AT + 25% N at PI	5.8	5.7	5.7	7.4	7.1	7.2	39.27	59.62	1.5
50% N at basal + 25% N at AT + 25% N at PI	5.6	5.4	5.5	7.1	6.7	6.8	39.27	55.73	1.4
LSD (p=0.05)	0.25	0.01	0.52	0.40	0.02	0.19	-	9.03	0.25

DAT: Days after transplanting; AT: Active tillering; PI: Particle initiation

Among the treatments of nitrogen scheduling, split application of nitrogen as 25% at 10 DAT + 50% at AT + 25% at PI recorded significantly the highest net return (₹ 71.07 x10^3/ha) and B: C ratio (1.8) over the others.

It was concluded that application of triafamone 20% +ethoxysulfuron 10% (ready-mix) 67.5 g/ha at 20 DAT along with scheduling of nitrogen as 25% at 10 DAT +50% at AT + 25% at PI would be an effective recommendation for ensuring cost-effective weed management as well as higher productivity in transplanted rice.

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Leaf colour chart-based nitrogen and weed management impacts on weeds, yield and nutrient uptake in dry direct-seeded rice

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ABSTRACT

A field experiment was conducted during *Kharif* (rainy season) 2016 and 2017 in sandy clay loam soils of experimental field at Banaras Hindu University, Varanasi, Uttar Pradesh India to find out the effect of leaf colour chart-based nitrogen and weed management practices on nutrient uptake and yield of direct-seeded rice. Minimum weed index, nutrient content and uptake by weeds and maximum weed control efficiency, yield and nutrient content and uptake by grain and straw were observed with application of nitrogen leaf colour chart LCC $\leq$ 5. Application of pyrazosulfuron 20 g/ha (PE) *fb* bispyribac 25 g/ha at 15-20 DAS recorded minimum weed index, nutrient content and uptake by weeds and maximum weed control efficiency, rice yield and nutrient content and uptake by rice grain and straw, which was comparable with two hand weedings at 20 and 40 DAS.

INTRODUCTION

Rice cultivation by direct-seeding is viewed as both cost and labour saving practice. Nitrogen is the most widely used fertilizer nutrient in rice and its consumption has increased substantially in the past decades. The quantity of rice grain produced per unit of applied N fertilizer (partial factor productivity) has constantly decreased to very low values (Dobermann *et al.* 2002). It has been observed that more than 60% of applied nitrogen is lost due to lack of harmonization between the nitrogen demand and nitrogen supply. Since farmers generally prefer to keep leaves of the crop dark green, it leads to more application of fertilizer N resulting in low use efficiency. The spectral properties of leaves should be used in a more coherent manner to guide need based N application at the right time and in right dose as it is critical for healthy plant environment (Tauseef *et al.* 2017). Thus, the International Rice Research Institute (Philippines) developed a leaf color chart (LCC) that helps to guide farmers for real-time nitrogen management in rice farming which is inexpensive, and easily affordable by most resource poor rice farmers (Islam *et al.* 2004).

In direct-seeded rice (DSR), weeds are a major biotic stress to rice production as they increase production costs and cause yield loss (Rao *et al.* 2007). Weeds reduce rice yield up to 40-100% in direct-seeded rice (Choubey *et al.* 2001). The shift from transplanted to DSR results in more hostile weed flora and increased dependence on herbicides, owing to increasing labour problem and in view of time consuming, burdensome and less effective nature of cultural and mechanical methods of weed control (Rao and Ladha 2014). Herbicide-based weed management is the smartest and viable option of weed control in DSR. It reduces the total energy requirement for rice cultivation. To have a broad-spectrum weed control in single application, herbicide mixtures (both concocted and tank) were tried and found to be effective (Rao and Nagamani 2010). Fractional application of nitrogen in right amount and proportion together with weed control practices facilitates higher absorption of applied nitrogen and thus increasing effectiveness of fertilizer nitrogen (Amarjit *et al.* 2006). The objectives include the effect of real time nitrogen application and weed management treatments on weed growth, NPK uptake by weed and the crop under different treatments.

MATERIALS AND METHODS

A field experiment was conducted during rainy (*Kharif*) season of 2016 and 2017 at Institute of Agricultural sciences, Banaras Hindu University, Varanasi, Uttar Pradesh, India. The soil was Gangetic alluvial having Sandy clay loam in texture with pH 7.80. It was moderately fertile, being low in available organic carbon (0.33%), available N (154.60 kg/ha), and medium in available P (12.10 kg/ha) and K (210.51 kg/ha).

The experiment was laid out in a split-plot design replicated thrice with four nitrogen management treatments, *viz*. recommended dose of nitrogen (RDN) (120 kg N/ha), LCC ≤ 3, LCC ≤ 4, LCC ≤ 5 as main plots and 5 weed management treatments, *viz*. weedy check, two hand weedings at 20 and 40 DAS, pendimethalin 1.0 kg/ha (PE) *fb* bispyribac 25 g/ha at 15-20 DAS, flufenacet 120 g/ha (PE) *fb* bispyribac 25 g/ha at 15-20 DAS, pyrazosulfuron 20 g/ha (PE) *fb* bispyribac 25 g/ha at 15-20 as sub-plots. Full dose of phosphorus (60 kg P/ha) and potash (40 kg K/ha) were applied as basal application and nitrogen was applied as per treatment. The leaf colour chart consisteds of 6 colour shades ranging from light yellowish green to dark green strips fabricated with veins resembling that of rice leaves. LCC readings were taken at 7 days interval starting from 10 days after sowing till emergence of heading stage. Ten disease free hills were selected at random from sampling area in each plot. From each hill top, most fully expanded leaf was selected and LCC readings were taken by placing the middle part of the leaf on the chart and leaf colour was observed by keeping the sun blocked by body as sunlight affects leaf colour reading. Whenever, the green colour of more than 5 out of 10 leaves were observed equal to or below a set critical limit of LCC score, nitrogen was applied as per treatment.

The dry seed of *'HUR 105'* variety of rice at 30 kg/ha was sown manually with the help of spade at a row spacing of 20 cm. The pre-emergence and post-emergence herbicides were sprayed as per treatment using spray volume of 500 L of water/ha using knap sack sprayer fitted with flat fan nozzle. Weed samples were collected by placing a quadrate (50 x 50 cm) randomly at two places in each plot at 20, 40, 60, 80 DAS and at harvest. The data on weeds were subjected to square-root transformation ($\sqrt{x+0.5}$) to normalize their distribution. The weed index (WI) was calculated based on the rice grain yield obtained from treatments using the formula as suggested by Gill and Vijaykumar (1969).

The plant samples of rice utilized for recording dry matter production at harvest and weed samples at 60 DAS were ground in a Willey mill to pass through 40 mesh sieve. The ground material was collected in butter paper bags and later used for chemical analysis. Nitrogen and phosphorus were estimated by Micro Kjeldahl's method (Jackson 1973), Vanadomolybdate phosphoric yellow colour method (Jackson 1973) respectively, and potassium was determined by Flame photometer method (Jackson 1973) and it was expressed in per cent.

RESULTS AND DISCUSSION

Weed flora, weed control efficiency, weed index and nutrient uptake by weeds

Major weed flora species infesting in the direct-seeded rice as observed in weedy check plots were *Echinochloa colona* (45.09%), *Echinochloa cruss-galli* (48.14%) and *Cyanodon dactylon* (39.25%) among grasses, *Cyperus rotundus* (62.92%) and *Cyperus iria* (58.22%) among sedges and *Eclipta alba* (45.02%) and *Caesulia auxillaris* (54.98%) among broad-leaved weeds.

Under different leaf colour chart based nitrogen schedules, LCC ≤5 recorded the highest weed control efficiency, lower weed index (11.39 and 11.99)

Table 1. Effect of leaf colour chart-based nitrogen management and weed management treatments on grain yield, straw yield and weed control efficiency in dry direct-seeded rice

Treatment	Grain yield (t/ha)		Straw yield (t/ha)		Weed control efficiency (%)		Weed index	
	2016	2017	2016	2017	2016	2017	2016	2017
Nitrogen management								
RDN (120 kg N/ha)	3.51	3.12	5.47	5.35	23.62	25.39	27.19	31.73
LCC ≤ 3	3.69	3.32	5.64	5.43	30.48	29.49	23.60	27.51
LCC ≤ 4	3.83	3.70	5.44	5.42	33.67	33.63	20.73	19.19
LCC ≤ 5	4.28	4.03	6.03	5.92	35.60	35.49	11.39	11.99
LSD (p=0.05)	0.34	0.21	0.24	0.22	-	-	-	-
Weed management								
Pendimethalin 1.0 kg/ha (PE) *fb* bispyribac 25 g/ha at 15-20 DAS	3.73	3.46	5.69	5.56	34.88	32.88	22.66	24.30
Flufenacet 120 g/ha (PE) *fb* bispyribac 25 g/ha at 15-20 DAS	3.39	3.08	5.42	5.36	30.98	29.01	29.83	32.58
Pyrazosulfuron 20 g/ha (PE) *fb* bispyribac 25 g/ha at 15-20 DAS	4.65	4.39	6.06	5.98	42.06	45.45	3.61	3.95
Two hand weedings at 20 and 40 DAS	4.83	4.57	6.09	6.01	46.28	47.66	0.00	0.00
Weedy check	2.53	2.19	4.96	4.74	0.00	0.00	47.54	52.21
LSD (p=0.05)	0.22	0.20	0.20	0.16	-	-	-	-

LCC: Leaf colour chart; RDN: Recommended dose of nitrogen

(**Table 1**) and minimum nutrient (N, P and K) content and depletion by weeds (**Table 2**) due to lower weed biomass at all the stages of crop growth during both the years. The RDN (120 kg/ha) registered lower weed control efficiency due to higher weed biomass (Nair *et al.* 2002, Chaudhary *et al*. 2011 and Singh *et al*. 2005).

The highest weed control efficiency, minimum weed index (3.61 and 3.95) and lower NPK depletion by weeds were recorded with pyrazosulfuron 20 g/ha (PE) *fb* bispyribac 25 g/ha at 15-20 DAS during both the years (**Table 1**) due to its effective control of complex weed flora, *viz*. grasses, sedges and broad-leaved weeds as it encouraged the earlier crop canopy closure/coverage. These results were in conformity with the findings of Devi and Singh (2018), Ghosh *et al.* (2017) in reference to nutrient content (%) and uptake (kg/ha), grain and straw yield of rice.

Application of LCC ≤ 5 recorded maximum nutrient content in grain and straw (**Table 3**) and maximum grain and straw yield than other nitrogen treatments (**Table 1**). The increased harvest index, grain and straw yield was perhaps as a result of better availability of nutrient as need based and reduced weed density, biomass and better weed control efficiency. These findings were in conformity with the results of Kumawat *et al.* (2017). The lower total N uptake with fixed schedule recommended N application method than with LCC managed N could be associated with suboptimal rates of N application in the recommendation, which could have limited rice

Table 2. Effect of leaf colour chart-based nitrogen and weed management on NPK removal by weed at harvest in direct-seeded rice

Treatment	N removal (kg/ha) by weed		P removal (kg/ha) by weed		K removal (kg/ha) by weed	
	2016	2017	2016	2017	2016	2017
Nitrogen management						
RDN (120 kg N/ha)	5.88(35.1)	6.85(50.4)	3.18(10.1)	3.91(16.3)	6.51(42.9)	7.30(56.6)
LCC ≤ 3	5.46(29.9)	6.55(44.5)	2.73(7.4)	3.39(12.1)	6.10(37.0)	7.05(50.2)
LCC ≤ 4	5.16(27.6)	6.16(38.1)	2.55(6.8)	3.11(10.2)	5.74(33.6)	6.73(45.3)
LCC ≤ 5	4.86(24.9)	5.67(32.7)	2.37(5.7)	2.59(7.0)	5.44(31.4)	6.32(41.0)
LSD (p=0.05)	0.12	0.15	0.06	0.08	0.14	0.16
Weed management						
Pendimethalin 1.0 kg/ha (PE) *fb* bispyribac 25 g/ha at 15-20 DAS	5.14(26.1)	6.15(37.8)	2.49(5.9)	2.94(8.5)	5.94(35.1)	6.77(45.6)
Flufenacet 120 g/ha (PE) *fb* bispyribac 25 g/ha at 15-20 DAS	5.42(28.9)	6.56(42.7)	2.73(7.0)	3.47(12.1)	6.15(37.6)	7.01(49.1)
Pyrazosulfuron 20 g/ha (PE) *fb* bispyribac 25 g/ha at 15-20 DAS	4.53(20.8)	5.26(27.7)	2.25(4.8)	2.40(5.3)	5.00(25.0)	5.96(35.2)
Two hand weedings at 20 and 40 DAS	4.37(19.0)	5.30(28.4)	2.02(3.7)	2.34(5.1)	5.14(27.5)	5.74(33.0)
Weedy check	7.24(52.1)	8.27(70.5)	4.05(16.1)	5.11(26.1)	7.50(56.1)	8.78(78.4)
LSD (p=0.05)	0.09	0.11	0.04	0.05	0.09	0.11

Data were subjected to square root transformation $\sqrt{x+0.5}$. Figures in parenthesis are original values

Table 3. Effect of leaf colour chart-based nitrogen and weed management on nutrient uptake by grain and straw in direct-seeded rice

Treatment	N uptake (kg/ha)				P uptake(kg/ha)				K uptake(kg/ha)			
	2016		2017		2016		2017		2016		2017	
	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw	Grain	Straw
Nitrogen management												
RDN (120 kg N/ha)	40.4	31.9	34.3	30.6	8.6	12.1	7.4	10.1	16.9	67.6	13.7	68.6
LCC ≤ 3	43.7	34.0	36.4	31.9	9.8	13.0	7.6	11.5	18.3	79.6	14.3	75.0
LCC ≤ 4	47.7	33.8	44.2	32.7	11.4	12.7	9.0	11.7	20.0	81.5	16.3	77.7
LCC ≤ 5	59.0	47.3	52.3	43.7	14.1	17.1	11.6	15.8	24.5	100.2	21.5	94.4
LSD (p=0.05)	10.5	6.0	7.1	6.4	2.7	1.9	2.0	2.6	3.2	15.2	3.0	10.0
Weed management												
Pendimethalin 1.0 kg/ha (PE) *fb* bispyribac 25 g/ha at 15-20 DAS	46.8	38.2	40.1	36.0	11.1	15.0	9.1	13.9	19.9	83.1	15.9	81.0
Flufenacet 120 g/ha (PE) *fb* bispyribac 25 g/ha at 15-20 DAS	40.2	33.2	33.4	31.5	7.1	9.3	5.5	8.3	14.8	72.1	11.0	69.3
Pyrazosulfuron 20 g/ha (PE) *fb* bispyribac 25 g/ha at 15-20 DAS	62.0	44.1	56.7	42.2	15.5	17.7	12.5	16.3	26.2	91.3	22.3	88.3
Two hand weedings at 20 and 40 DAS	66.4	47.5	59.7	44.5	17.3	19.6	14.6	17.7	28.3	101.7	24.4	98.3
Weedy check	23.1	20.9	19.1	19.2	3.9	7.0	2.7	5.3	10.3	63.0	8.8	57.6
LSD (p=0.05)	9.1	5.4	6.5	5.1	2.1	2.1	1.3	2.4	4.4	14.3	2.6	16.1

growth. Increase in P and K uptake with increased dose of N added evidence to the fact that N application has synergistic effect on the uptake of other nutrients besides N which was due to increase in biomass of the crop with increased N application. The results were in close proximity to Gupta *et al.* (2011) and Nachimuthu *et al.* (2007).

Amongst various weed management treatments, hand weeding twice at 20 and 40 DAS resulted in significantly higher grain and straw yield and higher N, P and K uptake by grain and straw of rice and was comparable with application of pyrazosulfuron 20 g/ha (PE) *fb* bispyribac 25 g/ha at 15-20 DAS than other weed management treatments (**Table 1**). Higher values for the uptake of N, P and K by crop under relatively weed free crop growing conditions was also reported earlier by Devi and Singh (2018). The increase in grain and straw yield in those two treatments might be due to the creation of weed free environment by effectively suppressing a broad-spectrum of weed population and consequently weed dry matter. Prevalence of weed free crop growing environment might have enabled congenial conditions for production of higher growth stature and better yield structure which might have eventually resulted in higher yields as expressed by Narolia *et al.* (2014).

Thus, it may be concluded that, application of LCC $\leq$ 5 and sequential application of pyrazosulfuron 20 g/ha (PE) *fb* bispyribac 25 g/ha at 15-20 DAS recorded the maximum weed control and grain yield in dry direct-seeded rice in Eastern Uttar Pradesh.

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Yellow-green algae (*Vaucheria* sp.): A new weed reported in transplanted rice from the coastal Karnataka and its management

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Coastal Karnataka, Herbicide, Rice, Vaucheria, Yellow-green algae

ABSTRACT

Vaucheria species from the coastal region of Karnataka were collected from a rice field during *Kharif* season from Kota hobli, Udupi Taluk, Coastal Karnataka. These were identified as *V. sessilis* (VAUCHER) DC and *V.geminata* (VAUCHER) DC. A field experiment was conducted during *Kharif* season of 2017 and 2018 at farmer's field Kota, Udupi taluk, Coastal Karnataka, India for the management of these algal species. Among herbicide combinations, pre-emergence application of pendimethalin at 750 g/ha at 3 DAT *fb* post-emergence application of penoxsulam at 22.5 g/ha at 15, 30 and 45 DAT recorded lower dry weight (6.0, 5.6 and 4.8 g/m^2 respectively) with higher weed control efficiency (92.37%). This treatment also recorded significantly higher plant height (95.18 cm), a higher number of tillers per hill (25.75), grain yield (5.33 t/ha), straw yield (6.24 t/ha) with B:C ratio (2.09-2.11).

INTRODUCTION

Rice (*Oryza sativa* L.) is the world's most important food crop catering the need of half of the world's population. Weeds are one of the major problems in increasing the productivity of rice. Transplanted rice faces the diverse type of weed flora consisting of grasses, broad-leaved weeds, sedges and algae. They usually grow faster than rice and absorb available water, nutrient earlier than the rice and suppress rice growth.

Vaucheria species belongs to family Vaucheriaceae, phylum Xanthophyta, commonly known as yellow-green algae are non-motile, single-celled or colonial algae, with a distinctive pigmentation that gives the cells a yellow or fresh green appearance. Although there is a wide range in morphology, this phylum contains relatively few species (compared to major groups such as green algae) and the mentioned algae tend to be ecologically restricted to small water bodies and damp soils. In Karnataka, *Vaucheria* species was first noticed at Kota hobli (13°302 543 N latitude 74°422 203 E longitude at an altitude of 18 meters above MSL) of Udupi Taluk in an area of 20 acres in a rice field during *Kharif* season (Johnson and Merrit 2002). This weed competes for the nutrients, water and sunlight with the rice crop and forms the green mat in the growing area and it won't allow the crop to produce tillers. Its life cycle is hardly 40 days, appears in the field soon after the transplanting of the crop (Zelazna-Wieczorek 2002). Removal of weed manually is tedious and costly. Use of conoweeder is not advisable because while passing of conoweeder, algae easily disperse due to its vegetative mode of propagation. In some instances, herbicides alone offer the most practical, effective and economical means of reducing weed competition (Balasubramanian *et al.* 1996). However, the choice of the best specific herbicide varies with agronomic, ecological and economic factors. Herbicides not only control the weeds timely and effectively but also offer great scope for minimizing the cost of weed control irrespective of the situations. Keeping these points in view the experiment was carried out at Farmer's field of Kota, Udupi taluk of Coastal Karnataka.

MATERIALS AND METHODS

A Field experiment was conducted during (*Kharif*) rainy season 2017 and 2018 at the farmer's field of Kota, Udupi taluk, coastal Karnataka to study the effect of herbicides in transplanted rice with special reference to *Vaucheria* spp. of yellow-green algae (YGA) under 13°302 543 N latitude and 74°422 203 E longitude with an altitude of 18 m above MSL. The soil of experimental site was sandy loam having high organic carbon (1.23%), high available phosphorus (62.01 kg/ha) and medium available nitrogen (336 kg/ha) and potassium (159 kg/ha) with pH 5.20. Twelve treatments were assigned in a randomized block design with three replications. The coastal zone is characterized by hot and humid climate with heavy rains during *Kharif* (June to September) and dry spell from November to May. The total normal annual rainfall of the area was 3748.1 mm (1984-2018). The major portion of rain was received during June to September months. The mean maximum air temperature ranged from 29.58^0 to 34.80 0C and minimum from $18.38\ ^0$ to 26.1^0C.

Twenty-one days old rice seedlings of medium duration red rice variety "*MO-4 (Bhadra)*" was transplanted at 20x10 cm spacing. The recommended dose of fertilizer (60:30:45 NPK kg/ha) was applied uniformly in three equal splits. Other agronomic and plant protection measures were adopted as recommended during crop growth. Quadrates (0.25 m^2) were placed in each plot at random. Weed fresh and dry weight within these quadrates were recorded.

All herbicides (**Table 1**) were applied using knap-sack sprayer fitted with flat-fan nozzle at spray volume of 500 L/ha at 3 DAT (pre-emergence) and 15 to 30 DAT (post-emergence) and compared with farmers practice (hand weeding at 15 DAT *fb* conoweeding at 30 and 45 DAT) and unweeded check. The data on fresh weight, dry weight and weed control efficiency were computed with the help of quadrate (0.25 x 0.25 m) and the values were subjected to square root transformation($\sqrt{x+0.5}$) prior to statistical analysis to normalize their distribution. Data on plant height (cm), number of tillers, grain yield (kg/ha), straw yield (kg/ha) and benefit cost ratio were recorded. The weed control efficiency was worked out based on weed dry matter production using the formula suggested by Mani *et al.* (1973). All the data obtained in the study were statistically analyzed using F-test, the procedure given by Gomez and Gomez (1984). Critical difference values at p=0.05 were used to determine the significance of differences between means.

RESULTS AND DISCUSSION

Weed flora

The predominant weed flora observed in the experimental field includes *Vaucheria* species of yellow-green algae, grassy weeds like *Panicum trypheron*, *Panicum repens*, *Echinochloa colona*, sedges like *Cyperus difformis*, *Cyperus procerus*, *Scirpus roylei*, broad-leaved weeds (BLW) like *Monochoria vaginalis*, *Ammania baccifera*, *Eclipta alba*, *Ludwigia parviflora*, and *Marsilea quadrifolia*.

Effect on weed density and dry weight

All the weed management treatments found effective in reducing the density and dry weight of *Vaucheria* spp. of yellow-green algae as compared to unweeded check (**Table 1**). At 15, 30 and 45 DAT, among different herbicide treatments, pre-emergence (PE) application of pendimethalin 750 g/ha at 3 DAT *fb* post-emergence (PoE) application of penoxsulam 22.5 g/ha at 30 DAT and PE application of pendimethalin 750 g/ha at 3 DAT *fb* PoE application of bispyribac-sodium 25 g/ha at 30 DAT were found more effective in controlling *Vaucheria* spp. as evidenced from lower fresh weight (32.8, 26.0, 13.2 and 35.6, 30.8,16.0 g/m^2, respectively), lower dry weight (6.0, 5.6,5.6 and 6.4,6.0, and 4.8 g/m^2, respectively). Pendimethalin being a broad-spectrum herbicide act as a mitotic poison by disrupting cell division and cell elongation through interference with microtubule assembly killing germinating seeds rather than seedlings. The herbicides penoxsulam and bispyribac-sodium belongs to group triazopyrimidine and pyrimidinyl (thio) benzoate, respectively. They act as ALS inhibitors retarding the synthesis of branched-chain amino acids valine, leucine, and isoleucine in plants by binding to the ALS enzyme, without these amino acids, protein synthesis and growth are inhibited, ultimately causing plant death. These findings are in line with Parthipan and Ravi (2014), Tranel and Wright (2002).

The crop yield is directly proportional to weed control efficiency, The weed control efficiency was maximum at 45 DAT with pendimethalin 750 g/ha at 3 DAT *fb* penoxsulam 22.5 g/ha at 30 DAT (**Table 1**), closely followed by pre-emergence application of pendimethalin 750 g/ha at 3 DAT *fb* PoE application of bispyribac-sodium 25 g/ha at 30. The similar results were reported by Deepthi and Subramanyam (2010) and Prabhakaran *et al.* (2014).

Growth, yield and yield attributing characters

The rice growth attributes, *viz*. plant height (cm) and no. of tillers at harvest and yield attributes, *viz*. total dry matter production, grain yield and straw yield were influenced significantly due to weed management treatments. Among the weed management treatments, pendimethalin 750 g/ha at 3 DAT *fb* penoxsulam 22.5 g/ha at 30 DAT found excellent in recording significantly higher growth and yield attributes as compared to others. However, it was at par with the pre-emergence application of pendimethalin *fb* bispyribac-sodium. Significantly the highest plant height (95.2 cm), a higher number of tillers per hill (25.7), total dry matter production (66.8

Table 1. Effect of weed management treatments on fresh weight, dry weight and weed control efficiency *Vaucheria* spp. of yellow-green algae in transplanted rice at different crop growth stages, pooled data (2017 and 2018)

Treatment	Fresh weight (g/m^2)			Dry weight (g/m^2)			Weed control efficiency (%)		
	15 DAT	30 DAT	45 DAT	15 DAT	30 DAT	45 DAT	15 DAT	30 DAT	45 DAT
Pretilachlor 750 g/ha at 3 DAT *fb* ethoxysulfuron 18.75 g/ha at 30 DAT	6.5 (41.6)	6.1 (37.2)	4.6 (20.8)	2.8 (7.6)	2.7 (6.8)	2.4 (5.2)	7.0 (49.2)	8.5 (71.6)	9.4 (88.9)
Pyrazosulfuron-ethyl 20 g/ha 3 DAT *fb* chlorimuron-ethyl + metsulfuron-methyl 4 g/ha at 30 DAT	6.4 (40.4)	6.0 (35.6)	4.5 (19.6)	2.8 (7.2)	2.6 (6.4)	2.3 (4.8)	7.2 (52.1)	8.6 (73.6)	9.6 (90.9)
Pendimethalin 750 g/ha at 3 DAT *fb* bispyribac-sodium 25 g/ha at 30 DAT	6.0 (35.6)	5.6 (30.8)	4.1 (16.0)	2.6 (6.4)	2.5 (6.0)	2.3 (4.8)	8.0 (63.6)	9.1 (82.4)	9.6 (91.3)
Butachlor 1000 g/ha at 3 DAT *fb* 2,4-D sodium salt 1000 g/ha at 30 DAT	7.1 (49.6)	6.8 (46.0)	5.3 (28.0)	2.8 (7.6)	2.8 (7.6)	2.5 (5.6)	6.8 (46.3)	7.7 (59.2)	9.3 (85.4)
Pendimethalin 750 g/ha at 3 DAT *fb* penoxsulam 22.5 g/ha at 30 DAT	5.8 (32.8)	5.1 (26.0)	3.7 (13.2)	2.5 (6.0)	2.5 (5.6)	2.3 (4.8)	8.5 (72.6)	9.4 (87.2)	9.6 (92.4)
Penoxsulam 22.5 g/ha at 15DAT *fb* 2,4-D sodium salt 1000 g/ha at 40 DAT	7.1 (50.4)	6.9 (46.8)	5.5 (29.6)	3.1 (9.2)	2.9 (8.0)	2.5 (6.0)	1.5 (1.7)	7.4 (54.8)	8.9 (79.4)
Bispyribac-sodium 25 g/ha at 15 DAT *fb* 2,4-D sodium salt 1000 g/ha at 40 DAT	6.9 (47.6)	6.6 (42.8)	5.1 (25.6)	3.1 (9.2)	2.8 (7.2)	2.4 (5.2)	2.3 (4.8)	7.9 (62.8)	9.3 (86.6)
Bispyribac-sodium 25 g/ha at 20 DAT *fb* one HW 40 DAT	7.0 (48.8)	6.6 (43.6)	5.2 (26.8)	3.1 (9.2)	2.8 (7.2)	2.4 (5.2)	2.0 (3.8)	7.8 (60.6)	9.4 (87.4)
Penoxsulam 22.5 g/ha 20 DAT *fb* one HW at 40 DAT	6.7 (44.0)	6.2 (38.7)	4.8 (22.4)	3.1 (9.2)	2.8 (7.2)	2.4 (5.2)	2.2 (4.3)	8.2 (66.8)	9.4 (88.6)
Chlorimuron-ethyl + metsulfuron-methyl 4 g/ha at 20 DAT *fb* one HW at 40 DAT	6.8 (45.2)	6.4 (40.4)	4.9 (24.0)	3.1 (9.2)	2.8 (7.2)	2.4 (5.2)	1.6 (2.2)	8.1 (64.8)	9.4 (87.4)
Farmers practice (hand weeding at 15 DAT *fb* conoweeding at 30 and 45 DAT)	6.3 (38.8)	5.9 (34.0)	4.4 (18.8)	3.0 (8.8)	2.6 (6.4)	2.3 (4.8)	2.4 (5.4)	8.7 (76.2)	9.4 (88.6)
Unweeded check	8.4 (70.4)	8.2 (67.2)	8.0 (63.6)	3.2 (10.0)	3.4 (10.8)	3.4 (11.2)	0.71 (0.0)	0.71 (0.0)	9.57 (91.0)
LSD (p=0.05)	1.3	6.0	5.6	0.3	0.2	0.2	5.0	7.3	9.7

Note: Square root $\sqrt{x+0.5}$ transformed values. Values in the parentheses are original values

Table 2. Plant height, no. of tillers, total dry matter production, grain yield, straw yield and economics as influenced by weed management treatments in transplanted rice at harvest

Treatment	Plant height at harvest (cm)	No. of tillers at harvest	Total dry matter production at harvest (g/hill)	Grain yield (t/ha)			Straw yield (t/ha)			B:C ratio
				2017	2018	Pooled	2017	2018	Pooled	
Pretilachlor 750 g/ha at 3 DAT *fb* ethoxysulfuron 18.75 g/ha at 30 DAT	88.6	23.3	62.4	4.86	4.95	4.9	5.84	5.92	5.89	1.98
Pyrazosulfuron-ethyl20 g/ha 3 DAT *fb* chlorimuron-ethyl + metsulfuron-methyl4 g/ha at 30 DAT	89.5	23.8	62.3	4.91	4.99	4.93	5.90	6.04	5.97	2.00
Pendimethalin750 g/ha at 3 DAT *fb* bispyribac-sodium 25 g/ha at 30 DAT	92.1	24.5	65.0	5.16	5.20	5.18	6.12	6.21	6.16	2.01
Butachlor 1000 g/ha at 3 DAT *fb* 2,4-D sodium salt 1000 g/ha at 30 DAT	84.8	20.5	53.7	4.30	4.36	4.33	5.36	5.47	5.42	1.78
Pendimethalin 750 g/ha at 3 DAT *fb* penoxsulam 22.5 g/ha at 30 DAT	95.2	25.7	66.8	5.33	5.35	5.33	6.22	6.26	6.24	2.09
Penoxsulam 22.5 g/ha at 15DAT *fb* 2,4-D sodium salt 1000 g/ha at 40 DAT	83.4	20.2	51.4	4.18	4.20	4.19	5.23	5.28	5.25	1.68
Bispyribac-sodium 25 g/ha at 15 DAT *fb* 2,4-D sodium salt 1000 g/ha at 40 DAT	85.8	21.9	55.2	4.60	4.65	4.63	5.59	5.65	5.62	1.81
Bispyribac-sodium 25 g/ha at 20 DAT *fb* one HW 40 DAT	85.3	21.2	53.4	4.49	4.49	4.49	5.45	5.62	5.53	1.68
Penoxsulam 22.5 g/ha 20 DAT *fb* one HW at 40 DAT	87.1	22.8	58.3	4.80	4.85	4.82	5.78	5.87	5.83	1.80
Chlorimuron-ethyl + metsulfuron-methyl 4 g/ha at 20 DAT *fb* one HW at 40 DAT	86.3	22.1	57.8	4.70	4.75	4.73	5.69	5.76	5.73	1.82
Farmers practice (hand weeding at 15 DAT *fb* conoweeding at 30 and 45 DAT)	90.5	23.9	63.1	4.99	5.05	5.02	5.99	6.04	6.02	1.86
Unweeded check	76.5	16.6	36.2	2.87	2.97	2.92	3.96	4.16	4.06	1.24
LSD (p=0.05)	4.8	1.3	2.7	0.50	0.50	0.50	0.60	0.60	0.60	-

g/hill) and higher grain yield (5.3 t/ha), straw yield (6.2 t/ha) with B:C ratio (2.09-2.11) was recorded in treatment application of pendimethalin at 750 g/ha at 3 DAT *fb* penoxsulam at 22.5 g/ha at 30 DAT (**Table 2**). The next best treatment was pre- pendimethalin at 750 g/ha at 3 DAT *fb* bispyribac-sodium 25 g/ha at 30 DAT as compared to unweeded check. The highest plant height of the specific treatments might be due to better nutrient utilization, accelerated cell enlargement and meristematic tissue development under the lower competition of weeds with the crop for light, nutrients and space along with the availability of water which allows the crop to grow to their potential. The higher yield in these treatments could be attributed to reduced weed density, weed biomass, better weed control efficiency, higher magnitude of growth parameters and helped to produce more photosynthates which were transformed into more number of productive tillers per hill helps in producing maximum grain yield. This was in line with the findings of Pandey and Tiwari (1996) and Saha (2005).

It was concluded that pre-emergence application of pendimethalin at 750 g/ha at 3 DAT *fb* PoE application of penoxsulam 24% CS at 22.5 g/ha at 30 DAT found most effective and economical in controlling the *Vaucheria* spp. of yellow-green algae in transplanted rice in coastal Karnataka.

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Tillage and weed management effects on productivity of wheat under dry seeded rice–wheat system on lateritic soils of West Bengal

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ABSTRACT

A field study was conducted during 2016-17and 2017-18 to evaluate the impact of four tillage systems, *viz.* zero tillage (ZT) both in rice and wheat, conventional tillage (CT) both in rice and wheat, ZT in rice – CT in wheat and CT in rice –ZT in wheat with four weed management practices (recommended herbicide, recommended herbicide + one hand weeding, weed free and weedy check) in dry seeded rice–wheat cropping system on a lateritic soil of West Bengal. Among weed management practices, application of sulfosulfuron + metsulfuron at 0.032 kg/ha at 20 DAS followed by one hand weeding at 40 DAS in wheat was found to be the most effective. The yield of wheat under ZT-ZT was found to be the highest (3.78 t/ha), which was at par with CT-ZT. Advantages in ZT-ZT were to the extent of 23.6 and 21.8% over CT-CT in first and second year, respectively. Among weed management practices, recommended herbicide followed by one hand weeding registered higher yield (3.78 t/ha) and was comparable with the weed free treatment. The highest B:C ratio was recorded in zero tillage in wheat (ZT-ZT and CT-ZT) in combination with the sole application of recommended herbicide. The continuous ZT, especially in wheat with recommended herbicide alone was promising for higher productivity and profitability under dry-seeded rice–wheat system on lateritic soils of Eastern India.

INTRODUCTION

Rice-wheat cropping system (RWCS) is called as Indian Food Security System which occupies the highest area in India. Globally RWCS occupies about 24 million (M) ha area, and in India it is the most popular and prevalent sequence covering ~10.5 Mha mainly in the Indo-Gangetic Plains (IGP) (Jat *et al.* 2014). Rice and wheat crops contribute 76% of the total food grain production in India (Economic Survey 2018-19).

Yield losses due to weeds in wheat have been estimated up to 33-47% (Meena *et al.* 2019). Whereas, Kumar *et al.* (2013) reported that reduction in wheat grain yield due to the uncontrolled weeds is up to 66%. Composition of weed flora and their competition with crop plants not only depend upon cropping system but also change dynamically with the soil, climate and management practices.

Tillage operations can have a major impact on the distribution of weed flora and weed seeds in the soil. In traditional RWCS, puddled transplanted rice is followed by the conventional till wheat, which requires large amount of water, labour and energy. Puddling deteriorates soil health, leads to compaction of sub soil, and lessens the soil porosity. However, accumulation of nutrient in surface soil, soil penetration resistance and increased weed competition by leaving most of the weed seeds on or close to the top layer of the soil surface are the negative impacts of long-term zero tillage cultivation.

Along with the tillage operation, use of effective herbicide can give the yield advantage by minimising the weed infestation in rice-based cropping system (Teja and Duary 2018). The ZT has been the function of weed management, not just in wheat but in rice as well (Malik *et al.* 2018). With ZT, the early emergence of wheat and the absence of soil disturbance in uncropped area resulted in less and late emergence of weeds. Therefore, crop-weed competition in wheat crop is greatly reduced. Thus, the present study was conducted to see the effect of tillage and weed management practices on weed growth and yield of wheat under direct-seeded rice-wheat cropping system.

MATERIALS AND METHODS

Field experiment was carried out during 2016-17 and 2017-18 at the Institute of Agriculture, Visva-Bharati, Sriniketan ($23^0 39'$ North latitude and $87^0 42'$ East longitude with an average altitude of 58.9 m above MSL), West Bengal. Experimental plot was having red and lateritic type of soil association group with sandy loam in texture (sand: 70.4, silt: 17.1 and clay: 12.5%) and acidic in soil reaction (6.10 pH). The top-soil (0-15 cm layer) at the beginning of the experiment was low (0.41%) in organic carbon, available nitrogen (135.0 kg/ha) and extractable K (124.4 kg/ha) whereas, medium (10.7 kg/ha) in available phosphorous.

The experiment was laid out in a split-plot design in three replications with four tillage practices in main plot and four weed management practices in sub-plot. Four tillage systems consisted of zero tillage (ZT) both in dry direct-seeded rice (DSR) and wheat (ZT-ZT), conventional tillage (CT) both in DSR and wheat (CT-CT), zero tillage (ZT) in DSR – conventional tillage (CT) in wheat (ZT-CT) and conventional tillage (CT) in DSR – zero tillage (ZT) in wheat (CT-ZT). Four weed management practices were: recommended herbicide *i.e.* pendimethalin at 1.0 kg/ha followed by bispyribac-sodium at 0.025 kg/ha in rice and sulfosulfuron + metsulfuron at 0.032 kg/ha in wheat, recommended herbicide + one hand weeding at 40 days after sowing (DAS), weed free and weedy check. Herbicide spraying was done by using knapsack sprayer with flat fan nozzle. In zero tilled plots, glyphosate at 1.0 kg/ha was sprayed well ahead before sowing.

Crop varieties '*MTU 1010*' and '*PBW 343*' were used for rice and wheat under the experimentation, respectively. Sowing was done mechanically by using zero till ferti-cum-seed drill machine (National Zero Till Ferti-cum-Seed Drill, Ludhiana). To accomplish the sowing, the row to row spacing of 20 cm was maintained. Seed rate was fixed by adjusting the zero till drill machine at 40 kg for rice and 100 kg/ha for wheat. The fertilizer was applied in the form of urea and 10-26-26 whereas the recommended dose of N, P and K for rice and wheat was 80:40:40 and 120:60:60 kg/ha, respectively. Zinc sulphate 25 kg/ha was also applied at final land preparation. The field was surface-irrigated and kept moist throughout the season and irrigation was stopped 2 weeks before crop harvest. Observations of the parameters were recorded at 60 DAS and at the time of harvest by following standard procedure. The density of the weeds was recorded at 60 DAS by placing a quadrate of 50 × 50 cm from the marked sampling area of 1.0 m^2 in each plot. For recording their biomass, weed samples were sun-dried and later oven dried at 70^oC until constant weight was attained. Grain yield was taken from undisturbed net plot area in the center of each plot at 14% moisture and statistically analyzed at a 5% level of significance. The cost of cultivation, gross return, net return and B:C ratio of wheat under different treatments were calculated by considering the cost of various inputs like seeds, fertilizers, herbicides and all other inputs including labour charges as per the local market price. The value of products like grain and straw was also calculated on the basis of Govt. of India Minimum Support Price (MSP) and available price at the local market. The weed data were subjected to a square root transformation to normalize their distribution.

RESULTS AND DISCUSSION

Digitaria sanguinalis was the most dominant grasses and *Gnaphalium indicum* and *Polygonum plebeium* were the predominant broad-leaved weeds under all the tillage practices in both the years in wheat. However, in second year, *Spilanthes acmella* and *Anagalis arvensis* were the broad-leaved weeds found under CT-CT and CT-ZT tillage practices along with the infestation of *G. indicum* and *P. plebeium*. Mitra *et al.* (2019) observed various species of *Polygonum* as dominant in all the stages of crop growth.

Irrespective of weed management practices, density and biomass of *D. sanguinalis* was significantly the lowest under CT-CT, whilst, it was significantly at par under ZT-CT in both the years (**Table 1** and **2**). Opposite trend was observed for *G. indicum* and *P. plebeium*, where continuous zero tilled plot registered the lowest biomass, which was statistically at par with CT-ZT for both the year. Likewise, CT-ZT tillage practice was found to be significantly superior over the others in reducing density of *P. plebeium*, followed by the ZT-ZT tillage practice in the second year (**Table 1**). The effect of tillage practice was found to be non-significant for density of *P. plebeium* for first year and other weed species densities in both the year (**Table 1**). Unlike densities of other weed species, the highest biomass was recorded under continuous conventionally tilled plot in the first year, whilst there was no significant difference among the tillage practices for other weeds in the second year (**Table 2**). In continuously conventional tilled plot (CT-CT) and zero tillage in rice *fb* conventional tillage in wheat (ZT-CT) registered significantly higher density and biomass of total weeds as compared to zero tilled wheat (ZT-ZT and/or CT-ZT) during both the years (**Table 1** and **2**).

The lowest weed density, biomass and weed growth rate across all the growth stages under zero tillage of maize as compared to other conventional tillage practices have been reported earlier (Khedwal *et al.* 2017). The biomass of *D. sanguinalis* under CT-CT was 31.16 and 24.16% lowered than ZT-ZT in first and second year, respectively. Total weed biomass in ZT-ZT had 18.96 and 12.53% less than CT-CT in first and second year, respectively.

The weed free check attained least weed count and biomass, which was closely followed by recommended herbicide with one hand weeding (**Table 1** and **2**). Application of recommended herbicide with one hand weeding registered similar result as that of weed free plot with respect to *P. plebeium* for both the years and *G. indicum* for the first year. All the weed management practices were found to be effective in total control of the *P. plebeium* population during second year of experimentation. The application of only recommended herbicide in wheat had 63.88 and 57.85% less total weed biomass than weedy check in first and second year, respectively (**Table 2**).

Mishra and Singh (2012) observed that ZT wheat sowing (either continuous or rotated with conventional) significantly increased population of grassy weeds like *A. ludoviciana* than conventional tillage (CT-CT or ZT-CT). Zero (ZT-ZT) and conventional tillage in rice *fb* zero tillage in wheat (CT-ZT) remained at par with each other in both the years. The lower emergence of weeds under ZT may be due to higher soil strength in ZT because of crust development in the absence of tillage after rice harvest, which can mechanically impede seedling emergence (Duary *et al.* 2016), and higher weed seed predation under ZT (Kumar *et al.* 2013).

Table 1. Species wise and total weed density at 60 DAS of wheat under rice-wheat system under different tillage and weed management practices

Treatment	Weed density (no./m^2)									
	2016-17					2017-18				
	D. sanguinalis	*G. indicum*	*P. plebeium*	Others	Total	*D. sanguinalis*	*G. indicum*	*P. plebeium*	Others	Total
Tillage										
ZT-ZT	2.58(6.1)	4.18(17.0)	4.39(18.7)	1.94(3.3)	7.01(48.6)	3.57(12.2)	2.96(8.3)	3.04(8.7)	4.32(18.2)	7.20(51.3)
CT-CT	1.99(3.5)	5.78(32.9)	5.09(25.4)	2.45(5.5)	8.43(70.5)	2.87(7.7)	3.99(15.4)	3.83(14.2)	3.88(14.5)	7.68(58.4)
ZT-CT	2.32(4.9)	5.05(25.0)	4.83(22.8)	2.21(4.4)	7.73(59.2)	2.95(8.2)	3.85(14.3)	3.80(13.9)	3.76(13.7)	7.57(56.8)
CT-ZT	2.52(5.8)	4.34(18.4)	4.46(19.4)	2.06(3.7)	7.27(52.3)	3.35(10.7)	3.41(11.1)	3.04(8.7)	3.57(12.3)	6.93(47.5)
LSD(p=0.05)	0.34	0.67	NS	NS	0.54	0.32	0.67	0.31	NS	0.54
Weed management										
RH	3.26(10.1)	4.67(21.3)	6.58(42.8)	3.36(10.8)	9.51(90.0)	3.92(14.9)	6.35(39.8)	0.71(0.0)	4.18(17.0)	8.58(73.1)
RH+HW	1.47(1.6)	4.04(15.8)	0.71(0.0)	0.71(0.0)	4.40(18.9)	2.55(6.0)	0.71(0.0)	0.71(0.0)	2.17(4.2)	3.27(10.2)
Weed free	0.71(0.0)	0.71(0.0)	0.71(0.0)	0.71(0.0)	0.71(0.0)	0.71(0.0)	0.71(0.0)	0.71(0.0)	0.71(0.0)	0.71(0.0)
Weedy	3.97(15.3)	9.93(98.1)	10.8(115.5)	3.88(14.6)	15.8(249.5)	5.58(30.6)	6.45(41.1)	11.6(133.7)	8.48(71.4)	16.8(282.2)
LSD(p=0.05)	0.28	0.52	0.37	0.33	0.45	0.27	0.63	0.37	0.47	0.52

Figures within parentheses indicate original values. Data were transformed to $\sqrt{x+0.5}$ before analysis
CT: Conventional tillage, ZT: Zero tillage, RH: Recommended herbicides, HW: Hand weeding

Table 2. Species wise and total weed biomass at 60 DAS of wheat under rice-wheat system under different tillage and weed management practices

Treatment	Weed biomass (g/m^2)									
	2016-17					2017-18				
	D. sanguinalis	*G. indicum*	*P. plebeium*	Others	Total	*D. sanguinalis*	*G. indicum*	*P. plebeium*	Others	Total
Tillage										
ZT-ZT	1.81(2.8)	1.87(3.0)	1.81(2.8)	1.43(1.5)	3.27(10.2)	1.85(2.9)	1.93(3.2)	1.43(1.5)	2.41(5.3)	3.67(13.0)
CT-CT	1.38(1.4)	2.51(5.8)	2.35(5.0)	2.01(3.5)	3.89(14.6)	1.49(1.7)	2.81(7.4)	1.79(2.7)	2.21(4.4)	4.13(16.5)
ZT-CT	1.61(2.1)	2.25(4.5)	2.25(4.6)	1.56(1.9)	3.57(12.3)	1.49(1.7)	2.59(6.2)	1.75(2.6)	2.32(4.9)	4.01(15.5)
CT-ZT	1.73(2.5)	2.01(3.5)	1.94(3.3)	1.39(1.4)	3.28(10.2)	1.69(2.3)	2.08(3.8)	1.46(1.6)	1.99(3.5)	3.41(11.1)
LSD(p=0.05)	0.30	0.25	0.32	0.31	0.27	0.17	0.38	0.19	NS	0.33
Weed management										
RH	2.21(4.4)	1.98(3.4)	2.53(5.9)	2.23(4.5)	4.43(19.1)	1.86(3.0)	4.02(15.7)	0.71(0.0)	2.48(5.6)	5.03(24.7)
RH+HW	1.08(0.7)	1.43(1.5)	0.71(0.0)	0.71(0.0)	1.62(2.1)	1.26(1.1)	0.71(0.0)	0.71(0.0)	1.13(0.8)	1.54(1.9)
Weed free	0.71(0.0)	0.71(0.0)	0.71(0.0)	0.71(0.0)	0.71(0.0)	0.71(0.0)	0.71(0.0)	0.71(0.0)	0.71(0.0)	0.71(0.0)
Weedy	2.53(5.9)	4.52(19.9)	4.41(18.9)	2.74(7.0)	7.26(52.2)	2.69(6.7)	3.98(15.3)	4.30(18.0)	4.61(20.8)	7.94(62.5)
LSD(p=0.05)	0.19	0.28	0.25	0.23	0.34	0.11	0.40	0.15	0.31	0.36

Figures within parentheses indicate original values. Data were transformed to $\sqrt{x+0.5}$ before analysis; CT: Conventional tillage, ZT: Zero tillage, RH: Recommended herbicides, HW: Hand weeding

Effect on yield of wheat

The yield levels of grain (3.48 and 3.78 t/ha) and straw (5.23 and 5.70 t/ha) were significantly the highest under ZT-ZT, in first and second year, respectively, compared with the others during *Rabi* season (**Table 3**). With respect to grain yield, advantages in ZT-ZT were to the extent of 23.59 and 21.75% over CT-CT in first and second year, respectively (**Table 3**). Although the ZT-ZT crop yielded the highest, then CT-ZT tillage practice, they did not differ from each other in respect of grain (3.34 and 3.62 t/ha) and straw (5.15 and 5.57 t/ha) yield, in first and second year, respectively. Irrespective of tillage practices, the highest productivity of grain (3.72 and 3.78 t/ha) and straw (5.56 and 6.31 t/ha) was significantly recorded with the weed free treatment, which, however, was found to maintain statistically similar yield levels with recommended herbicide with one hand weeding (grain yield 3.58 and 3.68 t/ha, straw yield 5.06 and 5.60 t/ha) in first and second year, respectively (**Table 3**). Compared with weedy check, yield advantages under these treatments ranged from 44.23 to 30.67% and 32.58 to 29.33%, on grain and straw yield, respectively (**Table 3**). Weed management treatments did not differ significantly in both the years in respect of harvest index.

Interaction amongst tillage and weed management practices on grain yield of wheat was significant in both the years. Weed free registered significantly the highest grain yield under all the tillage practices (**Figure 1** and **2**). After completion of two rounds of tillage practices in rice-wheat system, sole application of recommended herbicide remained at par with the weed free treatment under ZT-ZT and CT-ZT tillage practices. However, weed free under CT-ZT was comparable with sole application of recommended herbicide in ZT-ZT (**Figure 1** and **2**). Singh *et al.* (2017) also proved that metsulfuron + clodinafop applied in wheat with ZT preceding soybean resulted in higher grain and straw yields, than other combinations.Similarly, in CT-ZT, application of recommended herbicide was at par with weed free treatment under ZT-CT with respect to grain yield of wheat. ZT sowing of maize with recommended herbicide *fb* one HW resulted in lower weed infestation, higher productivity and economics returns (Khedwal *et al.* 2017).

Economics

The tillage cost was recorded highest in CT-CT, CT-ZT followed by ZT-CT and least in ZT-ZT. The tillage cost in ZT-ZT was lower by 7.13% and 7.14% than CT-CT during 2016-17 and 2017-18, respectively (**Table 3**). Similarly, the cost of weed management was recorded highest in weed free treatment. The cost of production was lower by 30.85 to 28.91% in ZT-ZT than CT-CT in 2016-17 and 2017-18, respectively. The gross return, net return and B:C ratio of wheat was highest in ZT-ZT which was closely followed by CT-ZT during both the year of investigation (**Table 3**). Among the weed management practices, sole application of recommended herbicide registered the highest net return as well as B:C ratio in the second year of experimentation (**Table 3**). Therefore, the highest B:C ratio was recorded in zero tillage in wheat (ZT-ZT and CT-ZT) in combination with the recommended herbicide alone (**Table 4**).

The cost of cultivation was significantly affected by the tillage and weed management practices. Consistent with our results, savings in

Table 3. Grain, straw yield and economics of wheat in rice-wheat cropping system under different tillage and weed management practices

Treatment	2016-17 Cost of cultivation (×10³ ₹/ha)	2016-17 Gross return (×10³ ₹/ha)	2016-17 Netreturn (×10³ ₹/ha)	2016-17 B:C ratio	2017-18 Cost of cultivation (×10³₹/ha)	2017-18 Gross return (×10³ ₹/ha)	2017-18 Net return (×10³ ₹/ha)	2017-18 B:C ratio	2016-17 Grain yield (t/ha)	2016-17 Straw yield (t/ha)	2017-18 Grain yield (t/ha)	2017-18 Straw yield (t/ha)
Tillage												
ZT-ZT	34.15	61.80	27.65	0.81	35.23	67.11	31.89	0.94	3.48	5.23	3.78	570
CT-CT	36.77	47.23	10.46	0.28	37.94	52.06	14.12	0.37	2.66	4.00	2.96	3.99
ZT-CT	36.77	52.58	15.81	0.42	37.94	57.88	19.94	0.53	2.97	4.34	3.25	5.11
CT-ZT	34.15	59.42	25.27	0.74	35.23	64.48	29.25	0.86	3.34	5.15	3.62	5.57
LSD(p=0.05)	-	6.67	6.67	0.19	-	4.38	4.38	0.11	0.38	0.78	0.29	0.64
Weed management												
RH	31.58	56.00	24.42	0.79	32.38	62.77	30.39	0.95	3.16	4.67	3.59	4.48
RH+HW	35.83	63.23	27.40	0.77	36.88	65.47	28.59	0.78	3.58	5.06	3.68	5.60
Weed free	44.76	65.96	21.20	0.48	46.64	67.82	21.18	0.46	3.72	5.56	3.78	6.31
Weedy	29.68	35.85	6.17	0.21	30.44	45.47	15.03	0.51	2.00	3.41	2.55	3.96
LSD(p=0.05)	-	2.58	2.58	0.08	-	2.52	2.52	0.07	0.15	0.53	0.14	0.76

CT: Conventional tillage, ZT: Zero tillage, RH: Recommended herbicides, HW: Hand weeding

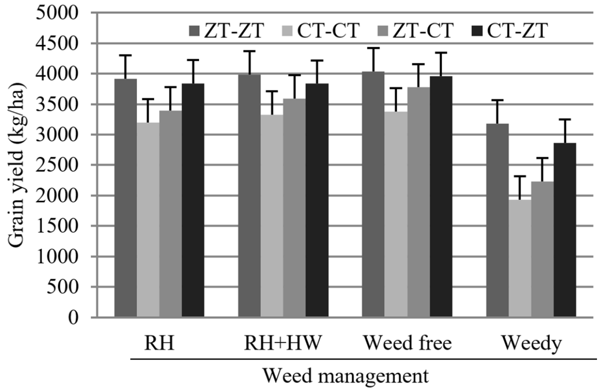

Figure 1. Interaction effect of tillage and weed management practices on grain yield of wheat under rice-wheat cropping system in second year

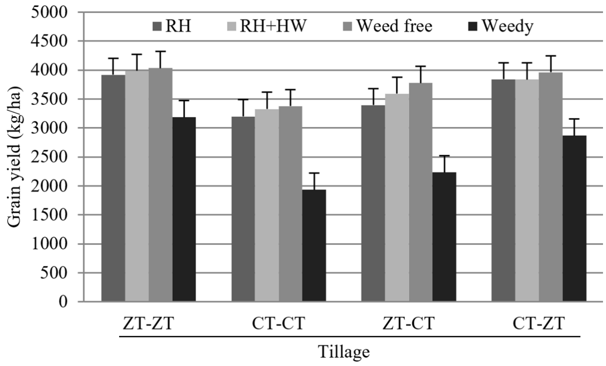

Figure 2. Interaction effect of weed management and tillage practices on grain yield of wheat under rice-wheat cropping system in second year

labor and production costs and higher net economic returns have been reported in zero tilled wheat (Stanzen *et al.* 2017). The results demonstrate that ZT in wheat seeding technology can play an important role in saving inputs and improving farmer's income.

Thus, after two cycles of rice-wheat system, ZT in wheat (ZT-ZT and/or CT-ZT) with recommended herbicide alone may be recommended for effective weed management and higher productivity and profitability of wheat in direct-seeded rice-wheat system on lateritic soils of Eastern India.

Table 4. Interaction effect of tillage and weed management practices on B:C ratio of wheat under rice-wheat cropping system in second year

Treatment	B:C ratio			
	Zero tillage-zero tillage	Conventional tillage-conventional tillage	Zero tillage-conventional tillage	Conventional tillage-zero tillage
RH	1.21	0.64	0.77	1.17
RH + HW	1.01	0.54	0.67	0.91
Weed free	0.60	0.26	0.41	0.57
Weedy	0.93	0.06	0.28	0.77
LSD (p=0.05)	T×W 0.14		W×T 0.16	

RH: Recommended herbicides; HW: hand weeding

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Weed management in wheat by pre-emergence and pre-mix post-emergence combinations of herbicides

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ABSTRACT

Field investigation was carried out at Akola, Maharashtra during three consecutive *Rabi* season of 2016-2017, 2017-18 and 2018-19 to assess the efficacy of herbicide combinations in wheat. Treatments comprised of twelve different pre-emergence and pre-mix combinations of post-emergence herbicides. Results revealed that pre-mix post-emergence application (PoE) of clodinafop propargyl + metsulfuron-methyl 0.06 + 0.004 kg/ha at 35 DAS and sulfosulfuron + metsulfuron-methyl 0.03 + 0.002 kg/ha at 35 DAS gave higher weed control efficiency (90 and 80%) and lower weed index (2.85 and 2.98%). These proved as effective as weed free treatment and recorded significantly higher grain yield of 4.37 and 4.36 t/ha, respectively over rest of the treatments. The highest net monetory returns and B:C ratio (₹ 64356/ha, 3.69) were registered with application clodinafop-propargyl + metsulfuron-methyl 0.06 + 0.004 kg/ha at 35 DAS followed by sulfosulfuron + metsulfuron-methyl 0.03 + 0.002 kg/ha at 35 DAS. (₹ 62162/ha and 3.40).

INTRODUCTION

Wheat (*Triticum aestivum*. L.) is the most widely cultivated as staple food crop of world playing crucial role in global food security by providing food to billions of people and half of the dietary protein and more than half of the calories (Meena *et al.* 2017). It is the second important food crop consumed next to rice and contributes to the extent of 25% of total food grain production of country.

In era of climate change and increasing biotic and abiotic stresses, maintaining yield up to required level is going to be formidable challenge in coming future. Productivity of the wheat depends upon several factors like crop establishment techniques, irrigation, weed management, fertilizers management and other cultural practices.Weeds are the major deterrent to the development of sustainable wheat crop production and causes enormous losses (37.0 to 57.1%) due to their interference. (Verma *et al.* 2015). Wheat in *Rabi* season is generally sown after pre-sowing irrigation to obtain the uniform stand of the crop, but at the same time irrigation favours germination of weed seeds. Under such a situation, it is very essential to control weeds during the first 35 to 45 days after sowing. Weed competiton for longer period results into reduction of surviving tillers and the tillers bear short ears, less number of grains in comparison to crop tillers produced in weed free situation. (Rathod and Vadodaria 2004).

In wheat, chemical weed control is a preferred practice due to scarce and costly labour as well as lesser feasibility of mechanical or manual weeding. Nowadays there are many good ready-mix combinations of herbicides used for weed control in wheat and they were found effective in controlling broad spectrum weeds in wheat. Combination of sulfosulfuron + metsulfuron, clodinafop + metsulfuron and mesosulfuron + iodosulfuron has been found promising against complex weed flora. Under such situation, a suitable combination of some broad-spectrum herbicides are needed. To control diverse weed flora, application of two or more herbicides and pre-mix combination is advantageous. Hence, an attempt was made to assess the efficancy of different post-emergence herbicide combinations on weed flora, growth and yield of wheat.

MATERIALS AND METHODS

The study was conducted at Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola during three consecutive *Rabi* season of the year 2016-2017, 2017-18 and 2018-19. The experiment was laid out in a randomized block design with twelve treatments replicated thrice. Treatments include pendimethalin

1.0 kg/ha, sulfosulfuron 0.025 kg/ha, metribuzin 0.21 kg/ha, clodinafop 0.06 kg/ha, pendimethalin + metribuzin 1.0 + 0.175 kg/ha, pendimethalin *fb* sulfosulfuron 1.0 + 0.018 kg/ha, sulfosulfuron + metsulfuron 0.3 + 0.002 kg/ha, pinoxaden + metsulfuron-methyl 0.6 + 0.004 kg/ha, mesosulfuron + iodosulfuron 0.012+ 0.0024 kg/ha, clodinafop-propargyl + metsulfuron 0.06 + 0.004 kg/ha, 2 hand weeding at 30 and 60 DAS and unweeded control. The soil was low in nitrogen, medium in available phosphorus and high in potassium content. Wheat variety '*AKAW-4627*' was sown on 20^{th} November, 17^{th} November and 26^{th} November during the year 2016-17, 2017-18 and 2018-19, respectively at 22.5 spacing with 120:60:60 NPK kg/ha. After sowing, a light irrigation was given to the crop for uniform germination and next day pre-emergence herbicides were applied. The application of herbicide was done as per the treatments with manually operated knapsack sprayer attached with a flat fan nozzle. After calibrating the sprayer, water volume used was 700 L/ha for PE and 500 L/ha for PoE.

The observations on weed density and weed biomass were taken at 30 days interval upto harvest from four randomly selected spots by using a quadrate of 50 x 50 cm from net plot area. The entire weeds inside the quadrat were uprooted and cut close to the transition of root and shoot in each plot and collected for dry matter accumulation. Then weeds were grouped as monocot species and dicot species. The samples were first dried in sun and kept in oven at 70 $\pm$ 2^0C. The dried samples were weighed and expressed as dry biomass (g/m^2). Square root transformation was done for weed density and weed biomass by using the formula ($\sqrt{x+1}$). Weed control efficiency (WCE) and weed index was calculated by using standard formula suggested by Mani *et al.* (1973). Phytotoxicity symptoms due to herbicides on crop was recorded by using a visual score scale of 0-10 scale method as proposed by Rao (2000). Visual assessment of herbicide toxicity on crop was monitored 10 days after application of herbicide in respective treatment. Cost of cultivation, gross returns and benefit cost ratio for each treatment were calculated by taking into consideration of total costs incurred and returns obtained. Data on various growth and yield attributing characters were analysed as per standard procedure.

RESULTS AND DISCUSSION

Weed flora

The experimental field was absolutely invaded with mixed population of weed flora consisting of both dicots and monocots. Among the total weeds, dicots (82%) were more prominent than monocot weeds (18%). Major dicot weed flora during *Rabi* season in wheat crop was dominated by *Amaranthus polygamus, Euphorbia geniculata, Phyllanthus niruri, Parthenium hysterophorus, Argemone mexicana, Amaranthus viridis, Chenopodium album, Chenopodium murale, Melilotus indica, Portulaca oleracae, Mimosa pudica, Alternanthera triandra* and among the monocots weeds *Cyperus rotundus, Cynodon dactylon, Dinebra Arabica, Poa annua, Digitaria sanguinalis, Dinebra retroflexa and Commelina benghalensis* were the weeds observed in the experimental field. Similar observations on weed flora in wheat was also reported by Khobragade and Sathawane (2014).

Crop phytotoxicity

The herbicide toxicity on crop stand and growth was recorded at 10 days after application of herbicide in respective treatment by using visual score scale of 0-10. Phytotoxicity rating revealed that, at 10 DAS pre-emergence application metribuzin 0.21 kg/ha gave setback to wheat crop by causing stunting and discolouration of crop, but recovered after some days. Similar symptoms of phytotoxicity was observed in case of pendimethalin + metribuzin 1.0 + 0.175 kg/ha as a pre-emergence application (**Table 1**). However,among the post-emergence herbicide combination of mesosulfuron-methyl + iodosulfuron-methyl showed phytotoxic effect (score 2) on wheat crop where stunting and discolouration of leaves was observed for a limited period and recovered thereafter without any effect on final yield of wheat.Similar results with regards to phytotoxicity was reported earlier by Chaudhari *et al.* (2017).

Effect on weed density and dry weight of weeds

Pooled analysis of data revealed significant reduction in all weed control treatments with respect to weed density and dry weed biomass over unweeded control as indicated in (**Table 1**). Highest reduction in weed density and dry matter of weeds were recorded under two hand weeding at 30 and 60 DAS (13.98 no./m^2 and 15.40 g/m^2) due to complete removal of the weeds among the herbicides, clodinafop-propargyl + metsulfuron-methyl was found to be more superior in curtailing the weed population and dry weight of weeds (18.89 no./m^2, 24.66 g/m^2) followed by sulfosulfuron + metsulfuron-methyl (31.01 no./m^2, 47.14 g/m^2) as compared to unweeded control (**Table 1**). Sole application of a single herbicide was less effective in controlling weeds as compared to their pre-mix application. The tank mixtures of broad-leaf and grassy weed killing herbicides provided higher order of performance in terms of weed density and intensity of total weeds as observed by Meena *et al.* (2017). Pre-mix combination of clodinafop-propargyl + metsulfuron-methyl provided excellent control of weeds. Total weed population was reduced significantly due to various weed control treatments. This might be due to the herbicidal application alone and in combination which were effective in timely reducing total weed population. Lekh Chand and Punia (2017) and Chaudhary *et al.* (2017) also reported similar results.

Effect on weed control efficiency and weed index

Weed control efficiency in wheat was significantly influenced by weed management treatments, where all the treatments resulted in increase of weed control efficiency over the weedy check. Highest value of weed control efficiency (92.4%) was obtained from hand weeding treatment. Amongst herbicides, maximum value of WCE was achieved by clodinafop-propargyl + metsulfuron-methyl (89.7%) followed by sulfosulfuron + metsulfuron-methyl (79.9%) application of pre-emergence herbicides while sole application of single herbicides registered low weed control efficiency (**Table 1**). This indicate that pre-mix herbicides have significant effect on minimizing the weed population, which resulted increased yield over control treatment. Similar results were also reported by Kumar *et al.* (2012) with clodinafop-propargyl + metsulfuron in wheat. The lowest weed index (2.85%) was obtained with clodinafop-propargyl + metsulfuron-methyl followed by sulfosulfuron + metsulfuron-ethyl (2.98%). Whereas yield reduction varied from 2.85% to 29.05% in the herbicide applied plots as compared to weed free treatment. Weed index was lower in all the treatments as compared to weedy check. which provided favourable conditions for crop growth which ultimately increased the grain yield of wheat crop as compared to weedy check treatment. Similar trends in weed control efficiency and weed index were also recorded.

Effect on growth and yield

Significant reduction in plant height was noticed in unweeded control treatment which might be due to competition between crop and weeds for soil moisture, plant nutrients, solar radiation and space during active growth period (**Table 2**). These results were in accordance with the results reported by Pradhan and Chakraborti (2010) and Kaur *et al.* (2017). Significantly the highest number of effective tillers/meter row length was recorded in two hand

Table 1. Phytotoxicity rating, weed count, weed dry matter, weed control efficiency and weed index as influenced by different weed control treatments (pooled of three years)

Treatment	Crop phytotoxicity visual rating score		Weed density/m²				Weed dry matter (g/m²)				WCE (%)	Weed index (%)
	Score	Effect on crop	2016-17	2017-18	2018-19	Pooled	2016-17	2017-18	2018-19	Pooled		
Pendimethalin 1.0 kg/ha PE	0	No injury	7.15 (50.7)	7.18 (51.0)	7.08 (49.6)	7.14 (50.4)	8.34 (69.1)	9.65 (92.7)	9.73 (94.2)	9.24 (85.3)	63.22	29.05
Sulfosulfuron 0.025 kg/ha PoE at 35 DAS	0	No injury	6.05 (36.2)	6.04 (36.0)	5.91 (34.4)	6.00 (35.5)	7.02 (48.8)	6.98 (48.3)	8.12 (65.5)	7.37 (54.2)	76.88	14.83
Metribuzin 0.21 kg/ha PE	1	Slight stunting, discoloration	7.45 (55.0)	7.45 (55.0)	7.24 (51.9)	7.38 (54.0)	8.54 (72.5)	8.51 (72.0)	9.95 (98.6)	9.00 (81.0)	65.46	18.97
Clodinafop 0.06 kg/ha PoE at 35 DAS	0	No injury	6.52 (42.0)	6.52 (42.0)	6.42 (40.7)	6.49 (41.5)	7.83 (60.8)	7.82 (60.7)	8.82 (77.3)	8.16 (66.3)	71.61	15.37
Pendimethalin + metribuzin 1.0 + 0.175 kg/ha (tank mix) PE	1	Slight stunting, discoloration	7.29 (52.7)	7.29 (52.7)	7.07 (49.5)	7.22 (51.6)	8.49 (71.7)	8.63 (74.0)	9.72 (94.0)	8.95 (79.9)	65.80	21.34
Pendimethalin *fb* sulfosulfuron 1.0 + 0.018 kg/ha PE and PoE	0	No injury	6.65 (43.8)	6.67 (44.0)	6.55 (42.4)	6.62 (43.4)	7.44 (54.8)	7.47 (55.3)	9.01 (80.7)	7.97 (63.6)	73.03	6.30
Sulfosulfuron + metsulfuron-methyl 0.03 + 0.002 kg/ha PM at 35 DAS as PoE	0	No injury	5.68 (31.8)	5.64 (31.3)	5.51 (29.9)	5.61 (31.0)	6.56 (42.6)	6.51 (42.0)	7.57 (56.8)	6.88 (47.1)	79.88	2.98
Pinoxaden + metsulfuron-methyl 0.06 + 0.004 kg/ha PM at 35 DAS as PoE	0	No injury	6.60 (43.1)	6.59 (43.0)	6.50 (41.7)	6.56 (42.6)	7.47 (55.3)	6.66 (44.3)	8.93 (79.3)	7.69 (59.7)	74.85	10.29
Mesosulfuron-methyl + iodosulfuron-methyl 0.012 + 0.0024 kg/ha PM at 35 DAS as PoE	2	Stunting & discoloration	6.25 (36.6)	6.23 (38.3)	6.01 (35.7)	6.16 (36.9)	7.05 (49.2)	7.03 (49.0)	8.26 (67.8)	7.45 (55.3)	76.44	7.89
Clodinafop-propargyl + metsulfuron-methyl 0.06 + 0.004 kg/ha PM at 35 DAS as PoE	0	No injury	4.47 (19.5)	4.45 (19.3)	4.29 (17.9)	4.40 (18.9)	4.52 (20.0)	4.52 (20.0)	5.87 (34.0)	4.97 (24.7)	89.66	2.85
Two hand weeding – (30 and 60 DAS)	-	-	3.87 (14.6)	3.80 (14.0)	3.72 (13.3)	3.80 (14.0)	3.37 (10.9)	3.23 (10.0)	5.08 (25.3)	3.89 (15.4)	92.41	0.00
Un-weeded control	-	-	12.52 (156)	12.51 (156)	12.25 (150)	12.43 (154)	14.49 (210)	14.48 (209)	16.88 (284)	15.28 (234)	0.00	47.54
LSD (p=0.05)			0.48	0.44	0.37	0.49	0.43	0.48	0.47	0.46		

Figures in parentheses are original values; PE- Pre-emergence; PoE- Post-emergence; PM- Pre-mix weeding treatment (102.17 no./m) but remained at par with all treatments where pre-mix combination of post-emergence herbicides were sprayed *i.e.* sulfosulfuron + metsulfuron-methyl, pinoxaden + metsulfuron-methyl, mesosulfuron-methyl + iodosulfuron-methyl and clodinafop-propargyl + metsulfuron-methyl. Data on grain per spike at harvest showed significant differences among treatments and showed the similar trends as in case of other growth attributes (**Table 2**). These results in accordance with the results reported by Amare *et al.* (2014) and Kaur *et al.* (2017).

Pooled analysis of different weed control treatments registered significant increase in grain yield of wheat compared to unweeded control during all the three years of study. Two hand weeding at 30 and 60 DAS recorded highest grain yield of 4.49 t/ha. Further data explicated that collective application of herbicides either as pre-mix, tank mix or sequentially gave significantly higher yield over single applied herbicides. Among the herbicides, higher value of grain yield in individual years and in pooled data was obtained with clodinafop-propargyl + metsulfuron-methyl 0.012 + 0.0024 kg/ha at 35 DAS (4.37 t/ha.) closely followed by sulfosulfuron + metsulfuron-methyl 0.03+0.002 kg/ha at 35 DAS (4.36 t/ha). Pooled data showed that both these treatments recorded 48.74% increase in grain yield over unweeded control was due to higher growth and yield attributes due to reduced weed infestation by these treatments, which helped the crop plants to accumulate more dry matter through more nutrient uptake that might have provided more quantity of photosynthates to developing sink in crop plants resulted in more yield. Similar results of improvement grain yield and weed control has been reported by Walia *et al.* (2010) and Chaudhari *et al.* (2017) with different herbicides combinations. Next best treatments in order of merit regarding the grain yield were pinoxaden + metsulfuron-methyland mesosulfuron-methyl + iodosulfuron-methyl, which brought about 46.66 and 45.78% increase in pooled grain yield over unweeded control. The solitary application of single herbicide resulted in lesser grain yield compared to pre-mix combination of post-emergence herbicides.

Economics of weed control

Although, hand weeding twice at 30 and 60 DAS recorded the maximum yield and gross returns (₹ 90920/ha), but the net returns (₹ 64356/ha,) and B:C ratio (3.69) was registered in clodinafop propargyl + metsulfuron-methyl 0.06 + 0.004 kg/ha at 35 DAS followed by sulfosulfuron + metsulfuron-methyl 0.03 + 0.002 kg/ha at 35 DAS. (₹ 62162 /ha and 3.40), which was about 61.36 and 59.99% of net returns over unweeded control (**Table 3**). Thus, results clearly endorsed to better economic feasibility of treatment linked with higher production potential over unweeded control as reported earlier by Meena *et al.* (2017), Punia *et al.* (2017) and Chauhan *et al.* (2017).

It was concluded that in wheat, weeds should be controlled by the pre-mix combination of post-emergence application of either clodinafop-propargyl + metsulfuron-methyl 0.06 + 0.004 kg/ha or sulfosulfuron + metsulfuron-methyl 0.03 + 0.002

Table 2. Growth and yield attributes of wheat as influenced by weed control treatments (pooled of three years)

Treatment	Plant height at harvest (cm)				No. of effective tillers (no./m)				No. of grains per spike			
	2016-17	2017-18	2018-19	Pooled	2016-17	2017-18	2018-19	Pooled	2016-17	2017-18	2018-19	Pooled
Pendimethalin 1.0 kg/ha PE	88.98	89.43	90.80	89.74	66.43	70.00	60.10	65.51	52.92	45.73	48.13	48.17
Sulfosulfuron 0.025 kg/ha PoE at 35 DAS	91.98	93.06	92.50	92.51	78.10	79.00	82.70	79.93	53.98	49.60	52.00	51.10
Metribuzin 0.21 kg/ha PE	90.38	90.77	91.20	90.78	68.80	72.00	70.10	70.30	50.85	45.67	48.07	47.44
Clodinafop 0.06 kg/ha PoE at 35 DAS	91.25	92.42	91.90	91.86	76.73	78.00	77.90	77.54	51.33	48.40	50.80	49.42
Pendimethalin + metribuzin 1.0 + 0.175 kg/ha (tank mix) PE	89.92	90.39	89.50	89.94	68.03	76.00	67.40	70.48	51.77	45.83	48.23	47.85
Pendimethalin *fb* sulfosulfuron 1.0 + 0.018 kg/ha PE and PoE	92.98	93.76	92.80	93.18	85.73	85.00	85.80	85.51	53.53	48.43	50.83	50.17
Sulfosulfuron + metsulfuron-methyl 0.03 + 0.002 kg/ha PM at 35 DAS as PoE	93.15	94.16	93.30	93.54	88.90	91.00	95.30	91.73	51.73	49.93	52.33	50.57
Pinoxaden + metsulfuron-methyl 0.06 + 0.004 kg/ha PM at 35 DAS as PoE	92.55	92.91	91.90	92.45	89.93	80.00	96.50	88.81	52.15	48.47	50.87	49.74
Mesosulfuron-methyl + iodosulfuron-methyl 0.012 + 0.0024 kg/ha PM at 35 DAS as PoE	91.98	91.65	91.50	91.71	83.88	82.00	84.40	83.43	51.17	48.20	50.60	49.23
Clodinafop-propargyl + metsulfuron-methyl 0.06 + 0.004 kg/ha PM at 35 DAS as PoE	94.52	94.75	92.80	94.02	91.03	102.00	92.10	95.04	56.23	50.20	52.60	52.25
Two hand weeding – (30 and 60 DAS)	96.05	96.97	93.90	95.64	94.52	110.00	102.00	102.17	57.77	52.47	54.87	54.28
Un-weeded control	84.35	84.33	88.40	85.69	57.10	50.00	55.90	54.33	47.32	38.13	40.53	41.24
LSD (p= 0.05)	3.45	3.20	3.88	1.70	10.17	8.76	10.74	7.79	3.77	4.28	3.36	1.98

Table 3. Grain yield, gross monetary returns, net monetary returns and B:C ratio as influenced by weed control treatments in wheat (pooled of 3 years)

Treatment	Grain yield (t/ha)				GMR (x10³₹/ha)				NMR (x10³₹/ha)				B:C ratio
	2016-17	2017-18	2018-19	Pooled	2016-17	2017-18	2018-19	Pooled	2016-17	2017-18	2018-19	Pooled	
Pendimethalin 1.0 kg/ha PE	3.42	3.25	2.84	3.17	67.40	62.77	62.37	64.18	45.96	37.38	36.98	40.11	2.69
Sulfosulfuron 0.025 kg/ha PoE at 35 DAS	3.78	3.61	4.04	3.81	74.50	69.59	88.77	77.62	50.89	45.98	60.16	52.34	3.07
Metribuzin 0.21 kg/ha PE	3.60	3.43	3.83	3.62	70.77	66.02	84.33	73.71	47.96	41.21	55.52	48.23	2.90
Clodinafop 0.06 kg/ha PoE at 35 DAS	3.75	3.58	4.03	3.79	73.74	68.79	88.62	77.05	53.23	44.28	60.11	52.54	3.17
Pendimethalin + metribuzin 1.0 + 0.175 kg/ha (tank mix) PE	3.57	3.40	3.57	3.52	70.29	65.59	78.63	71.50	45.35	39.54	52.59	45.83	2.79
Pendimethalin *fb* sulfosulfuron 1.0 + 0.018 kg/ha PE and PoE	4.09	3.91	4.06	4.02	80.69	75.26	89.21	81.72	56.68	50.25	60.20	55.71	3.15
Sulfosulfuron + metsulfuron-methyl 0.03 + 0.002 kg/ha PM at 35 DAS as PoE	4.48	4.31	4.28	4.36	88.32	82.29	94.14	88.25	64.90	54.87	66.72	62.16	3.40
Pinoxaden + metsulfuron-methyl 0.06 + 0.004 kg/ha PM at 35 DAS as PoE	4.32	4.15	4.13	4.20	85.04	79.30	90.77	85.04	63.63	53.89	59.36	58.96	3.33
Mesosulfuron-methyl + iodosulfuron-methyl 0.012 + 0.0024 kg/ha PM at 35 DAS as PoE	4.27	4.09	4.02	4.13	84.00	78.29	88.42	83.57	62.39	52.68	58.81	57.96	3.31
Clodinafop-propargyl + metsulfuron-methyl 0.06 + 0.004 kg/ha PM at 35 DAS as PoE	4.45	4.28	4.38	4.37	87.45	81.53	96.32	88.43	66.04	56.12	70.91	64.36	3.69
Two hand weeding – (30 and 60 DAS)	4.59	4.41	4.45	4.49	90.72	84.05	97.99	90.92	65.05	54.44	68.38	62.62	3.23
Un-weeded control	2.58	2.15	2.00	2.24	50.60	43.06	44.00	45.89	32.13	20.77	21.71	24.87	2.21
LSD (p= 0.05)	0.64	0.58	0.60	0.51	12.66	10.08	13.38	6.42	12.66	10.08	13.38	6.42	-

kg/ha at 35 DAS for getting higher yield and monetary benefits. Use of pre-mix herbicides may help in effective and eco-freindly weed management in wheat.

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Bio efficacy and phyto-toxicity of dicamba 48%SL against broad-leaved weeds in maize

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ABSTRACT

A field experiment was conducted to evaluate the bio-efficacy of dicamba 48% SL on the associated broad-leaf weeds of maize and to assess its phyto-toxicity on the crop in GBPUA&T, Pantnagar for two consecutive years during 2016 and 2017. The results revealed that application of dicamba 48% SL at 300 and 360 g/ha provided superior control of broad-leaved weeds as compared to 2,4-D Amine salt 58% SL 500 g/ha in maize. The same two treatments *i.e.* dicamba 48% SL at 300 and 360 g/ha also provided a total weed control efficiency of 100% in all the stages of crop growth. Maximum grain yield was recorded in the weed free plots to the tune of 5.45 t/ha and 5.22 t/ha in 2016 and 2017, respectively, which was at par with dicamba 48% SL at 300, 360 and 720 g/ha and the other yield attributing characters followed the same trend in both the years. However, numerically maximum yield was obtained in weed free plots, probably due to effectiveness of dicamba only against the broad-leaf weeds but hand weeding took care of broad spectrum of weeds. It was also revealed that, there were no symptoms of phytotoxicity on maize at any doses of dicamba 48% SL. Hence, it may be concluded that dicamba 48% SL at 300 g/ha was found to be effective against broad-leaved weeds in maize in Pantnagar region of Uttarakhand.

INTRODUCTION

Maize (*Zea mays* L.) is the third most vital cereal crop of India, commonly called as queen of cereals due to its very high genetic yield potential. It serves dual uses like both fodder and grain purpose. Out of several biotic factors, weeds are the most important yield reducing factor. In maize crop, it is evident that weeds cause 28 to 100% yield reduction as per infestation of weeds (Patel *et al*. 2006). In Indian condition, the associated weeds cause yield reduction by 27-60%, based on the growth and persistence of weed population in maize crop (Kumar *et al*. 2015 and Jat *et al*. 2012). However, Yakadri *et al*. (2015) reported that due to initial slow growth rate and wider spacing of maize during the first 3-4 weeks is congenial to offer severe competition, which brings in 30-93% yield losses among all the weed species associated with maize crop. Broad-leaf weeds are very much dominant over grassy weeds and sedges. Kannan and Chinnagounder (2014), reported 12 species of broad-leaved weeds, 5 species of grasses and a sedge weed is associated with maize. The same type of result was also reported by Ravisankar *et al*. (2013). This fact reveals the importance of broad-leaf weeds in maize crop. Chemical weed management in maize by using herbicides is gaining importance now a day due to its effectiveness and economic point of view. Among the post-emergence herbicides, dicamba (3,6-dichloro-2-methoxybenzoic acid) is very effective in controlling the broad-leaf weeds in maize. The current experiment was conducted to standardize the effective dose of the herbicide concerned, as well as to assess its bioefficacy on broad-leaf weeds and phyto-toxicity on maize.

MATERIALS AND METHODS

A two years field experiment was carried out during 2016 and 2017 at G. B. Pant University of Agriculture & Technology, Pantnagar (lat/long/altitude), U.S. Nagar, Uttarakhand. The crop received total rainfall of 1290.2 mm and the average maximum and minimum temperatures were 32.4ºC and 24.1ºC (June to September). The soil of the experimental site was sandy loam with a high percentage of organic carbon *i.e.* 0.82%. The pH of soil was 7.2. Available N, P and K content in the soil was 252.6, 17.8 and 283.4 kg/ha, respectively.

Maize variety of *'Gaurav'* was grown with a seed rate of 22 kg/ha. Sowing was done manually with 60 × 25 cm plant in geometry during both of the years in a plot of 2.5 x 5.0 m. The crop was provided with to 120:60:40 kg N, P and K/ha. All phosphatic and potassic fertilizers were applied as at basal and N was applied in three splits (50% basal, 25% at knee height, and 25% at tasseling). The experiment was conducted in a randomized block design (RBD) with three replications. The required amount of herbicides was applied using 500 L/ha of water with knap-sack sprayer fitted with a flat-fan nozzle.

At sampling time (30 and 60 days after application (DAA), a quadrate of 0.25 m^2 was placed at four places in each plot marked with wooden pegs and observations like weed population, relative weed density, weed dry weight, weed control efficiency and phyto-toxicity percentage were calculated based on the formulae given below. Yield and yield attributes were calculated on the basis of net plot and expressed in kg/ha.

The data were analyzed by using the standard procedure for randomized block design with the STPR software. Weed density and dry weight were square root transformed by using formula $(\sqrt{x+1})$ before analysis. 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.

The phyto-toxicity rating was given as per the list mentioned below: No injury(0), Slight stunting, injury or discoloration(1), Some stand loss, stunting / discoloration(2), Injury more pronounced but not persistent(3), Moderate injury, recovery possible(4), Injury more persistent, recovery doubtful(5), More severe injury, no recovery possible(6), Severe injury, stand loss(7), Almost destroyed few plants surviving(8), Very few plants alive(9), Complete destruction (10). The numbers given in the parentheses are the corresponding phyto-toxicity ratings as per the phyto-toxicity symptoms.

RESULTS AND DISCUSSION

Relative weed density before herbicide application

In *Kharif* 2016 and 2017, the major weed flora observed in maize crop *i.e.* grassy, broad-leaved and sedges were recorded in untreated check plot. The grassy weed flora in experimental field consisted of *Eleusine indica*, *Echinochloa colona*, *Dactyloctenium aegyptium* and *Digitaria sanguinalis,* which accounted 9.0, 8.1, 2.7 and 5.4%, and 11.8%, 6.9%, 6.4% and 4.4% in 2016 and 2017, respectively. Among the broad-leaved weeds, *Celosia argentea* (12.5 and 22.8%), *Trianthema monogyna* (6.3 and 16.3%), and *Phyllanthus niruri* (6.3 and 9.8%), *Cleome viscosa* (4.7 and 11.4%), *Mollugo stricta* (62.5 and 26.0%), where as in sedgs *Cyperus rotundus* (12.6 and 10.8%) and *Cyperus iria* (4.5 and 9.9%), were observed during 2016 and 2017, respectively.

Density of broad-leaf weeds at 30 days after herbicide application

In *Kharif* 2016, at 30 days after application of dicamba 48% SL at all the doses and standard check, 2,4-D amine salt completely controlled all the broad-leaf weeds except *Cleome viscosa* and *Mollugo stricta* with the lowest dose of dicamba at 180 g/ha. Twice hand weeding (20 and 45 DAS) completely controlled all the BLWSs except *Celosia argentea* and *Mollugo stricta.*

In *Kharif* 2017, at 30 days after herbicide application, *Celosia argentea* and *Digera arvensis* were completely controlled under the application of dicamba 48% SL DMA salt at 720 and 360 g/ha. Whereas, rest of the BLWs were completely controlled by all the doses of dicamba 48% SL DMA except its lowest dose at 180 g/ha. Twice hand weeding (20 and 45 DAS) completely controlled the *Phyllanthus niruri* at this stage.

Density of broad-leaf weeds at 60 days after herbicide application

At 60 days after application (DAA) of herbicides all the weeds except *Mollugo stricta* were completely controlled with the application of dicamba 48% SL DMA salt at all the doses and standard check, 2,4-D amine salt at 500g/ha. *Trianthema monogyna* and *Cleome viscosa* were also not effectively controlled with 2,4-D amine salt as compared to other BLWs at this stage in *Kharif* 2016.

Application of dicamba DMA salt at 720 and 360 g/ha, completely controlled all the broad-leaf weeds at 60 days after herbicide application. However, Among the BLWs, *Digera arvensis* and *Phyllanthus niruri* were not controlled with the spray of dicamba 48% SL DMA salt at 300 g/ha. Twice hand weeding (20 and 45 DAS) completely eliminated *Celosia argentea* and *Phyllanthus niruri* amongst all the broad-leaf weeds in *Kharif* 2017.

Total weed density and dry weight

Among the weed flora, broad-leaf weeds had the maximum share in both the years. Application of dicamba 48% SL at all the doses except the lower dose (180 and 240 g/ha) completely controlled all the broad-leaf weeds and recorded the lowest total weed density and dry weight at 30 DAA. At 60 days after herbicide application, the total weed density of broad-leaf weeds was effectively reduced by application of dicamba 48% SL DMA at 720 g/ha followed by its lower doses. Similarly, total weed dry weight was also effectively reduced with the application of dicamba 48% SL applied at 720 g/ha followed by its lower doses.

Weed control efficiency

The weed control efficiency in broad-leaf weeds at 60 DAS, was found the highest (100%) with all the doses of dicamba 48%SL except 180 and 240 g/ha in both the years under study.

The yield and yield attributing characters of maize, *viz*. plants (1000/ha), cobs (1000/ha), kernel (wt./cob), kernel (no./cob) and 100 kernel weight (g) were significantly affected by different treatments. In *Kharif* 2016 and 2017, highest grain yield (5.45 t/ha and 5.22 t/ha respectively) was recorded with twice hand weeding (20 and 45 DAS) which was at par

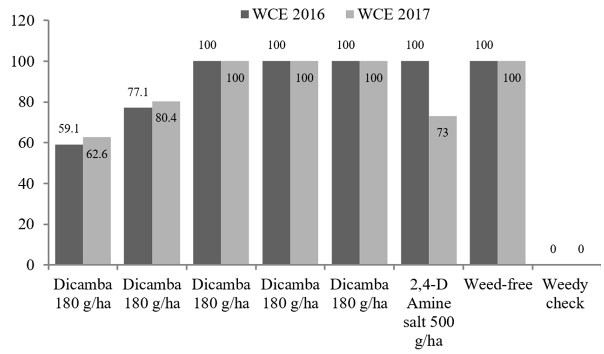

Figure 1. Weed control efficiency at 30 DAS in 2016 and 2017 yield and yield attributing character of maize crop

with dicamba 48% SL DMA applied at 720, 360 and 300 g/ha. Higher grain yield of these treatments was mainly attributed to more number of plants per unit area, thousand cobs per unit area and kernel weight per cob. Weedy check recorded 52.9% and 52.5% lower grain yield as compared to highest grain yield producing treatment *i.e.* hand weeding in 2016 and 2017, respectively.

Table 1. Effect of treatment on total density and dry weight of broad-leaf weeds at 30 and 60 days after herbicide application

Treatment	Weed density (no./m^2)				Weed dry matter (g/m^2)			
	30 DAA		60 DAA		30 DAA		60 DAA	
	2016	2017	2016	2017	2016	2017	2016	2017
Dicamba 48% SL (180 g/ha)	4.5(19.3)	4.3(17.3)	3.3(25.3)	4.2(16.3)	4.3(18.4)	4.1(15.7)	4.8(22.9)	4.6(20.4)
Dicamba 48% SL (240 g/ha)	3.1(9.0)	3.2(9.7)	4.1(15.7)	3.2(9.0)	3.5(11.8)	3.1(8.3)	3.7(12.8)	3.4(10.7)
Dicamba 48% SL (300 g/ha)	1.0(0.0)	1.0(0.0)	1.0(0.0)	1.0(0.0)	1.0(0.0)	1.0(0.0)	1.0(0.0)	1.0(0.0)
Dicamba 48% SL (360 g/ha)	1.0(0.0)	1.0(0.0)	1.0(0.0)	1.0(0.0)	1.0(0.0)	1.0(0.0)	1.0(0.0)	1.0(0.0)
Dicamba 48% SL (720 g/ha)	1.0(0.0)	1.0(0.0)	1.0(0.0)	1.0(0.0)	1.0(0.0)	1.0(0.0)	1.0(0.0)	1.0(0.0)
2,4-D amine salt 58% SL (500 g/ha)	2.9(7.3)	3.3(9.7)	2.6(5.7)	3.6(12.0)	2.3(4.6)	3.4(10.3)	2.8(7.4)	3.9(14.7)
Weed-free HW 20 and 45 DAS	1.0(0.0)	1.0(0.0)	1.0(0.0)	1.0(0.0)	1.0(0.0)	1.0(0.0)	1.0(0.0)	1.0(0.0)
Weedy check	6.6(43.3)	6.5(41.3)	6.7(44.0)	6.5(41.0)	5.7(31.7)	6.7(44.1)	7.5(56.0)	7.3(52.0)
Untreated	6.6(42.3)	6.7(44.0)	6.9(46.7)	6.7(44.3)	5.8(32.9)	6.9(46.3)	7.6(57.5)	7.5(54.5)
LSD (p=0.05)	0.31	0.30	0.33	0.26	0.18	0.15	0.15	0.21

Table 2. Effect of treatment on yield and yield attribute characters of maize

Treatment	Plant (1000/ha)		Cob (1000/ha)		Kernel wt./cob		Kernel (no./cob)		100 kernel weight (g)		Grain yield (t/ha)	
	2016	2017	2016	2017	2016	2017	2016	2017	2016	2017	2016	2017
Dicamba 48% SL (180 g/ha)	68.9	64.7	70.7	67.3	56.8	56.7	332	335	17.1	16.9	3.98	3.87
Dicamba 48% SL (240 g/ha)	76.0	70.0	77.0	74.0	60.8	60.0	347	342	17.5	17.8	4.63	4.45
Dicamba 48% SL (300 g/ha)	78.8	69.3	82.9	74.3	64.1	62.7	357	352	18.0	17.9	5.22	4.65
Dicamba 48% SL (360 g/ha)	81.1	70.1	82.1	74.3	64.8	63.3	361	353	18.5	18.0	5.31	4.77
Dicamba 48% SL (720 g/ha)	80.4	70.0	81.5	73.0	65.9	63.3	354	354	18.5	18.0	5.28	4.68
2,4-D amine salt 58% SL (500 g/ha)	69.7	64.7	72.2	64.7	61.2	60.7	350	347	17.4	17.5	4.33	4.03
Weed-free HW 20 and 45 DAS	80.6	72.0	82.7	77.3	66.0	64.0	358	363	18.4	17.7	5.45	5.22
Weedy check	56.0	50.0	55.0	52.0	45.0	43.3	271	271	16.5	16.2	2.57	2.53
Untreated	56.0	47.7	55.0	50.0	45.1	46.7	276	280	16.3	16.4	2.58	2.38
LSD (p=0.05)	4.0	8.8	3.3	5.9	3.1	4.3	23.7	7.5	1.1	0.8	0.32	0.40

Table 3. Effect of treatments on cost of cultivation, gross return, net return and B:C ratio

Treatment	Cost of cultivation (x10³ ₹/ha)		Gross return (x10³ ₹/ha)		Net return (x10³ ₹/ha)		B:C ratio	
	2016	2017	2016	2017	2016	2017	2016	2017
Dicamba 48% SL (180 g/ha)	28.37	28.37	53.77	55.10	25.40	26.73	0.90	0.94
Dicamba 48% SL (240 g/ha)	28.57	28.57	62.54	63.41	33.97	34.84	1.19	1.22
Dicamba 48% SL (300 g/ha)	28.77	28.77	70.43	66.26	41.66	37.49	1.45	1.30
Dicamba 48% SL (360 g/ha)	28.97	28.97	71.66	67.93	42.69	38.96	1.47	1.34
Dicamba 48% SL (720 g/ha)	30.17	30.17	71.32	66.73	41.15	36.56	1.36	1.21
2,4-D amine salt 58% SL (500 g/ha)	26.44	26.44	58.49	57.47	32.05	31.03	1.21	1.17
Weed-free HW 20 and 45 DAS	33.57	33.57	73.57	71.34	40.00	37.77	1.19	1.12
Weedy check	25.37	25.37	34.65	36.09	9.28	10.72	0.37	0.42
Untreated	25.67	25.67	34.87	33.96	9.20	8.29	0.36	0.32

Phyto-toxicity symptoms

No chlorosis, stunting, leaf tip injury, wilting, vein clearing, epinasty and hyponasty were seen in maize crop due to application of dicamba 48% w/v SL at any of the doses at 1, 3, 5, 7, 10, 15 and 30 DAA.

Economic analysis

The amount of net return was found maximum in dicamba 48% SL DMA applied at 360 g/ha which was ₹ 42687 and 38958 respectively in 2016 and 2017, which was followed by the treatment with dicamba applied at 300 g/ha (₹ 41658 and 37491, respectively in 2016 and 2017). The benefit- cost ratio also followed the similar trend. Maximum B:C ratio was achieved in 48% SL DMA applied at 360 g/ha (1.42 and 1.34 in 2016 and 2017, respectively). Handweeding labbed behind the chemical treatments in terms of net return and B:C ratio due to its high cost of cultivation in terms of labour cost.

Conclusion

Among all the concerned treatments, 48% SL DMA applied at 360 g/ha was found better in terms of yield and net return achieved. Hence, it can be a very suitable option for controlling the broad-leaved weed flora associated with maize crop.

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Pre- and post-emergence herbicides effect on weed dynamics, microbial population and yield of summer blackgram

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ABSTRACT

An investigation was carried out at Sher-e-Kashmir University of Agricultural Sciences and Technology of Jammu during 2015 and 2016 to study the effect of pre- and post-emergence application of herbicides on weed dynamics, microbial population and yield of summer blackgram. Thirteen weed management treatments was comprised of imazethapyr 70 g/ha as pre and post-emergence, imazethapyr 80 g/ha as pre- and post-emergence, imazethapyr + imazamox 70 g/ha as pre- and post-emergence, imazethapyr + imazamox 80 g/ha as pre- and post-emergence, pendimethalin 1000 g/ha as pre-emergence, imazethapyr + pendimethalin 1000 g/ha as pre-emergence, two hoeings at 15 and 30 DAS, weedy check and weed free were assessed. The results revealed that a significant reduction in total weed density and total weed biomass was observed with two hoeings at 15 and 30 DAS, imazethapyr + pendimethalin 1000 g/ha as pre-emergence and imazethapyr + imazamox 80 g/ha as post-emergence. Aapplication of imazethapyr + pendimethalin 1000 g/ha as pre-emergence recorded the highest seed yield and B:C ratio. Initially, after the herbicides treatment (15 and 30 DAS) microbial counts were slightly less in pre-emergence, reaching a maximum at 30 DAS.

INTRODUCTION

Blackgram (*Vigna mungo* L.) is one of the most important pulse crops, which can be grown in tropical and sub-tropical countries. It is grown in (*Kharif*) rainy and summer seasons in India where weed infestation causes considerable loss in yield. The weed causes maximum damage initially (25 to 35 days after sowing) (Randhawa *et al.* 2002), and reduces the yield up to 43.2-64.1% (Rathi *et al.* 2004). Therefore, removal of weeds at appropriate time using a suitable method is essential to obtain high yields of blackgram. In blackgram, weeds can be controlled by hand weeding (Chand *et al.* 2004). Hand weeding is laborious, time consuming, costly and tedious. Many a times labours are not available at the critical period of weed removal. Furthermore, weather conditions during *Kharif* do not permit timely hand weeding due to wet field conditions. Use of herbicides offers an alternative for possible effective control of weeds. Therefore, in the present study, the effect of various herbicides was compared with hand weeding for weed control and yield in blackgram.

MATERIALS AND METHODS

A field experiment was conducted during summer seasons of 2015 and 2016 at Sher-e-Kashmir University of Agricultural Sciences and Technology of Jammu under irrigated conditions. The soil of the experimental field was sandy clay loam in texture with slightly alkaline in reaction (pH 7.81), medium in organic carbon (0.51%), available phosphorus (11.63 kg/ha) and potassium (147.3 kg/ha) and low in available nitrogen (246.5 kg/ha). The treatments comprised of imazethapyr 70 g/ha as pre-emergence, imazethapyr 80 g/ha as pre-emergence, imazethapyr 70 g/ha at 3-4 leaf stage, imazethapyr 80 g/ha at 3-4 leaf stage, imazethapyr + imazamox 70 g/ha as pre-emergence, imazethapyr + imazamox (RM) 80 g/ha as pre-emergence, imazethapyr + imazamox (RM) 70 g/ha at 3-4 leaf stage, imazethapyr + imazamox (RM)

80 g/ha at 3-4 leaf stage, pendimethalin 1000 g/ha as pre-emergence, imazethapyr + pendimethalin (RM) 1000 g/ha as pre-emergence, two hoeings 15 and 30 DAS, weedy check) and weed free. The experiment was laid out in a randomized block design replicated thrice.

Blackgram variety *'Uttara'* was sown on 20th April in 2015 and 17th April in 2016, with a plant to plant distance of 10 cm in a row spacing of 30 cm. The crop was harvested on 6th July in 2015 and 3rd July in 2016. Recommended dose of fertilizers 16 kg N and 40 kg P/ha was applied to the crop at time of sowing through di-ammonium phosphate (DAP). Pre-emergence (PE) application was made on next day of sowing and post-emergence (PoE) application was done at 18 DAS (3-4 leaf stage of weeds) by knapsack sprayer fitted with flat fan nozzle by using 500 l/ha of water. Likewise four and five irrigations was applied during the crop growth period.

Observations on growth of crop and weeds were recorded at 15 and 30 DAS. In each plot, grasses, broad-leaves and sedges were counted from 2 randomly selected places in each plot using 0.5 × 0.5 m quadrate. Weed count was expressed as no./m^2 and subjected to square-root transformation to normalize their distribution. The weeds removed from the selected areas were dried at 65°C to obtain constant weight and the weight was expressed in g/m^2. Weed control efficiency (WCE) was calculated by using the formulae suggested by Mishra and Mishra (1997). Benefit: cost ratio was calculated on the basis of prevailing market prices of inputs and produce. Enumeration of fungi, bacteria and actinomycetes was done by the serial dilution-agar plating method or viable plate count method. A known amount (10 ml or 10 g) of material is suspended or agitated in known volume of sterile water blank (90 ml or so to make the volume to 100 ml) to make a microbial suspension. Serial dilution 10^{-2}, 10^{-3}, …10^{-7} are made by pipetting measured volumes (usually 1.0 ml or 10.0 ml) into additional dilution blanks (having 99 ml or 90 ml sterile water). Finally, 1.0 ml aliquat of various dilutions are added to sterile petri dishes (triplicate for each dilution) to which are added 15 ml (approx.) of sterile, cool, molten (45°C) media (Nutrient agar for bacteria, Glycerol yeast agar for actinomycetes and Sabouraud agar medium, supplemented with streptopenicillin, 10 µg/ml, for fungi). The dilutions 10^{-2} to 10^{-5} are selected for enumeration of fungi, 10^{-3} to 10^{-6} for actinomycetes and 10^{-4} to 10^{-7} for bacteria relative to their proportion in soil. Upon solidification, plates are incubated, in an inverted position for 3-7 days at 25°C. The number of colonies appearing on dilution plates are counted, average and multiplied by the dilution factor to find the number of cells/spores per gram (or millimeter) of the sample:

RESULTS AND DISCUSSION

The predominant weed flora in summer blackgram comprised of mainly *Cyperus rotundus, C. iria*, *Cynodon dactylon, Digitaria sanguinalis, Solanum nigrum, Physalis minima* and *Phyllanthus niruri* during both the years of experimentation and their mean relative weed density were 35.46, 19.06, 10.00, 8.87, 8.12 and 12.45% at 15 DAS and at 30 DAS, 39.24, 16.87, 10.34, 8.57, 8.85 and 11.38%, respectively.

Effect on crop growth

Different weed management treatments significantly influenced the plant height and dry matter accumulation at 30 DAS during summer seasons of 2015 and 2016 **(Table 1)**. Being non-significant, treatment weed free recorded numerically the highest plant height (6.40 and 6.33 cm) and dry matter accumulation (7.00 and 7.25 g/m^2) over weedy check. At 30 DAS, weed free treatment recorded significantly the highest plant height (26.15 and 28.69 cm) and dry matter accumulation (17.52 and 19.02 g/m^2) whereas the lowest plant height and dry matter accumulation were recorded in weedy check. The increase in growth parameters was due to the reduction in weed competitiveness with the crop which ultimately favored better environment for growth and development of crop. Similar findings were reported by Kaur *et al.* (2009). Application of imazethapyr + pendimethalin 1000 g/ha as pre-emergence recorded significantly the highest plant height (24.93 and 27.26 cm) and dry matter accumulation (16.30 and 17.80 g/m^2), which was at par with imazethapyr + imazamox 80 g/ha at 3-4 leaf stage, imazethapyr 80 g/ha at 3-4 leaf stage, imazethapyr + imazamox 70 g/ha at 3-4 leaf stage and imazethapyr 70 g/ha at 3-4 leaf stage. The increasing trend in terms of growth parameters might have happened due to better control of both grassy as well as broad-leaved weeds during early crop growth period and also due to safe behaviour of herbicides against crop plants and phytotoxic effects on weeds. These results were in close confirmity with those reported by Yadav *et al.* (2015) and Kaur *et al.* (2016).

Effect on weeds

Application of imazethapyr + pendimethalin 1000 g/ha as pre-emergence recorded significantly the lowest total weed density (4.6 and 4.6/m^2) and total weed dry weight (1.60 and 1.70 g/m^2), which was statistically at par with imazethapyr + imazamox 80 g/ha as pre-emergence. While at 30 DAS and 75 DAS, imazethapyr + pendimethalin 1000 g/ha as pre-emergence significantly reduced the total weed density and weed dry weight, and was at par with imazethapyr + imazamox 80 g/ha at 3-4 leaf stage, imazethapyr 80 g/ha at 3-4 leaf stage, imazethapyr + imazamox 70 g/ha at 3-4 leaf stage and imazethapyr 70 g/ha at 3-4 leaf stage. The better performance of combination of herbicides was due to the synergistic effect between the two herbicides reducing the population as well as dry matter accumulation of different weed species (Singh *et al.* 2016). Imazethapyr + pendimethalin 1000 g/ha as pre-emergence at 15 DAS recorded the maximum weed control efficiency among herbicidal treatments. Whereas, at 30 and 75 DAS two hoeing at 15 and 30 DAS (79.02, 79.02% and 71.55, 70.52%) and imazethapyr + pendimethalin 1000 g/ha as pre-emergence (71.75, 71.78% and 69.01, 68.94%) showed better performance (**Table 2** and **3**). Higher weed control efficacy and long lasting effects of imazethapyr in reducing weed dry matter might be due to broad-spectrum activity of herbicide particularly on established plants of both narrow and broad-leaf weeds and its greater efficiency. The lowest weed control efficiency was recorded with treatment weedy check. Similar findings with respect to weed control efficiency were reported by Kumar *et al.* (2015).

Table 1. Effect of pre- and post-emergence application of herbicides on growth parameters of summer blackgram

Treatment	15 DAS				30 DAS			
	Plant height (cm)		Dry matter accumulation (g/m^2)		Plant height (cm)		Dry matter accumulation (g/m^2)	
	2015	2016	2015	2016	2015	2016	2015	2016
Imazethapyr 70 g pre-emergence (PE)	5.77	5.84	6.40	6.51	20.70	21.83	14.12	14.72
Imazethapyr 80 g (PE)	6.00	6.10	6.60	7.20	21.30	22.96	14.50	15.40
Imazethapyr 70 g (3-4 leaf stage)	5.57	5.52	5.70	6.10	23.70	25.68	15.49	16.55
Imazethapyr 80 g (3-4 leaf stage)	5.43	5.49	5.33	5.60	24.27	26.37	15.82	17.02
Imazethapyr + imazamox 70 g (PE)	5.57	5.63	6.20	6.80	21.00	22.52	14.31	15.21
Imazethapyr + imazamox 80 g (PE)	6.33	6.44	6.70	7.30	21.47	23.52	14.60	15.80
Imazethapyr + imazamox 70 g (3-4 leaf stage)	5.40	5.45	5.60	6.20	24.07	26.00	15.49	16.59
Imazethapyr + imazamox 80 g (3-4 leaf stage)	5.53	5.64	5.40	5.30	24.63	26.67	15.93	17.23
Pendimethalin 1000 g (PE)	5.63	5.69	6.20	6.50	22.50	21.52	14.00	14.60
Imazethapyr + pendimethalin 1000 g (PE)	6.27	6.37	6.75	7.00	24.93	27.26	16.30	17.80
Hoeing (2) 15 and 30 DAS	5.40	5.44	5.40	5.40	25.20	27.61	16.82	18.32
Weedy check	5.43	5.49	5.35	5.70	18.50	19.30	11.51	12.11
Weed free	6.40	6.33	7.00	7.25	26.15	28.69	17.52	19.02
LSD (p=0.05)	NS	NS	NS	NS	3.17	3.66	2.22	2.56

Table 2. Effect of pre- and post-emergence application of herbicides on weed density, weed dry weight and weed control efficiency of summer blackgram

Treatment	15 DAS						30 DAS					
	Weed density (no./m^2)		Weed dry weight (g/m^2)		Weed control efficiency (%)		Weed density (no./m^2)		Weed dry weight (g/m^2)		Weed control efficiency (%)	
	2015	2016	2015	2016	2015	2016	2015	2016	2015	2016	2015	2016
Imazethapyr 70 g (PE)	5.8(33.0)	6.1(36.7)	1.9(2.8)	2.0(3.0)	66.31	66.1	7.7(58.3)	8.0(63.7)	4.0(15.1)	4.2(16.6)	45.4	43.8
Imazethapyr 80 g (PE)	5.6(30.7)	5.8(33.3)	1.9(2.5)	1.9(2.6)	69.73	70.6	7.3(53.0)	7.6(56.3)	3.8(13.7)	4.0(14.8)	50.5	49.9
Imazethapyr 70 g (3-4 leaf stage)	8.6(73.3)	9.0(79.3)	3.0(8.3)	3.2(9.3)	-	-	6.8(45.7)	7.1(49.0)	3.3(9.8)	3.4(10.5)	64.7	64.5
Imazethapyr 80 g (3-4 leaf stage)	8.8(76.0)	9.1(81.3)	3.0(8.0)	3.1(8.4)	-	-	6.5(41.3)	6.6(43.3)	3.1(9.0)	3.2(9.4)	67.6	67.9
Imazethapyr + imazamox 70 g (PE)	5.2(26.3)	5.6(30.0)	1.9(2.6)	1.9(2.8)	68.19	68.4	7.4(54.0)	7.8(59.3)	3.9(14.2)	4.0(15.3)	48.7	48.1
Imazethapyr + imazamox 80 g (PE)	4.9(23.3)	5.1(24.7)	1.8(2.3)	1.9(2.5)	71.44	72.3	7.2(50.7)	7.5(55.3)	3.7(12.9)	3.8(13.7)	53.5	53.5
Imazethapyr + imazamox 70 g (3-4 leaf stage)	8.8(77.3)	9.2(83.0)	3.0(8.0)	3.1(8.7)	-	-	6.5(41.7)	6.8(45.7)	3.2(9.3)	3.3(9.8)	66.3	66.6
Imazethapyr + imazamox 80 g (3-4 leaf stage)	8.7(74.7)	9.0(79.3)	3.0(8.2)	3.1(8.5)	-	-	6.4(40.0)	6.6(43.0)	3.1(8.6)	3.2(9.2)	68.8	68.8
Pendimethalin 1000 g (PE)	6.0(35.7)	6.4(41.0)	1.9(2.7)	2.0(3.0)	66.44	66.0	7.7(58.0)	8.0(64.0)	4.1(15.7)	4.3(17.1)	43.3	41.8
Imazethapyr + pendimethalin 1000 g (PE)	4.6(20.0)	4.6(20.0)	1.6(1.6)	1.7(1.9)	80.85	79.0	6.3(39.0)	6.1(36.3)	3.0(7.8)	3.0(8.3)	71.7	71.8
Hoeing (2) 15 and 30 DAS	8.5(72.3)	9.0(79.7)	3.0(8.2)	3.2(9.1)	-	-	5.2(26.7)	5.4(28.0)	2.6(5.8)	2.7(6.2)	79.0	79.0
Weedy check	8.9(78.0)	9.1(82.7)	3.0(8.2)	3.1(8.9)	-	0.0	10.4(107)	10.9(118)	5.3(27.7)	5.5(29.5)	0.0	0.0
Weed free	1.0(0.0)	1.0(0.0)	1.0(0.0)	1.0(0.0)	100.0	100.0	1.0(0.0)	1.0(0.0)	1.0(0.0)	1.0(0.0)	100.0	100.0
LSD(p=0.05)	0.62	0.56	0.10	0.11	-	-	0.55	0.55	0.20	0.19		

Effect on yield attributes and yield

Among different weed management treatments, yield attributes, *viz*. number of seeds/pod showed non-significant results. Weed free treatment significantly recorded the highest values of yield attributes, *viz*. number of branches/plant (7.00 and 7.06), pods/plant (20.00 and 19.00) and 1000-seed weight (35.54 g and 35.33 g), which was at par with 2 hoeing at 15 and 30 DAS (**Table 4**).This was perhaps due to minimized competition of weeds with the crop for various resources, *viz*. space, light, nutrients and moisture due to adaptation of effective weed control methods. Thus, reduced crop-weed competition resulted into overall improvement in crop growth and better development of reproductive structures and translocation of photosynthates to the sink. These results were in close conformity with those of Singh *et al.* (1994) and Yadav *et al.* (2014).

Among the herbicidal treatments, application of imazethapyr + pendimethalin 1000 g/ha as pre-emergence significantly recorded the highest yield attributes, *viz*. number of branches per plant (6.54 and 6.61), pods per plant (18.33 and 17.00) and 1000-seed weight (33.00 g and 32.71 g), which was statistically at par with imazethapyr + imazamox 80 g/ha at 3-4 leaf stage, imazethapyr 80 g/ha at 3-4 leaf stage, imazethapyr + imazamox 70 g/ha at 3-4 leaf stage and imazethapyr 70 g/ha at 3-4 leaf stage which were significantly superior over rest of the treatments and remained superior to treatment weedy check. This might have happened due to effective control of weeds, less crop weed competition throughout the crop growth period and due to better control of both grassy as well as broad-leaved weeds during early crop growth period, which ultimately resulted in improved yield attributes of the crop. Almost similar findings were reported by Yadav *et al.* (2015), Singh *et al.* (2016) and Balyan *et al.* (2016).

Seed and stover yield of blackgram recorded significant variations with respect to different weed management treatments. It was observed that among the different weed management treatments, weed free recorded significantly highest seed yield (910 and 883 kg/ha) and stover yield (2.15 and 2.49 t/ha) which was at par with treatment 2 hoeing at 15 and 30 DAS **(Table 4)**. The increase in seed and stover yield of blackgram under weed free conditions were obviously due to reduced crop weed competition, higher weed control efficiency by providing below threshold weed situation. Thus, the crop plants being vigorous efficiently utilized nutrients, moisture, sunlight, space and other input factors hence, gave better yield. Whereas, the weedy check plots recorded significantly lowest yields due to heavy competition for nutrients, moisture and light between the crop and weeds at critical phenophases of crop. Similar findings were reported by Chand *et al.* (2003), Mirjha *et al.* (2013) and Yadav *et al.* (2015).

Among the herbicidal treatments, application of imazethapyr + pendimethalin 1000 g/ha as pre-emergence significantly recorded highest seed yield (786 kg/ha and 743 kg/ha) and stover yield (1.88 and 2.18 t/ha), which was statistically at par with imazethapyr + imazamox 80 g/ha at 3-4 leaf stage, imazethapyr 80 g/ha at 3-4 leaf stage, imazethapyr + imazamox 70 g/ha at 3-4 leaf stage and imazethapyr 70 g/ha at 3-4 leaf stageand significantly superior over rest of the treatments, which were at par and remained superior to weedy check . This might have happened probably due to better control of both

Table 3. Effect of pre- and post-emergence application of herbicides on weed density, weed dry weight and weed control efficiency of summer blackgram

Treatment	75 DAS					
	Weed density (no./m^2)		Weed dry weight (g/m^2)		Weed control efficiency (%)	
	2015	2016	2015	2016	2015	2016
Imazethapyr 70 g pre-emergence (PE)	7.88 (61.3)	8.59 (73.0)	4.95 (23.6)	5.14 (25.5)	47.36	47.88
Imazethapyr 80 g (PE)	7.81 (60.0)	8.18 (66.0)	4.91 (23.1)	5.12 (25.2)	48.45	48.53
Imazethapyr 70 g (3-4 leaf stage)	5.94 (34.3)	6.53 (41.7)	4.16 (16.3)	4.36 (18.0)	62.71	62.74
Imazethapyr 80 g (3-4 leaf stage)	5.50 (29.3)	5.94 (34.3)	4.09 (15.7)	4.28 (17.3)	64.84	64.60
Imazethapyr + imazamox 70 g (PE)	7.83 (60.3)	8.35 (68.7)	4.97 (23.8)	5.18 (25.8)	46.93	47.27
Imazethapyr + imazamox 80 g (PE)	7.52 (55.7)	8.04 (63.7)	4.86 (22.6)	5.08 (24.8)	49.43	49.43
Imazethapyr + imazamox 70 g (3-4 leaf stage)	5.63 (30.7)	6.19 (37.3)	4.07 (15.6)	4.28 (17.4)	65.08	64.54
Imazethapyr + imazamox 80 g (3-4 leaf stage)	5.38 (28.0)	5.77 (32.3)	3.99 (14.9)	4.14 (16.1)	66.67	67.06
Pendimethalin 1000 g (PE)	8.08 (64.3)	8.65 (74.0)	5.04 (24.4)	5.26 (26.7)	45.48	45.50
Imazethapyr + pendimethalin 1000 g (PE)	5.18 (26.0)	5.40 (28.3)	3.86 (13.9)	4.03 (15.2)	69.01	68.94
Hoeing (2) 15 and 30 DAS	6.63 (43.0)	7.57 (56.3)	3.71 (12.7)	3.93 (14.4)	71.55	70.52
Weedy check	10.70 (113.7)	11.07 (121.7)	6.76 (44.8)	7.07 (49.0)	0.00	0.00
Weed free	1.00 (0.0)	1.00 (0.0)	1.00 (0.0)	1.00 (0.0)	100.00	100.00
LSD(p=0.05)	0.82	1.13	0.32	0.35	-	-

grassy as well as broad-leaved weeds during early crop growth stages, higher weed control efficiency, higher nutrient uptake by the crop and better yield attributes (Yadav *et al.* 2015). However significantly the lowest seed and stover yields were recorded in weedy situations due to excessive weed infestations.

Economics

Among the different weed management tretaments, imazethapyr + pendimethalin 1000 g/ha as pre-emergence) recorded the highest B:C ratio of 2.56, which was closely followed by imazethapyr 80 g/ha at 3-4 leaf stage, imazethapyr + imazamox 80 g/ha at 3-4 leaf stage and imazethapyr + imazamox 70 g/ha at 3-4 leaf stage (**Table 4**). Whereas, the lowest B:C ratio (0.68) was obtained with weedy check.

Effect on microbial population

Initially, after the herbicides treatment (15 DAS) microbial counts were slightly less in pre-emergence of imazethapyr, imazethapyr + imazamox and pendimethalin, reaching a maximum at 30 DAS (**Table 5**). The toxic effect of herbicides normally appears immediately after the application when their concentration in the soil is the highest. Later on, micro-organism take part in degradation process and herbicide concentration and its toxic effect decrease (Radivojevic *et al.* 2004). The total microbial population was the highest with cultural operations and lower with herbicides. The application with herbicides in recommended dose did not affect the microbial population significantly. Balasubramanian and Sankaran (2004) also reported initial suppression of soil micro flora by the herbicides application in different soils, which recovered later on.

Conclusion

It can be concluded that imazethapyr + pendimethalin 1000 g as pre-emergence or imazethapyr 80 g at 3-4 leaf stage found suitable for

Table 4. Effect of different weed management practices on yield attributes, seed yield, stover yield and benefit cost ratio of summer blackgram

Treatment	No. of branches /plant		No. of pods/plant		No. of seeds/pod		1000-seed weight (g)		Seed yield (kg/ha)		Stover yield (t/ha)		B:C ratio	
	2015	2016	2015	2016	2015	2016	2015	2016	2015	2016	2015	2016	2015	2016
Imazethapyr 70 g pre-emergence (PE)	5.83	5.92	13.33	12.00	4.67	5.00	29.85	29.20	623	581	1.36	1.58	1.97	1.71
Imazethapyr 80 g (PE)	5.93	5.95	14.33	13.00	5.00	4.67	30.03	29.46	686	642	1.50	1.74	2.23	1.96
Imazethapyr 70 g (3-4 leaf stage)	6.24	6.29	17.00	15.33	5.00	4.67	31.31	30.82	730	690	1.81	2.10	2.48	2.22
Imazethapyr 80 g (3-4 leaf stage)	6.34	6.42	17.67	16.33	5.33	5.00	32.15	31.89	746	695	1.85	2.14	2.52	2.21
Imazethapyr + imazamox 70 g (PE)	5.90	5.93	14.00	12.67	4.67	4.67	29.87	29.16	666	621	1.38	1.60	2.08	1.81
Imazethapyr + imazamox 80 g (PE)	6.05	6.10	14.67	13.67	5.00	4.67	30.22	29.89	688	646	1.61	1.87	2.13	1.88
Imazethapyr + imazamox 70 g (3-4 leaf stage)	6.27	6.33	17.33	15.67	5.00	4.67	31.80	31.39	743	690	1.82	2.12	2.44	2.13
Imazethapyr + imazamox 80 g (3-4 leaf stage)	6.44	6.54	18.00	16.67	5.33	5.00	32.33	32.03	759	711	1.88	2.18	2.46	2.17
Pendimethalin 1000 g (PE)	5.73	5.76	12.67	11.67	4.67	4.33	29.70	29.09	620	565	1.24	1.43	1.94	1.62
Imazethapyr + pendimethalin 1000 g (PE)	6.54	6.61	18.33	17.00	5.33	5.00	33.00	32.71	786	743	1.88	2.18	2.56	2.29
Hoeing (2) 15 and 30 DAS	6.68	6.78	18.67	18.33	5.67	5.33	34.70	34.46	820	782	1.90	2.21	1.92	1.74
Weedy check	5.22	5.17	10.33	9.00	4.33	4.00	24.52	24.13	316	297	1.09	1.26	0.68	0.55
Weed free	7.00	7.06	20.00	19.00	5.33	5.33	35.54	35.33	910	883	2.15	2.49	1.43	1.33
LSD (p=0.05)	0.36	0.39	1.62	1.77	NS	NS	4.25	4.21	96	100	0.24	0.27	-	-

Table 5. Effect of different weed management practices on microbial count at 15 and 30 DAS in summer blackgram

Treatment	Bacteria (x 10^6 CFU/g) 2015		Fungi (x 10^3 CFU/g) 2015		Actinomycytes (x 10^4 CFU/g) 2015	
	15 DAS	30 DAS	15 DAS	30 DAS	15 DAS	30 DAS
Imazethapyr 70 g pre-emergence (PE)	13.83	18.74	11.43	15.83	9.14	14.35
Imazethapyr 80 g (PE)	13.55	18.54	11.35	15.66	9.08	14.11
Imazethapyr 70 g (3-4 leaf stage)	15.42	17.23	13.21	14.15	11.14	12.17
Imazethapyr 80 g (3-4 leaf stage)	15.31	17.11	13.14	13.94	10.96	11.97
Imazethapyr + imazamox 70 g (PE)	13.76	18.84	11.27	15.82	8.98	14.23
Imazethapyr + imazamox 80 g (PE)	13.45	18.56	11.08	15.91	8.85	14.05
Imazethapyr + imazamox 70 g (3-4 leaf stage)	15.46	16.95	13.29	13.85	11.04	12.07
Imazethapyr + imazamox 80 g (3-4 leaf stage)	15.54	17.28	13.34	13.67	11.14	11.97
Pendimethalin 1000 g (PE)	13.91	19.07	11.76	15.88	9.32	14.53
Imazethapyr + pendimethalin 1000 g (PE)	13.23	18.52	11.02	15.06	8.73	13.92
Hoeing (2) 15 and 30 DAS	15.48	19.90	13.31	15.97	11.14	15.10
Weedy check	15.57	19.87	13.27	15.88	11.03	14.97
Weed free	15.72	20.14	13.63	16.20	11.41	15.27
LSD (p=0.05)	1.62	1.67	1.50	1.57	1.40	1.55

weed control in summer blackgram as these provide higher seed yield and B:C ratio with higher weed control efficiency.

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Weed seedbank dynamics: Estimation and management in groundnut

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Weed indices

ABSTRACT

Effective weed management necessitates sound knowledge of weed seedbank dynamics. The experiment was laid out in split plot design with three replications. The main plots have three residue management treatments and sub-plots comprised seven weed management treatments. Results revealed that highest pod yield (1.47 t/ha) was recorded under wheat residue incorporation *fb* soil solarization. Among weed management, the highest pod yield (1.68 t/ha) and haulm yield (3.35 t/ha) was recorded with weed free and unweeded check registered lowest pod yield (722 kg/ha). The lowest dry weight of weeds was obtained under wheat residue incorporation *fb* soil solarization and weed free. Wheat residue incorporation *fb* soil solarization depleted correspondingly 54 (25.32%), 10 (5.29%) and 32 (16.16%) seeds per core from the initial weed seedbank in 2014, 2015 and pooled results, respectively. The highest seedbank depletion was observed with weed free by depletion of 147 (68.37%), 123 (68.20%) and 135 (68.29%) weed seeds per core. Pendimethalin 900 g/ha as pre-emergence *fb* IC and HW at 45 DAS depleted 129 (59.84%), 103 (57.09%) and 116 (58.59%) weed seeds per core. Pendimethalin 900 g/ha as pre-emergence *fb* pre-mix imazethapyr + imazamox 70 g/ha as post-emergence at 25 DAS depleted 126 (58.40%), 101 (55.86%) and 113 (57.24%) weed seeds per core and suicidal germination *fb* killing the weed flush by subsequent tillage *fb* IC and HW at 45 DAS depleted 116 (53.85%), 86 (47.64%) and 101 (51.01%) weed seeds per core in 2014, 2015 and pooled results, respectively as compared to the initial weed seedbank. While, unweeded check resulted in to addition of 609 (283.31%), 695 (384.16%) and 652 (329.41%) weed seeds per core sample (15 cm depth and 4 cm diameter) in the soil weed seedbank in comparison to initial weed seedbank.

INTRODUCTION

The weed seedbank is the main source of weeds in agricultural fields. Most weeds start their life cycle from a single seed in the soil. If these weeds escape control, they grow and produce thousands of seeds, depending on the species. These seeds are returned to the soil seedbank and become the source of future weed populations. Therefore, knowledge of seed return and seedbank dynamics can help in future weed management. The weed seedbank refers to the natural storage of seeds and vegetative propagules, often dormant, within the soil of most ecosystems. Understanding the dynamics of weed seedbanks is an essential first step in improving weed management plans. Lack of weed seedbank studies represents an important knowledge gap for producers. This study aims to acquire the information on weed seedbank dynamics and its management by integrating cultural, physical and chemical methods. Management of weeds in particular area would require prior information regarding weed seedbank which can helpful in designing weed management practices related to a particular microclimate in an area. Thus, there will almost always be some weeds that tolerate, or even thrive on, whatever combination of seedbank management strategies to be adopted.

Effective weed management requires knowledge of weed seedbank dynamics, germination pattern and environmental conditions suitable for seedling emergence. Weed seedbank affects the weed flora and its density because of the good relationship between the weed flora and the weed seedbank in the soil (Sousa *et al.* 2003). In principle of reducing weed seedbank, there are three approaches to reduce the seedbank size: i) kill the seeds while they are in the soil (using chemical compounds), ii) stimulate germination of seeds and destroy the seedlings called as ‘suicidal’ germination, and iii) remove weeds before seed set. Based on these three principles, the integrated approach has to be selected for managing weed seedbank, which involves wheat residue management, solarisation, stale seedbed, suicidal germination, herbicides, hand weeding, and inter-culturing techniques. Very meagre efforts were made to estimate weed seedbank in soil and practically very little research work was carried out regarding weed seedbank estimation under the influence of different weed management practices. Wheat (*Rabi*)-fallow (summer)-groundnut (*Kharif*) is the pre-dominant crop sequence in the Saurashtra region of Gujarat state in India. Owing to labour shortage and its high cost, harvesting of wheat is mostly carried out by combine harvester, which left large quantities of wheat residue. Now their usefulness considered as an important resource that can bring significant physical, chemical, biological changes into the soil and suppresses weeds and prevent weed seeds to recycle in soil (Sharma 2014). Considering the facts and views highlighted, an experiment was undertaken to study weed seedbank dynamics estimation and management in groundnut.

MATERIALS AND METHODS

A field experiment was conducted at Weed Control Research Farm, Department of Agronomy, Junagadh Agricultural University, Junagadh (Gujarat) during *Kharif* seasons of 2014 and 2015. The soil of the experimental field was clayey in texture and slightly alkaline in reaction, medium in organic carbon, low in available N, medium in available P and K. The experiment was laid out in a split plot design with three replications. The main plots comprised residue management treatments, *viz*. burning of wheat residues, wheat residue incorporation by rotavator *fb* soil solarization with 25 µm polythene sheet for 15 days and wheat residue incorporation by rotavator *fb* application of *Trichoderma viride* 5 kg/ha + 20 kg N/ha and sub plots contained weed management treatments, *viz*. stale seedbed (pre-sowing irrigation *fb* killing the weed flush by subsequent tillage) *fb* IC and HW at 45 DAS, suicidal germination (application of ethylene 2000 ppm + KNO_3 2000 ppm with pre-sowing irrigation) *fb* killing the weed flush by subsequent tillage) *fb* intercultural (IC) and hand weeding (HW) at 45 DAS, pendimethalin 900 g/ha as PE *fb* IC and HW at 45 DAS, HW and IC at 15 DAS *fb* pre-mix imazamox + imazethapyr 70 g/ha as PoE at 25 DAS, pendimethalin 900 g/ha as PE *fb* pre-mix imazamox + imazethapyr 70 g/ha as PoE at 25 DAS, weed free-three IC + five HW and unweeded check. The groundnut (cv. *Gujarat Groundnut-20*) was sown at 60 x 10 cm spacing using seed rate of 120 kg/ha. The crop was fertilized with 12.5-25-50 kg N-P-K/ha. The herbicides were sprayed as per treatments using knapsack sprayer fitted with flat-fan nozzle using spray volume of 500 L/ha water. Data were recorded and statistically analyzed for level of significance.

Weed seedbank estimation: Five soil samples were taken from the experimental soil before sowing of the crop and one composite sample was prepared, while plot-wise samples were taken after harvest of the crop. The soil samples were drawn by core sampler of 4 cm in diameter from 15 cm depth as per the FAO protocol (Forcella *et al.* 2011). Each soil core was individually bagged and numbered. Seed extraction was done by sieving of the samples through copper sieves of 5 mm in diameter. This was followed by their rinsing by water and sieving of the samples through a descending series of sieves up to sieve of 0.5 mm in diameter. Seeds were then dried at the room temperature and separated manually. Determination of the separated seeds was performed visually and sample-wise seed count was recorded. Species wise weed seed identification was determined by growing weed seeds in controlled conditions. Total viable and non-viable/dormant seeds were also recorded.

RESULTS AND DISCUSSION

Crop yields

Residue management and weed management treatments significantly influenced groundnut yield (**Table 1**). Significantly, the highest pod yield (1.47 t/ha) was recorded under the wheat residue incorporation *fb* soil solarization with increased magnitude of 14.2% over the burning of residues. Among the weed management, significantly, the highest pod yield (1.68 t/ha) and haulm yield (3.35 t/ha) was recorded under the weed free, which was statistically at par with the treatments pendimethalin *fb* imazethapyr + imazamox and pendimethalin *fb* IC and HW with increased magnitude of 124.9 and 124.5%. Conversely, the unweeded check registered significantly the lowest pod yield (722 kg/ha). The higher yield under these treatments could be ascribed to lower dry weight of weeds ultimately reduced the crop-weed competition hence less nutrients removed by the weeds and better utilization of nutrients by the crop. Conversely, burning of residues and unweeded check recorded lowest pod and haulm yields. Deprived growth and development of the crop under the treatment owing to severe crop-weed competition for resources might have poor yields. These findings are in agreement with earlier reports (Khairnar *et al.* 2014, Kumbar *et al.* 2014, and Sharma 2014).

Weed flora

The following weed species were observed during both the years of experiment:

Weed species		% dominance at experimental site 2014	2015
Monocots	*Echinochloa colona*	23.65	53.76
	Eluropus villosus	14.86	1.55
	Indigofera glandulosa	6.53	5.80
	Brachiaria ramosa	2.03	-
	Dactyloctenium aegyptium	-	3.68
Dicots	*Ammannia baccifera*	18.02	-
	Leucas aspera	5.40	1.47
	Digera arvensis	2.70	5.40
	Commelina benghalensis	2.03	2.61
	Eclipta alba	2.03	5.72
	Portulaca oleracea	1.58	0.98
	Commelina nudiflora	0.68	0.57
	Phyllanthus niruri	0.45	1.88
	Euphorbia hirta	-	1.14
	Parthenium hysterophorus	-	0.65
	Tridax procumbens	-	0.57
Sedge	*Cyperus rotundus*	20.04	14.22

Weed seedbank dynamics and weed indices

Significantly the lowest dry weight of weeds and weed seedbank, lowest weed index and higher weed control index was recorded under the wheat residue incorporation *fb* soil solarization and weed free (**Table 1**). Among the weed management pendimethalin *fb* imazamox + imazethapyr, pendimethalin *fb* IC and HW and suicidal germination *fb* tillage *fb* IC and HW. Soil solarization might have destroyed weed seeds and propagules present in the upper soil, but not so effective against sedge propagules existed deeper in soil, hence there would be less population of weeds than other treatments, while *Trichoderma viride* might have decomposed weed seeds and propagules which reflected in less number of weeds and ultimately lower weed biomass under both these treatments. This might be attributed to the effective control of weeds under these treatments through hand weeding or integration of hand weeding with herbicides, which reflected in a smaller number of weeds and ultimately lower weed biomass and weed seedbank. In addition to this, dense crop canopy might have suppressed weed growth and ultimately less biomass. These findings are in conformity with those reported by Forcella *et al.* (1993), Khankhane *et al.* (2009) and Branko *et al.* (2011).

Different residue management treatments significantly influenced the status of final soil weed seedbank after harvesting of crop. Significantly, the lowest weed seedbank (161, 171 and 166 weed seeds per core sample (15 cm depth and 4 cm diameter) in 2014, 2015 and pooled results, respectively) was estimated under the treatment wheat residue incorporation *fb* soil solarization. While, the highest soil weed seedbank (259 and 250 weed seeds per core sample (15 cm depth and 4 cm diameter) in 2014 and pooled results, respectively) was estimated with the treatment burning of wheat residues, which was statistically at par with the treatment wheat residue incorporation *fb* application of *Trichoderma viride* + N having weed seeds of 234 and 240 in 2014 and pooled results, respectively (**Table 2**). On an average, the treatment wheat residue incorporation *fb* soil solarization depleted correspondingly 54 (25.32%), 10 (5.29%) and 32 (16.16%) seeds per core from the initial weed seedbank in 2014, 2015 and pooled results, respectively. On the contrary, on an average of both the years, the treatments burning of wheat

Table 1. Groundnut yields, weed indices and status of weed seedbank under various residue and weed management strategies

Treatment	Pod yield (t/ha)	Haulm yield (t/ha)	Weed index (%) 2014	Weed index (%) 2015	Dry weight of weeds (kg/ha) 2014	Dry weight of weeds (kg/ha) 2015	Weed control efficiency (%) 2014	Weed control efficiency (%) 2015	Number of weed seeds/core 2014	Number of weed seeds/core 2015
Residues management									215 (initial)	181 (initial)
Burning of wheat residues	1.28	3.11	-	-	1142	1419	-	-	259	242
Wheat residue incorporation *fb* soil solarization	1.47	2.86	-	-	687	951	-	-	161	171
Wheat residue incorporation *fb* *T. viride* + N	1.36	3.13	-	-	813	1229	-	-	234	245
LSD (p=0.05)	0.07	NS	-	-	151	200	-	-	45	51
Weed management										
Stale seedbed *fb* IC and HW	1.08	2.88	38.07	32.72	979	1272	62.38	66.90	168	170
Suicidal germination *fb* tillage *fb* IC and HW	1.59	3.14	6.62	4.35	788	870	68.97	77.21	99	95
Pendimethalin *fb* IC and HW	1.62	3.22	4.65	1.91	521	553	79.94	85.49	86	78
HW and IC *fb* imazethapyr + imazamox	1.26	3.16	25.18	24.26	770	1188	70.56	68.98	191	180
Pendimethalin *fb* imazethapyr + imazamox	1.62	3.27	4.35	2.70	489	628	81.04	83.67	89	80
Weed free	1.68	3.35	0.00	0.00	40	58	98.49	98.48	68	58
Unweeded check	0.72	2.21	55.10	59.32	2577	3825	0.00	0.00	824	876
LSD (p=0.05)	0.08	0.29	-	-	128	159	-	-	50	56

Groundnut yields are pooled of two years; IC- Intercultural; HW- Hand weeding residues and wheat residue incorporation *fb* application of *Trichoderma viride* + N resulted in to addition of 52 and 42 weed seeds per core sample (15 cm depth and 4 cm diameter) (26.50 and 21.03%) in the soil weed seedbank, respectively as compared to initial soil weed seedbank.

Different weed management treatments displayed their significant influence on soil weed seedbank. The lowest number of weed seeds (68, 58 and 63 weed seeds per core sample (15 cm depth and 4 cm diameter) in 2014, 2015 and pooled results, respectively) was found under the treatment weed free, which was statistically at par with the treatments pendimethalin *fb* IC and HW, pendimethalin *fb* imazethapyr + imazamox and suicidal germination *fb* killing the weed flush by subsequent tillage *fb* IC and HW. Whereas, the highest number of weed seeds (824, 876 and 850 weed seeds per core sample (15 cm depth and 4 cm diameter) in 2014, 2015 and pooled results, respectively) was observed under the treatment unweeded check. However, all the treatments have depleted weed seedbank over the treatment unweeded check during both the years of investigation. On an average of both years, the weed seedbank depleted over the control treatments for all treatments were 80.10, 88.60, 90.40, 78.20, 90.00 and 92.60%, respectively. Weed management treatments depleted weed seedbank except the treatment unweeded check. On an average, higher seedbank depletion was observed with the treatments weed free with depletion of 147 (68.37%), 123 (68.20%) and 135 (68.29%) weed seeds per core sample (15 cm depth and 4 cm diameter), pendimethalin *fb* IC and HW depleted 129 (59.84%), 103 (57.09%) and 116 (58.59%) weed seeds per core, pendimethalin *fb* imazethapyr + imazamox depleted 126 (58.40%), 101 (55.86%) and 113 (57.24%) weed seeds per core and suicidal germination *fb* killing the weed flush by subsequent tillage *fb* IC and HW depleted 116 (53.85%), 86 (47.64%) and 101 (51.01%) weed seeds per core sample (15 cm depth and 4 cm diameter) in 2014, 2015 and pooled results, respectively as compared to the initial weed seedbank. On the contrary, the unweeded check resulted in to addition of 609 (283.31%), 695 (384.16%) and 652 (329.41%) weed seeds per core sample (15 cm depth and 4 cm diameter) in the soil weed seedbank in comparison to the initial weed seedbank of soil (**Table 2**). The weed parameters and weed seedbank findings are parallel to those of Sousa *et al.* (2003), Chauhan *et al.* (2006), Mishra *et al.* (2010), Nyambilila *et al.* (2010) and Sharma (2014).

Species wise weed seeds were identified from initial and final soil sample by growing the weed seeds and sprouted weeds were counted and classified as monocot, dicot, sedge and dormant or non-viable. Data presented indicated that initial weed seedbank was dominated by monocot weed seeds of 100 (46.51%), followed by dicot weed seeds of 77 (35.81%), dormant or non-viable weed seeds of 30 (13.95%) and sedge weed seeds of 8 (3.72%) totalling to 215 seeds per core sample (15 cm depth and 4 cm diameter) in 2014. But in 2015, the weed seedbank was dominated by dicot weed seeds of 86 (47.51%), followed by monocots weed seeds of 60 (33.15%), dormant or non-viable weed seeds of 25 (13.81%) and sedge weed seeds of 11 (6.08%) totalling to 181 seeds per core sample (15 cm depth and 4 cm diameter) (**Table 3**).

Species wise addition or depletion in soil weed seedbank over initial status also presented in **Table 4**

Table 2. Addition/depletion in weed seedbank over initial status

Treatment	Number of weed seeds/core					
	2014		2015		Average	
	Final	Addition (+) / Depletion (-)	Final	Addition (+) / Depletion (-)	Final	Addition (+) / Depletion (-)
Initial weed seedbank	215		181		198	
Residues management						
Burning of wheat residues	259	+44 (+20.53)	242	+61 (+33.60)	250	+52 (+26.50)
Wheat residue incorporation *fb* soil solarization	161	-54 (-25.32)	171	-10 (-5.29)	166	-32 (-16.16)
Wheat residue incorporation *fb* *T. viride* + N	234	+19 (+8.99)	245	+64 (+35.33)	240	+42 (+21.03)
Weed management						
Stale seedbed *fb* IC and HW	168	-47 (-21.96)	170	-11 (-6.08)	169	-29 (-14.70)
Suicidal germination *fb* tillage *fb* IC and HW	99	-116 (-53.85)	95	-86 (-47.64)	97	-101 (-51.01)
Pendimethalin *fb* IC and HW	86	-129 (-59.84)	78	-103 (-57.09)	82	-116 (-58.59)
HW and IC *fb* imazethapyr + imazamox	191	-24 (-11.06)	180	-1 (-0.80)	185	-13 (-6.37)
Pendimethalin *fb* imazethapyr + imazamox	89	-126 (-58.40)	80	-101 (-55.86)	85	-113 (-57.24)
Weed free	68	-147 (-68.37)	58	-123 (-68.20)	63	-135 (-68.29)
Unweeded check	824	+609 (+283.31)	876	+695 (+384.16)	850	+652 (+329.41)

Figures in parentheses indicate percent addition or depletion and **5** for the year 2014 and 2015, respectively. The probable estimation of weed seedbank size per hectare with addition and depletion in the size of weed seedbank at harvest over initial status also given for experimentations (**Table 6** and **7**).

The weed seedbank was dominated by monocot weed seeds under wheat residue incorporation *fb* application of *Trichoderma viride* + N, while that by dicot weed seeds under burning of wheat residues and wheat residue incorporation *fb* soil solarisation (**Table 3**). The dynamics of post-harvest soil weed seedbank was significantly influenced by different residue management treatments. The treatment wheat residue incorporation *fb* soil solarization contained the lowest soil weed seedbank. While, the highest soil weed seedbank was estimated with burning of wheat residues in 2014 and pooled results and wheat residue incorporation *fb* application of *Trichoderma viride* + N in 2015. On an average, the treatment wheat residue incorporation *fb* soil solarization depleted 32.00 seeds per core (16.16%) from the initial weed seedbank. On the contrary, the treatment burning of wheat residues and wheat residue incorporation *fb* application of *Trichoderma viride* + N resulted in addition of 52.00 (26.50%) and 42.00 (21.03%) weed seeds per core sample (15 cm depth and 4 cm diameter) in the soil weed seedbank, respectively as compared to the initial soil weed seedbank. Though the distribution of weed seeds in soil is heterogeneous, most of the seeds of annual weeds are present in upper 5-7.5 cm soil layer, soil solarisation might have desiccated these weed seeds by high temperature under moist condition and thus depleted weed seedbank. Weed seedbank affects the weed flora and its density because of good relationship between the weed flora and the weed seedbank in the soil. Forcella *et al.* (1993), Mishra and Singh (2008), Branko *et al.* (2011), Forcella *et al.* (2011), Arora and Tomar (2012) and Hosseini *et al.* (2014) also studied weed seedbank dynamics. During 2014 and 2015, the weed seedbank was dominated by dicot weed seeds

Table 3. Species wise number of weed seeds (2014 and 2015)

Treatment	Number of weed seeds/core (2014)					Number of weed seeds/core (2015)				
	Total	Monocot	Dicot	Sedge	Dormant or non-viable	Total	Monocot	Dicot	Sedge	Dormant or non-viable
Initial weed seedbank (total weed seeds)	215	100(46.5)	77(35.8)	8(3.7)	30(13.9)	181	60(33.1)	85(47.0)	11(6.1)	25(13.8)
Residues management										
Burning of wheat residues	259	95(36.8)	107(41.3)	7(2.5)	50(19.3)	242	120(49.6)	83(41.3)	9(3.8)	30(12.3)
Wheat residue incorporation *fb* soil solarization	161	61(37.9)	64(39.8)	3(2.1)	32(19.9)	171	85(49.9)	65(39.8)	6(3.5)	15(8.6)
Wheat residue incorporation *fb T. viride* + N	234	106(45.4)	82(35.1)	5(2.3)	41(17.3)	245	129(52.6)	83(35.1)	8(3.3)	25(10.1)
Weed management										
Stale seedbed *fb* IC and HW	168	43(25.8)	82(48.9)	2(1.5)	40(23.7)	170	52(30.5)	89(52.4)	5(3.1)	24(14.0)
Suicidal germination *fb* tillage *fb* IC and HW	99	26(26.4)	56(56.6)	4(3.8)	13(13.5)	95	30(31.1)	46(47.9)	6(6.8)	13(13.9)
Pendimethalin *fb* IC and HW	86	21(24.0)	42(49.0)	2(1.9)	22(25.5)	78	23(29.5)	39(50.1)	5(6.0)	11(14.0)
HW and IC *fb* imazethapyr + imazamox	191	54(28.2)	111(58.0)	8(4.2)	19(9.7)	180	54(29.9)	96(53.1)	10(5.7)	20(11.0)
Pendimethalin *fb* imazethapyr + imazamox	89	23(26.0)	46(51.4)	4(4.1)	17(19.0)	80	24(30.1)	39(49.0)	7(8.3)	10(12.4)
Weed free	68	14(21.2)	31(45.4)	1(2.0)	21(31.4)	58	19(32.0)	28(47.5)	4(7.1)	7(12.6)
Unweeded check	824	432(52.4)	223(27.1)	15(1.8)	154(18.7)	876	579(66.1)	204(23.2)	17(1.9)	77(8.7)

Figures in parentheses indicate species wise weed seedbank percent over total weed seedbank in respective treatments

Table 4. Species wise addition/depletion in soil weed seedbank over initial status (2014)

Treatment	Number of weed seeds per core							
	Monocot		Dicot		Sedge		Dormant/non-viable	
	Final	Addition (+) / depletion (-)	Final	Addition (+) / depletion (-)	Final	Addition (+) / depletion (-)	Final	Addition (+) / depletion (-)
Initial weed seedbank	100		77		8		30	
Residues management								
Burning of wheat residues	95	-5 (-4.6)	107	+30 (+39.1)	7	-1 (-17.9)	50	+20 (+66.8)
Wheat residue incorporation *fb* soil solarization	61	-39 (-38.9)	64	-13 (-16.8)	3	-5 (-58.3)	32	+2 (+6.8)
Wheat residue incorporation *fb T. viride* + N	106	+6 (+6.3)	82	+5 (+6.6)	5	-3 (-32.1)	41	+11 (+35.1)
Weed management								
Stale seedbed *fb* IC and HW	43	-57 (-56.6)	82	+5 (+6.6)	2	-6 (-69.4)	40	+10 (+33.0)
Suicidal germination *fb* tillage *fb* IC and HW	26	-74 (-73.9)	56	-21 (-27.3)	4	-4 (-52.8)	13	-17 (-55.6)
Pendimethalin *fb* IC and HW	21	-79 (-79.3)	42	-35 (-45.3)	2	-6 (-79.2)	22	-8 (-27.0)
HW and IC *fb* imazethapyr + imazamox	54	-46 (-46.1)	111	-34 (-43.9)	8	-0 (-0.0)	19	-11 (-38.1)
Pendimethalin *fb* imazethapyr + imazamox	23	-77 (-76.9)	46	-31 (-40.5)	4	-4 (-54.2)	17	-13 (-43.7)
Weed free	14	-86 (-85.6)	31	-46 (-59.9)	1	-7 (-83.3)	21	-9 (-28.9)
Unweeded check	432	+432 (+331.8)	223	+146 (+189.9)	15	+7 (+86.1)	154	+124 (+414.1)

Figures in parentheses indicate per cent addition or depletion in all the weed management treatments except the unweeded check, which was dominated by monocot weed seeds (**Table 4** and **5**).

On an average, higher seedbank depletion was observed with the treatment weed free with depletion of 135 (68.29%) weed seeds per core sample (15 cm depth and 4 cm diameter) from initial seedbank, which might be due to regular removal of weeds before seed production. The treatment pendimethalin *fb* IC and HW depleted 116 (58.59%) weed seeds per core, because pre-emergence applied pendimethalin controlled weeds right from the start and weeds those escaped were controlled by hand weeding, hence not allowed weeds to set seeds and reduced the size of soil weed seedbank. The treatment pendimethalin *fb* imazethapyr + imazamox depleted 113 (57.24%) weed seeds per core sample (15 cm depth and 4 cm diameter), which might be due to pre-emergence applied pendimethalin controlled weeds right from the start and weeds those escaped were controlled by subsequent post-emergence imazethapyr + imazamox and hence not allowed weeds to set seeds and depleted the size of soil weed seedbank. Likewise, the treatment suicidal germination *fb* killing the weed flush by subsequent tillage *fb* IC and HW depleted 101 (51.01%) weed seeds per core sample. In this treatment, before sowing of crop the weed seed germination enhancing chemicals were applied in soil which emerged out the weeds at a time from soil and these weeds were destroyed by the subsequent tillage and weeds emerged later were removed by manual weeding. Hence weeds were removed before seed setting, which ultimately depleted soil weed seedbank. On the contrary, the unweeded check resulted in to addition of 652 (329.41%) weed seeds per core in the soil weed seedbank in comparison to the initial weed seedbank of soil (**Table 4** and **5**). It might be due to abundant weed seed production

Table 5. Species wise addition/depletion in soil weed seedbank over initial status (2015)

Treatment	Number of weed seeds per core							
	Monocot		Dicot		Sedge		Dormant/non-viable	
	Final	Addition (+) / depletion (-)	Final	Addition (+) / depletion (-)	Final	Addition (+) / depletion (-)	Final	Addition (+) / depletion (-)
Initial weed seedbank	60		85		11		25	
Residues management								
Burning of wheat residues	120	+60 (+100.0)	83	-2 (-2.5)	9	-2 (-16.9)	30	+5 (+19.2)
Wheat residue incorporation *fb* soil solarization	85	+25 (+42.3)	65	-20 (-23.1)	6	-5 (-45.9)	15	-10 (+41.1)
Wheat residue incorporation *fb T. viride* + N	129	+69 (+115.0)	83	-2 (-2.2)	8	-3 (-26.4)	25	+0 (+0.0)
Weed management								
Stale seedbed *fb* IC and HW	52	-8 (-13.7)	89	+4 (+4.8)	5	-6 (-52.5)	24	-1 (-4.4)
Suicidal germination *fb* tillage *fb* IC and HW	30	-30 (-50.7)	46	-39 (-46.4)	6	-5 (-41.4)	13	-12 (-47.1)
Pendimethalin *fb* IC and HW	23	-37 (-61.7)	39	-46 (-54.0)	5	-6 (-57.6)	11	-14 (-56.4)
HW and IC *fb* imazethapyr + imazamox	54	-6 (-10.4)	96	+11 (+12.4)	10	-1 (-6.1)	20	-5 (-20.4)
Pendimethalin *fb* imazethapyr + imazamox	24	-36 (-59.8)	39	-46 (-53.9)	7	-4 (-39.4)	10	-15 (-60.4)
Weed free	19	-41 (-69.1)	28	-57 (-67.6)	4	-7 (-62.6)	7	-18 (-70.7)
Unweeded check	579	+519 (+865.7)	204	+119 (+139.6)	17	+6 (+51.5)	77	+52 (+206.2)

Figures in parentheses indicate percent addition or depletion

Table 6. Estimation of weed seedbank per hectare in 15 cm soil depth (2014)

Treatment	Bulk density (mg/m^3) (A)	Bulk density (kg/m^3) (A x 1000) (B)	Volume of one ha 15 cm soil depth (m^3) (C)	Weight of soil per ha up to 15 cm (kg) (B x C) (D)	Vol. of core sample 4 cm diameter and 15 cm length (m^3) ($\pi r^2 h$) (E)	Weight of core sample BD=w/v (A x E) (F)	Soil weed seedbank per core sample (G)	Estimated weed seeds per ha in 15 cm depth (= D x G/F) (x 10^{10} seeds)
Initial weed seedbank	1.36	1360	1500	2040000	0.00942	0.0128	215	3.42
Residues management								
Burning of wheat residues	1.31	1312	1500	1967857	0.00942	0.0124	259	4.13
Wheat residue incorporation *fb* soil solarization	1.30	1301	1500	1951429	0.00942	0.0123	161	2.56
Wheat residue incorporation *fb T. viride* + N	1.29	1288	1500	1932143	0.00942	0.0121	234	3.73
Weed management								
Stale seedbed *fb* IC and HW	1.31	1306	1500	1958333	0.00942	0.0123	168	2.67
Suicidal germination *fb* tillage *fb* IC and HW	1.30	1304	1500	1956667	0.00942	0.0123	99	1.58
Pendimethalin *fb* IC and HW	1.29	1293	1500	1940000	0.00942	0.0122	86	1.37
HW and IC *fb* imazethapyr + imazamox	1.30	1298	1500	1946667	0.00942	0.0122	191	3.04
Pendimethalin *fb* imazethapyr + imazamox	1.31	1308	1500	1961667	0.00942	0.0123	89	1.42
Weed free	1.28	1284	1500	1926667	0.00942	0.0121	68	1.08
Unweeded check	1.31	1309	1500	1963333	0.00942	0.0123	824	13.12

Table 7. Estimation of weed seedbank per hectare in 15 cm soil depth (2015)

Treatment	Bulk density (mg/m^3) (A)	Bulk density (kg/m^3) (A x 1000) (B)	Volume of one ha 15 cm soil depth (m^3) (C)	Weight of soil per ha up to 15 cm (kg) (B x C) (D)	Vol. of core sample 4 cm diameter and 15 cm length (m^3) ($\pi r^2 h$) (E)	Weight of core sample BD=w/v (A x E) (F)	Soil weed seedbank per core sample (G)	Estimated weed seeds per ha in 15 cm depth (= D x G/F) (x 10^{10} seeds)
Initial weed seedbank	1.32	1320	1500	1980000	0.00942	0.0124	181	2.88
Residues management								
Burning of wheat residues	1.29	1289	1500	1933571	0.00942	0.0121	242	4.13
Wheat residue incorporation *fb* soil solarization	1.29	1287	1500	1930000	0.00942	0.0121	171	2.56
Wheat residue incorporation *fb T. viride* + N	1.28	1277	1500	1915000	0.00942	0.0120	245	3.73
Weed management								
Stale seedbed *fb* IC and HW	1.29	1290	1500	1935000	0.00942	0.0122	170	2.71
Suicidal germination *fb* tillage *fb* IC and HW	1.29	1288	1500	1931667	0.00942	0.0121	95	1.51
Pendimethalin *fb* IC and HW	1.29	1287	1500	1930000	0.00942	0.0121	78	1.24
HW and IC *fb* imazethapyr + imazamox	1.29	1288	1500	1931667	0.00942	0.0121	180	2.86
Pendimethalin *fb* imazethapyr + imazamox	1.29	1287	1500	1930000	0.00942	0.0121	80	1.27
Weed free	1.26	1260	1500	1890000	0.00942	0.0119	58	0.92
Unweeded check	1.29	1290	1500	1935000	0.00942	0.0122	876	13.95

which were returned to the soil and increased the soil weed seedbank. Forcella *et al.* (1993), Branko *et al.* (2011), Forcella *et al.* (2011), Arora and Tomar (2012), Hosseini *et al*. (2014) and Gohil *et al*. (2016) also studied weed seedbank dynamics.

Conclusion

It can be concluded that effective management of soil weed seedbank in *Kharif* groundnut can be achieved by incorporation of wheat residues in soil by rotavator followed by soil solarization with 25 µm polythene sheet for 15 days during hot summer or application *Trichoderma viride* 5 kg/ha + 20 kg N/ha and pre-emergence application of pendimethalin 900 g/ha supplemented with either IC and HW at 45 DAS or pre-mix imazamox + imazethapyr 70 g/ha as post-emergence at 25 DAS or suicidal germination *fb* killing the weed flush by subsequent tillage *fb* IC and HW at 45 DAS, resulting in to less problems of weeds in the next growing season.

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Weed management in spring planted sugarcane growing under West Bengal situtions

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ABSTRACT

A field experiment was conducted at Bidhan Chandra Krishi Viswavidyalaya, West Bengal, India during 2017-2018 and 2018-19 to study the effect of different herbicide molecules in spring planted sugarcane. *Cyperus rotundus*, *Cynodon dactylon* and *Alternanthera philoxeroides* were dominant weed flora in the sugarcane field. Application of ametryn 1.0 kg/ha at 30 days after planting (DAP) followed by (*fb*) 2,4-D 1.0 kg/ha at 60 DAP effectively suppressed the grasses, sedges and broad-leaved weeds, improved yield attributes and registered higher cane yield (102.49 t/ha), juice recovery (52.80%) and B:C ratio (2.90) due to better weed control efficiency (71.05%). Next best treatments were atrazine 1.0 kg/ha at 30 DAP *fb* glyphosate 1.0 kg/ha at 60 DAP; and three hand weeding at 30, 60 and 90 DAP. Application of ametryn 1.0 kg/ha at 30 DAP + 2,4-D 1.0 kg/ha at 60 DAP proved to be a cost-effective option for getting higher cane yield in new alluvial zone of West Bengal.

INTRODUCTION

Sugarcane (*Saccharum officinarum* L.) is a major commercial crop of India, occupies an area of 4.74 million hectares with a production of 379.90 million tonnes with an average yield of 80.20 t/ha in the country during 2017-18 (Anonymous 2020). Losses in cane yield, quality and recovery occur at a varying extent (43.40-73.70%), depending on the nature and stage of weed infestation (Srivastava 2001, Tomar *et al.* 2003, Verma 2000). Sugarcane, by virtue of its long duration, has a longer critical period of 60-120 days for weed competition (Chauhan and Srivastava 2002a). None of the herbicides, either pre- or post-emergence, can take care of weeds for such a long period. Sequential spray of atrazine 2.0 kg/ha and 2,4-D 1.0 kg/ha has been recommended for effective control of weeds in sugarcane (Srivastava *et al.* 1998, Mondal 2018). It has been reported that continuous use of atrazine at lower dose has given rise to resistant biotypes, apart from increased metabolism reduced absorption and translocation, which can also impart PS-II-inhibitor resistance (Jugulam and Shyam 2019). Identification of alternative herbicides is of urgent necessity for reducing the possibility of evolution of resistant weed biotypes and improving sugarcane yield and sugar recovery as well. Hence, the present experiment was conducted to test the efficacy of some herbicide molecules.

MATERIALS AND METHODS

A field experiment was conducted during 2017-18 and 2018-19 at the Bidhan Chandra Krishi Viswavidyalaya, Nadia, West Bengal (22°87'N latitude, 88°32' E longitude, 9.75 m above mean sea level) India. The texture of the soil was sandy loam with medium fertility and neutral soil reaction. The annual rainfall received during the experimental period was 1289.0 and 1420.5 mm during 2017-18 and 2018-19, respectively. The experiment was laid out in a randomized block design with ten treatments replicated thrice. The treatments were: untreated control, ametryn 1.5 kg/ha at 30 days after planting (DAP) followed by (*fb*) one hand weeding (HW) at 45 DAP, ametryn 3.0 kg/ha at 30 DAP, ametryn 1.0 kg/ha at 30 DAP *fb* 2,4-D (sodium salt) 1.0 kg/ha at 60 DAP, atrazine 1.0 kg/ha at 30 DAP *fb* 2,4-D (sodium salt) 1.0 kg/ha at 60 DAP, two HW at 30 and 60 DAP, atrazine 1.0 kg/ha at 30 DAP, 2,4-D (sodium salt) 1.0 kg/ha at 30 DAP, atrazine 1.0 kg/ha at 30 DAP *fb* glyphosate 1.0 kg/ha at 60 DAP and three HW at 30, 60 and 90 DAP. The herbicides were applied with a spray volume of 700 L/ha, using a knapsack sprayer. Three-budded sugarcane setts were planted in the trenches in end-to-end system at an inter-row spacing of 100 cm during March in both the cropping seasons and harvested at February. Sugarcane variety used in the experiment was '*Swapan*' (CoB 99161). The recommended fertilizer dose of 180:80:60

kg N:P:K/ha was applied through urea, single super phosphate and muriate of potash, respectively. Necessary intercultural operations like mulching, earthing up, tying, irrigation and pest management were done as and when required. The data on weeds, crop yield, juice quality parameters like brix and juice recovery percentage were estimated following the standard procedures.

RESULTS AND DISCUSSION

Weed density

The dominant weed flora were *Cyperus rotundus* (sedge) (31.28%), *Cynodon dactylon* (grassy weeds) (22.55%) and *Alternanthera philoxeroides* (broad-leaved weeds) (30.49%).

There was no significant difference in treatment effects on weed density at 30 DAP (**Table 1**). However, the least population of *Cyperus rotundus* was registered with ametryn 3.0 kg/ha at 30 DAP, followed by three HW at 30, 60 and 90 DAP. The density of *C. rotundus* at 60 DAP was significantly highest in untreated control plot, compared with other treatments. Based on pooled data of two years, the lowest weed density at 60 DAP was observed with ametryn 1.0 kg/ha at 30 DAP *fb* 2,4-D 1.0 kg/ha at 60 DAP, which was significantly better than other treatments. Maximum density of *C. rotundus* was noticed at 90 DAP in untreated control, whereas it was significantly the least with the application of ametryn 1.0 kg/ha at 30 DAP *fb* 2,4-D 1.0 kg/ha at 60 DAP. *C. rotundus* population was significantly controlled by treatment ametryn 1.0 kg/ha at 30 DAP *fb* 2,4-D 1.0 kg/ha at 60 DAP. Although the density of *C. dactylon* did not significantly vary under all the treatments at 30 DAP, it was minimum under ametryn 1.5 kg/ha at 30 DAP *fb* one HW at 45 DAP, which was followed by sole application of ametryn 3.0 kg/ha at 30 DAP. Lower density of *C. dactylon* at 90 DAP was also observed with ametryn 1.0 kg/ha at 30 DAP *fb* 2,4-D 1.0 kg/ha at 60 DAP and atrazine 1.0 kg/ha at 30 DAP *fb* glyphosate 1.0 kg/ha at 60 DAP, which were significantly superior to all other treatments. There was a similar trend of treatment effect on the density of *A. philoxeroides* as in case with *C. rotundus* at 30 DAP. The density of *A. philoxeroides* at 30 DAP was the lowest with combined application of atrazine 1.0 kg/ha at 30 DAP + glyphosate 1.0 kg/ha at 60 DAP, which was followed by three HW. Highest density of *A. philoxeroides* was at 60 DAP in untreated plot and significantly poor to other treatments. At 90 DAP, maximum density of *A. philoxeroides* was recorded in untreated control plot. Least weed population was found with the ametryn 1.0 kg/ha at 30 DAP *fb* 2,4-D 1.0 kg/ha at 60 DAP and the treatment was significantly superior to other treatments. The second-best result was recorded in atrazine 1.0 kg/ha at 30 DAP *fb* glyphosate 1.0 kg/ha at 60 DAP. In case of other weed flora, herbicides failed to produce any significant difference in weed density at 30 DAP. However, minimum number of other weeds was observed under atrazine 1.0 kg/ha at 30 DAP *fb* glyphosate 1.0 kg/ha at 60 DAP. Observation at 60 DAP revealed that lowest weed population registered with the ametryn 1.0 kg/ha at 30 DAP *fb* 2,4-D 1.0 kg/ha at 60 DAP and it was significantly better than other treatments. The sequential application of ametryn 1.0 kg/ha at 30 DAP *fb* 2,4-D 1.0 kg/ha at 60 DAP lowered the weed count than sole application either of ametryn, atrazine or 2,4-D. This was in agreement with findings of Kundu *et al.* (2020).

Weed biomass

The weed biomass at 30, 60 and 90 DAP has been presented in (**Table 2**). At 30 DAP minimum weed biomass was observed with only application of ametryn 3.0 kg/ha at 30 DAP followed by ametryn 1.0 kg/ha at 30 DAP *fb* 2,4-D 1.0 kg/ha at 60 DAP and atrazine 1.0 kg/ha at 30 DAP *fb* 2,4-D 1.0 kg/ha at 60 DAP. However, at 60 DAP, the lowest weed biomass was observed with ametryn 1.0 kg/ha at 30 DAP *fb* 2,4-D 1.0 kg/ha at 60 DAP treated plot, which was significantly superior to other treatments. At 90 DAP, minimum biomass of *C. rotundus* observed from ametryn 1.0 kg/ha at 30 DAP *fb* 2,4-D 1.0 kg/ha at 60 DAP treatment and which was significantly better than other assignment of different plot. In case of *C. dactylon* at 30 DAP, lowest weed biomass was found in combination of ametryn 1.5 kg/ha at 30 DAP *fb* one HW at 45 DAP. Least biomass of *C. dactylon* was recorded with ametryn 1.0 kg/ha at 30 DAP *fb* 2,4-D 1.0 kg/ha at 60 DAP, which was significantly better than other treatments. At 90 DAP, minimum biomass of *C. dactylon* recorded from same herbicide management practices *i.e.* ametryn 1.0 kg/ha at 30 DAP *fb* 2,4-D 1.0 kg/ha at 60 DAP and was statistically superior over other treatments. However highest weed biomass of this weed was registered with the untreated control plot followed by 2,4-D 1.0 kg/ha at 30 DAP and ametryn 1.5 kg/ha at 30 DAP *fb* HW at 45 DAP. Observations revealed that minimum weed biomass of *A. philoxeroides* at 30 DAP was observed with untreated control treatment followed by ametryn 1.0 kg/ha at 30 DAP *fb* 2,4-D 1.0 kg/ha at 60 DAP and atrazine 1.0 kg/ha at 30 DAP *fb* glyphosate 1.0 kg/ha at 60 DAP. At 60 DAP, treatments gave positive results with various observations. Least biomass of *A. philoxeroides* was recorded with ametryn 1.0 kg/ha at 30 DAP *fb* 2,4-D 1.0 kg/ha at 60 DAP, which was significantly better than other treatment. Further found that at 90 DAP minimum biomass of *Alternanthera philoxeroides* recorded from ametryn 1.0 kg/ha at 30 DAP *fb* 2,4-D 1.0 kg/ha at 60 DAP treated plot and was statistically better to other treatments. However, the highest weed biomass of the weeds registered with the untreated control plot, followed by ametryn 1.5 kg/ha at 30 DAP *fb* HW at 45 DAP. Minimum biomass of other weeds was observed with only application of ametryn 3.0 kg/ha at 30 DAP. Observation at 60 DAP revealed the lowest biomass with the ametryn 1.0 kg/ha at 30 DAP *fb* 2,4-D 1.0 kg/ha at 60 DAP and which was significantly better to other weed control measures. At 90 DAP, lowest biomass observed with the same treatment *i.e.* ametryn 1.0 kg/ha at 30 DAP *fb* 2,4-D 1.0 kg/ha at 60 DAP and which was significantly superior to all other treatments. It was followed by atrazine 1.0 kg/ha at 30 DAP *fb* glyphosate 1.0 kg/ha at 60 DAP. Use of ametryn 1.0 kg/ha at 30 DAP *fb* 2,4-D 1.0 kg/ha at 60 DAP and atrazine 1.0 kg/ha at 30 DAP *fb* glyphosate 1.0 kg/ha at 60 DAP was found better than other weed control measures. Dry biomass of weeds was found decreased with advancement of crop age with ametryn 1.0 kg/ha at 30 DAP *fb* 2,4-D 1.0 kg/ha at 60 DAP of sugarcane. The second-best treatment was three HW at 30, 60 and 90 DAP which reduced the biomass of *C. rotundus, C. dactylon, A. philoxeroides* and other weeds. More weed biomass reduced cane yield (**Figure 1**). Such differential behaviour might have been attributed to more competition offered by crop plants in treated plots which had the lowest weeds dry matter accumulation. Reduction in weeds dry matter, attributed to three inter cultural operations, has also been reported by Chauhan and Srivastava (2002b) and Bhullar *et al.* (2008). Ametryn 1.0 kg/ha + 2,4-D 1.0 kg/ha recorded the highest weed control efficiency (71.05%) (**Figure 2**), followed by three rounds of HW (66.69%). Higher WCE under these treatments was mainly due to better control of grassy weeds with ametryn plus inhibiting action of 2,4-D against sedges and broadleaved weeds. Singh *et al.* (2008) reported that uncontrolled weeds on an average caused 69.20% reduction in cane yield as compared to three rounds of hoeing at 30, 60 and 90 DAP.

Effect on crop yield

Application of ametryn 1.0 kg/ha at 30 DAP *fb* 2,4-D 1.0 kg/ha at 60 DAP significantly improved different yield attributes as compared to other treatments (**Table 3**). All the weed control treatments led to significant increase in millable cane count and accounted for low shoot mortality by virtue of reduced competition of weeds for nutrient, space, moisture and light. Ametryn 1.0 kg/ha at 30 DAP *fb* 2,4-D 1.0 kg/ha at 60 DAP resulted in the highest number of millable canes (10.33/m^2) due to effective suppression of weeds. Three HW (30, 60 and 90 DAP) and atrazine 1.0 kg/ha (30 DAP) + glyphosate 1.0 kg/ha (60 DAP) were the next best treatments in registering higher millable cane count (10.00/m^2). The highest weight of millable cane (991.67 g) was recorded with ametryn 1.0 kg/ha at 30 DAP *fb* 2,4-D

Table 1. Effect of different treatments on weed density (no./m^2) at different stages of crop growth (pooled data of two seasons)

Treatment	*Cyperus rotundus*			*Cynodon dactylon*			*Alternanthera philoxeroides*			Other weeds		
	30DAP	60DAP	90DAP	30DAP	60DAP	90DAP	30DAP	60DAP	90DAP	30DAP	60DAP	90DAP
Ametryn 1.5 kg/ha at 30 DAP *fb* hand	6.07	12.03	10.43	4.56	6.89	7.05	6.97	3.76	4.27	3.12	4.14	3.26
weeding at 45 DAP	(35.9)	(143.7)	(107.8)	(19.8)	(46.5)	(48.7)	(47.5)	(13.1)	(17.2)	(8.7)	(16.1)	(9.6)
Ametryn 3.0 kg/ha at 30 DAP	6.05	11.71	9.10	4.58	6.61	5.69	6.97	3.48	3.07	3.10	3.52	2.54
	(35.6)	(136.3)	(81.8)	(20.0)	(42.8)	(31.5)	(47.6)	(11.1)	(8.4)	(8.6)	(11.4)	(5.4)
Ametryn 1.0 kg/ha at 30 DAP *fb* 2,4-D	6.10	8.06	5.46	4.71	4.27	4.37	6.84	3.28	2.27	3.02	2.34	1.91
1.0 kg/ha at 60 DAP	(36.3)	(64.0)	(28.8)	(21.2)	(17.3)	(18.2)	(45.8)	(9.7)	(4.1)	(8.1)	(4.5)	(2.6)
Atrazine 1.0 kg/ha at 30 DAP *fb* 2,4-D	6.10	11.05	8.39	4.68	6.63	5.27	6.90	3.40	2.79	2.98	3.36	2.37
1.0 kg/ha at 60 DAP	(36.2)	(121.0)	(69.4)	(21.0)	(43.1)	(26.8)	(46.7)	(10.5)	(6.8)	(7.9)	(10.3)	(4.6)
Two HW at 30 and 60 DAP	6.10	11.42	8.74	4.70	6.68	5.50	7.04	3.47	2.85	2.92	3.51	2.50
	(36.2)	(129.4)	(75.4)	(21.1)	(43.8)	(29.3)	(48.5)	(11.0)	(7.1)	(7.5)	(11.3)	(5.3)
Atrazine 1.0 kg/ha at 30 DAP	6.06	12.02	10.13	4.58	6.74	7.27	6.91	3.60	4.05	2.99	3.81	2.75
	(35.7)	(143.5)	(101.6)	(20.1)	(44.4)	(51.9)	(46.7)	(12.0)	(15.4)	(7.9)	(13.5)	(6.6)
2,4-D 1.0 kg/ha at 30 DAP	6.07	12.04	10.23	4.66	6.41	7.26	6.90	3.46	4.19	3.16	4.08	2.84
	(35.8)	(144.0)	(103.7)	(20.8)	(40.2)	(51.7)	(46.5)	(11.0)	(16.5)	(9.0)	(15.7)	(7.1)
Atrazine 1.0 kg/ha at 30 DAP *fb*	6.10	9.39	6.44	4.72	4.45	4.49	6.82	3.31	2.60	2.90	3.08	2.12
glyphosate 1.0 kg/ha at 60 DAP	(36.2)	(87.3)	(40.5)	(21.3)	(18.8)	(19.2)	(45.5)	(9.9)	(5.8)	(7.4)	(8.5)	(3.5)
Three HW at 30, 60 and 90 DAP	6.07	9.72	7.10	4.64	4.62	4.98	6.83	3.32	2.67	3.07	3.12	2.30
	(35.8)	(93.7)	(49.4)	(20.6)	(20.3)	(23.8)	(45.7)	(10.0)	(6.1)	(8.5)	(8.7)	(4.3)
Untreated control	6.07	15.70	16.04	4.61	9.56	11.86	6.78	11.57	12.57	3.01	5.13	5.06
	(35.9)	(245.7)	(256.2)	(20.3)	(90.4)	(139.7)	(44.9)	(132.8)	(156.9)	(8.1)	(25.3)	(24.6)
LSD (p=0.05)	NS	1.14	0.84	NS	0.44	0.31	NS	0.62	0.45	NS	0.68	0.33

[Original figures in parentheses were subjected to square root transformation before statistical analyses] DAP: Days after planting; *fb*: followed by; HW: hand weeding, NS: Not significant

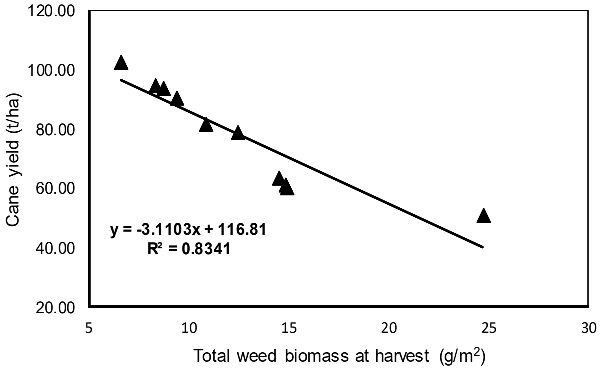

Figure 1. Relationship between cane yield and weed biomass at harvest

1.0 kg/ha at 60 DAP, which was followed by atrazine 1.0 kg/ha at 30 DAP *fb* glyphosate 1.0 kg/ha at 60 DAP (948.67 g). Similar observation was made by Ramesh and Sundri (2006). Land productivity in terms of yield varied significantly due to different weed management practices (**Table 3**). Application of ametryn 1.0 kg/ha at 30 DAP *fb* 2,4-D 1.0 kg/ha at 60 DAP proved to be best in terms of cane yield. This might be due to better crop growth in ametryn 1.0 kg/ha at 30 DAP *fb* 2,4-D 1.0 kg/ha at 60 DAP. Application of ametryn 1.0 kg/ha + 2,4-D 1.0 kg/ha gave significantly the highest cane yield (102.49 t/ha), which was followed by atrazine 1.0 kg/ha + glyphosate 1.0 kg/ha (94.87 t/ha) and three HW (93.83 t/ha). The plots treated with ametryn 1.0 kg/ha at 30 DAP *fb* 2,4-D 1.0 kg/ha at 60 DAP registered 49.97% higher cane yield than the untreated control.

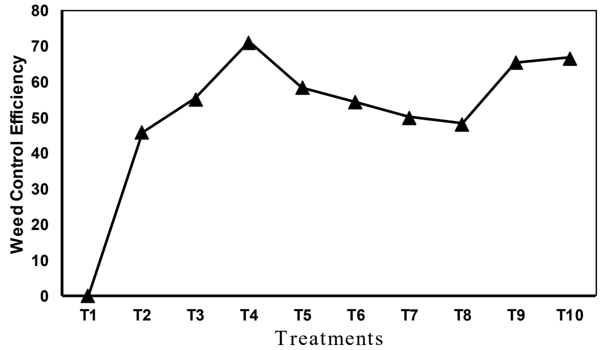

Figure 2. Weed control efficiency (%) of different treatments at 90 DAP in spring planted sugarcane

[T_1- Untreated control; T_2- Ametryn 1.5 kg/ha at 30 DAP *fb* HW at 45 DAP; T_3- Ametryn 3.0 kg/ha at 30 DAP; T_4- Ametryn 1.0 kg/ha at 30 DAP *fb* 2,4-D 1.0 kg/ha at 60 DAP; T_5- Atrazine 1.0 kg/ha at 30 DAP *fb* 2,4-D 1.0 kg/ha at 60 DAP; T_6- Two HW at 30 and 60 DAP; T_7- Atrazine 1.0 kg/ha at 30 DAP; T_8- 2,4-D 1.0 kg/ha at 30 DAP; T_9- Atrazine 1.0 kg/ha at 30 DAP *fb* glyphosate 1.0 kg/ha at 60 DAP; T_{10}- Three HW at 30, 60 and 90 DAP]

The highest harvest index was found under three rounds of HW (82.73%), followed by atrazine 1.0 kg/ha + 2,4-D 1.0 kg/ha (81.86%) and ametryn 1.0 kg/ha + 2,4-D 1.0 kg/ha (81.53%). Increase in cane yield under these treatments might be attributed to effective suppression of weeds. Quality attributes (juice extraction and brix value) did not show any significant variation due to weed control treatments (**Table 3**). Similar results were reported by Mathew *et al.* (2002) and Bhullar *et al.* (2008). However, three HW at 30, 60 and 90 DAP recorded marginally higher juice recovery (52.99%) possibly due to reduced

Table 2. Effect of different herbicides on dry biomass of weed (g/m^2) at different stages of crop growth (pooled data of 2 seasons)

Treatment	*Cyperus rotundus*			*Cynodon dactylon*			*Alternanthera philoxeroides*			Other weeds		
	30 DAP	60 DAP	90 DAP	30 DAP	60 DAP	90 DAP	30 DAP	60 DAP	90 DAP	30 DAP	60 DAP	90 DAP
Ametryn 1.5 kg/ha at 30 DAP *fb* hand weeding at 45 DAP	2.43 (4.9)	11.90 (140.6)	10.85 (116.7)	2.09 (3.4)	6.17 (37.1)	6.98 (47.7)	4.07 (15.5)	3.94 (14.5)	5.79 (32.5)	1.72 (2.0)	4.80 (13.4)	4.71 (12.8)
Ametryn 3.0 kg/ha at 30 DAP	2.38 (4.7)	11.40 (129.1)	9.72 (93.6)	2.13 (3.5)	5.78 (32.4)	5.18 (25.8)	4.07 (15.5)	3.67 (12.5)	4.16 (16.3)	1.69 (1.9)	4.31 (9.9)	3.96 (7.8)
Ametryn 1.0 kg/ha at 30 DAP *fb* 2,4-D 1.0 kg/ha at 60 DAP	2.39 (4.7)	7.59 (56.7)	5.57 (30.0)	2.13 (3.5)	3.98 (14.8)	4.26 (17.2)	3.98 (14.9)	3.17 (9.1)	3.14 (8.8)	1.73 (2.0)	3.09 (3.4)	3.03 (3.1)
Atrazine 1.0 kg/ha at 30 DAP *fb* 2,4-D 1.0 kg/ha at 60 DAP	2.54 (5.5)	10.94 (118.8)	8.60 (73.1)	2.13 (3.5)	5.50 (29.2)	5.58 (30.2)	4.03 (15.2)	3.50 (11.3)	3.74 (13.0)	1.72 (2.0)	4.14 (8.9)	3.80 (6.8)
Two hand weeding at 30 and 60 DAP	2.41 (4.8)	11.15 (123.5)	9.05 (81.0)	2.13 (3.5)	5.98 (34.8)	5.38 (27.9)	4.11 (15.8)	3.57 (11.7)	3.82 (13.6)	1.73 (2.0)	4.23 (9.4)	5.71 (27.6)
Atrazine 1.0 kg/ha at 30 DAP	2.43 (4.9)	11.84 (139.3)	10.50 (109.3)	2.15 (3.6)	5.78 (32.4)	7.23 (51.3)	4.03 (15.3)	3.67 (12.4)	5.62 (30.5)	1.74 (2.0)	4.41 (10.6)	4.27 (9.7)
2,4-D 1.0 kg/ha at 30 DAP	2.49 (5.2)	11.91 (140.9)	10.55 (110.4)	2.16 (3.6)	5.78 (32.4)	6.31 (38.8)	4.03 (15.2)	3.66 (12.4)	5.67 (31.1)	1.73 (2.0)	4.55 (11.6)	4.41 (10.6)
Atrazine 1.0 kg/ha at 30 DAP *fb* glyphosate 1.0 kg/ha at 60 DAP	2.43 (4.9)	9.11 (82.1)	7.24 (51.5)	2.16 (3.7)	4.07 (15.5)	4.43 (18.6)	3.99 (14.9)	3.19 (9.1)	3.35 (10.2)	1.74 (2.0)	3.74 (6.5)	3.39 (4.7)
Three hand weeding at 30, 60 and 90 DAP	2.43 (4.9)	9.40 (87.5)	7.67 (57.9)	2.17 (3.7)	4.18 (16.4)	2.92 (23.2)	3.99 (14.9)	3.48 (11.1)	3.65 (12.3)	1.72 (1.9)	3.76 (6.6)	4.56 (26.4)
Untreated control	2.53 (5.4)	14.92 (221.7)	16.69 (277.6)	2.11 (3.5)	8.96 (79.3)	11.81 (138.5)	3.96 (14.7)	10.64 (112.3)	15.97 (254.2)	1.72 (2.0)	5.85 (22.5)	7.95 (47.2)
LSD (p=0.05)	NS	0.03	0.06	NS	0.06	0.33	NS	0.03	0.06	NS	0.06	2.49

[Original figures in parentheses were subjected to square root transformation before statistical analyses] DAP: Days after planting; *fb*: followed by; HW: hand weeding, NS: Not significant

Table 3. Yield and quality attributes, cane yield and production economics as influenced by different treatments in sugarcane (pooled data of 2 seasons)

Treatment	Millable cane (no./m^2)	Cane weight (g)	Cane yield (t/ha) 2017-18	Cane yield (t/ha) 2018-19	Cane yield (t/ha) Pooled	Harvest index (%)	B:C ratio	Juice recovery (%)	Brix value (%)
Ametryn 1.5 kg/ha at 30 DAP *fb* hand weeding at 45 DAP	8.23	736.04	57.34	63.48	60.41	79.52	1.60	52.89	19.19
Ametryn 3.0 kg/ha at 30 DAP	9.30	847.63	77.45	80.27	78.86	82.62	2.30	52.80	18.53
Ametryn 1.0 kg/ha at 30 DAP *fb* 2,4-D 1.0 kg/ha at 60 DAP	10.33	991.67	99.89	105.09	102.49	81.53	2.90	52.97	18.60
Atrazine 1.0 kg/ha at 30 DAP *fb* 2,4-D 1.0 kg/ha at 60 DAP	10.12	893.75	88.20	92.80	90.50	81.86	2.50	52.76	18.71
Two hand weeding at 30 and 60 DAP	9.21	885.52	80.14	82.92	81.53	81.09	2.20	52.89	18.60
Atrazine 1.0 kg/ha at 30 DAP	8.52	743.59	60.96	65.76	63.36	79.42	1.83	52.93	18.55
2,4-D 1.0 kg/ha at 30 DAP	8.47	724.88	59.78	63.00	61.39	77.42	1.77	52.76	18.36
Atrazine 1.0 kg/ha at 30 DAP *fb* glyphosate 1.0 kg/ha at 60 DAP	10.00	948.67	92.22	97.52	94.87	81.06	2.85	52.73	18.62
Three hand weeding at 30, 60 and 90 DAP	10.00	938.33	92.16	95.50	93.83	82.73	2.60	52.99	18.64
Untreated control	7.33	699.06	49.52	52.96	51.24	74.47	1.56	52.81	18.56
LSD (p=0.05)	0.51	10.83	13.52	14.21	13.31	0.32	-	NS	NS

interference of weeds and higher millable cane weight, which was followed by ametryn 1.0 kg/ha + 2,4-D 1.0 kg/ha and atrazine 1.0 kg/ha. There was minimum juice recovery with the application of atrazine + glyphosate. However, maximum brix value was recorded with ametryn 1.5 kg/ha at 30 DAP + HW at 45 DAP (19.19%), followed by atrazine 1.0 kg/ha at 30 DAP + 2,4-D 1.0 kg/ha at 60 DAP (18.71%), whereas it was minimum under the application of 2,4-D 1.0 kg/ha at 30 DAP (18.36%). Singh and Tomar (2005) opined that sucrose content was not significantly influenced due to imposition of weed management practices.

Economics

The maximum benefit: cost ratio (2.90) was recorded in ametryn 1.0 kg/ha at 30 DAP + 2,4-D 1.0 kg/ha at 60 DAP due to lower weed control cost and better cane yield. The second-best treatment was sequential application of atrazine 1.0 kg/ha at 30 DAP + glyphosate 1.0 kg/ha at 60 DAP (2.85). The lowest B:C ratio (1.56) was recorded under unweeded control.

Conclusion

It can be concluded that application of ametryn 1.0 kg/ha at 30 DAP *fb* 2,4-D 1.0 kg/ha at 60 DAP would be a cost-effective recommendation for suppression of all types of weeds and obtaining higher cane yield with more economic returns in the Gangetic Inceptisol of West Bengal.

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Weed management in non-cropped areas with pre-mix of indaziflam and glyphosate in Punjab

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ABSTRACT

Non-cropped areas are infested with diverse weed flora including annual and perennial grasses, sedges and broad-leaf weeds. The field efficacy of pre-mix of indaziflam plus glyphosate was evaluated for effective weed management in these areas. The field experiment was conducted over two years in Ludhiana (India). Seven treatments including pre-mix formulation of indaziflam-20 + glyphosate 400-420 SC (60 + 1200, 70 + 1400 and 80 + 1600 g/ha), glyphosate (1230 and 1600 g/ha) and indaziflam (80 g/ha) along with untreated control were evaluated. Major weed species at the experimental site were *Cannabis sativa*, *Parthenium hysterophorus*, *Verbesina encelioides* and *Xanthium strumarium*. All herbicidal treatments recorded complete mortality of *C. sativa* and *P. hysterophorus* till 30 days after application (DAA) while in case of *V. encelioides* and *X. strumarium,* complete mortality was recorded till 120 DAA. Pre-mix of indaziflam plus glyphosate at 80 + 1600 g/ha had >80% control of all weed species during both years till 60 DAA, and it was at par to its lower dose of 70 + 1400 g/ha; results with sole application of indaziflam and glyphosate were inconsistent.

INTRODUCTION

Weeds are one of the major biological constraints to agricultural production system causing damage in cropped and non-cropped lands. Many weeds like *Cannabis sativa*, *Parthenium hysterophorus*, *Verbesina encelioides* and *Xanthium strumarium* infest non-cropped areas and roadsides of Punjab. Among these, *P. hysterophorus* (common ragweed) is the most noxious weed, which rapidly colonizes urban areas thereby replacing the native vegetation (Bajwa *et al.* 2016). Fast growth rate, high reproductive potential and interference via allelopathy are the major factors responsible for its wide spread infestation in waste lands/non-cropped areas as well as cultivated fields (Kohli *et al.* 2006 and Sushilkumar 2014). *V. encelioides* commonly known as golden crownbeard is a major roadside weed especially in South West Punjab districts including Ferozepur, Fazilka, Bathinda, Barnala and Sangrur (Goyal *et al.* 2019). It contains a chemical named galegine which can cause poisoning in livestock. *C. sativa* (Indian hemp) is another common weed found along roadsides and non-cropped areas of Punjab that has also started to infest wheat fields in sub-montane and central zones of Punjab including the districts Hoshiarpur, Kapurthala, Jalandhar and Ludhiana (Kaur *et al.* 2015). Ingestion of *C. sativa* can cause short term memory loss. *X. strumarium* (cocklebur) has also been reported as a major weed found along roadsides and rice fields throughout the tropical parts of India (Kamboj and Saluja 2010).The allelochemicals produced from different parts of *X. strumarium* inhibit the seed germination and seedling growth of many crops *viz.* soybean, cotton, peanut, wheat, maize, pearl millet, chickpea, rapeseed, tobacco and lettuce (Singh and Pandey 2019). Management of these weeds growing along roadsides or field boundaries is important to prevent their invasion into croplands.

Glyphosate (N-phosphonomethyl modified derivative of glycine) is the most widely used herbicide for the management of weeds growing on field bunds, field boundaries, non-cropped areas and wastelands. Glyphosate kills plants by inhibiting the enzyme 5-enolpyruvyl-shikimate-3-phosphate synthase, which catalyzes synthesis of aromatic amino acids (phenylalanine, tyrosine and tryptophan) involved in the formation of essential proteins in plants (Sammons and Gaines 2014). Resistance to this shikimate pathway inhibitor has been reported in more than 20 species from many parts of the world (Heap 2017). Paraquat (1,1′-dimethyl-4,4′-bipyridinium ion) is another major herbicide used for weed control in non-croplands. But there are many studies which report the reduced efficacy of this herbicide owing to evolution of resistant weed populations (Heap 2017). But none of these herbicides can provide long-term control of invasive weeds when used alone, resulting in rapid re-infestations by weeds (Mangold *et al.* 2015). This emphasizes the need to evaluate new herbicide formulations along with the mixture for efficient and economic control of these weeds under non-cropped situations. Indaziflam, a broad-spectrum herbicide belonging to the chemical class alkylazine, kills susceptible plants by inhibiting biosynthesis of cellulose (Kaapro and Hall 2012). The present study evaluated the efficacy of pre-mix of indaziflam and glyphosate against weeds infesting non-cropped areas.

MATERIALS AND METHODS

The experiment was laid out on the link road to village Lalton, Ludhiana, Punjab (India) which is situated at 30°84'N latitude and 75°78'E longitude. The study was conducted during 2015 and 2016 with seven treatments in randomized complete block design. The herbicide treatments included three doses of pre-mix formulation of indaziflam-20 plus glyphosate 400-420 SC (60 + 1200, 70 + 1400 and 80 + 1600 g/ha), two doses of glyphosate (1230 and 1600 g/ha) and one dose of indaziflam (80 g/ha) along with untreated control. The herbicides were sprayed along roadsides with knap-sack sprayer fitted with flat-fan nozzle using 500 L/ha spray volume at peak growth of weeds before flowering/setting seeds. Weed density and dry biomass were recorded from three spots at 30, 60, 90 and 120 days after application (DAA) from one m^2 area. For recording weed biomass, three plants from each plot were uprooted; dried in sunlight and then oven dried at 60°C for 48 hours. Dry weight was taken till constant weight was achieved.

RESULTS AND DISCUSSION

The dominant weed flora at experimental area included *C. sativa*, *P. hysterophorus* and *X. strumarium* in 2015 and, *C. sativa*, *P. hysterophorus* and *V. encelioides* during 2016.The percent composition of weed spp., *viz. C. sativa*, *P. hysterophorus* and *X. strumarium* was 49, 28 and 23, respectively during 2015. In 2016, per cent composition of *C. sativa*, *P. hysterophorus* and *V. encelioides* was 15, 24 and 60, respectively. At 30 days after application (DAA), indaziflam and glyphosate sole and as pre-mix, at all doses, gave complete kill of all the four weed species and in both years, and in case of *V. encelioides* and *X. strumarium* the complete kill was recorded till 120 DAA. At 60 DAA, indaziflam plus glyphosate at all doses and indaziflam and glyphosate sole recorded significantly lower density of all weeds as compared to untreated control (**Table 1** and **2**). Re-emergence of *C. sativa* and *P. hysterophorus* was, however, observed at 45 DAA under all treatments. Density of all weed species decreased with every increase in dose of indaziflam plus glyphosate. At 90 and 120 DAA, density of *C. sativa* and *P. hysterophorus* in all herbicide treatments was at par with untreated control (**Table** 1 and **2**). There was no emergence of *V. encelioides* and *X. strumarium* after herbicides application. Indaziflam plus glyphosate at 80 + 1600 g/ha gave >80% control of all weeds as compared to untreated control till 60 DAA in both the years, however, the results were not consistent with sole application of indaziflam and glyphosate. Ko *et al.* (2019) reported that glyphosate applied alone at 1.0 X (3 L/ha) and 0.5 X (1.5 L/ha) doses was not effective for control of *Oenothera biennis* (evening primrose) with < 70 and 50% weed control efficiency. Singh *et al.* (2004) reported that under non-cropped situation, 2,4-D, atrazine,

Table 1. Effect of pre-mix of indaziflam plus glyphosate on weed density in 2015

Treatment	Dose (g/ha)	Weed density (no./m^2) DAA											
		Cannabis sativa				*Parthenium hysterophorus*				*Xanthium strumarium*			
		30	60	90	120	30	60	90	120	30	60	90	120
Indaziflam + glyphosate	60+1200	1.0 (0)	2.31 (4.3)	3.91 (14.3)	4.51 (19.3)	1.0 (0)	1.82 (2.33)	3.55 (11.7)	4.07 (15.7)	1.0 (0)	1.0 (0)	1.0 (0)	1.0 (0)
Indaziflam + glyphosate	70+1400	1.0 (0)	2.15 (3.7)	3.69 (12.7)	4.54 (19.7)	1.0 (0)	1.72 (2.0)	3.58 (12.0)	4.24 (17.0)	1.0 (0)	1.0 (0)	1.0 (0)	1.0 (0)
Indaziflam + glyphosate	80+1600	1.0 (0)	1.99 (3.0)	3.55 (11.7)	4.51 (19.3)	1.0 (0)	1.63 (1.7)	3.37 (10.3)	4.28 (17.3)	1.0 (0)	1.0 (0)	1.0 (0)	1.0 (0)
Indaziflam	80	1.0 (0)	2.08 (3.3)	3.55 (11.7)	4.47 (19.0)	1.0 (0)	1.72 (2.0)	3.65 (12.3)	4.00 (17.3)	1.0 (0)	1.0 (0)	1.0 (0)	1.0 (0)
Glyphosate	1230	1.0 (0)	1.99 (3.0)	3.46 (11.0)	4.61 (20.3)	1.0 (0)	2.16 (3.7)	3.74 (13.0)	4.36 (18.0)	1.0 (0)	1.0 (0)	1.0 (0)	1.0 (0)
Glyphosate	1600	1.0 (0)	2.08 (3.3)	3.83 (13.7)	4.65 (20.7)	1.0 (0)	2.38 (4.7)	3.79 (13.0)	4.47 (19.0)	1.0 (0)	1.0 (0)	1.0 (0)	1.0 (0)
Untreated control	-	2.58 (5.7)	3.15 (9.0)	3.78 (13.3)	4.54 (19.7)	2.08 (3.3)	2.51 (5.3)	3.36 (10.3)	4.00 (15.0)	1.91 (2.7)	2.16 (3.7)	2.23 (4.0)	2.44 (5.0)
LSD (p=0.05)		0.15	0.37	NS	NS	0.09	0.34	NS	NS	0.10	0.09	0.15	0.15

Parentheses are original values; data was square root ($\sqrt{x+1}$) transformed before analysis, DAA-Days after application metribuzin, metsulfuron and glufosinate failed to control *P. hysterophorus* while glyphosate at 2.7 and 5.4 kg/ha provided > 90% control even after 18 weeks of treatment. Sebastian *et al.* (2017) reported that indaziflam tank mixed with imazapic and picloram provided > 90% control of *Linaria dalmatica* (dalmatian toadflax) and *Bromus tectorum* (downy brome) as compared to treatments without indaziflam which had < 70 and 25% control of dalmatian toadflax and downy brome, respectively.

At 30 DAA, all herbicidal treatments gave complete kill of all weed species, hence, no weed biomass was recorded. All weed control treatments continued to provide complete kill of *V. encelioides* and *X. strumarium* till 120 DAA during both the years and, so no weed biomass of these weeds was recorded. At 60 DAA, all weed control treatments including indaziflam plus glyphosate at all doses and indaziflam and glyphosate alone recorded significantly lower biomass of all weeds as compared to untreated control (**Table 3** and **4**). At 60 DAA, indaziflam plus glyphosate at 80 g + 1600 g/ha reduced biomass of all weeds by > 80% during both the years and it was at par to its lower dose of 70 + 1400 g/ha, in 2015. The results, however, were not consistent when indaziflam and glyphosate used alone. At 90 and 120 DAA, dry biomass of *C. sativa* and *P. hysterophorus* under all herbicide treatments was at par with untreated control. Sikkema *et al.* (2008) reported that glyphosate at 900 g/ha provided > 80% reduction in dry biomass of cocklebur than untreated check. Gaikwad *et al.* (2008) reported that glyphosate (0.50 and 0.75%), atrazine (0.2 and 0.3%) and 2,4-D-ethyl ester (EE) (0.2 and 0.3%) caused significant reduction in density and biomass of *Parthenium* at 30 DAA. Khan *et al.* (2012) reported that glyphosate and metribuzin applied at rosette and bolting stages of *P. hysterophorus* gave > 90 and 70% mortality at 30 DAA than 2,4-D, atrazine plus s-metolachlor, atrazine, s-metolachlor. Clark *et al.*

Table 2. Effect of pre-mix of indaziflam plus glyphosate on weed density in 2016

Treatment	Dose (g/ha)	Weed density (no./m²) DAA											
		Cannabis sativa				*Parthenium hysterophorus*				*Verbesina encelioides*			
		30	60	90	120	30	60	90	120	30	60	90	120
Indaziflam + glyphosate	60+1200	1.0 (0)	2.08 (3.3)	3.46 (11.0)	4.51 (19.3)	1.0 (0)	2.44 (5.0)	3.37 (10.3)	4.86 (22.7)	1.0 (0)	1.0 (0)	1.0 (0)	1.0 (0)
Indaziflam + glyphosate	70+1400	1.0 (0)	1.99 (3.0)	3.31 (10.0)	4.43 (18.7)	1.0 (0)	2.44 (5.0)	3.46 (11.0)	5.13 (25.3)	1.0 (0)	1.0 (0)	1.0 (0)	1.0 (0)
Indaziflam + glyphosate	80+1600	1.0 (0)	2.08 (3.3)	3.37 (10.3)	4.43 (18.7)	1.0 (0)	2.22 (4.0)	3.41 (10.7)	4.78 (22.0)	1.0 (0)	1.0 (0)	1.0 (0)	1.0 (0)
Indaziflam	80	1.0 (0)	1.82 (2.3)	3.36 (10.3)	4.50 (19.3)	1.0 (0)	1.91 (2.7)	3.55 (11.7)	4.65 (20.7)	1.0 (0)	1.0 (0)	1.0 (0)	1.0 (0)
Glyphosate	1230	1.0 (0)	2.23 (4.0)	3.35 (10.3)	4.54 (19.7)	1.0 (0)	2.82 (7.0)	3.26 (9.7)	4.75 (21.7)	1.0 (0)	1.0 (0)	1.0 (0)	1.0 (0)
Glyphosate	1600	1.0 (0)	2.23 (4.0)	3.35 (10.3)	4.51 (19.3)	1.0 (0)	2.23 (4.0)	3.69 (12.7)	5.00 (24.0)	1.0 (0)	1.0 (0)	1.0 (0)	1.0 (0)
Untreated control	-	1.63 (1.7)	2.44 (5.0)	3.60 (12.0)	4.47 (19.0)	1.91 (2.7)	3.16 (9.0)	3.46 (11.0)	4.75 (21.7)	2.76 (6.7)	2.94 (7.7)	2.94 (7.7)	3.25 (9.7)
LSD (p=0.05)	-	0.12	NS	NS	NS	0.10	0.35	NS	NS	0.14	0.07	0.07	0.26

Parentheses are original values; data was square root ($\sqrt{x+1}$) transformed before analysis, DAA-Days after application

Table 3. Effect of pre-mix of indaziflam plus glyphosate on weed biomass in 2015

Treatment	Dose (g/ha)	Weed biomass (g/m²) DAA											
		Cannabis sativa				*Parthenium hysterophorus*				*Xanthium strumarium*			
		30	60	90	120	30	60	90	120	30	60	90	120
Indaziflam + glyphosate	60+1200	1.0 (0)	3.37 (10.5)	7.16 (50.4)	7.72 (58.6)	1.0 (0)	2.22 (3.9)	5.45 (28.9)	6.24 (38.0)	1.0 (0)	1.0 (0)	1.0 (0)	1.0 (0)
Indaziflam + glyphosate	70+1400	1.0 (0)	2.57 (5.8)	6.89 (46.8)	7.81 (60.1)	1.0 (0)	1.97 (3.0)	5.30 (27.9)	6.33 (39.1)	1.0 (0)	1.0 (0)	1.0 (0)	1.0 (0)
Indaziflam + glyphosate	80+1600	1.0 (0)	2.14 (3.7)	6.99 (47.9)	7.87 (60.9)	1.0 (0)	1.75 (2.1)	5.20 (26.1)	6.35 (39.3)	1.0 (0)	1.0 (0)	1.0 (0)	1.0 (0)
Indaziflam	80	1.0 (0)	3.07 (8.5)	6.71 (44.2)	7.70 (59.4)	1.0 (0)	3.21 (9.4)	5.46 (29.1)	6.23 (37.8)	1.0 (0)	1.0 (0)	1.0 (0)	1.0 (0)
Glyphosate	1230	1.0 (0)	2.63 (6.0)	6.88 (46.5)	7.86 (60.9)	1.0 (0)	2.96 (7.9)	5.88 (33.7)	6.24 (37.9)	1.0 (0)	1.0 (0)	1.0 (0)	1.0 (0)
Glyphosate	1600	1.0 (0)	2.29 (4.3)	7.60 (56.8)	7.84 (60.4)	1.0 (0)	1.75 (2.1)	5.82 (32.9)	6.18 (37.3)	1.0 (0)	1.0 (0)	1.0 (0)	1.0 (0)
Untreated control	-	3.89 (14.2)	5.46 (28.9)	7.40 (53.9)	7.70 (58.3)	2.59 (5.7)	3.99 (15.0)	5.72 (32.0)	6.26 (38.2)	3.43 (10.8)	4.63 (20.5)	5.68 (31.7)	6.67 (43.5)
LSD (p=0.05)	-	0.18	0.70	NS	NS	0.07	0.58	NS	NS	0.15	0.45	0.56	0.07

Parentheses are original values; data was square root ($\sqrt{x+1}$) transformed before analysis, DAA-Days after application

Table 4. Effect of pre-mix of indaziflam plus glyphosate on weed biomass in 2016

Treatment	Dose (g/ha)	Weed biomass (g/m^2) DAA											
		Cannabis sativa				*Parthenium hysterophorus*				*Verbesina encelioides*			
		30	60	90	120	30	60	90	120	30	60	90	120
Indaziflam + glyphosate	60+1200	1.0 (0)	2.82 (6.9)	5.38 (28.0)	6.22 (37.8)	1.0 (0)	2.22 (3.9)	4.39 (18.3)	5.43 (28.5)	1.0 (0)	1.0 (0)	1.0 (0)	1.0 (0)
Indaziflam + glyphosate	70+1400	1.0 (0)	2.38 (4.7)	4.97 (23.9)	6.30 (38.7)	1.0 (0)	2.01 (3.1)	4.17 (16.4)	5.21 (26.3)	1.0 (0)	1.0 (0)	1.0 (0)	1.0 (0)
Indaziflam + glyphosate	80+1600	1.0 (0)	1.86 (2.6)	5.30 (27.2)	6.18 (37.3)	1.0 (0)	1.79 (2.2)	3.90 (14.4)	5.47 (29.0)	1.0 (0)	1.0 (0)	1.0 (0)	1.0 (0)
Indaziflam	80	1.0 (0)	1.84 (2.4)	4.94 (23.6)	6.37 (39.6)	1.0 (0)	1.49 (1.2)	4.10 (15.8)	5.29 (27.1)	1.0 (0)	1.0 (0)	1.0 (0)	1.0 (0)
Glyphosate	1230	1.0 (0)	2.87 (7.3)	5.13 (25.7)	6.30 (38.8)	1.0 (0)	2.74 (6.6)	4.23 (17.0)	5.35 (27.7)	1.0 (0)	1.0 (0)	1.0 (0)	1.0 (0)
Glyphosate	1600	1.0 (0)	2.71 (6.3)	5.28 (27.1)	6.44 (40.4)	1.0 (0)	1.97 (2.9)	4.51 (19.6)	5.35 (27.7)	1.0 (0)	1.0 (0)	1.0 (0)	1.0 (0)
Untreated control	-	2.54 (5.5)	3.87 (14.1)	5.45 (28.8)	6.20 (37.5)	2.51 (5.3)	3.52 (11.5)	4.47 (19.0)	5.42 (28.4)	5.09 (25.1)	6.75 (44.7)	7.27 (51.9)	8.27 (67.3)
LSD (p=0.05)	-	0.11	0.47	NS	NS	0.11	0.38	NS	NS	0.35	0.31	0.27	0.13

Parentheses are original values; data was square root ($\sqrt{x+1}$) transformed before analysis, DAA-Days after application

(2019) reported that indaziflam can provide multiyear control of downy brome (*Bromus tectorum* L.) in non-cropped sites without any impact to native perennial species.

The study concluded that pre-mix of indaziflam plus glyphosate at 70 + 1400 g/ha could provide efficient weed management of *Cannabis sativa* and *Parthenium hysterophorus* until up to 60 DAA, and of *Xanthium strumarium* and *Verbesina encelioides* even for longer time (120 DAA) in non-cropped areas.

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Residue dynamics and degradation behaviour of pyrazosulfuron-ethyl in the rice field environment

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ABSTRACT

Pyrazosulfuron-ethyl is used in rice fields to manage a range of annual and perennial weeds. Its long-term herbicide residue dynamics in rice ecosystem and degradation pattern is poorly characterized. Therefore, in the present study, field experiments were conducted for consecutive two years to investigate the residue dynamics and degradation of pyrazosulfuron-ethyl in the soil, rice plant, water and fishes in the rice field. Pyrazosulfuron-ethyl residues were found to be below the maximum residues levels (0.01 mg/kg) in the soil, rice grains, and straw. In the fishes, pyrazosulfuron-ethyl residues were in the range of 0.056- 0.013 µg/g. Half-life of pyrazosulfuron-ethyl in the soil of rice field was found to be 9.41 to 13.9 days. Results showed that pyrazosulfuron-ethyl at 25 g/ha application rate did not cause any environmental hazards and can be safely applied in the rice fields for management of annual and perennial weeds.

INTRODUCTION

Herbicides are commonly used in the modern agriculture to minimize potential yield losses by the weeds. According to an estimate, approximately 80% of applied pesticide in agricultural practices did not reach to its target and dispersed through the air, soil, and water (Sondhia 2014). As a result, they are frequently been detected in the air, surface and ground water, sediment, soil, vegetable and to some extent in the processed foods (Battanlin 2000, Sondhia 2014). In many instances herbicide applications resulted in the accumulation of residues and metabolites in the soils above the prescribed residues limits (Shalaby and Abdou 2010, Sondhia 2014). Besides this, pesticides are also found into aquatic ecosystems through runoff water.

Pyrazosulfuron-ethyl,[ethyl-5-[(4,6-dimethoxypyrimidin-2-ylcarbamoyl)sulfamoyl]-1-methyl pyrazole-4-carboxylate is one of the sulfonylurea group of herbicide which is widely used to control perennial and annual weeds, especially broad-leaved weeds and sedges in the rice fields in rice growing countries as pre-emergence or early post-emergence application (Sondhia *et al.* 2013). It retards growth of weed through inhibition of acetolactate synthase (ALS), a key enzyme that catalyzes the biosynthesis of three important amino acids, *viz.* valine, leucine, and isoleucine which are essential for the protein synthesis of plants (Zhu *et al.* 2002, Sondhia 2009, Sondhia *et al.* 2013). Due to high persistence in soil, a few leguminous crops are reported to be highly sensitive to the residues of sulfonylurea herbicides (Ye *et al.* 2003, Sondhia *et al.* 2016, Sondhia 2019).

Excessive use of pyrazosulfuron-ethyl in the rice fields may have adverse effects on the agricultural production, environment and human health (Ding *et al.* 2010, Sondhia *et al.* 2016) and may significantly decrease the soil biota (Xu *et al.* 2009). In earlier studies, Zheng *et al.* (2008) demonstrated dissipation of pyrazosulfuron-ethyl in water by chemical hydrolysis. Xu *et al.* (2009) and Sondhia *et al.* (2013) reported fungal degradation of pyrazosulfuron-ethyl in the soil and identified major and minor metabolites. Singh *et al.* (2012) provided translocation of ^{14}C pyrazosulfuron-ethyl in the rice plant but did not study its complete fate in the rice ecosystem. Therefore, this study was undertaken to investigate degradation behaviour and residues dynamics of pyrazosulfuron-ethyl in the soil, plant, fishes and water under rice field environment.

MATERIALS AND METHODS

The study was conducted during rainy seasons in 2012 and 2013. In both the years, approximately

25-days old seedlings of rice Cv. '*Kranti*' were transplanted in the soil of experimental field with a row spacing of 20 x 15 cm. Pyrazosulfuron-ethyl was sprayed as a post-emergence to control mix flora of weeds in the rice field at recommended dose of 25 g/ha along with a check (no herbicide). Rice crop was raised according to irrigated conditions with the recommended package of practices. The experimental soil was found to be of clay loam texture with 67.32% sand, 10.0% silt, and clay 22.68%, pH 7.4 and organic carbon 0.85%. Commercial and analytical grade pyrazosulfuron-ethyl was purchased from United Phosphorus Limited Company, Gujarat. Analytical grade chemicals and solvents were used in the studies which were purchased from E Merck. Germany.

Collection of soil, water, plant and fish samples

Degradation of pyrazosulfuron were determined in the treated and untreated soils collected in polyethylene bags from the rice field at 0, 5, 10, 20, 30, 60, 90 days after the herbicide application and at harvest. Rice plant samples were collected on 1, 10, 20, 30, 60, and at harvest after the herbicide application. Water samples were taken at 5, 10, 20, 30, 60, 90 days after the herbicide application to evaluate pyrazosulfuron-ethyl residues as a result of runoff. Fishes were collected from the adjacent ponds to determine pyrazosulfuron-ethyl residues at 30, 60, and 100 days after the herbicide application in the rice field.

Determination of pyrazosulfuron-ethyl residues

Ten g of the soil from each sample was weighed and transferred to an Erlenmeyer flask of 250 ml capacity. Pyrazosulfuron-ethyl was then extracted and analyzed from the soil samples following methods of Sondhia *et al.* (2013). The limit of detection (LOD) of pyrazosulfuron-ethyl in the various matrixes was detected with acceptable certainty as demonstrated by Sondhia (2008) and European Commission Safety of the Food Chain Pesticides and Biocides guidelines (2015). The LOD and the LOQ for pyrazosulfuron-ethyl were found to be 0.001 and 0.01 µg/mL, respectively.

Pyrazosulfuron residues in the soil, rice, water, and fishes were determined by the HPLC attached to a Photo Diode Array Detector utilizing a C-18 column (ODS) of 250 mm length and 4.6 mm of internal diameter. A mobile phase consisted of acetonitrile: water (70:30) was used with a flow rate of 0.9 mL/ min-. HPLC system was injected with standard solutions (20 µL) of pyrazosulfuron-ethyl in acetonitrile with a concentration range of 0.001 to 10 µg/mL. Detection of pyrazosulfuron-ethyl was done at a wavelength at 215 nm and peak areas (µV/sec) was measured and plotted versus concentrations (µg/ mL) and fitted to a simple linear regression to obtain an equation for the standard curve. The residues of pyrazosulfuron-ethyl in each sample were calculated based on the basis of slope of the standard curve which was found to be y=-13431x +36462 (R^2 0.99). The data were calculated as mean ± S.D and analyzed following analysis of variance technique (ANOVA). Degradation kinetics was described using a first-order reaction model: $Ct = C0 \times e^{-kt}$, where C_0 (mg kg) was the initial concentration in the soil, Ct (mg kg) was the concentration at time t (min) and k (per min) is the rate constant. The half-life *i.e.* the time of dissipation of was calculated as $t1/2 = \ln(2)/k$, where K is the degradation rate constant.

RESULTS AND DISCUSSION

Residue dynamics of pyrazosulfuron-ethyl in the soil of rice field

Degradation of pyrazosulfuron-ethyl in the soil of rice field is presented in **Figure 1**. After two hours of spray, the pyrazosulfuron-ethyl residues were found to be 0.0595 µg/g in the soil of rice field. Pyrazosulfuron-ethyl residues were found to be degraded rapidly from the rice soil and decreased to 0.025, 0.018 and 0.017, 0.0010 µg/g after 5, 10 and 20, 30 days, respectively. At 90 days residues of pyrazosulfuron-ethyl were found below <0.001 µg/g in the soil of rice field. However, in 2013, after two hours of application of pyrazosulfuron-ethyl, 0.095 µg/g residues were detected in the soil which dissipated to 0.0219 and 0.0088 µg/g at 20 and 30 days, respectively. At 60 and 90 days, residues of pyrazosulfuron-ethyl were reached to a level of <0.001 µg/g in the soil of rice field.

Pyrazosulfuron-ethyl residues in the water

As a result of runoff from the rice field to the adjacent ponds, an amount of 0.033 and 0.0167 µg/mL pyrazosulfuron-ethyl residues were detected in the pond water at 10 and 20 days, respectively after herbicide application in the rice field. Residues of pyrazosulfuron-ethyl in the pond water were found to be below <0.001 µg/mL after 30 days in 2012 (**Table 1**). However, in 2013, at 5 and 10 days, 0.0349 and 0.0314 µg/mL residues of pyrazosulfuron-ethyl were detected in pond water which degraded to 0.0096 µg/ mL at 20 days, respectively. Residues of pyrazosulfuron-ethyl were dissipated to below 0.001 µg/mL after 60 days in the pond water.

Residue of pyrazosulfuron-ethyl in the rice plants

An amount of 0.0116 and 0.036 µg/g pyrazosulfuron residues were found in the green plant at 10 and 30, days, respectively in 2012. Residues were found to be below the detection limit (<0.001 µg/g) at 60 days. Pyrazosulfuron-ethyl residues were also found below the detection limit (0.001µg/g) in the rice straw at harvest (**Table 1**). In 2013, residues of pyrazosulfuron-ethyl were in the range of 0.2384 to 0.012 µg/g in the green rice plants at 10 to 30 days.

Residues of pyrazosulfuron-ethyl in the fishes

In 2012, pyrazosulfuron residues as a result of runoff in the fishes were found to be 0.013 µg/g after 30 days; however, residues were degraded to below the limit of detection after 60 days. In the fishes, 0.056 µg/g residues of pyrazosulfuron-ethyl were found after 30 days in the fishes in 2013. At 60 days pyrazosulfuron-ethyl, residues in fishes were found below the detection limit (<0.001 µg/g) (**Table 1**).

Pyrazosulfuron –ethyl was found to degrade in the soil according to first order equations: y = -0.023x +1.068 (linear) and y = -0.032x +1.508 in 2012 and 2013, respectively. The degradation trends of pyrazosulfuron-ethyl residues on soil at various days, determination coefficients, and half-life are given in **Table 2**, and **Figure 1** and **2**. On the basis of dissipation equations, the half-life of pyrazosulfuron-ethyl in the soil of rice field was found to be 13.86 and 9.41 days under field conditions in 2012 and 2013, respectively.

Singh *et al.* (2012) found half-life of pyrazosulfuron approximately 5 days at 20-30 g/ha rates of applications, whereas Ishii *et al.* (2004) found half-life of pyrazosulfuron-ethyl as 11 and 1.9 days in rice field soil and water, respectively. Chu *et al.* (2002), reported half-life of pyrazosulfuron-ethyl as 16.2–24.4 days in the surface soil, 5.8–7.8 days in the bottom soil having low pH and high organic matter in a rice field experiment. The half-life found in this study in both the years was in similar range to first-order kinetics with half-life reported for other sulfonylurea herbicides such as chlorsulfuron (20-147 days), and metsulfuron-methyl (17-135 days) in soils having pH range from 3.9 to 7.0 (Sondhia 2009). In literature, degradation of sulfonylureas was reported to be less in neutral pH soils than in the acidic soils (Hultgren *et al.* 2002).

During the experiment in 2012 and 2013, total rainfall during the rice crop growth period was found to be 1309.9 and 2331.4 mm, respectively, that had a

Table 2. Rate kinetics equations, R^2 value and half-life of pyrazosulfuron-ethyl residues in the soil under rice field conditions

Year of study	Equation	R^2	DT_{50} (days)
2012	y = -0.023x + 1.068	0.88	13.9
2013	y= -0.032x+1.508	0.92	9.41

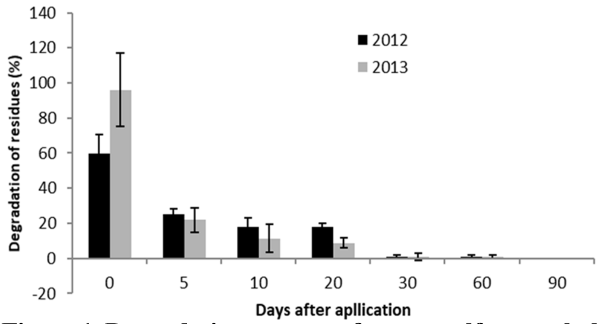

Figure 1. Degradation pattern of pyrazosulfuron-ethyl residues in the soil of rice field

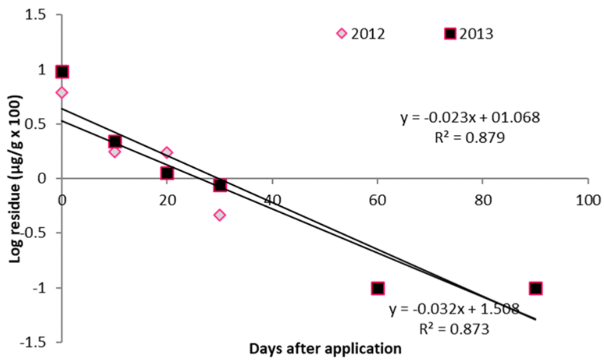

Figure 2. Dissipation rate kinetics of pyrazosulfuron-ethyl in the soil of rice field

Table 1. Residues of pyrazosulfuron-ethyl in the pond water and rice plants

Days	Residues (µg/g)					
	Pond water		Rice plants		Fishes	
	2012	2013	2012	2013	2012	2013
1	-	-	0.246*± 0.048**	0.312± 0.011	-	-
5	<0.001	0.0349± 0.010	-	-	-	-
10	0.033 ± 0.010	0.0314± 0.008	0.116± 0.010	0.238± 0.090	-	-
20	0.0167± 0.013	0.0096± 0.001	0.072± 0.010	0.163± 0.010	-	-
30	<0.001	0.0074± 0.0005	0.036± 0.006	0.012± 0.004	0.013± 0.004	0.056± 0.017
60	<0.001	<0.001	0.001	0.007± 0.001	<0.001	<0.001
90	<0.001	<0.001	<0.001	<0.001	-	-
100	-	-	-	-	<0.001	<0.001

* Mean of three replications; **Standard deviation

significant effect on residue dynamics in the soil, water, and plants. Due to continuous heavy rains in the month of June (422.3 mm) and July (613.8 mm) in 2013, more residues were reached to pond water as a result of runoff and detected even after 5 days of pyrazosulfuron–ethyl application in the rice field. Whereas in 2012 uneven rain in the month of June (130.4) and July (671.2), which caused the difference in the pyrazosulfuron-ethyl residues. Literature demonstrated that due to dry spell herbicide usually tend to adsorbed more in the soil and not moved by runoff (Suo *et al.* 2019) and hence pyrazosulfuron residues were not detected after 30 days in the pond water in 2012 (**Table 1**).

In our experiment, approximately neutral soil pH (7.4) and high organic carbon might have favored degradation of pyrazosulfuron-ethyl in the rice field by the process of hydrolysis and resulted in below detection levels of residues in the soil at harvest. Similar results were also reported by Zheng *et al.* (2013). The movement of pyrazosulfuron in the bottom layer of soil was also reported by Chu *et al.* (2002) besides its degradation via biochemical process, photolysis and through uptake by plants (Wang *et al.* 2013). In general, the degradation of pyrazosulfuron-ethyl was rapid in the soil of rice field in both the years.

Conclusion

In this study, pyrazosulfuron-ethyl was found to degrade quickly in the soil of rice field in both the years. Flooded conditions due to heavy rains, almost neutral pH and high organic carbon favored rapid degradation of pyrazosulfuron-ethyl in the soil of rice growing field and residues were not detected at harvest in the soil, grain and straw. Residues were also found below the maximum residue levels (MRL) of 0.01 mg/kg in the rice plants prescribed by Indian government under the prevention of food adulteration act and rules and therefore, pyrazosulfuron-ethyl can be considered as an effective and safe herbicide to be applied at 25 g/ha in transplanted rice to control sedges and broad-leaved weeds.

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Describing morphological characters of seedlings of some dicotyledonous weeds for their identification and management

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ABSTRACT

Seedling traits of 60 weeds under 24 families of Magnoliopsida have been studied in some crop fields of Dakshin Dinajpur district of West Bengal. Conservative seedling characters emphasize that the studied taxa may be enlisted in four artificial groups *i.e*, Type I to IV, each having some families and/or genera. Artificial keys have been made for identification under field observations. The bearing of this study has also been addressed by camping seedling data with other botanical disciplines. Peculiar juvenile behaviors like heteroblastic developments have also been observed. Seedling study is very much significant for eradication of weeds at juvenile stage before display of variable weeds in crop fields.

INTRODUCTION

Weeds are undesired plant species that grow with cultivated crops and intervene or compete with the crops for growth and nutrients and in this way affect the productivity leading to economic loss (Marwart *et al.* 2013). Most of the weeds are annual and complete their life cycle within a short period of time producing a large number of viable seeds that germinates immediately in almost every season to interact with crops. Therefore, rapid and accurate identification of weeds in seedling stage might be helpful for a successful weed management that can save both time and cost of production as well as lower chemical herbicide usage (Parkinson *et al.* 2013).

Importance of studying phenotypic traits of weed seedlings for their correct identification has a major role in suggesting suitable post-emergence herbicides for effective weed management. It is a common practice for the farmers in most parts of Eastern India that they use herbicides on mature weeds during pre or post harvesting period while abundant seeds have already been added by the weeds in the soil. Seeds protected by hard seed coats are not affected by the herbicides and they germinate into the next generation of weeds demanding proportional use of herbicides over the years. Hence, a strategy of weed management using herbicide or manual labor may be administered at the seedling stage *i.e.*, before flowering and fruiting to stop the next generation before it germinates. For this, weeds must be identified at the seedling stage through proper keys constructed based of their juvenile traits of cotyledons or other parts, which are conservative and viable for weeds growing in any geological or ecological conditions and this process has already advocated by some workers (Parkinson *et al.* 2013, Chomas *et al.* 2001, Chancellor 1966).

MATERIALS AND METHODS

Thorough survey for collection of seeds and/or seedlings has been done from March, 2017 to February, 2018 in the crop fields located in different mouzas (administrative unit) of Balurghat block. The list of seedlings studied is given in **Table 1**. The taxa are arranged family wise after Takhtajan, 1997 and alphabetically with author's name(s), and photograph number within each family. The seedlings are collected in pre- and post-harvesting periods as well as growth stages of crops. The seeds are air-dried and sown in prepared seedbeds separately from time to time with proper tagging to raise seedlings in the experimental garden of Balurghat College. So-raised seedlings were compared to natural ones for proper identification. Few seedlings were also identified following literatures of Chancellor (1966), Chomas *et al.* (2001) and Parkinson *et al.* (2013). The seedlings were described with following Duke (1965), Burger (1972), de Vogel (1980), Paria *et al.* (1990, 2006), and Das and Kamilya (2014). Field photographs taken with Nikon digital camera of all the seedlings with highlighted paracotyledons and first two leaves have

Table 1. List of species studied with author's names and photograph numbers arranged under each families following Takhtajan (1997)

Ranunculaceae	Oxalidaceae
Ranunculus sceleratus L. [Figure A1]	*Oxalis corniculata* L. [Figure B15]
Papaveraceae	Apiaceae
Argemone mexicana L. [Figure A2]	*Centella asiatica* Urban [Figure C1]
Fumaria indica (Hasskn.) Pugsley [Figure A3]	*Hydrocotyle sibthorpioides* Lam. [Figure C2]
Molluginaceae	*Oenanthe benghalensis* (Roxb.) Benth. & Hook. *f.* [Figure C3]
Glinus lotoides L. [Figure A4]	Asteraceae
Glinus oppositifolius (L.) Aug. DC. [Figure A5]	*Ageratum conyzoides* L. [Figure C4]
Caryophyllaceae	*Ageratum haustonianum* Mill. [Figure C5]
Drymaria cordata (L.) Willd. *ex*Schult. [Figure A6]	*Centipeda minima* (L.) A.Br. & Asch. [Figure C6]
Polycaarpon prostratum (Forssk.) Asch. & Schweinf. [Figure A7]	*Eclipta prostrata* (L.) L. [Figure C7]
Portulacaceae	*Gnaphalium polycaulon* Pers. [Figure C8]
Portulaca oleracea L. [Figure A8]	*Grangea maderaspatana* (L.) Poir. [Figure C9]
Amaranthaceae	*Xanthium strumarium* L. [Figure C10]
Achyranthus aspera L. [Figure A9]	Rubiaceae
Alternanthera paronychoides A.St. Hil. [Figure A10]	*Dentella repens* L. [Figure C11]
Alternanthera sessilis (L.) R.Br. *ex* DC. [Figure A11]	*Oldenlandia corymbosa* L. [Figure C12]
Amaranthus gangeticus L. [Figure A12]	Convolvulaceae
Amaranthus viridis L. [Figure A13]	*Evolvulus nummularius* (L.) L. [Figure C13]
Chenopodiaceae	Solanaceae
Chenopodium album L. [Figure A14]	*Physalis minima* L. [Figure C14]
Chenopodium ambrosioides L. [Figure A15]	*Physalis peruviana* L. [Figure C15]
Polygonaceae	*Solanum nigrum* L. [Figure D1]
Persicaria hydropiper (L.) Delabre [Figure B1]	*Nicotiana plumbaginifolia* Viv. [Figure D2]
Persicaria orientalis (L.) Spach [Figure B2]	Boraginaceae
Polygonum plebeium L. [Figure B3]	*Coldenia procumbens* L. [Figure D3]
Rumex dentatus L. [Figure B4]	*Heliotropium indicum* L. [Figure D4]
Malvaceae	Scrophulariaceae
Sida rhomboidea Roxb. *ex*Flaming [Figure B5]	*Lindernia ciliata* (Colsm.) Pennell [Figure D5]
Sterculiaceae	*Lindernia crustacea* (L.) F. Muell. [Figure D6]
Melochia corchorifolia L. [Figure B6]	*Lindernia nummulariifolia* (D. Don) Wettst. [Figure D7]
Urticaceae	*Lindernia parviflora* (Roxb.) Haines [Figure D8]
Pouzolzia zeylanica (L.) Benn. & R.Br. [Figure B7]	*Lindernia procumbens* (Krock.) Philcox [Figure D9]
Euphorbiaceae	*Mazus pumilus* (Burm. *f.*) Steinis [Figure D10]
Acalypha indica L. [Figure B8]	*Mecardonia procumbens* (Mill.) Small. [Figure D11]
Chrozophora rottleri (Geiseler) A. Juss. *ex*Spreng. [Figure B9]	*Scoparia dulcis* L. [Figure D12]
Croton bonplandianus Baill. [Figure B10]	Acanthaceae
Euphorbia hirta L. [Figure B11]	*Hygrophilla difformis* Blume [Figure D13]
Onagraceae	Lamiaceae
Ludwigia perennis L. [Figure B12]	*Leucas aspera* (Willd.) Link. [Figure D14]
Fabaceae	*Salvia plebeia* R.Br. [Figure D15]
Desmodium triflorum (L.) DC. [Figure B13]	
Senna tora (L.) Roxb. [Figure B14]	

been displayed in **Plate A** to **D**. A table (**Table 2**) has been prepared with the major qualitative traits (given in abbreviated form) used for the diagnosis of the seedlings. Artificial keys have been constructed using both qualitative and quantitative traits to identify the seedlings of the weeds. In the key to the families, single species in a family has been mentioned in the parenthesis.

Artificial key (applicable for the studied taxa only)

Key to the seedling types

1. First two leaves subopposite to alternate…2
1a. First two leaves opposite………….……..3
2. First two leaves exstipulate……..……Type I
2a. First two leaves stipulate……..……Type II
3. First two leaves exstipulate……..….Type III
3a. First two leaves stipulate……..…...Type IV

Key to the families of Type I

1. Seedlings with latex; venation of paracotyledons parallelodromous……..…………....…Papaveraceae
1a. Seedlings without latex; venation of paracotyledons hyphodromous or actinodromous………………..……2
2. First two leaves with three or more primary veins……… ………………..3
2a. First two leaves with single primary vein ....……4
3. Margin of second leaf entire…..............................……….....…Ranunculaceae [*Ranunculus sceleratus*]
3a. Margin of second leaf crenate…......................………………..…Apiaceae
4. Pracotyledons narrowly oblong, apex obtuse; first internode angular......……...5
4a. Paracotyledons otherwise, apex acute or rounded; first internode round……...........................…….…..6

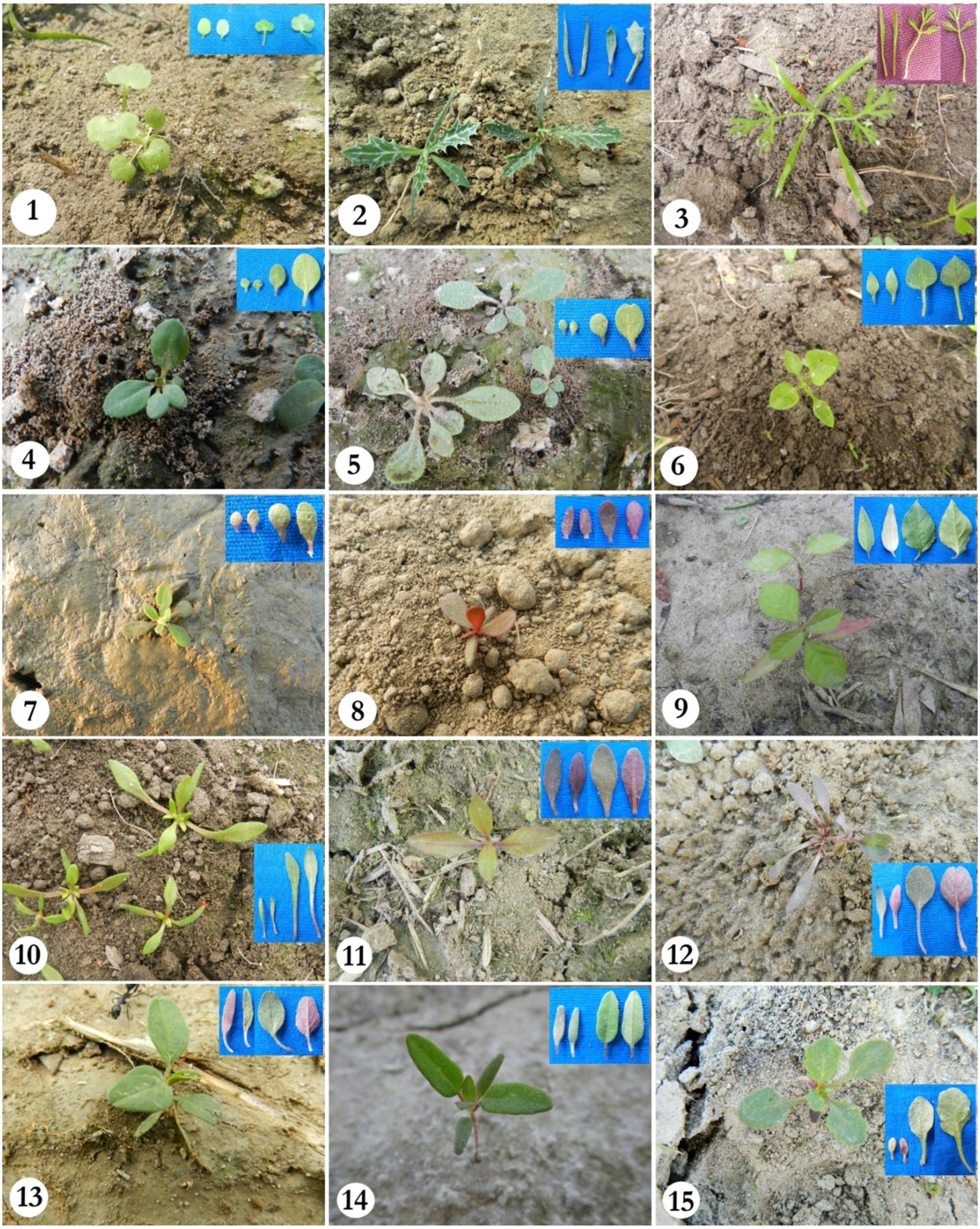

Plate A: 1. ***Ranunculus sceleratus***; 2. ***Argemone mexicana***; 3. ***Fumaria indica***; 4. ***Glinus lotoides***; 5. ***Glinus oppositifolius***; 6. ***Drymaria cordata***; 7. ***Polycarpon prostratum***; 8. ***Portulaca oleracea***; 9. ***Achyranthus aspera***; 10. ***Alternanthera paronychioides***; 11. ***Alternanthera sessilis***; 12. ***Amaranthus gangeticus***; 13. ***Amaranthus viridis***; 14. ***Chenopodium album***; 15. ***Chenopodium ambrosioides.***

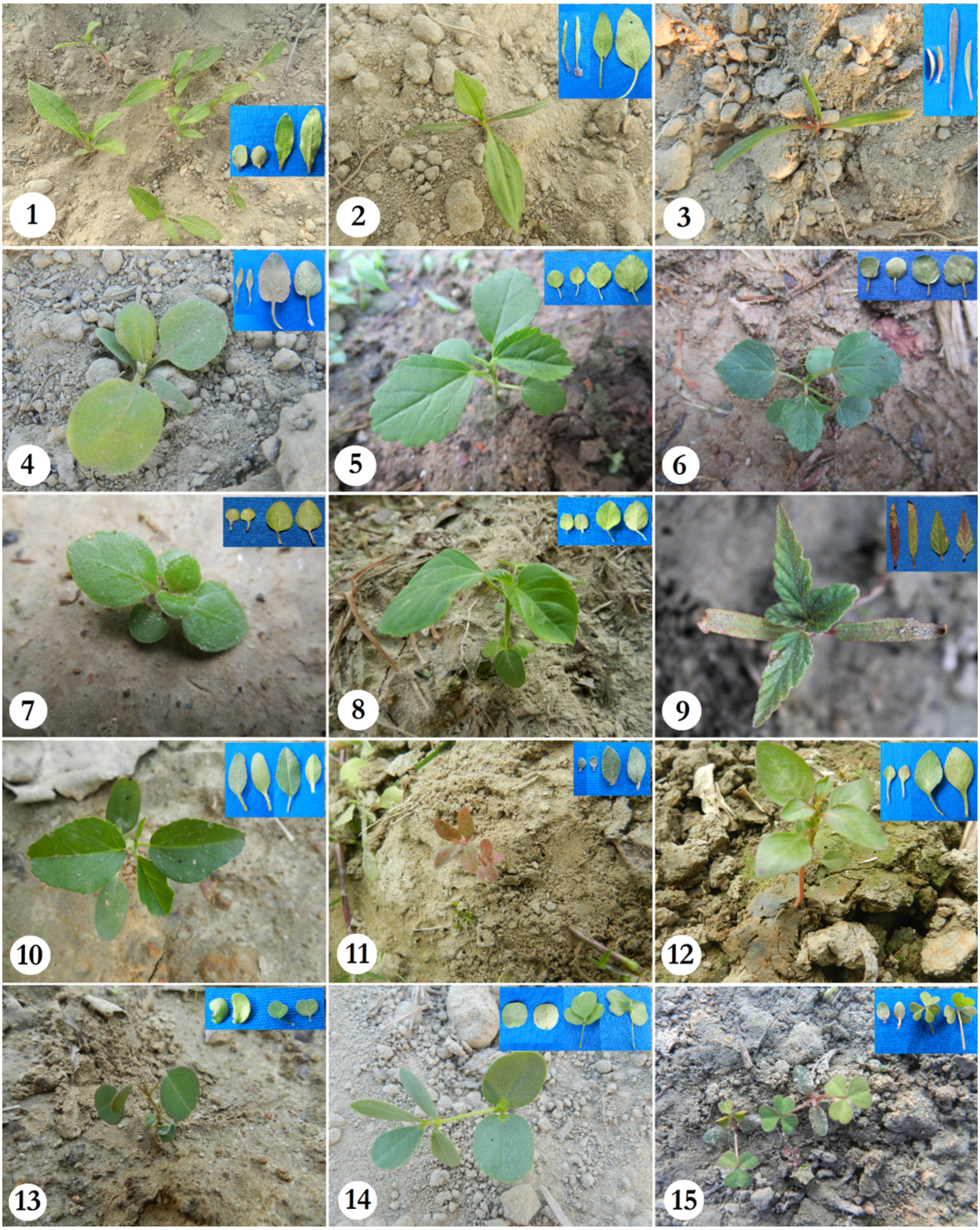

Plate B: 1. ***Persicaria hydropiper***; 2. ***Persicaria orientalis***; 3. ***Polygonum plebeium***; 4. ***Rumex dentatus***; 5. ***Sida rhomboidea***; 6. ***Melochia corchorifolia***; 7. ***Pouzolzia zeylanica***; 8. ***Acalypha indica***; 9. ***Chrozophora rottleri***; 10. ***Croton bonplandianus***; 11. ***Euphorbia hirta***; 12. ***Ludwigia perennis***; 13. ***Desmodium triflorum***; 14. ***Senna tora***; 15. ***Oxalis corniculata.***

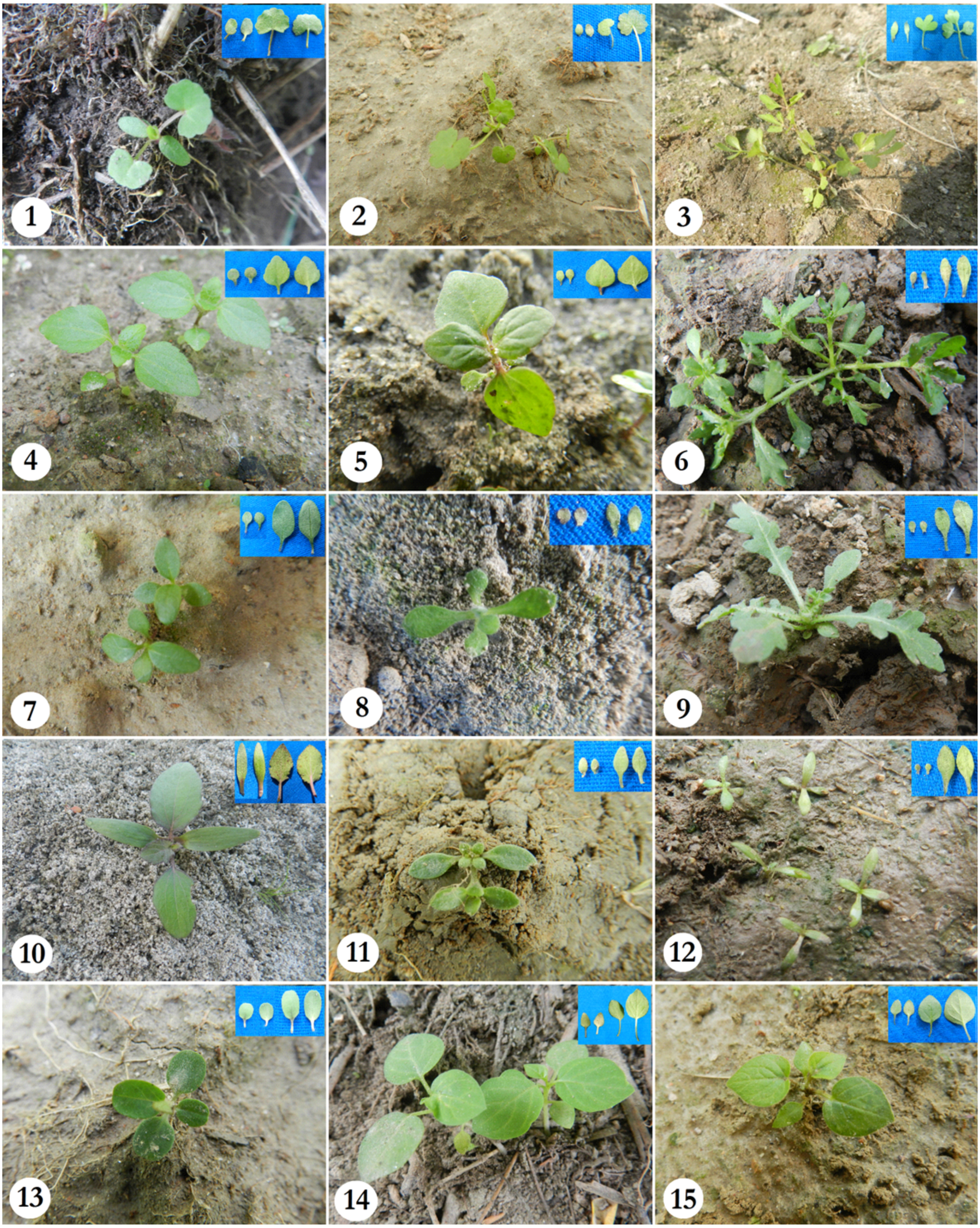

Plate C: **1.** ***Centella asiatica***; **2.** ***Hydrocotyle sibthorpioides***; **3.** ***Oenanthe benghalensis***; **4.** ***Ageratum conyzoides***; **5.** ***Ageratum haustonianum***; **6.** ***Centipeda minima***; **7.** ***Eclipta prostrate***; **8.** ***Gnaphalium polycaulon***; **9.** ***Grangea maderaspatana***; **10.** ***Xanthium strumarium***; **11.** ***Dentella repens***; **12.** ***Oldenlandia corymbosa***; **13.** ***Evolvulus nummularius***; **14.** ***Physalis minima***; **15.** ***Physalis peruviana.***

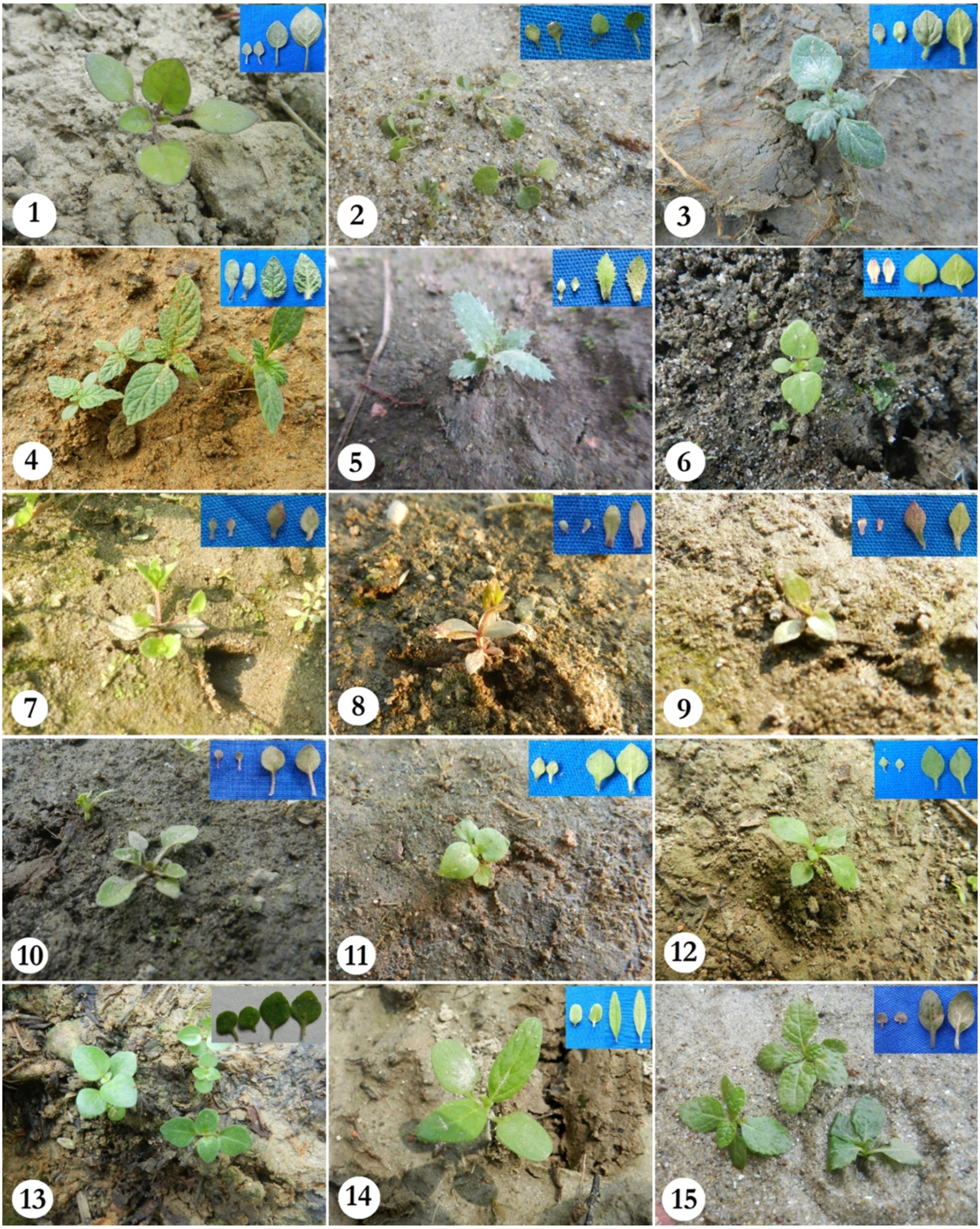

Plate D: 1. *Solanum nigrum*; 2. *Nicotiana plumbaginifolia*; 3. *Coldenia procumbens;* 4. *Heliotropium indicum*; 5. *Lindernia ciliata*; 6. *Linternia crustacea*; 7. *Lindernia nummulariifolia*; 8. *Lindernia parviflora*; 9. *Lindernia procumbens*; 10. *Mazus pumilus*; 11. *Mecardonia procumbens*; 12. *Scoparia dulcis*; 13. *Hygrophilla difformis*; 14. *Leucas aspera*; 15. *Salvia plebeian.*

Name of the species	Hypocotyl		Paracotyledons										First two leaves											First internode	
	Shape	Surface	Texture	Surface	Petiole	Shape	Base	Apex	Margin	Pri. veins	Venation	Phyllotaxy	Nature	Texture	Surface	Petiole	Stipule	Shape	Base	Apex	Margin	Pri. veins	Venation	Shape	Surface
Ranunculus sceleratus	r	glb	her	glb	1	obl	s.rnd	rnd	ent	1	hyp	alt	smp	her	glb	1	0	3lb	s.crd	rnd	ent	3	act	r	glb
Argemone mexicana	r	glb	thk	glb	0	lin	cnt	acu	ent	4	prl	alt	smp	her	glb	0	0	spt	atn	acu	spn-dnt	1	cam	r	glb
Fumaria indica	r	glb	her	glb	1	lin	atn	obt	ent	3 4	prl	alt	smp	her	glb	1	0	pinn	cnt	acu	ent	1	cam	r	glb
Glinus lotoides	r	glb	her	glb	1	ov-s.orb	cnt	obt	ent	1	hyp	alt	smp	her	glb	1	1	ov-elp	cnt	rnd	ent	1	hyp	an	glb
Glinus oppositifolius	r	glb	her	glb	1	obvs.orb	cnt	rnd	ent	1	hyp	alt	smp	her	glb	1	1	obv-elp	atn	rnd	ent	1	hyp	an	glb
Drymaria cordata	4-an	glb	her	glb	1	ov-lnc	cnt	acu	ent	1	hyp	opp	smp	her	m.pub	1	0	b.ov	s.trn	acu	ent	1	cam	4-an	pub
Polycaarpon prostratum	4-an	glb	her	glb	1	ov-elp	s.rnd	s.rnd	ent	1	hyp	opp	smp	her	glb	1	0	obv	cnt	s.rnd	ent	1	hyp	4-an	tom
Portulaca oleracea	r	glb	fls	glb	1	obl	s.rnd	obt	ent	1	hyp	opp	smp	her	glb	1	0	obv	cnt	s.rnd	ent	1	hyp	r	glb
Achyranthus aspera	r	glb	her	glb	1	lnc	cnt	acu	ent	1	cam	opp	smp	her	pub	1	0	elp-rhm	cnt	acu	ent	1	cam	4-an	pub
Alternanthera paronychioides	r	scb	fls	glb	1	n.lnc	atn	obt	ent	1	hyp	opp	smp	her	sp.pub	1	0	oblnc	atn	s.acu	ent	1	cam	r	pub
Alternanthera sessilis	r	glb	fls	glb	1	elp-obl	atn	rnd	ent	1	hyp	opp	smp	her	glb	1	0	obv	atn	obt	ent	1	cam	4-an	pub
Amaranthus gangeticus	r	glb	her	glb	1	n.obl	cnt	obt	ent	1	hyp	alt	smp	her	glb	1	0	obv	cnt	emr	ent	1	cam	4-an	glb
Amaranthus viridis	r	glb	her	glb	1	n.obl	cnt	obt	ent	1	hyp	alt	smp	her	glb	1	0	ov-elp	cnt	rts	ent	1	cam	4-an	glb
Chenopodium album	r	glb	fls	glb	1	n.obl	cnt	obt	ent	1	hyp	alt	smp	crs	scb	1	0	obl-lnc	cnt	obt	ent	1	cam	4-an	pub
Chenopodium ambrosioides	r	glb	her	glb	1	n.obl	cnt	obt	ent	1	hyp	alt	smp	crs	glb	1	0	ov-obl	cnt	s.rnd	s.ent	1	cam	4-an	m.hsp
Persicaria hydropiper	r	glb	her	glb	1	obt-recs.orb	s.cnt	rnd	ent	1	cam	alt	smp	cor	glb	1	1	elp-obl	atn	obt	ent	1	cam	r	sp.pub
Persicaria orientalis	r	glb	her	glb	1	lin	atn	acu	ent	1	hyp	alt	smp	her	pub	1	1	elp-lnc	atn	acu	ent	1	cam	r	hrs
Polygonum plebeium	r	scb	her	glb	0	lin-flc	atn	obt	ent	1	hyp	alt	smp	her	glb	1	1	lin	atn	acu	ent	1	hyp	r	scb
Rumex dentatus	r	glb	her	glb	1	n.obl	cnt	obt	ent	1	hyp	alt	smp	her	glb	1	1	ov	s.trn	obt	ent	1	cam	r	glb
Sida rhomboidea	r	hrs	her	hrs	1	s.orb	s.rnd	s.rts	ent	3	acr	alt	smp	her	pub	1	f.l	ov.rhm	cnt	obt	srt	3	act	r	hrs
Melochia corchorifolia	r	pub	her	glb	1	s.orb	rnd	rnd	ent	5	act	alt	smp	her	pub	1	1	s.orb.b.ov	s.rnd	obt	crn-srt	3	act	r	pub
Pouzolzia zeylanica	r	scb	her	d.pub	1	orb.ov	s.rnd	rts	ent	1	cam	opp	smp	her	hrs	1	1	ov	s.trn	obt	ent	3	act	4-an	m.hrs
Acalypha indica	r	scb	her	sp.pub	1	elp-s.orb	rnd	s.trn	ent	3	acr	opp	smp	her	scb	1	1	ov	rnd	acu	srt	3	act	r	scb
Chrozophora rottleri	r	scb	her	sp.pub	1	b.elp.s.orb	rnd	s.trn	ent	3	acr	opp	smp	her	scb	1	1	ov	rnd	acu	d.srt	3	act	r	scb
Croton bonplandianus	r	stl	crs	stl	1	obl	cnt	s.rnd	ent	3	acr	alt	smp	her	stl	1	1	ov-elp	s.rnd	acu	srt	3	act	r	stl
Euphorbia hirta	r	glb	her	glb	1	obl	s.rnd	s.rnd	ent	1	hyp	opp	smp	her	pub	1	0	obv	cnt	s.rnd	ent	1	cam	r	d.pub
Ludwigia perennis	r	glb	her	glb	1	ov	b.cnt	acu	ent	1	hyp	opp	smp	her	glb	1	0	ov	b.cnt	acu	ent	1	cam	r	glb
Desmodium triflorum	r	pub	thk	scb	0	flc-obl	obq	rnd	ent	3	act	opp	smp	her	glb	1	f.l	b.obv	b.cnt	sh.emr	ent	1	cam	6-an	hrs
Senna tora	r	sp.pub	thk	glb	0	obv-obl	aur	rnd	ent	3	act	alt	cmp	her	pub	1	f.l	obv	obq.trn	rts	ent	1	cam	4-an	pub
Oxalis corneculata	r	sp.pub	her	glb	1	ov.elp	cnt	rnd	ent	1	hyp	alt	cmp	her	glb	1	1	obcrd	cnt	dp.emr	ent	3	act	r	hrs
Centella asiatica	r	glb	her	glb	1	obl-rec	s.rnd	rnd	ent	1	hyp	alt	smp	her	glb	1	0	s.ren	crd	rnd	crn	5	act	r	glb
Hydrocotyle sibthorpioides	r	glb	her	glb	1	ov	s.rnd	rnd	ent	1	hyp	alt	smp	her	glb	1	0	ren	s.crd	rnd	und	7 8	act	r	glb
Oenanthe benghalensis	r	glb	her	glb	1	elp	cnt	obt	ent	1	hyp	alt	smp	her	glb	1	0	3-lb	s.trn	rnd		3	act	r	glb
Ageratum conyzoides	r	scb	her	glb	1	ov	cnt	rts	ent	1	hyp	opp	smp	her	m.pub	1	0	ov	s.trn	acu	d.srt	3	acr	r	pub
Ageratum haustonianum	r	scb	her	scb	1	ov	cnt	rts	ent	1	hyp	opp	smp	her	pub	1	0	ov	b.cnt	obt	d.srt	3	acr	r	hrs
Centipeda minima	r	glb	her	glb	1	elp	cnt	s.rnd	ent	1	hyp	opp	smp	her	glb	1	0	elp-obv	atn	obt	ent	1	hyp	r	glb
Eclipta prostrata	r	glb	her	glb	0	obvs.orb	cnt	rnd	ent	1	cam	opp	smp	her	pub	1	0	ov-elp	cnt	s.acu-obt	d.srt	3	acr	r	pub
Gnaphalium polycaulon	r	glb	her	glb	1	s.orb	s.rnd	rnd	ent	1	hyp	alt	smp	her	d.pub	1	0	elp	atn	obt	ent	1	hyp	r	tom
Grangea maderaspatana	r	glb	her	glb	0	obv-elp	atn	s.rnd	ent	1	hyp	alt	smp	her	pub	1	0	obv-obl	atn	obt	ent	1	hyp	r	hrs
Xanthium strumarium	r	glb	cor	glb	1	elp-lnc	atn	s.acu	ent	3	acr	opp	smp	cor	d.pub	1	0	ov	s.rnd	acu	srt	3	acr	r	hrs
Dentella repens	4-an	glb	her	glb	1	b.ov	rnd	obt	ent	1	hyp	opp	smp	her	glb	1	int	n.elp	cnt	acu	ent	1	hyp	4-an	glb
Oldenlandia corymbosa	r	glb	her	glb	1	ov-s.orb	s.trn	rnd	ent	3	act	opp	smp	her	scb	1	1	n.elp	cnt	obt	ent	1	cam	4-an	glb
Evolvulus nummularius	r	glb	her	glb	1	rec-s.orb	b.cnt	rnd	ent	3	act	alt	smp	her	glb	1	0	obv	b.cnt	rts	ent	1	cam	r	hrs
Physalis minima	r	m.pub	her	scb	1	ov	rnd	acu	ent	1	hyp	alt	smp	her	s.glb	1	0	ov	obq.s.rnd	acu	ent	1	cam	r	pub
Physalis peruviana	r	pub	her	sp.pub	1	ov	b.cnt	acu	ent	1	hyp	alt	smp	her	pub	1	0	ov	obq.s.rnd	obt	irr.und	1	cam	r	tom
Solanum nigrum	r	pub	her	glb	1	ov-lnc	cnt	acu	ent	1	hyp	alt	smp	her	m.pub	1	0	b.ov	s.rnd	acu	wvy	1	cam	r	hrs
Nicotiana plumbaginifolia	r	glb	her	glb	1	s.orb	s.rnd	rnd	ent	1	hyp	alt	smp	her	glb	1	0	b.ov	s.trn	acu	ent	1	cam	r	glb
Coldenia procumbens	r	d.pub	cor	hrs	1	ov.rec	b.cnt	rnd	ent	1	hyp	opp	smp	her	vil	1	0	ov	b.cnt	acu	ent	1	cam	r	glb
Heliotropium indicum	r	pub	her	pub	1	ov-obl	cnt	rnd	ent	1	hyp	opp	smp	her	d.pub	1	0	ov	rnd	acu	ent	1	cam	r	hrs
Lindernia ciliata	r	glb	her	scb	0	ov	cnt	obt	ent	1	hyp	opp	smp	her	hrs	0	0	obl-spat	atn	acu	dnt	1	hyp	4-an	m.pub
Lindernia crustacea	r	scb	±thk	glb	1	ov	s.trn	obt	ent	1	hyp	opp	smp	her	glb	1	0	ov	s.trn	obt	crn	1	hyp	4-an	glb
Lindernia nummulariifolia	r	glb	her	glb	1	elp	cnt	acu	ent	1	hyp	opp	smp	her	glb	1	0	ov-elp	cnt	acu	ent	1	hyp	4-an	glb
Lindernia parviflora	r	glb	her	glb	1	elp	cnt	s.rnd	ent	1	hyp	opp	smp	her	glb	0	0	elp	atn	acu	ent	1	hyp	4-an	glb
Lindernia procumbens	r	glb	her	glb	1	elp-s.orb	cnt	s.rnd	ent	1	hyp	opp	smp	her	glb	1	0	elp-ov	cnt	acu	ent	3	acr	4-an	glb
Mazus pumilus	r	glb	her	glb	1	b.ov	s.rnd	acu	ent	1	hyp	opp	smp	her	pub	1	0	ov	atn	obt	ent	1	cam	4-an	glb
Mecardonia procumbens	r	glb	her	glb	1	ov	cnt	obt	ent	1	hyp	opp	smp	her	glb	1	0	b.ov	b.cnt	obt	ent	1	hyp	4-an	glb
Scoparia dulcis	r	scb	her	glb	1	ov	cnt	acu	ent	1	hyp	opp	smp	her	pub	1	0	ov	cnt	acu	ent	1	cam	4-an	scb
Hygrophilla difformis	r	glb	her	glb	1	s.orb	s.rnd	s.rts	ent	1	hyp	opp	smp	her	pub	1	0	b.ov	cnt	obt	ent	1	cam	4-an	pub
Leucas aspera	r	hrs	her	scb	1	obl-rec	b.cnt	rnd	ent	1	hyp	opp	smp	her	pub	1	0	n.elp	atn	acu	srt	1	cam	4-an	pub
Salvia plebeia	r	glb	her	glb	1	s.orb	trn	rnd	ent	1	hyp	opp	smp	her	pub	1	0	ov	atn	obt	srt	1	cam	4-an	d.pub

Abbreviations: act: actinodromous; acm: acuminate; acu: acute; alt: alternate; ang: angular; atn: attenuate; aur: auriculate; b: broadly; bip: bipinnate; cam: camptodromous; cmp: compound; cnt: cuneate; crs: coriaceous; crd: cordate; cre: crenate; dnt: dentate; elp: elliptic; emg: emarginate; ent: antire; ep: epigeal; flb: flabellate; flc: falcate; glb: glabrous; her: herbaceous; hsp: hispid; hrs: hirsute; hyp: hyphodromous; irr: irregularly; lnc: lanceolate; lin: linear; min: minutely; muc: mucronate; n: narrowly; obl: oblong; obt: obtuse; obv: obovate; obq: oblique; opp: opposite; orb: orbicular; ov: ovate; plt: peltate; pm: palmately; prl: parallel; pub: pubescent; r: round; ren: reniform; rhm: rhomboidal; rnd: rounded; rtn: rectangular; rts: retuse; s: sub; scb: scabrous; sh: shallowly; sint: sinuately; smp: simple; sp: sparsely; spn: spiny; srt: serrate; str: strigose; tk: thick; tmn: tomentose; trn: truncate; wvy: wavy; 0: absent; 1: present; 3an: triangular; 4an: 4-angular; (species are arranged according to table 1)

5. First two leaves with apex emarginate or retuse; margin of subsequent leaves entire, first internode glabrous……..Amaranthaceae

5a. First two leaves with apex subrounded or obtuse; margin of subsequent leaves toothed, first internode hairy…………Chenopodiaceae

6. Venation of paracotyledons actinodromous; apex of first two leaves retuse…… …Convolvulaceae [*Evolvulus nummularius*]

6a. Venation of paracotyledons hyphodromous; apex of first two leaves acute or obtuse…………7

7. First two leaves elliptic or obovate oblong, base attenuate; length of first internode comparatively short (±1mm)…… ...Asteraceae

7a. First two leaves ovate, base oblique or subrounded; length of first internode comparatively long (5-12mm)…… Solanaceae

Key to the families of Type II

1. Subsequent leaves simple…… …………...2
1a. Subsequent leaves compound…………....6
2. Stipule ochreate……..………Polygonaceae
2a. Stipule linear…… …………….......…… .3
3. Venation of paracotyledons hyphodromous; first two leaves glabrous, venation hyphodromous; first internode angular, glabrous, comparatively short (±1mm)........………………………….. Molluginaceae
3a. Venation of paracotyledons acrodromous or actinodromous; first two leaves hairy, venation actinodromous; first internode hairy, round, comparatively long (3.5-10mm)............…..........…. .4
4. Paracotyledons oblong; apex of first two leaves acute; seedlings aromatic; latex and stellate hair present…………..….….…Euphorbiaceae [*Croton bonplandianus*]
4a. Paracotyledons suborbicular; apex of first two leaves obtuse; seedlings not aromatic; latex and stellate hair absent……..…….....................……..5
5. Paracotyledons hirsute, primary veins 3; first two leaves ovate-rhomboid, base cuneate; first internode hirsute…………Malvaceae [*Sida rhomboidea*]
5a. Paracotyledons glabrous, primary veins 5; first two leaves suborbicular to broadly ovate, base subrounded; first internode pubescent …................Sterculiaceae [*Melochia corchorifolia*]
6. Paracotyledons with venation actinodromous; venation of first two leaves camptodromous; first internode angular; apex of subsequent leaves not emarginate.......… ……………………......…Fabaceae
6a. Paracotyledons with venation hyphodromous; venation of first two leaves actinodromous; first internode round; apex of subsequent leaves emarginate……...............……Oxalidaceae [*Oxalis corneculata*]

Key to the families of Type III

1. Hypocotyl angular……......….Caryophyllaceae
1a. Hypocotyl round……………………..............…2
2. Seedlings with milky latex…………….……… …….............…Euphorbiaceae [*Euphorbia hirta*]
2a. Seedlings without milky latex……...............……3
3. Margin of subsequent leaves entire….......……4
3a. Margin of subsequent leaves serrate or toothed… … ……………..............................……………6
4. Venation of first two leaves hyphodromous….. ....Portulacaceae [*Portulaca oleracea*]
4a. Venation of first two leaves camptodromous……5
5. First two leaves ovate………………………..…… ....Onagraceae [*Ludwigia perennis*]
5a. First two leaves otherwise……..…..…..……… ……………….….……Amaranthaceae
6. Venation of first two leaves acrodromous; first internode round……..…..Asteraceae [exception *Centipeda minima*]
6a. Venation of first two leaves camptodromous or hyphodromous; first internode angular……....7 [exception *Lindernia procumbens*]
7. Paracotyledons hairy…………...........Boraginaceae
7a. Paracotyledons glabrous…… ……….................…8
8. Hypocotyl reduced (±1mm); paracotyledons elliptic or ovate, comparatively smaller (1.5-2mm × 1-1.5 mm)…………...............................Scrophulariaceae
8a. Hypocotyl elongating; paracotyledons suborbicular or rectangular-oblong, comparatively larger (2.5-6mm ×2-4mm)…...................................9
9. Apex of paracotyledons subretuse, margin of first two leaves entire…… Acanthaceae [*Hygrophila difformis*]
9a. Apex of paracotyledons rounded, margin of first two leaves serrate…………Lamiaceae

Key to the families of Type IV

1. Paracotyledons hairy, venation camptodromous or acrodromous; first two leaves ovate, base subtruncate or rounded, venation actinodromous, comparatively larger (3-7mm × 2-7 mm)……....……2
1a. Paracotyledons glabrous, venation hyphodromous; first two leaves narrowly elliptic, base cuneate, venation hyphodromous, comparatively smaller (1-2mm × 1-2mm)……........………………Rubiaceae
2. Apex of paracotyledons retuse, venation camptodromous; first two leaves hirsute, base subtruncate, margin entire; subsequent leaves opposite decussate; first internode angular…… Urticaceae [*Pouzolzia zeylanica*]
2a. Apex of paracotyledons subtruncate, venation acrodromous; first two leaves scabrous, base rounded, margin serrate; subsequent leaves alternate; first internode round……….....………… ……...……Euphorbiaceae

Key to the genus/species of Type I

Papaveraceae

1. Paracotyledons sessile, apex acute; first two leaves sessile, margin spiny dentate……………… ……….......................…*Argemone mexicana*
1a. Paracotyledons petiolate, apex obtuse; first two leaves petiolate, margin pinnatisect…… …………………………*Fumaria indica*

Amaranthaceae

Key to the species under *Amaranthus*

1. First two leaves obovate, apex emarginate…… …….*Amaranthus gangeticus*

1a. First two leaves ovate-elliptic, apex retuse…… ……………...*Amaranthus viridis*

Chenopodiaceae

Key to the species under *Chenopodium*

1. First two leaves ovate-elliptic, apex subrounded …….*Chenopodium ambrosioides*

1a. First two leaves oblong-lanceolate, apex obtuse……. ………… ...*Chenopodium album*

Apiaceae

1. First two leaves trilobed, base subtruncate, margin entire, primary veins three; subsequent leaves compound…… *Oenanthe benghalensis*

1a. First two leaves not lobed, reniform, base subcordate, margin crenate, primary veins more than three; subsequent leaves simple….2

2. Paracotyledons oblong-rectangular…...................… …………………………*Centella asiatica*

2a. Paracotyledons ovate……....................…*Hydrocotyle sibthorpioides*

Asteraceae

1. Paracotyledons suborbicular; first two leaves elliptic; margin of subsequent leaves entire; first internode tomentose......................……*Gnaphalium polycaulon*

1a. Paracotyledons obovate-elliptic; first two leaves obovate-oblong; margin of subsequent leaves sinuate; first internode hirsute.........................…… …………………*Grangea maderaspatana*

Solanaceae

1. Hypocotyl hairy; paracotyledons ovate or ovate-lanceolate, apex acute, comparatively larger (4-9 mm × 3-5 mm)…… ……………2

1a. Hypocotyl glabrous; paracotyledons suborbicular, apex rounded, comparatively smaller (1.5-2.5 mm × 1-2 mm)…...........……………………………*Nicotiana plumbaginifolia*

2. Parcotyledons ovate; base of first two leaves oblique…… ……………………*Physalis*

2a. Paracotyledons ovate-lanceolate; base of first two leaves subrounded…....................… *Solanum nigrum*

Key to the species under *Physalis*

1. First two leaves glabrous; first internode sparsely pubescent…… ……*Physalis minima*

1a. First two leaves pubescent; first internode tomentose…… …………*Physalis peruviana*

Key to the genus/ species of Type II

Molluginaceae

Key to the species under *Glinus*

1. Paracotyledons ovate-suborbicular; first two leaves ovate-elliptic…… *Glinus oppositifolius*

1a. Paracotyledons obovate-suborbicular; first two leaves obovate-elliptic……*Glinus lotoides*

Polygonaceae

1. Apex of paracotyledons obtuse…………2

1a. Apex of paracotyledons acute or rounded…… ……………………*Persicaria*

2. Paracotyledons sessile, linear-falcate; first two leaves linear, apex acute, venation hyphodromous…….……*Polygonum plebeium*

2a. Paracotyledons petiolate, narrowly oblong; first two leaves ovate, apex obtuse, venation hyphodromous……………….*Rumex dentatus*

Key to the species under *Persicaria*

1. Paracotyledons obtuse-suborbicular, venation camptodromous…………*Persicaria hydropiper*

1a. Paracotyledons linear, venation hyphodromous…… ……*Persicaria orientalis*

Fabaceae

1. Paracotyledons falcate-oblong, base oblique; first two leaves simple, comparatively smaller (2.5-3mm × 3-3.5mm)…*Desmodium triflorum*

1a. Paracotyledons obovate-oblong, base auriculate; first two leaves compound, comparatively larger (13.5-16 mm × 12.5-14 mm)…..............................… ……………………*Senna tora*

Key to the genus/ species of Type III

Caryophyllaceae

1. Hypocotyl elongated (21-32mm); paracotyledons ovate-lanceolate, apex acute; first two leaves broadly ovate, base subtruncate, apex acute…… ………*Drymaria cordata*

1a. Hypocotyl reduced (±1mm); paracotyledons ovate-elliptic, apex subrounded; first two leaves obovate, base cuneate, apex subrounded………*Polycarpon prostratum*

Amaranthaceae

1. Hypocotyl comparatively longer (50-58mm); venation of paracotyledons camptodromouus; first two leaves elliptic-rhomboid…...........................… …………*Achyranthes aspera*

1a. Hypocotyl comparatively reduced (6-9mm); venation of paracotyledons hyphodromouus; first two leaves oblanceolate or obovate……………*Alternanthera*

Key to the species under *Alternanthera*

1. First two leaves oblanceolate, petiole longer (4-5mm)…….............…*Alternanthera paronychioides*

1a. First two leaves obovate, petiole reduced (1-1.5mm)……………*Alternanthera sessilis*

Asteraceae

1. Paracotyledons coriaceous, primary veins three, venation acrodromous…… *Xanthium strumarium*

1a. Paracotyledons herbaceous, primary veins one, venation hyphodromous or camptodromous….....2

2. Venation of first two leaves hyphodromous; subsequent leaves spirally alternate……....………… ……..................................…… *Centipeda minima*

2a. Venation of first two leaves acrodromous; subsequent leaves opposite decussate…...……3

3. Paracotyledons obovate-suborbicular, first two leaves with margin entire…..................… *Eclipta prostrata*

3a. Paracotyledons ovate, first two leaves with margin serrate…… ………………*Ageratum*

Key to the species under *Ageratum*

1. First internode pubescent……..........…*Ageratum conyzoides*

1a. First internode hirsute……..........………*Ageratum haustonianum*

Boraginaceae

1. Paracotyledons hirsute; base of first two leaves cuneate, margin dentate…… *Coldenia procumbens*

1a. Paracotyledons pubescent; base of first two leaves rounded, margin irregularly wavy…..........……...…… ……......................................…*Heliptropium indicum*

Scrophulariaceae

1. Paracotyledons ovate or broadly ovate…...........…2

1a. Paracotyledons elliptic or elliptic-suborbicular (exceptions *Lindernia ciliata, L. crustacea*)…… ………………..…*Lindernia*

2. Apex of paracotyledons acute; venation of first two leaves camptodromous……...........................………3

2a. Apex of paracotyledons obtuse; venation of first two leaves hyphodromous……...........……………… …..................................…*Mecardonia procumbens*

3. Base of paracotyledons subrounded; apex of first two leaves obtuse……..................…*Mazus pumilus*

3a. Base of paracotyledons cuneate; apex of first two leaves acute……..................................…*Scopariadulcis*

Key to the species under *Lindernia*

1. First two leaves oblong-spathulate, hirsute, margin spiny dentate……........................…*Lindernia ciliata*

1a. First two leaves ovate, elliptic or ovate-elliptic, glabrous, margin entire or inconspicuously crenate…… ……..…………2

2. First two leaves with three primary veins, venation acrodromous……...……*Lindernia procumbens*

2a. First two leaves with single primary vein, venation hyphodromous…………………...3

3. Paracotyledons elliptic, base cuneate; apex of first two leaves acute……………………4

3a. Paracotyledons ovate, base subtruncate, apex obtuse……………*Lindernia crustacea*

4. Apex of paracotyledons acute, first two leaves petiolate…...*Lindernia nummulariifolia*

4a. Apex of paracotyledons subrounded; first two leaves sessile………*Lindernia parviflora*

Lamiaceae

1. Hypocotyl comparatively elongated (18-26mm); paracotyledons oblong-rectangular; first two leaves narrowly elliptic, apex acute; first internode comparatively longer (6-12.5 mm)…….……..…… …… *Leucas aspera*

1a. Hypocotyl comparatively reduced (2-3mm); paracotyledons suborbicular; first two leaves ovate, apex obtuse; first internode comparatively shorter (3-5mm)……. *Salvia plebeia*

Key to the genus/ species of Type IV

Euphorbiaceae

1. Paracotyledons oblong-suborbicular, apex subtruncate; first two leaves broadly elliptic-ovate, apex obtuse, margin entire……….........………… ………………………*Acalypha indica*

1a. Paracotyledons narrowly oblong, apex obtuse; first two leaves ovate-lanceolate, apex acute, margin crenate…… ……*Chrozophora rottleri*

Rubiaceae

1. Paracotyledons elliptic, apex obtuse; base of first two leaves cuneate……..........................*Dentella repens*

1a. Paracotyledons ovate-suborbicular, apex rounded; base of first two leaves attenuate…… …… …*Oldenlandia corymbosa*

RESULTS AND DISCUSSION

The artificial key revealed that all the seedlings are of phanerocotylar epigeal types. In the artificial key, the sixty taxa from twenty four families of Magnoliopsida have been separated into four types based on naturally adapted characters such as phyllotaxy and presence of stipules of the first two leaves. Each type contains many families with exclusively all studied taxa but some types contain taxa not confined to it exclusively but to other types also. Thus, type I consists of families such as Papaveraceae, Ranunculaceae, Apiaceae, Chenopodiaceae, Convolvulaceae, Solanaceae, genus

Amaranthus of Amaranthaceae, genera *Grangea* and *Gnaphalium* of Asteraceae. Type II is represented by the families Polygonaceae, Molluginaceae, Malvaceae, Sterculiaceae, Fabaceae, Oxalidaceae and genus *Croton* of Euphorbiaceae. Type III contained families like Caryophyllaceae, Portulacaceae, Onagraceae, Boraginaceae, Scrophulariaceae, Acanthaceae, Lamiaceae, and the genus *Euphorbia* of Euphorbiaceae, the genera *Achyranthus* and *Alternanthera* of Amaranthaceae, and four genera of Asteraceae. At last Rubiacaeae, Urticaceae and two genera of Euphorbiaceae (*Acalypha* and *Chrozophora*) belonged to seedling type IV.

This classification is totally based on seedling morphological traits and showsed somehomology with other traditional system of plant classifications. For example, under type I, Amaranthaceae and Chenopodiaceae share some common characters such as narrowly oblong paracotyledons with obtuse apex and angular first internode. They also belong to the order Caryophyllales in Takhtajan's system (1997). Similarly, Malvaceae and Sterculiaceae under type II display common juvenile traits like simple subsequent leaves, suborbicular paracotyledons, obtuse apex of first two leaves they remain together in order Malvales under subclass Dilleniidae of Takhtajan's system and they differ from Fabaceae and Oxalidaceae having compound subsequent leaves. The latter two are belonging to subclass Rosidae. Under type III, Scrophulariaceae, Acanthaceae and Lamiaceae (subclass Lamiidae of Takhtajan, 1997) remain associated together having round hypocotyl, margin of subsequent leaves serrate or toothed, venation of first two leaves camptodromous or hyphodromous, angular first internode. Similarly, Urticaceae and Euphorbiaceae show close affinity based on hairy paracotyledons with camptodromous or acrodromous venation; first two leaves ovate with base subtruncate or rounded and venation actinodromous supporting quite parallel inclusion of them under subclass Dillenidae in Takhtajan's system (1997).

Juvenile characters have also supported few other botanical disciplines such as pollen morphology, cytology, phytochemistry, *etc*. of the studied taxa. Fatinah *et al.* (2012) worked on phylogeny of six members of Amaranthaceae using RAPD and showed that *Achyranthes* and *Alternanthera* tend to stay together while *Amaranthus* separated out from them. From juvenile traits, it has been seen that *Amaranthus* having sub-opposite to alternate exstipulate first two leaves belonging to type I seedling while the other two taxa having opposite, exstipulate first two leaves represented type III, thus supporting their phylogenetic correlation based on RAPD. A study on the pollen grains of a few *Chenopodium* spp. by Pinar and Inceoglu (1999) showed that *C. album* and *C. ambrosioides* share similar radial symmetrical, isopolar, pantopolyporate spheroidal pollen grains with scabrate ornamentation. In seedling morphology, these two taxa also share some similar characters such as first two leaves coriaceous, apex subrounded or obtuse; margin of subsequent leaves toothed and first internode hairy indicating the similarities between these two taxa. Rahman *et al,* (2013) investigated stomata and trichome characters of 36 species of Asteraceae and showed that while *Ageratum, Grangea* and *Gnaphalium* share similar characters such as anomocytic stomata and non-glandular multicellular trichomes but *Xanthium* displays anisocytic stomata and non-glandular unicellular trichomes. Our seedling study contradicts with their findings in such a way that *Grangea* and *Gnaphalium* represent seedling type I while *Ageratum* and *Xanthium* belonging to type III, thus partially supporting the above study.

Although this work was considered keeping in mind about the identification of weeds in seedling stage which is crucial for eradication and creating an opportunity towards integrated weed management (Chomas *et al.* 2001, Parkinson *et al.* 2013) but after the discussion it is clear that study of weeds at juvenile stage has some taxonomic values too. The morphological markers used for the identification of the taxa are useful for delimitation of the taxa into different taxonomic groups showing an insight about the usefulness of juvenile features. The traits are highly conservative and hence the key is viable independent of habitat, climate or soil nature. The comparison with an accepted existing system and a few other botanical disciplines gives new ideas about plant systematic which are vital in many a ways.

Furthermore, the most applied outcome of this work is weed management through seedlings. Since, number of seed production, seed production rate, seed viability and resistance to environment are higher in weeds compared to crops, vigorous germination of seeds occur during pre- or post- harvest periods establishing abundant seedlings. Even occurrence of flowering can be observed in these weeds at seedling stage indicating their partly ephemeral behaviour. This makes it a lot harder for their total eradication from the field because they immediately disperse enumerable seeds. However, eradication at the seedling stage minimizes the chance of further weed dispersal by limiting their life cycle before flowering.

Thus, proper identification of weeds at seedling stage may reduce the chemical herbicides proving it to be more economic and eco-friendly.

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Broad-spectrum weed management in wet-seeded rice by pre-mix herbicide combinations

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ABSTRACT

Three pre-mix herbicide combinations at two different times of application, *viz.* pendimethalin + penoxsulam at 5 and 10 DAS, cyhalofop-butyl + penoxsulam and florpyrauxifen-benzyl + cyhalofop-butyl both applied at 12 and 18 DAS were evaluated along with sequential spray of cyhalofop-butyl *fb* chlorimuron-ethyl 10% + metsulfuron-methyl 10% at 18 and 19 DAS, bispyribac-sodium at 18 DAS, hand weeding at 20 and 40 DAS and unweeded control. At 30 DAS, the lowest weed dry matter and highest weed control efficiency was obtained with application of florpyrauxifen-benzyl + cyhalofop-butyl (150 g/ha) at 12 DAS. The highest numbers of yield attributes and crop yields in rice were recorded in hand weeding followed by florpyrauxifen-benzyl + cyhalofop-butyl at 12 DAS and pendimethalin + penoxsulam (625 g/ha) at 5 DAS.

In wet seeded rice culture, weed growth occurs throughout the season causing yield reduction of about 65% compared to weed-free situation (Mukherjee *et al.* 2008). Application of pre-mix herbicides in a single spray to control a broad spectrum of weeds is a viable option and nowadays several new commercial herbicides are available in markets.

In this study, an attempt to assess the effectiveness of three new pre-mix herbicides was made. The study was conducted during October 2019 to January 2020 in *Kole* areas of Alappad, Thrissur district (Kerala). The soil was clayey and belonged to Inceptisols with 1.2% organic carbon and pH 4.7. Available N, P and K content of soil were 178.3, 20.5 and 142.1 kg/ha, respectively. Pre-germinated seeds of rice variety '*Manuratna*' (100 days' duration) was broadcasted at the rate of 80 kg/ha. Plot size adopted was 20 m^2.

The experiment was laid out in randomized complete block design with 10 treatments replicated thrice. Three pre-mix herbicides applied at two different times, *viz.* pendimethalin + penoxsulam 625 g/ha at 5 and 10 DAS, cyhalofop-butyl + penoxsulam 135 g/ha at 12 and 18 DAS, and florpyrauxifen-benzyl + cyhalofop-butyl 150 g/ha at 12 and 18 DAS were evaluated along with sequential spray of cyhalofop-butyl 80 g/ha *fb* chlorimuron-ethyl 10% + metsulfuron-methyl 10% (8 g/ha) at 18 and 19 DAS, alone bispyribac-sodium 25 g/ha at 18 DAS, hand weeding at 20 and 40 DAS and unweeded check. All the herbicides were applied using 500 litres of water per hectare with knapsack sprayer.

At sampling time (30 and 60 DAS), weed dry weight was determined by placing 0.25 m^2 quadrat randomly at each plot, where the weeds were uprooted, cleaned and dried at 70^{0}C for 48 hours. Weed control efficiency was calculated as per the standard formula. At harvest, number of panicles/m^2, grains per panicle, percentage of filled grains, test weight (g) and crop yields (t/ha) were recorded along with computing harvest index. Statistical processing of data was done with OPSTAT (Sheoran *et al.* 1998) to evaluate the difference between treatments.

Weed flora

The major weed species found in the study area were grasses comprised mainly of weedy rice (*Oryza sativa* f. *spontanea*), *Echinochloa stagnina* and *Leptochloa chinensis*; Sedges, composed of *Cyperus* spp and *Fimbristylis miliacea* as well as broad-leaf weeds such as *Ludwigia perennis*, *Limnophila heterophylla* and *Eichhornia crassipes* were also found.

Weed dry matter production (WDMP)

At 30 DAS, the lowest WDMP was acquired in florpyrauxifen-benzyl + cyhalofop-butyl (150 g/ha) sprayed at 12 DAS, followed by same herbicide applied at 18 DAS (**Table 1**). Among herbicide treatments, highest WDMP was in bispyribac-sodium (probably due to resistant biotypes of *Leptochloa chinensis*). By 60 DAS, the lowest WDMP was recorded in hand weeding followed by florpyrauxifen-benzyl + cyhalofop-butyl (150 g/ha) at 12 DAS and pendimethalin + penoxsulam (625 g/ha) at 5 DAS.

At 30 DAS, the herbicide combinations pendimethalin + penoxsulam at 10 DAS, cyhalofop-butyl + penoxsulam at 18 DAS, and florpyrauxifen-benzyl + cyhalofop-butyl at 12 DAS recorded less WDMP. However, at 60 DAS lowest WDMP was recorded in pendimethalin + penoxsulam at 5 DAS, cyhalofop-butyl + penoxsulam and florpyrauxifen-benzyl + cyhalofop-butyl, both at 12 DAS.

Weed control efficiency (WCE)

At 30 DAS, highest WCE of 84.71% was recorded in florpyrauxifen-benzyl + cyhalofop-butyl (150 g/ha) applied at 12 DAS. The treatments pendimethalin + penoxsulam (625 g/ha) at 5 and 10 DAS, and florpyrauxifen-benzyl + cyhalofop-butyl at 18 DAS recorded WCE greater than 83% (**Table 1**). Sreedevi *et al.* (2020) recorded a WCE of 78% and 85% in rice in years 2015 and 2016 respectively with florpyrauxifen-benzyl + cyhalofop-butyl (150 g/ha) sprayed at 20 DAS. At 60 DAS, highest WCE of 92.63% was observed in hand weeding followed by florpyrauxifen-benzyl + cyhalofop-butyl at 12 DAS (82.96%) and pendimethalin + penoxsulam at 5 DAS (81.18%).

Comparing the time of application of pre-mix herbicides, it was seen that application of both pendimethalin + penoxsulam applied at 5 and 10 DAS and florpyrauxifen-benzyl + cyhalofop-butyl at 12 and 18 DAS resulted in higher WCE values, ranging from 83 to 84% at 30 DAS and from 79 to 82% at 60 DAS. Cyhalofop-butyl + penoxsulam had slightly lower values ranging from 76 to 78% at 30 DAS and from 73 to 74% at 60 DAS.

Yield attributes of rice

The highest number of panicles (221 and 216 no./m^2), grains per panicle (120 and 118 no.) and percentage of filled grains per panicle (91.86% and 91.66%) in rice were seen in hand weeding and florpyrauxifen-benzyl + cyhalofop-butyl (150 g/ha) at 12 DAS, respectively (**Table 2**) and it was followed by pendimethalin + penoxsulam (625 g/ha) at 5 DAS. The lowest values for all the yield attributes were recorded in unweeded control.

Grain and straw yield

The highest grain yield of 4.6 t/ha was recorded in hand weeding followed by florpyrauxifen-benzyl + cyhalofop-butyl (150 g/ha) at 12 DAS with 4.5 t/ha and pendimethalin + penoxsulam at 5 DAS with 4.43 t/ha (**Table 2**). All the pre-mix herbicides were superior to sequential spray of cyhalofop-butyl *fb* chlorimuron-ethyl 10% + metsulfuron-methyl 10%, bispyribac-sodium and unweeded control and this could be due to high WCE obtained at 30 DAS, which fell within the critical crop-weed competition period as reported by Singh *et al.* (2008). Straw yield followed the trend of grain yield and there was no significant difference between the treatments in terms of harvest index.

Table 1. Effect of herbicide combinations on weed dry weight and weed control efficiency

Treatment	Weed dry weight (kg/ha)		Weed control efficiency (%)	
	30 DAS	60 DAS	30 DAS	60 DAS
Pendimethalin + penoxsulam 625 g/ha at 5 DAS	37.00^{de}	246.60^{f}	83.98	81.18
Pendimethalin + penoxsulam 625 g/ha at 10 DAS	36.66^{de}	265.00^{e}	84.13	79.78
Cyhalofop-butyl + penoxsulam 135 g/ha at 12 DAS	54.33^{bcd}	336.60^{d}	76.48	74.31
Cyhalofop-butyl + penoxsulam 135 g/ha at 18 DAS	49.33^{cde}	346.60^{c}	78.65	73.55
Florpyrauxifen-benzyl + cyhalofop-butyl 150 g/ha at 12 DAS	35.33^{e}	223.30^{g}	84.71	82.96
Florpyrauxifen-benzyl + cyhalofop-butyl 150 g/ha at 18 DAS	35.66^{de}	263.30^{e}	84.56	79.90
Cyhalofop-butyl *fb* chlorimuron-ethyl 10% + metsulfuron-methyl 10% 80+8 g/ha at 18 and 19 DAS	72.66^{bc}	350.00^{bc}	68.55	73.29
Bispyribac-sodium 25 g/ha at 18 DAS	76.33^{b}	386.60^{b}	66.96	70.49
Hand weeding 20 and 40 DAS	42.33^{de}	96.60^{h}	81.68	92.63
Unweeded control	231.00^{a}	1310.26^{a}	-	-
LSD (p=0.05)	5.59	3.32	-	-

Table 2. Effect of herbicide combinations on yield attributes and rice yields

Treatment	Yield attributes of rice				Crop yields		
	Panicles per m^2	Grains per panicle	Filled grains (%)	Test weight (g)	Grain yield (t/ha)	Straw yield (t/ha)	Harvest index
Pendimethalin + penoxsulam 625 g/ha at 5 DAS	208.89^b	115.87^a	90.60^a	29.05	4.43^a	4.47^a	0.5
Pendimethalin + penoxsulam 625 g/ha at 10 DAS	198.44^d	106.65^c	89.05^a	28.71	4.29^{ab}	4.51^a	0.49
Cyhalofop-butyl + penoxsulam 135 g/ha at 12 DAS	204.96^c	109.76^b	90.44^a	29.08	4.38^{ab}	4.40^a	0.5
Cyhalofop-butyl + penoxsulam 135 g/ha at 18 DAS	191.76^e	108.32^c	89.73^a	28.37	4.24^{ab}	4.41^a	0.49
Florpyrauxifen-benzyl + cyhalofop-butyl 150 g/ha at 12 DAS	216.57^a	118.85^a	91.65^a	29.13	4.50^a	4.58^a	0.5
Florpyrauxifen-benzyl + cyhalofop-butyl 150 g/ha at 18 DAS	201.47^d	109.43^b	90.56^a	28.84	4.32^{ab}	4.48^a	0.49
Cyhalofop-butyl *fb* chlorimuron-ethyl 10% + metsulfuron-methyl 10% 80+8 g/ha at 18 and 19 DAS	187.91^f	106.89^c	88.32^a	28.19	3.52^{bc}	3.68^a	0.49
Bispyribac sodium 25 g/ha at 18 DAS	176.64^g	107.93^c	87.34^b	28.55	3.40^c	3.61^a	0.49
Hand weeding 20 and 40 DAS	221.47^a	120.13^a	91.86^a	29.20	4.60^a	4.67^a	0.5
Unweeded control	125.29^h	80.71^d	75.42^c	27.24	1.99^d	2.11^b	0.48
LSD (p=0.05)	6.04	5.88	4.31	NS	0.72	0.54	NS

With regard to time of herbicide application, highest yield attributes and crop yields were recorded in pendimethalin + penoxsulam at 5 DAS and cyhalofop-butyl + penoxsulam and florpyrauxifen-benzyl + cyhalofop-butyl, both at 12 DAS.

The pre-mix herbicides, *viz.* pendimethalin + penoxsulam (625 g/ha) at 5 and 10 DAS, cyhalofop-butyl + penoxsulam (135 g/ha) and florpyrauxifen-benzyl + cyhalofop-butyl (150 g/ha) both applied at 12 and 18 DAS performed effective against weeds and were adjudged as good as two hand weeding (20 and 40 DAS) with respect to grain and straw yields in wet direct-seeded rice in the *Kole* areas of Thrissur.

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Effect of tillage, seed rate and nitrogen levels on weeds and yield of wheat

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ABSTRACT

A field experiment was conducted to assess the effect of tillage, seed rate and nitrogen levels on weed and yield of wheat at College of Agriculture, S.K. Rajasthan Agricultural University, Bikaner during *Rabi* (winter) seasons of 2015-16 and 2016-17. It was laid out in a split plot design with three replications with six main plots comprising three levels of tillage (conventional, minimum and zero tillage) and two levels of seed rate (100 and 125 kg/ha) and four levels of nitrogen (80, 100, 120 and 140 kg N/ha) as sub-plots and comprising a total of 24 treatment combinations. The conventional tillage significantly increased the grain, straw and biological yields of wheat over zero and minimum tillage. Conventional tillage lowered the weed density and weed biomass as compared to zero and minimum tillage systems. Seed rate of 125 kg/ha and application of 120 kg N/ha significantly increased the grain, straw and biological yields over 100 kg/ha seed rate and 80 and 100 kg N.

Wheat (*Triticum aestivum* L.) is one of the most important staple food grain crops of India, which is the second leading producer of wheat next to China in the world (Usadadiya and Patel 2013). In India, wheat is cultivated in 30.0 million hectares with total production of 107 million tons; with average yield of 3400 kg/ha (IASRI 2019). The arguments in favour as well as against no tillage suggest that the tillage effects on crop yields need to be assessed in relation to management factors (Gajri *et al.* 2002) like fertilizers and seed rate. Tillage operations reduce the organic carbon, however no tillage with crop residue increased the soil organic carbon. Zero tillage favours proper management of crop residue which results in enhanced nutrient status.

Tillage strongly influences number and diversity of weed seed bank, and has overriding influence on weed shift (Akdbundu 1987). Type of tillage has profound effect on weed crop interference. Zero tillage had higher energy use efficiency than other tillage types. Nitrogen is a key nutrient in crop production and often an important limiting factor for the productivity of crops. Excessive use of N may increase input cost to farmers and environmental problems such as greenhouse gases emissions, leaching of NO_3^-, eutrophication, and reduce crop yield (Mali *et al.* 2001).

Seed rate is an important variable affecting yield and profit of crop production. Manipulation of seed rate has been emerged as an option for weed management particularly under conservation agriculture. High seed rate caused reduction in weed density and biomass in rice (Gill 2008). The information pertaining to influence of variable seed rate on weed dynamics of zero-till wheat for hot arid region is lacking. Weeds are competitive and adaptable to all adverse environments of the total annual loss of agricultural produce from various pests in India, which is about 45 per cent. (Yaduraju 2006). Wheat crop usually suffers from stress created by weeds through competition for water, nutrients, space and sunlight along with interference caused by releasing toxic substances into the rhizosphere (Rice 1984). This study was conducted to assess the effect of tillage, seed rate and nitrogen levels on weed and yield of wheat.

An experiment was conducted at the research farm, College of Agriculture, S.K. Rajasthan Agricultural University, Bikaner during *Rabi* seasons of 2015-16 and 2016-17. College of Agriculture is situated at 28.01^{0}N latitude, 73.22^{0}E longitude and at an altitude of 234.7m above mean sea level. The field experiment on wheat consisting of 3 tillage practices (conventional, minimum and zero tillage) and 2 levels of seed rate (100 and 125 kg/ha), thus 6 treatment combinations of tillage and seed rate were assigned to main plots and 4 levels of nitrogen (80, 100, 120 and 140 kg N/ha) to sub-plots, making total of 24 treatment combinations were tested in split plot design with three replications. The seed bed was prepared after pre-sowing irrigation depending on the main plot treatments. Two harrowing + two ploughings followed by planking were done as preparatory tillage for the conventional tillage. Whereas, for minimum tillage, one harrowing + one cultivator followed by planking were done during both the crop seasons. In zero tillage plots, no tillage operations were carried out during crop seasons. The calculated seed rate of 100 and 125 kg/ha were used as per treatment. The recommended dose of phosphorus (40 kg P/ha) and potassium (20 kg K/ha) was applied to wheat during both the seasons as basal. Whereas; nitrogen was applied as per treatment. The source of nitrogen, phosphorus and potassium were urea, DAP and muriate of potash (MOP), respectively.

Weed density and biomass were significantly affected owing to different tillage systems. There were 15.29 and 9.97 per cent reduction in total weed density at harvest in conventional tillage (CT) (**Table 1**) when compared with zero (ZT) and minimum tillage (MT), respectively. Greater weed density in zero tillage might be owing to presence of weed seeds to the upper soil layers (Singh *et al.* 2001). Maximum weed biomass was recorded in zero tillage which was 14.36 and 7.93% greater when compared with minimum and conventional tillage, respectively because weeds germinated along with the crop owing to preceding irrigation and accumulated maximum dry matter. The greater weed density and biomass reduction in conventional tillage might be due to the disturbance of soil with deep placement of weed seeds and frequent cutting of weed parts during tillage practices and superior establishment of crop. Similar findings were also stated by Pandey *et al.* (2005), Monsefi *et al.* (2013) and Upasani *et al.* (2014).

The higher grain and straw production were observed in CT compared to ZT and MT but the difference between ZT and MT were only marginal (**Table 2**). The rise in grain production of wheat under CT could be attributed to greater yield attributes whereas the rise in biological production was owing to greater dry matter production. To some extent, it could also attributed to superior soil environment (Idnani and Kumar 2012). This was probably owing to superior rooting induced by reduced soil strength in the upper 10-15 cm layer. ZT had the lowest production owing to greater weed intensity in the growing period. Soil compaction, higher weed density and improper seed coverage at sowing are the major factors which resulted in less yield under ZT. Limited covering the seeds with soil along with plant debris accretion a top soil surface, less seedling production owing to low seed germination and more growth of weedy plants may have caused this greater production loss (Unger 1978). Bahrani *et al.* (2002) also found that conventional tillage produced greater wheat grain productions as compared to zero and reduced tillage methods. Findings of Schllinger (2005) indicated that the use of no tillage compared with conventional tillage systems leads to a significant reduction in wheat, oats and barley production. Reduced seedling establishment and growth, exposure to heat at the end of season, weed density and changes in the physical properties of the soil are among reasons for the reduced grain production stated by different workers (Farooq *et al.* 2007). Also, others (Jug *et al.* 2011 and Wozniak 2013) demonstrated greater cereal production in the conventional system than in no-till system. According to De Vita *et al.* (2007) in areas with precipitation below 300 mm in the vegetative

Table 1. Effect of tillage, seed rate and nitrogen levels on weed density and total weed density of wheat

Treatment	Weed density (no./m^2)				Weed density (no./m^2)		Weed biomass (no./m^2)	
	Monocot		Dicot					
	30 DAS	At harvest	30 DAS	At harvest	30 DAS	At harvest	30 DAS	At harvest
Tillage								
ZT	0.61	1.41	5.53	14.17	6.14	15.57	10.27	27.78
MT	0.57	1.29	5.36	13.35	5.92	14.65	9.53	25.84
CT	0.50	1.17	4.68	12.01	5.18	13.19	8.81	23.79
LSD (p=0.05)	0.02	0.05	0.34	0.63	0.36	0.65	0.32	0.83
Seed rate (kg/ha)								
100	0.58	1.35	5.41	13.67	5.99	15.02	9.82	26.60
125	0.54	1.24	4.97	12.68	5.51	13.92	9.26	25.00
LSD (p=0.05)	0.02	0.04	0.28	0.51	0.29	0.53	0.26	0.67
Nitrogen levels (kg/ha)								
80	0.53	1.25	5.08	13.04	5.61	14.29	8.73	23.66
100	0.55	1.29	5.16	13.14	5.72	14.43	9.42	25.53
120	0.57	1.31	5.24	13.23	5.81	14.54	9.98	26.85
140	0.58	1.32	5.28	13.30	5.86	14.29	10.03	27.18
LSD (p=0.05)	NS	NS	NS	NS	NS	14.43	0.31	0.80

LSD- Least significant difference at the 5% level of significance; DAS - Days after sowing; ZT- Zero tillage; MT- Minimum tillage; CT- Conventional tillage

Table 2. Effect of tillage, seed rate and nitrogen levels on yields of wheat

Treatment	Grain yield (kg/ha)			Straw yield (kg/ha)			Biological yield (kg/ha)			Harvest index (%)		
	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled	2015-16	2016-17	Pooled
Tillage												
ZT	2.95	2.84	2.90	4.09	4.04	4.06	7.04	6.88	6.96	41.9	41.3	41.6
MT	3.07	2.99	3.03	4.46	4.28	4.37	7.53	7.27	7.40	40.8	41.2	41.0
CT	3.21	3.11	3.16	4.77	4.45	4.61	7.98	7.55	7.77	40.2	41.2	40.7
LSD (p=0.05)	0.11	0.11	0.07	0.15	0.15	0.10	0.26	0.25	0.17	NS	NS	NS
Seed rate (kg/ha)												
100	3.03	2.93	2.98	4.35	4.14	4.25	7.38	7.07	7.23	41.1	41.5	41.3
125	3.13	3.03	3.08	4.53	4.37	4.45	7.65	7.40	7.52	40.9	41.0	40.9
LSD (p=0.05)	0.09	0.09	0.06	0.12	0.12	0.08	0.21	0.21	0.14	NS	NS	NS
Nitrogen levels (kg/ha)												
80	2.71	2.71	2.71	3.95	3.91	3.93	6.66	6.62	6.64	40.8	40.9	40.9
100	3.05	2.92	2.99	4.40	4.19	4.29	7.45	7.11	7.28	41.0	41.2	41.1
120	3.24	3.10	3.17	4.64	4.42	4.53	7.87	7.52	7.70	41.1	41.3	41.2
140	3.33	3.18	3.25	4.77	4.50	4.64	8.10	7.68	7.89	41.1	41.4	41.2
LSD (p=0.05)	0.14	0.10	0.09	0.19	0.13	0.11	0.32	0.23	0.19	NS	NS	NS

LSD, least significant difference at the 5% level of significance; DAS - Days after sowing

period superior growth are achieved with the ploughing than with the no-till system.

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Glyphosate use in transgenic maize: Effect on weeds and crop productivity in North-Western Indo-Gangetic Plains of Haryana

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ABSTRACT

A field experiment was conducted during *Kharif* 2012 at Khrindwa research farm of CCS Haryana Agricultural University, Regional Research Station, Karnal, under the Bio-safety Research Trial Level-1 for transgenic maize hybrids to evaluate the bio-efficacy of glyphosate as post-emergence herbicide against weeds. There were 14 treatment combinations, including two transgenic hybrids of Monsanto, *Hishell-NK603* and *900M Gold-NK603*. Weed flora of the field included *Echinochloa crus-galli, Dactyloctenium aegyptium, Brachiaria reptans* and *Eragrostis tenella* among grassy weeds, *Physalis minima* and *Phyllanthus niruri* among broadleaf weeds and *Cyperus rotundus* among sedges along with few other minor weeds. Use of glyphosate 900-1800 g/ha in transgenic maize hybrids *Hishell-NK603* and *900M Gold-NK603*, provided 98.2-99.5% weed control efficiency, which was higher than the atrazine 750 g/ha treatments (62.1-68.6%); and resulted in improved grain yield of maize (7.7-8.7 t/ha) than unweeded checks (4.7-5.9 t/ha) and atrazine treatments (5.8-7.5 t/ha). At 60 DAT, minimum weed population (8.0-9.3/m^2) was recorded in the glyphosate treatment at both the doses in transgenic maize hybrids, which was significantly lower than the atrazine treatments (19.3-21.3/m^2) in transgenic/ conventional hybrids, as well as the non-weeded (37.3-41.3/m^2) checks in conventional hybrids. Glyphosate 900-1800 g/ha in *900M Gold-NK603* produced maximum grain yield (8.6-8.7 t/ha) which was followed by glyphosate 900-1800 g/ha in *Hishell-NK603* (7.7-7.8 t/ha). The growth, yield and yield attributes indicated superiority of *900M Gold-NK603* over *Hishell-NK603*, however, the differences in yield were not significant. Present study indicated the suitability of glyphosate use as post-emergence in transgenic maize hybrids *Hishell-NK603* and *900M Gold-NK603*. There was no phyto-toxicity of glyphosate 900-1800 g/ha on the transgenic crop.

Maize (*Zea mays* L.) is one of the most important cereals in the world agricultural economy, and grown over an area of 197 mha with production of 1135 m tonnes and productivity of 5.75 t/ha in 2017 (FAO 2019). It ranks as the third most important food grain crop next to rice and wheat in the country. In India, maize is grown in a wide range of situations, extending from extreme semi-arid to sub-humid and humid regions. The average productivity of maize (2.68 t/ha) in India is far below world average of 5.75 t/ha. Weeds are the major constraints in maize to lower down the production; and being a *Kharif* season crop, diverse type of weeds infest the crop which are difficult to control with a single herbicide. Initial slow growth, wider spacing and high moisture during rainy season are the factors favouring the growth of weeds in maize. Herbicides are one of the most important weed management tools in maize. Sustainability of maize under zero-tillage systems has been well documented (Jat *et al*. 2013, Khedwal *et al*. 2017).

Herbicide tolerant and insect resistant GM crops have become leading features in agro- ecosystem of many of the world's agricultural regions (ISAAA 2016). During the recent past, many transgenic and non-transgenic herbicide tolerant crops (HTCs) have been made available to cultivators in many countries. But in India, HTCs are in the initial stage of field evaluation (Chinnusamy *et al.* 2014). Glyphosate ready maize was first marketed in the late 1990s. This technology confers tolerance to glyphosate by production of glyphosate-tolerant CP4 EPSPS (5-enolpyruvylshikimate-3-phosphate synthase) proteins. A glyphosate-based system has many advantages, including low cost, excellent crop safety, broad spectrum of weed control, and application flexibility (Norsworthy *et al.* 2001, Dewar 2009, Creech *et al.* 2012). The efficacy of glyphosate tolerant transgenic stack maize hybrids against insect-pests like *Chillo partellus, Helicoverpa armigera etc.* has also been documented, indicating dual-benefit of such transgenic maize hybrids

(Sushilkumar *et al*. 2017). This paper presents the results of efficacy of glyphosate tolerant transgenic maize for control of weed complex in Haryana conditions in North-Western Indo-Gangetic Plains.

A field experiment was conducted during *Kharif* (rainy) season of 2012 at Khrindwa Research Farm of CCS Haryana Agricultural University, Regional Research Station, Karnal, under the Bio-safety Research Trial Level-1 for transgenic maize hybrids to evaluate the bio-efficacy of glyphosate as post-emergence against weeds. The geographical location of the experiment was situated at 30°11'N latitude and 76°93'E longitude with an altitude of 252 m above mean sea level in Kurukshetra district of Haryana. The climate of the area was typically sub-tropical with an average annual rainfall of about 700 mm. During the crop season, the daily minimum and maximum temperatures were 13.8-29.5 ^{0}C and 27.0-37.2^{0}C, respectively, with total rainfall of 285 mm. The soil of the research farm was low in nitrogen, medium in phosphorus and potash. Two transgenic stacked corn hybrids of Monsanto, *viz. Hishell* and *900M Gold* containing CP4 EPSPS genes (Event NK603) were evaluated in the trial. There were 14 treatment combinations, including two GM-hybrids *Hishell (NK603)* and *900M Gold (NK603)* each with application of glyphosate (MON 76366) 900, 1800 g/ha (at 2-4 leaf stage) and atrazine 750 g/ha (0-3 DAS), and conventional (non-GM) hybrids *Hishell*, *900M Gold*, national check (*Pro 4640*) and local check (*HM 10*) each with atrazine 750 g/ha (at 0-3 DAS) and non-weeded check. The experiment was laid out in randomized block design with three replications. The sowing of maize was done at a spacing of 60 x 25 cm using seed rate of 22.5 kg/ha on 10 July, 2012. The plot size was 5.0 × 3.6 m. The herbicide atrazine was applied as pre-emergence (PE) on 12th July, 2012, and glyphosate as post-emergence (PoE) on 2nd August, 2012 with knapsack sprayer fitted with flat fan nozzle using a spray volume of 250 L/ha. At the time of glyphosate spray, mean leaf stage values of different weeds were 3.6-3.7 (**Table 1**) with plant height of 9.1-9.3 cm (**Table 1**) and total ground coverage of 50-52% (**Table 2**). Recommended doses of fertilizer nutrients (150:60:60 kg of NPK/ha) were given in the form of urea, diammonium phosphate and muriate of potash. Crop was raised by adopting the recommendations of the state University for hybrid maize. As per protocol, buffer crop of fodder maize variety *'African Tall'* was grown all around the experimental area to act as barrier to aerial dispersal of pollens; in addition, an aerial isolation distance of 300 m was maintained in periphery of experimental area. Total area of the experimental field including *'African Tall'* was 2632 m^2 (70 x 37.6 m), out of which 324 m^2 was under transgenic maize cultivars.

The data on weed density was recorded at the time of application of glyphosate, 30 and 60 days after treatment (DAT), weed dry weight at 21 DAT and at maturity/ harvest, and yield at harvest. Crop was harvested on 18-19 October, 2012. The weed control efficiency (WCE) was computed based on dry weight of weeds by using the following formula,

Table 2. Percent ground cover by weeds at the time of glyphosate herbicide application

Maize hybrids	Ground cover by weed (%)			
	Hishell-NK603		*900M Gold-NK603*	
	GS (900 g/ha)	GS (1800 g/ha)	GS (900 g/ha)	GS (1800 g/ha)
Echinochloa crus-galli	8.7	7.7	8.0	8.3
Dactyloctenium aegyptium	17.0	17.0	18.0	16.3
Brachiaria reptans	4.3	4.7	5.3	5.3
Eragrostis tenella	1.7	2.0	2.0	2.3
Physalis minima	8.0	7.3	7.7	6.7
Phylanthus niruri	6.3	6.0	6.7	5.7
Other broad-leaf weeds	3.0	3.7	2.7	3.3
Cyperus rotundus	2.3	2.7	2.0	2.7
Total	51.3	51.0	52.3	50.7

GS: Glyphosate

Table 1. Leaf stage and plant height of weeds at the time of glyphosate herbicide application

Maize hybrids	Leaf stage of weed				Plant height of weed (cm)			
	Hishell-NK603		*900M Gold-NK603*		*Hishell-NK603*		*900M Gold-NK603*	
	Glyphosate (900 g/ha)	Glyphosate (1800 g/ha)	Glyphosate (900 g/ha)	Glyphosate (1800 g/ha)	Glyphosate (900 g/ha)	Glyphosate (1800 g/ha)	Glyphosate (900 g/ha)	Glyphosate (1800 g/ha)
Echinochloa crus-galli	4.3	4.1	4.6	4.3	16.2	15.0	14.5	16.8
Dactyloctenium aegyptium	3.3	3.6	3.6	3.3	8.0	7.2	7.7	7.2
Brachiaria reptans	3.3	3.0	3.2	3.0	5.7	5.5	6.0	5.2
Eragrostis tenella	4.0	3.8	3.9	3.8	7.7	8.3	8.5	7.5
Physalis minima	3.7	3.9	4.0	3.8	12.8	12.8	13.5	12.1
Phylanthus niruri	3.3	3.4	3.4	3.3	6.8	6.8	7.3	6.5
Other broad-leaf weeds	4.0	3.9	3.7	3.8	9.3	8.9	8.6	9.2
Cyperus rotundus	3.3	3.0	3.2	3.2	8.2	8.1	8.5	8.1
Mean	3.7	3.6	3.7	3.6	9.3	9.1	9.3	9.1

$$\text{WCE (\%)} = \frac{\text{(Weed dry weight in unweeded plot – Weed dry weight in treated plot)}}{\text{Weed dry weight in unweeded plot}} \times 100$$

From four unweeded checks, the treatment having maximum weed dry weight was used for calculation of WCE. The data were subjected to the Fisher's method of analysis of variance (ANOVA) (Fisher 1958) and significant treatment effect was judged with the help of 'F' test at the 5% level of significance by adopting the procedure described by Panse and Sukhatme (1985). Before statistical analysis, the data on density of weeds were subjected to square root transformation ($\sqrt{x+1}$) to improve the homogeneity of the variance.

Effect on weeds

Density of weeds: Weed flora of the field included *Echinochloa crus-galli, Dactyloctenium aegyptium, Brachiaria reptans* and *Eragrostis tenella* among grassy weeds, *Physalis minima* and *Phyllanthus niruri* among broad-leaf weeds and *Cyperus rotundus* among sedges along with few minor weeds (**Table 3** and **4**). At the time of glyphosate application, maximum weed density was recorded under the non-weeded plots of different conventional hybrids (*900M Gold*-Conv., *Pro 4640, HM10*) (166.0-194.0/m^2), and under glyphosate treatments of both GM hybrids (*Hishell-NK603, 900M Gold-KN603*) (168.7-188.7/m^2), which were statistically similar to each other and lower than the atrazine treatments of different GM and non-GM hybrids (31.3-38.0/m^2). Similar trends were observed for different weed species and weed groups (**Table 3** and **4**). Higher density of weeds under glyphosate treatments was expected, as these plots were maintained as unweeded till the date of this observation *i.e.* before glyphosate spray.

At 30 DAT, minimum density of weeds was under glyphosate (MON 76366) 1800 g/ha (in both GM hybrids) closely followed by glyphosate 900 g/ha (in both GM hybrids) with total of 4.7, 6.0, 7.3 and 8.7 weeds per sq m, respectively, in transgenic corn hybrids *Hishell-NK603* and *900M Gold-NK 603* (**Table 5, 6** and **7**). However, these treatments were statistically similar to each other. In the treatments where atrazine was applied, population at this stage ranged from 34 to 42 weeds/m^2. This was significantly higher than that observed in glyphosate treatments. Among different weed groups, grassy weeds were maximum, followed by broad-leaf weeds and sedges with a similar pattern of density except no control of sedges under atrazine. Among grasses, *Echinochloa crus-galli* and *Dactyloctenium aegyptium* were maximum in density.

At 60 DAT, overall weed density reduced in all the treatments including weedy checks. Non-weeded check treatments recorded maximum weed population (37.3-41.3/m^2), and weed density under the atrazine treatments (19.3-21.3/m^2) were lower than the weedy check (**Table 5**, **6** and **7**). Minimum weed population (8.0-9.3/m^2) was found in the glyphosate treatment at both the doses, which was significantly lower than the atrazine treatments as well as the non-weeded checks. Similar to 30 DAT, grassy weeds were maximum in weed count. Among grassy weeds, *Echinochloa crus-galli* and *Brachiaria reptans,* and *Physalis minima* among BLW were on the higher side.

Dry weight of weeds

At 21 DAT, maximum dry weight of weeds (160.35-169.14 g/m^2) was recorded in non-weeded checks (**Table 8**). It was negligible under glyphosate

Table 3. Weed density (group wise) under different herbicidal treatments in GM-Corn at the time of glyphosate herbicide application

Maize hybrid	Herbicide	Weed density (no./m^2)			
		Grassy weeds	Broad-leaf weeds	Sedges	Total weeds
Hishell-NK603	Glyphosate 900 g/ha	10.3(105.3)	7.5(56.0)	2.8(7.3)	13.0(168.7)
Hishell-NK603	Glyphosate 1800 g/ha	10.4(107.3)	8.2(66.7)	2.7(6.7)	13.5(180.7)
Hishell-NK603	Atrazine 750 g/ha	4.4(19.3)	2.5(5.3)	3.1(8.7)	5.8(33.3)
900M Gold-NK603	Glyphosate 900 g/ha	10.5(109.3)	8.2(67.3)	2.8(6.7)	13.5(183.3)
900M Gold-NK603	Glyphosate 1800 g/ha	10.7(114.7)	8.1(64.7)	3.1(9.3)	13.8(188.7)
900M Gold-NK603	Atrazine 750 g/ha	4.4(18.7)	1.7(2.0)	3.3(10.0)	5.6(30.7)
Hishell Conv.	Atrazine 750 g/ha	4.4(19.3)	2.0(4.0)	2.7(8.0)	5.6(31.3)
Hishell Conv.	No weeding	10.1(102.0)	7.6(57.3)	2.5(6.7)	12.9(166.0)
900M Gold Conv.	Atrazine 750 g/ha	4.7(22.0)	1.5(1.3)	3.2(9.3)	5.8(32.7)
900M Gold Conv.	No weeding	10.2(104.7)	8.0(62.7)	2.8(6.7)	13.2(174.0)
National check hybrid (*Pro 4640*)	Atrazine 750 g/ha	5.0(24.0)	2.3(4.7)	3.2(9.3)	6.2(38.0)
National check hybrid (*Pro 4640*)	No weeding	10.9(117.3)	8.5(71.3)	2.5(5.3)	14.0(194.0)
Local check hybrid (*HM 10*)	Atrazine 750 g/ha	4.6(20.7)	1.9(2.7)	3.2(9.3)	5.8(32.7)
Local check hybrid (*HM 10*)	No weeding	10.4(108.0)	8.4(70.7)	3.1(8.7)	13.7(187.3)
LSD (p=0.05)		1.26	1.12	NS	1.09

*Original figures in parentheses were subjected to square root transformation before statistical analysis

Table 4. Density of different weed species under different herbicidal treatments in GM-Corn at the time of glyphosate herbicide application

Maize hybrid	Herbicide	Density of weeds (no./m^2)*							
		Ec	Da	Br	Et	Pm	Pn	OBLW	Cr
Hishell-NK603	Glyphosate 900 g/ha	4.9(24.0)†	7.5(56.0)	4.4(18.7)	2.7(6.7)	4.8(22.0)	5.3(27.3)	2.8(6.7)	2.8(7.3)
,,	Glyphosate 1800 g/ha	4.9(23.3)	7.6(57.3)	4.6(20.7)	2.6(6.0)	5.4(28.7)	5.4(28.7)	3.2(9.3)	2.7(6.7)
,,	Atrazine 750 g/ha	3.1(8.7)	2.3(5.3)	2.0(3.3)	1.7(2.0)	1.5(2.0)	1.2(0.7)	1.8(2.7)	3.1(8.7)
900M Gold-NK603	Glyphosate 900 g/ha	4.8(22.7)	7.8(60.7)	4.6(20.0)	2.6(6.0)	5.2(26.0)	5.9(34.7)	2.8(6.7)	2.8(6.7)
,,	Glyphosate 1800 g/ha	4.8(22.0)	8.0(63.3)	4.9(23.3)	2.6(6.0)	5.0(24.7)	5.8(32.7)	2.8(7.3)	3.1(9.3)
,,	Atrazine 750 g/ha	2.9(7.3)	3.0(8.7)	1.7(2.0)	1.2(0.7)	1.0(0.0)	1.4(1.3)	1.2(0.7)	3.3(10.0)
Hishell Conv.	Atrazine 750 g/ha	3.0(8.0)	2.8(7.3)	1.8(2.7)	1.4(1.3)	1.7(2.7)	1.0(0.0)	1.5(1.3)	2.7(8.0)
,,	No weeding	5.0(24.7)	7.3(52.7)	4.3(18.0)	2.8(6.7)	4.6(20.7)	5.4(28.7)	3.0(8.0)	2.5(6.7)
900M Gold Conv.	Atrazine 750 g/ha	2.5(5.3)	3.2(10.0)	2.3(4.7)	1.7(2.0)	1.0(0.0)	1.0(0.0)	1.5(1.3)	3.2(9.3)
,,	No weeding	5.2(26.7)	7.2(51.3)	4.5(19.3)	2.9(7.3)	4.9(22.7)	5.7(32.0)	3.0(8.0)	2.8(6.7)
National check hybrid (Pro 4640)	Atrazine 750 g/ha	2.7(6.7)	3.4(10.7)	2.3(4.7)	1.7(2.0)	1.0(0.0)	1.7(2.7)	1.7(2.0)	3.2(9.3)
,,	No weeding	5.2(26.7)	7.8(59.3)	5.0(24.7)	2.8(6.7)	5.1(25.3)	5.9(34.7)	3.5(11.3)	2.5(5.3)
Local check hybrid (HM 10)	Atrazine 750 g/ha	2.9(8.0)	2.7(7.3)	2.1(4.0)	1.4(1.3)	1.0(0.0)	1.0(0.0)	1.9(2.70)	3.2(9.3)
,,	No weeding	5.1(25.3)	7.4(54.0)	4.7(21.3)	2.8(7.3)	5.2(26.0)	6.1(36.7)	3.0(8.0)	3.1(8.7)
LSD (p=0.05)		0.82	1.30	1.11	0.87	0.94	1.03	0.73	NS

*Original figures in parentheses were subjected to square root transformation before statistical analysis

Abbreviation: Ec, *Echinochloa crus-galli*; Da, *Dactyloctenium aegyptium*; Br, *Bracharia reptans*; Et, *Eragrostis tenella*; Pm, *Physalis minima*; Pn, *Phylanthus niruri*; OBLW, Other broad-leaf weeds; Cr, *Cyperus rotundus*

Table 5. Weed density (group wise) at 30 and 60 days after application of glyphosate in GM-Corn

Maize hybrid	Herbicide	Weed density (no./m^2)							
		30 DAT				60 DAT			
		Grassy weeds	Broad-leaf weeds	Sedges	Total weeds	Grassy weeds	Broad-leaf weeds	Sedges	Total weeds
Hishell-NK603	Glyphosate 900 g/ha	1.2(0.7)	2.8(7.3)	1.2(0.7)	3.1(8.7)	1.2(0.7)	2.9(7.3)	1.0(0.0)	3.0(8.0)
Hishell-NK603	Glyphosate 1800 g/ha	1.0(0.0)	2.3(4.7)	1.0(0.0)	2.3(4.7)	1.0(0.0)	2.9(7.3)	1.2(0.7)	3.0(8.0)
Hishell-NK603	Atrazine 750 g/ha	5.1(25.3)	2.5(5.3)	3.0(8.0)	6.3(38.7)	3.3(10.0)	2.5(5.3)	2.2(4.0)	4.5(19.3)
900M Gold-NK603	Glyphosate 900 g/ha	1.2(0.7)	2.6(6.0)	1.2(0.7)	2.9(7.3)	1.2(0.7)	3.0(8.7)	1.0(0.0)	3.1(9.3)
900M Gold-NK603	Glyphosate 1800 g/ha	1.2(0.7)	2.3(4.7)	1.2(0.7)	2.6(6.0)	1.0(0.0)	2.8(7.3)	1.2(0.7)	2.9(8.0)
900M Gold-NK603	Atrazine 750 g/ha	5.2(26.0)	1.8(2.7)	3.1(8.7)	6.2(37.3)	3.3(10.0)	2.5(5.3)	2.2(4.0)	4.5(19.3)
Hishell Conv.	Atrazine 750 g/ha	5.3(28.0)	2.8(6.7)	2.9(7.3)	6.5(42.0)	3.3(10.0)	2.5(5.3)	2.4(4.7)	4.6(20.0)
Hishell Conv.	No weeding	8.6(72.7)	5.3(27.3)	1.0(0.0)	10.0(100.0)	4.9(22.7)	3.9(14.7)	1.0(0.0)	6.2(37.3)
900M Gold Conv.	Atrazine 750 g/ha	4.8(22.7)	2.1(4.0)	2.8(7.3)	5.9(34.0)	3.5(11.3)	2.5(5.3)	2.1(3.3)	4.6(20.0)
900M Gold Conv.	No weeding	8.7(74.7)	5.3(28.0)	1.0(0.0)	10.2(102.7)	4.9(23.3)	4.2(16.7)	1.4(1.3)	6.5(41.3)
National check hybrid (*Pro 4640*)	Atrazine 750 g/ha	5.1(24.7)	2.3(4.7)	3.1(8.7)	6.2(38.0)	3.3(10.0)	2.7(6.7)	2.3(4.7)	4.7(21.3)
National check hybrid (*Pro 4640*)	No weeding	8.7(74.0)	5.5(30.0)	1.0(0.0)	10.2(104.0)	4.7(21.3)	4.4(18.7)	1.0(0.0)	6.4(40.0)
Local check hybrid (*HM 10*)	Atrazine 750 g/ha	4.8(22.7)	2.6(7.3)	3.3(10.0)	6.4(40.0)	3.3(10.0)	3.0(8.0)	2.1(3.3)	4.7(21.3)
Local check hybrid (*HM 10*)	No weeding	8.4(70.7)	5.3(27.3)	1.0(0.0)	9.9(98.0)	4.9(22.7)	4.0(15.3)	1.0(0.0)	6.2(38.0)
LSD (p=0.05)		0.98	1.17	0.64	0.91	0.57	0.69	0.60	0.85

*Original figures in parentheses were subjected to square root transformation before statistical analysis

Table 6. Density of different weed species at 30 days after application of glyphosate in GM-Corn

Maize hybrid	Herbicide	Weed density (no./m^2)							
		Ec	Da	Br	Et	Pm	Pn	OBLW	Cr
Hishell-NK603	Glyphosate 900 g/ha	1.2(0.7)	1.0(0.0)	1.0(0.0)	1.0(0.0)	1.0(0.0)	1.0(0.0)	2.8(7.3)	1.2(0.7)
Hishell-NK603	Glyphosate 1800 g/ha	1.0(0.0)	1.0(0.0)	1.0(0.0)	1.0(0.0)	1.0(0.0)	1.2(0.7)	2.2(4.0)	1.0(0.0)
Hishell-NK603	Atrazine 750 g/ha	3.1(8.7)	3.2(9.3)	2.8(7.3)	1.0(0.0)	1.0(0.0)	1.0(0.0)	2.5(5.3)	3.0(8.0)
900M Gold-NK603	Glyphosate 900 g/ha	1.2(0.7)	1.0(0.0)	1.0(0.0)	1.0(0.0)	1.0(0.0)	1.2(0.7)	2.5(5.3)	1.2(0.7)
900M Gold-NK603	Glyphosate 1800 g/ha	1.2(0.7)	1.0(0.0)	1.0(0.0)	1.0(0.0)	1.0(0.0)	1.2(0.7)	2.2(4.0)	1.2(0.7)
900M Gold-NK603	Atrazine 750 g/ha	2.6(6.0)	3.6(12.0)	3.0(8.0)	1.0(0.0)	1.0(0.0)	1.2(0.7)	1.7(2.0)	3.1(8.7)
Hishell Conv.	Atrazine 750 g/ha	3.2(9.3)	3.5(12.0)	2.7(6.7)	1.0(0.0)	1.7(2.0)	1.0(0.0)	2.3(4.7)	2.9(7.3)
Hishell Conv.	No weeding	5.5(30.0)	5.3(27.3)	4.0(15.3)	1.0(0.0)	4.2(17.3)	2.6(6.0)	2.2(4.0)	1.0(0.0)
900M Gold Conv.	Atrazine 750 g/ha	2.7(6.7)	3.2(9.3)	2.7(6.7)	1.0(0.0)	1.0(0.0)	1.2(0.7)	2.0(3.3)	2.8(7.3)
900M Gold Conv.	No weeding	5.6(30.7)	5.4(28.7)	4.0(15.3)	1.0(0.0)	4.3(18.0)	2.5(5.3)	2.3(4.7)	1.0(0.0)
National check hybrid (*Pro 4640*)	Atrazine 750 g/ha	3.2(9.3)	3.0(8.0)	2.8(7.3)	1.0(0.0)	1.0(0.0)	1.7(2.0)	1.8(2.7)	3.1(8.7)
National check hybrid (*Pro 4640*)	No weeding	5.4(28.0)	5.6(30.7)	4.0(15.3)	1.0(0.0)	4.4(18.7)	2.8(7.3)	2.1(4.0)	1.0(0.0)
Local check hybrid (*HM 10*)	Atrazine 750 g/ha	2.7(6.7)	3.3(10.0)	2.6(6.0)	1.0(0.0)	1.0(0.0)	1.7(2.0)	2.3(5.3)	3.3(10.0)
Local check hybrid (*HM 10*)	No weeding	5.3(27.3)	5.3(27.3)	4.0(16.0)	1.0(0.0)	4.1(16.0)	2.6(6.0)	2.5(5.3)	1.0(0.0)
LSD (p=0.05)		0.87	0.75	0.83	NS	0.73	0.73	NS	0.64

*Original figures in parentheses were subjected to square root transformation before statistical analysis

900 g/ha (1.58-1.87 g/m^2) and 1800 g/ha (0.00-0.26 g/m^2) in both the transgenic maize hybrids *Hishell-NK603* and *900M Gold-NK603*. In the treatments where atrazine was applied (GM and Non-GM hybrids), dry weight of weeds was 30.53-35.68 g/m^2, which was higher than the glyphosate treatments. However, it was significantly lower than the un-weeded checks. In all the treatments, grassy weeds *Echinochloa crus-galli* and *Dactyloctenium aegyptium* accumulated higher dry weight under the treatments with atrazine and weedy checks. Maximum dry weight of sedges (*Cyperus rotundus*) was recorded under atrazine treatments.

At crop maturity, overall weed dry weight was reduced than what it was at 21 DAT, obviously due to drying of weeds till this stage. In non-weeded checks, dry weight of weeds was recorded to be maximum (77.83-83.75 g/m^2) among all the treatments (**Table 8**). In atrazine PE treatments, weed dry weight was 26.95-31.30 g/m^2, which was significantly lower than weedy checks, but higher than the glyphosate 900-1800 g/ha treatments in GM-Corn hybrids (0.41-1.49 g/m^2). The glyphosate treatments were the best among all the treatments in reducing the dry weight of weeds, and both the doses of glyphosate were similar to each other.

Weed control efficiency

Based on dry weight reduction at 21 DAT, the treatments with atrazine in transgenic/ conventional

Table 7. Density of different weed species at 60 days after application of glyphosate in GM-Corn

Maize hybrid	Herbicide	Weed density (no./m^2)							
		Ec	Da	Br	Et	Pm	Pn	OBLW	Cr
Hishell-NK603	Glyphosate 900 g/ha	1.2(0.7)	1.0(0.0)	1.0(0.0)	1.0(0.0)	1.9(2.7)	1.5(1.3)	2.0(3.3)	1.0(0.0)
Hishell-NK603	Glyphosate 1800 g/ha	1.0(0.0)	1.0(0.0)	1.0(0.0)	1.0(0.0)	2.1(3.3)	1.5(1.3)	1.9(2.7)	1.2(0.7)
Hishell-NK603	Atrazine 750 g/ha	2.2(4.0)	1.5(1.3)	2.4(4.7)	1.0(0.0)	2.1(3.3)	1.2(0.7)	1.4(1.3)	2.2(4.0)
900M Gold-NK603	Glyphosate 900 g/ha	1.2(0.7)	1.0(0.0)	1.0(0.0)	1.0(0.0)	1.9(2.7)	1.5(1.3)	2.3(4.7)	1.0(0.0)
900M Gold-NK603	Glyphosate 1800 g/ha	1.0(0.0)	1.0(0.0)	1.0(0.0)	1.0(0.0)	1.7(2.0)	1.2(0.7)	2.4(4.7)	1.2(0.7)
900M Gold-NK603	Atrazine 750 g/ha	2.1(3.3)	1.7(2.0)	2.4(4.7)	1.0(0.0)	1.7(2.0)	1.2(0.7)	1.9(2.7)	2.2(4.0)
Hishell Conv.	Atrazine 750 g/ha	2.2(4.0)	1.9(2.7)	2.1(3.3)	1.0(0.0)	1.7(2.0)	1.2(0.7)	1.8(2.7)	2.4(4.7)
Hishell Conv.	No weeding	3.1(8.7)	2.5(5.3)	3.1(8.7)	1.0(0.0)	3.6(12.0)	1.0(0.0)	1.9(2.7)	1.0(0.0)
900M Gold Conv.	Atrazine 750 g/ha	2.2(4.0)	1.7(2.0)	2.5(5.3)	1.0(0.0)	1.7(2.0)	1.5(1.3)	1.7(2.0)	2.1(3.3)
900M Gold Conv.	No weeding	3.4(10.7)	2.4(4.7)	3.0(8.0)	1.0(0.0)	3.8(13.3)	1.0(0.0)	2.1(3.3)	1.4(1.3)
National check hybrid (*Pro 4640*)	Atrazine 750 g/ha	2.1(3.3)	1.7(2.0)	2.4(4.7)	1.0(0.0)	1.4(1.3)	1.7(2.0)	2.1(3.3)	2.3(4.7)
National check hybrid (*Pro 4640*)	No weeding	3.0(8.0)	2.5(5.3)	3.0(8.0)	1.0(0.0)	3.7(12.7)	1.0(0.0)	2.6(6.0)	1.0(0.0)
Local check hybrid (*HM 10*)	Atrazine 750 g/ha	2.1(3.3)	1.9(2.7)	2.2(4.0)	1.0(0.0)	1.9(2.7)	1.7(2.0)	2.1(3.3)	2.1(3.3)
Local check hybrid (*HM 10*)	No weeding	3.1(8.7)	2.4(4.7)	3.2(9.3)	1.0(0.0)	3.4(10.7)	1.0(0.0)	2.4(4.7)	1.0(0.0)
LSD (p=0.05)		0.48	0.44	0.44	NS	0.77	NS	NS	0.60

*Original figures in parentheses were subjected to square root transformation before statistical analysis

Abbreviations: Ec, *Echinochloa crus-galli*; Da, *Dactyloctenium aegyptium*; Br, *Bracharia reptans*; Et, *Eragrostis tenella*; Pm, *Physalis minima*; Pn, *Phylanthus niruri*; OBLW, Other broad-leaf weeds; Cr, *Cyperus rotundus*

Table 8. Dry weight of weeds at 21 days after application of glyphosate and at harvest under different herbicidal treatments in GM-Corn

Maize hybrid	Herbicide	Dry weight of weed (g/m^2)								Weed control efficiency (%)	
		21 DAT				At harvest					
		Grassy weeds	BLW	Sedges	Total weeds	Grassy weeds	BLW	Sedges	Total weeds	21 DAT	At harvest
Hishell-NK603	Glyphosate 900 g/ha	1.09	0.21	0.57	1.87	0.55	0.95	0.00	1.49	98.9	98.2
Hishell-NK603	Glyphosate 1800 g/ha	0.00	0.00	0.00	0.00	0.00	0.35	0.21	0.55	100.0	99.3
Hishell-NK603	Atrazine 750 g/ha	24.77	2.21	4.31	31.29	21.18	8.52	1.33	31.03	81.5	62.9
900M Gold-NK603	Glyphosate 900 g/ha	0.73	0.14	0.71	1.58	0.26	1.03	0.00	1.29	99.1	98.5
900M Gold-NK603	Glyphosate 1800 g/ha	0.26	0.00	0.00	0.26	0.00	0.23	0.17	0.41	99.8	99.5
900M Gold-NK603	Atrazine 750 g/ha	23.30	2.15	5.09	30.53	23.29	6.71	1.29	31.30	81.9	62.6
Hishell Conv.	Atrazine 750 g/ha	26.96	1.99	4.40	33.35	20.53	5.49	1.39	27.40	80.3	67.3
Hishell Conv.	No weeding	136.18	22.07	2.09	160.35	58.99	23.27	0.00	81.59	-	-
900M Gold Conv.	Atrazine 750 g/ha	25.47	2.05	4.39	31.91	18.71	6.21	1.04	25.95	81.1	69.0
900M Gold Conv.	No weeding	142.88	23.53	2.73	169.14	57.87	25.83	0.05	83.75	-	-
National check hybrid (*Pro 4640*)	Atrazine 750 g/ha	28.53	2.19	4.96	35.68	18.91	6.57	1.46	26.95	78.9	67.8
National check hybrid (*Pro 4640*)	No weeding	136.08	23.91	2.36	162.35	53.75	24.08	0.00	77.83	-	-
Local check hybrid (*HM 10*)	Atrazine 750 g/ha	26.71	2.56	5.15	34.42	22.77	6.97	1.07	30.81	79.6	63.2
Local check hybrid (*HM 10*)	No weeding	138.23	24.02	2.21	164.46	56.17	26.46	0.00	82.63	-	-
LSD (p=0.05)		8.80	2.92	0.96	10.50	6.93	3.36	0.44	6.48	-	-

Abbreviations: DAT- Days after treatment, BLW- broad-leaf weeds hybrids of maize gave 78.9-81.9% weed control efficiency (**Table 8**). Maximum weed control efficiency (98.9-100.0%) was recorded under the glyphosate 900-1800 g/ha treatments in GM-Corn hybrids. At maturity/ harvest, the atrazine treatments gave 62.1-68.6% weed control efficiency, which was lower than the WCE (98.2-99.5%) recorded under the glyphosate 900-1800 g/ha treatments. This indicated suitability of glyphosate use as PoE in transgenic maize hybrids *Hishell-NK603* and *900M Gold-NK603*. Both the doses of glyphosate provided almost similar weed control efficiency indicating 900 g/ha to be the optimum dose for use in transgenic maize.

The safe use of glyphosate for effective weed control in transgenic maize hybrids has been reported in other parts of the country earlier also. Chinnusamy *et al.* (2014) reported that post-emergence application of glyphosate at 900 g/ha registered lower weed density, dry weight and higher weed control efficiency in transgenic maize hybrids in Tamil Nadu conditions of peninsular India. In studies at Jabalpur, complete control of weeds with glyphosate in all transgenic maize hybrids was reported by Dixit *et al.* (2016).

Effect on crop

Growth and yield attributes: Hybrid *900M Gold* (GM/ Conv.) had the maximum plant height (213.9-216.8 cm) closely followed by *HM 10* (212.4 cm) under herbicide treated plots. *Hishell* (GM/ Conv.) (203.6-207.5 cm) and *Pro 4640* (206.3 cm) had lower plant height than *900M Gold* (**Table 9**). Plant height of different hybrids except *HM 10* was lower under weedy situations. There was no suppression of plant height of *Hishell-NK603* and *900M Gold-NK603* under glyphosate treatments at both the doses, indicating its safety to the transgenic hybrids.

Maximum cob length (20.2-20.4 cm) was found in local check hybrid '*HM 10*', under herbicide treated as well as non-weeded plots, and was significantly higher than the rest of the treatments (**Table 9**). It indicated the varietal character of better cob length and weed competitive ability in this respect. The herbicide treated plots under hybrids *Hishell, 900M Gold* (GM/ Conv.) and *Pro 4640* produced statistically similar cob length and were superior to unweeded plots; however, the differences were not always significant. Cob length under un-weeded plots was lower than herbicidal treatment of the same hybrid, except *Pro 4640* where these were similar. Maximum cob girth (4.96 cm) was recorded under *900M Gold-NK603* (glyphosate 1800 g/ha), which was similar to *900M Gold-NK603* (glyphosate 900 g/ha), *900M Gold* (atrazine 750 g/ha), and *Pro 4640* (atrazine 750 g/ha). Minimum cob girth (4.46 cm) was recorded in *Hishell-NK603* (atrazine 750 g/ ha), which was similar to *Hishell-NK603* (glyphosate 900 g/ha), *Hishell* (atrazine 750 g/ha) and *HM 10* (atrazine 750 g/ha). The cob girth was lower under unweeded plots, but the differences with herbicide treated counterparts were not significant. Maximum shelling percentage (81.9%) was recorded in *Hishell-NK603* (atrazine 750 g/ha), which was statistically similar to *Hishell-NK603* (glyphosate 900 or 1800 g/ha), *900M Gold-NK603* (glyphosate 900 or 1800 g/ha, atrazine 750 g/ha), *Hishell* Conv. (atrazine 750 g/ha), and *900M Gold* Conv. (atrazine 750 g/ha). Lower shelling percentage (72.2-74.5%) was recorded under *HM 10* (atrazine 750 g/ha) and *Pro 4640* (atrazine 750 g/ha).

Yield

Glyphosate 900-1800 g/ha in *900M Gold-NK603* produced maximum grain yield (8.6-8.7 t/ha) which was followed by glyphosate 900-1800 g/ha in

Table 9. Growth, yield attributes and yield of conventional and GM-Corn hybrids under different herbicidal treatments

Maize hybrid	Herbicide	Plant height (cm)	Cob length (cm)	Cob girth (cm)	Shelling (%)	Grain yield (t/ha)	Stover yield (t/ha)
Hishell-NK603	Glyphosate 900 g/ha	203.6	17.8	4.52	81.9	7.7	9.7
Hishell-NK603	Glyphosate 1800 g/ha	204.1	17.0	4.67	81.2	7.8	9.4
Hishell-NK603	Atrazine 750 g/ha	206.3	17.8	4.46	81.9	7.2	9.4
900M Gold-NK603	Glyphosate 900 g/ha	213.9	16.7	4.79	78.4	8.7	11.0
900M Gold-NK603	Glyphosate 1800 g/ha	214.1	17.4	4.96	79.8	8.6	11.0
900M Gold-NK603	Atrazine 750 g/ha	216.5	16.5	4.75	78.9	7.5	10.5
Hishell Conv.	Atrazine 750 g/ha	207.5	17.7	4.62	81.6	7.0	9.5
Hishell Conv.	No weeding	191.6	15.6	4.52	79.7	6.4	8.0
900M Gold Conv.	Atrazine 750 g/ha	216.8	16.5	4.80	79.0	7.4	10.8
900M Gold Conv.	No weeding	206.1	16.3	4.79	78.7	5.9	8.3
National check hybrid (*Pro 4640*)	Atrazine 750 g/ha	206.3	17.7	4.92	74.5	6.9	9.7
National check hybrid (*Pro 4640*)	No weeding	192.3	16.2	4.74	73.9	4.7	5.3
Local check hybrid (*HM 10*)	Atrazine 750 g/ha	212.4	20.4	4.55	72.2	5.8	8.9
Local check hybrid (*HM 10*)	No weeding	211.3	20.2	4.50	72.5	5.0	7.1
LSD (p=0.05)		9.4	1.5	0.19	4.7	1.5	1.8

Hishell-NK603 (7.7-7.8 t/ha) (**Table 9**). Glyphosate 900-1800 g/ha in transgenic maize hybrids gave grain yield higher than atrazine treatment; however, the differences were not significant. Minimum grain yield was recorded under weedy check plots in *Pro 4640* (4.7 t/ha) which was followed by unweeded checks in *HM 10* (5.0 t/ha), *900M Gold* (5.9 t/ha) and *Hishell* (6.4 t/ha).

Maximum stover yield was obtained from treatments of glyphosate 900-1800 g/ha in *900M Gold-NK603* (11.0 t/ha), which was similar to glyphosate 900-1800 g/ha in *Hishell-NK603* (9.4-9.7 t/ha), atrazine treated plots in *900M Gold* (10.8 t/ha), *900M Gold-NK603* (10.5 t/ha), *Hishell* (9.5 t/ha), *Hishell-NK603* (9.4 t/ha), *Pro 4640* (9.7 t/ha) and *HM 10* (8.9 t/ha) (**Table 9**). Minimum stover yield was recorded in conventional weedy check plots of *Pro 4640* (5.3 t/ha) followed by *HM 10* (7.1 t/ha), *Hishell* (8.0 t/ha) and *900M Gold* (8.3 t/ha).

Chinnusamy *et al.* (2014) also reported higher weed control efficiency under glyphosate in transgenic maize hybrids with improved grain yields in Tamil Nadu. Dixit *et al.* (2016) reported complete control of weeds with glyphosate in all transgenic maize hybrids and three times higher yield than the normal hybrid with conventional herbicidal treatment in Jabalpur. Sushilkumar *et al.* (2017) also reported higher yields of stacked transgenic hybrids *Hishell-NK603* and *900M Gold-NK603*.

Based on this study, it may be concluded that glyphosate 900 g/ha in transgenic maize hybrids *Hishell-NK603* and *900M Gold-NK603* provided effective control of weeds with improved grain yields and with no phyto-toxicity even up to 1800 g/ha dose. Hence, herbicide tolerant cultivars of maize may be the viable options from weed management point of view provided due permission and regulatory approvals are granted by the appropriate authority based on research inputs and other safety considerations.

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DISCLAIMER

The findings of this study are presented for sharing scientific information only; and in no way endorse the adoption of transgenic maize in India, for which legal procedures of GOI are in place for decisions to be taken at appropriate platforms. The authors and CCS Haryana Agricultural University, Hisar will not be responsible for any fallout arising due to use/ misuse of the information by any individuals/ institutions/ organizations/ authorities etc in India or abroad, and this information cannot be used for legal purposes.

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Impact of weed management on weed dynamics and yield of rainy (*Kharif*) crops

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Weedy check

ABSTRACT

Two years field study was conducted during 2010 and 2011 at research farm of SKRAU, Bikaner to evaluate the effect of different weed control measures on weed dynamics and yield in *Kharif* crops. Experiment was laid out in factorial randomized block design with three replications comprising different treatment combinations three *Kharif* crops as pearl millet, cluster bean, groundnut and three weed control measures- weedy check, mechanical method (two hand weeding) and chemical methods. The major weed species observed in the experimental plots were *Digera arvensis* L., *Tribulus terrestris* L., *Cenchrus biflorus* L., and *Euphorbia microphylla* L. with respect to their mean density at 30 DAS. The results of experiment showed that among *Kharif* crops, pearl millet recorded maximum density of weeds at 30 DAS whereas groundnut recorded maximum density of *Digera arvensis* and *Euphorbia macrophylla* at 30 DAS and maximum dry weight of all weed species at harvest. Two hand weeding significantly reduced the weed density at 30 DAS and weed dry weight at harvest. Application of atrazine 0.5 kg/ha in pearl millet and pendimethalin at 1.0 kg/ha in cluster bean and groundnut significantly reduced density and dry weight of weeds except that of *Digera arvensis,* which was not significantly controlled by pendimethalin in both cluster bean and groundnut. In pearl millet, cluster bean and groundnut, two hand weeding and chemical method increased the grain and straw yield over weedy check, on pooled mean basis.

Pearl millet, cluster bean and groundnut are traditional rainy season crops cultivated in arid zone of Rajasthan. Wherever irrigation facility is available, these crops are followed by wheat, barley, mustard and cumin in winter season. In North- Western Rajasthan, especially in IGNP (Indira Gandhi Nahar Pariyojana; Indira Gandhi Canal Project) command area, these crops are grown in place of high-water requiring crops like cotton due to limited irrigations. Cropping sequence particularly those that include legumes, often result in improved soil quality and crop yield. Therefore, production technology or management practices should be developed keeping in view all the crops grown in a year.

Weeds compete with crop for moisture, nutrient, light and space and the potential yield losses due to weeds can be as high as about 65% depending on the crop, degree of weed infestation, weed species and management practices (Yaduraju *et al*. 2006). So weed control is essential in crops either by chemical or conventional methods. Chemical weed control is a better supplement to conventional methods and forms an integral part of the modern crop production. Recently, use of herbicides has become popular over mechanical methods, because of the concomitant increase in crop yield. Pendimethalin and atrazine are commonly used herbicides to control weeds in *Kharif* crops but these herbicides may persist for a longer period under low soil moisture and poor organic matter. There are evidences that pendimethalin and atrazine had residual effects on succeeding crops in Western Rajasthan and Gujarat condition (Patel and Barevadia 1999, Yadav and Lal 2001). Atrazine is widely used herbicide for weed control in pearl millet, but it persists in soil for varying lengths of time depending on dose, soil and agro climatic conditions. The objective of this study was to find out the effect of different weed control measures (like hand weeding and chemical control) as compared to weedy check on weed dynamics and yield in different *Kharif* crops.

Two years field study was conducted during 2010 and 2011 at research farm of College of Agriculture, Swami Keshwanand Rajasthan

Agricultural University, Bikaner (28.01^{0}N, 73.22^{0}E, 234.7 m above mean sea level). Bikaner falls under Hot Arid Eco-region. The average annual rainfall of the tract is about 260 mm, which is mostly received during the rainy season. Soils are loamy sand with 0.08% organic carbon, N 133.7 kg/ha, P 16.2 kg/h and K 198.4 kg/ha. Experiment was laid out in factorial randomized block design with three replications comprising two factors *i.e.,* first factor as different *Kharif* crops as pearl millet, cluster bean, groundnut and second factor as three weed control measures- weedy check, mechanical method two hand weeding and chemical methods with gross plot size of 48 m^2/plot.

Pearl millet '*HHB-67*' 5 kg/ha, cluster bean '*RGC-986'* 20 kg/ha and groundnut '*HNG-10*' 80 kg/ha were sown in 30 cm row spacing on 5 July 2010 and 8 July 2011 under irrigated condition. Recommended dose of phosphorus and potassium and half dose of nitrogen were applied at the time of sowing through urea, SSP and MOP, respectively in *Kharif* crops. The remaining half dose of nitrogen was top dressed through urea in two equal splits at 25 and 40 DAS in pearl millet only. The herbicides atrazine 0.50/ha sprayed one day after sowing as pre-emergence in pearl millet and pendimethalin 1.0 kg/ha also sprayed one day after sowing as pre-emergence in cluster bean and groundnut. These herbicides were sprayed with the help of knapsack sprayer using 500 liters of water per hectare. In hand weeding treatments, hand weeding was performed at 25 and 45 DAS in all the *Kharif* crops. For the control of bacterial blight in cluster bean, foliar spray of dithane M-45 2 g/litre water was undertaken.

A survey for weed identification was done at 30 DAS of crops with a quadrate of 0.25 m^2, it was placed at four places in each plot to determine the density and dry weight of different weeds. Weed dry weight was recorded after drying of weed samples at 80 ^{o}C in an electric oven for 48 hours and weighed to obtain weed dry weight. The data were subjected to square root transformation $\sqrt{x+0.5}$ to normalize their distribution before analysis. Timely harvesting of all three crops in September and November were done during both the years. Different crop observations as seed, straw and biological yields of each net plot (inclusive of tagged plants) were recorded in kg/plot after cleaning the threshed produce and were converted in to t/ha. The data obtained from the study of two years were analyzed statistically using the F-test, as per the standard procedure described by Panse and Sukhatme (1985).

Weed flora

Weed flora of experimental field consisted of *Digera arvensis* L.*, Tribulus terrestris* L., *Cenchrus biflorus* L., *Euphorbia microphylla* L.*, Corchorus tridens* L.*, Cyperus rotundus* L., *Cynodon dactylon* L.*,* Pers.*, Portulaca oleracea* L. However, predominant weeds were *Digera arvensis* L.*, Tribulus terrestris* L., *Cenchrus biflorus* L., and *Euphorbia microphylla* L.

Weed density at 30 DAS

Effect of *Kharif* crops: *Digera arvensis* was one of the major weeds of the crops. The maximum population of this weed was obtained in groundnut after that in cluster bean followed by pearl millet. Pearl millet reduced the weed density by 46.40 and 38.07% over groundnut and cluster bean, respectively, in pooled mean. Maximum density of *Tribulus terrestris* was obtained in pearl millet. Groundnut recorded significantly lower weed density compared to pearl millet and cluster bean. On basis of pooled mean groundnut reduced the weed density by 46.21 and 14.91% over pearl millet and cluster bean, respectively. Maximum weed density of *Cenchrus biflorus* was recorded in pearl millet and cluster bean. However, groundnut reduced the weed density to an extent of 68.70 and 54.60% over pearl millet and cluster bean, respectively on the basis of pooled mean. *Euphorbia microphylla*, maximum weed density of this weed was recorded in groundnut and cluster bean. Pearl millet reduced the weed density to an extent of 18.70 and 11.98% over groundnut and cluster bean, respectively. Maximum weed density of total weeds was found in pearl millet and cluster bean during both the years and in pooled mean. However, groundnut reduced the weed density to an extent of 23.33 and 6.69% over pearl millet and cluster bean, respectively at 30 DAS (**Table 1**).

Effect of weed control measures: Data (**Table 1**) showed that weed control measures decreased the weed density significantly in both the years and in pooled data over weedy check. Two hand weeding significantly reduced the density of *Digera arvensis* as compared to chemical method. Two hand weeding and chemical method decreased the density of this weed to an extent of 95.93 and 43.41% over weedy check, respectively. Two hand weeding and chemical method significantly decreased the density of *Tribulus terrestris* by 80.36 and 77.56 percent over weedy check, respectively. Two hand weeding and chemical method significantly decreased the density of *Cenchrus biflorus* was to the tune of 95.72 and 78.14% over weedy check, respectively on pooled mean basis. Two hand weeding and chemical method significantly decreased the density of *Euphorbia microphylla* to an extent of 94.83 and 69.01 percent over weedy check, respectively. Two hand weeding and chemical method significantly decreased the density of total weeds to the tune of 90.03 and 63.17% over weedy check respectively. Pendimethalin absorbed by germinating weeds inhibits cell division in the meristematic tissues resulting in death of most of the weeds within a few days of their emergence. It also plays a role in microtubule disruption and inhibits mitosis because it blocks synthesis of nucleic acids or any other requisites for mitosis (Devine *et al.* 1993). Such inhibiting effect of pendimethalin might have been responsible for reduced weed population and weed dry weight accumulation. These results were in corroboration with the findings of Yadav *et al.* (2011) and Malik *et al.* (2005).

Interactive effect of *Kharif* crops and weed control measures on weed density of total weeds

The interaction data (**Table 3**) revealed that atrazine 0.5 kg/ha applied in pearl millet significantly reduced the density of total weeds as compared to pendimethalin 1.0 kg/ha applied in cluster bean and groundnut. The maximum density of total weeds was recorded in pearl millet with weedy check and it was found at par with cluster bean in weedy check but significantly higher than groundnut at 30 DAS.

Weed dry weight at 30 DAS

Effect of *Kharif* crops: It is evident from data (**Table 2**) that significantly minimum dry weight of *Digera arvensis* was recorded in pearl millet over cluster bean and groundnut in pooled mean. Pearl millet reduced the weed dry weight by 11.69 and 5.46% over groundnut and cluster bean, respectively at harvest in pooled mean basis. Pearl millet significantly reduced dry weight of *Tribulus terrestris* but it was statistically at par with cluster bean in pooled mean. Pearl millet reduced the weed dry weight to the tune of 10.95 and 5.07% over groundnut and cluster bean respectively, at harvest in pooled mean basis. Minimum dry weight of *Cenchrus biflorus* weed was recorded in pearl millet over groundnut and cluster bean in pooled mean. Pearl millet reduced the weed dry weight by 10.86 and 5.32% over groundnut and cluster bean, respectively. Minimum dry weight of *Euphorbia microphylla* was recorded in pearl millet over groundnut and cluster bean. Pearl millet reduced the weed dry weight by 10.78 and 5.26% over groundnut and cluster bean. Whereas, minimum dry weight of total weeds was recorded in pearl millet but it was non-significantly differed from the dry weight of total weeds reduced by cluster bean. Pearl millet reduced the weed dry weight to the tune of 10.14 and 4.97% over groundnut and cluster bean, respectively at harvest in pooled mean basis.

Table 1. Effect of *Kharif* crops and weed control measures on weed density (no./m^2) 30 DAS

Treatment	*Digera arvensis*		*Tribulus terrestris*		*Cenchrus biflorus*		*Euphorbia macrophylla*		Total weed	
	2010	2011	2010	2011	2010	2011	2010	2011	2010	2011
Kharif crop										
Pearl millet	1.91(3.1)	1.75(2.5)	2.04(3.7)	2.82(7.4)	2.27(4.6)	2.09(3.9)	1.64(2.2)	1.61(2.1)	4.09(16.3)	4.51(19.8)
Cluster bean	2.33(4.9)	2.17(4.2)	1.95(3.3)	2.01(3.5)	1.94(3.2)	1.77(2.6)	1.74(2.5)	1.67(2.3)	4.01(15.6)	3.81(14.0)
Ground nut	2.53(5.9)	2.28(4.7)	1.85(2.9)	1.85(2.9)	1.41(1.5)	1.30(1.2)	1.80(2.7)	1.76(2.6)	3.91(14.8)	3.65(12.8)
LSD (p=0.05)	0.24	0.22	0.08	0.63	0.45	0.44	0.10	0.10	0.09	0.62
Weed control method										
Weedy check	3.27(10.2)	3.01(8.5)	3.25(10.1)	3.00(8.5)	3.07(8.9)	2.83(7.5)	2.73(7.0)	2.52(5.8)	6.42(40.8)	5.89(34.2)
Two hand weeding	0.97(0.4)	0.90(0.3)	0.93(0.4)	2.12(4.0)	0.97(0.4)	0.87(0.3)	0.80(0.1)	1.02(0.5)	1.59(2.0)	2.52(5.8)
Chemical method	2.52(5.8)	2.30(4.8)	1.66(2.3)	1.55(1.9)	1.57(2.0)	1.46(1.6)	1.65(2.2)	1.51(1.8)	4.00(15.5)	3.56(12.2)
LSD (p=0.05)	0.24	0.22	0.08	0.63	0.45	0.44	0.10	0.10	0.09	0.62

Weed density transformed to $\sqrt{x+0.5}$, Figures in parentheses were original

Table 2. Effect of *Kharif* crops and weed control measures on weed dry weight (g/m^2) at harvest

Treatment	*Digera arvensis*		*Tribulus terrestris*		*Cenchrus biflorus*		*Euphorbia macrophylla*		Total weed	
	2010	2011	2010	2011	2010	2011	2010	2011	2010	2011
Kharif crop										
Pearl millet	8.16	7.40	3.90	3.59	3.36	3.05	3.21	2.91	22.68	20.87
Cluster bean	8.59	7.87	4.10	3.78	3.53	3.22	3.38	3.08	23.86	21.97
Ground nut	9.12	8.50	4.32	4.08	3.71	3.46	3.55	3.31	25.19	23.28
LSD (p=0.05)	0.57	0.61	0.29	0.32	0.25	0.31	0.24	0.05	1.77	1.85
Weed control method										
Weedy check	17.21	15.77	9.98	9.29	8.59	7.87	8.21	7.53	54.37	50.13
Two hand weeding	0.41	0.38	0.10	0.09	0.09	0.08	0.08	0.08	0.79	0.74
Chemical method	8.25	7.63	2.24	2.06	1.93	1.78	1.84	1.70	16.58	15.26
LSD (p=0.05)	0.57	0.61	0.29	0.32	0.25	0.31	0.24	0.05	1.77	1.85

Table 3. Interactive effect of *Kharif* crops and weed control measures on weed density (no./m^2) of total weeds at 30 DAS

Kharif (rainy) crops	Weed control method								
	2010			2011			Pooled		
	Weedy check	Two hand weeding	Chemical method	Weedy check	Two hand weeding	Chemical method	Weedy check	Two hand weeding	Chemical method
Pearl millet	6.85(46.46)	1.65(2.24)	3.77(13.74)	6.29(39.02)	3.81(14.04)	3.43(11.26)	6.57(42.66)	2.73(6.97)	3.60(12.47)
Cluster bean	6.40(40.43)	1.53(1.85)	4.10(16.29)	5.87(33.91)	1.90(3.10)	3.67(12.96)	6.13(37.10)	1.71(2.44)	3.88(14.58)
Groundnut	6.02(35.37)	1.59(2.02)	4.12(16.40)	5.52(30.00)	1.85(2.93)	3.58(12.34)	5.77(32.82)	1.72(2.46)	3.85(14.33)
LSD (p=0.05)	0.16			1.07			0.52		

Weed density transformed to $\sqrt{x+0.5}$, Figures in parenthesis are original, Chemical method: (atrazine (0.50 kg/ha in pearl millet) and pendimethalin (1.0 kg/ha in cluster bean and groundnut)

Table 4. Effect of weed control measures on grain yield (t/ha) and straw yield (t/ha) of *kharif* crops

Kharif (rainy) crops	Weed control method					
	Grain yield (pooled)			Straw yield (pooled)		
	Weedy check	Two hand weeding	Chemical method	Weedy check	Two hand weeding	Chemical method
Pearl millet	1.34	1.92	1.81	2.30	3.21	3.08
Cluster bean	0.89	1.38	1.22	2.55	3.76	3.44
Ground nut	1.76	2.75	2.58	4.20	6.45	6.08

Effect of weed control measures: Data (**Table 2**) showed that weed control measures decreased the dry weight of weeds significantly over weedy check. Two hand weeding and chemical method significantly reduced the weed dry weight of *Digera arvensis* by 97.63 and 51.84% over weedy check, respectively on the basis of pooled mean at harvest. Two hand weeding and chemical method significantly reduced the dry weight of *Tribulus terrestris* by 98.96 and 77.69% over weedy check. Two hand weeding and chemical method significantly reduced the weed dry weight of *Cenchrus biflorus* which was 98.90 and 77.52% over weedy check. Two hand weeding and chemical method significantly reduced the weed dry weight to an extent of 98.98 and 77.50% over weedy check, respectively, in pooled mean at harvest. Two hand weeding and chemical method significantly reduced the weed dry weight total weeds by 98.54 and 69.53% over weedy check. Highest weed dry weight of production was recorded at harvest under weedy check. The increase in dry weight production of weeds under weedy check may be attributed to uninterrupted weed growth throughout the crop season. Two hand weeding gave almost season long control of weeds obviously due to weed free environment for a sufficiently long time. The results were in close conformity with those of Ram *et al.* (2005), Sharma and Gautam (2010) and Singh (2011). Pendimethalin exerts its herbicidal effect by inhibiting both root and shoot growth and development through disruption of ATP formation (Wang *et al.* 1974) and inhibition of cell division in the meristematic tissue (Rao 1983).

Effect of weed control measures on grain yield of *Kharif* crops: It is evident from data (**Table 4**) that in pearl millet, two hand weeding and chemical method increased the grain yield to the tune of 43.28 and 35.07% over weedy check, respectively. In cluster bean, two hand weeding and chemical method increased grain yield of 55.05 and 37.07% over weedy check, respectively. Whereas, in groundnut, increment in grain yield due to hand weeding and chemical method was 56.25 and 46.59% over weedy check, respectively. Sharma and Jain (2003) observed that all the weed control measures significantly increased the seed and stover yield of pearl millet compared with weedy check. Datta *et al.* (2001) also reported similar findings.

Effect of weed control measures on straw yield of kharif crops: Data (**Table 4**) revealed that among different control measures, two hand weeding and chemical method significantly increased the straw yield in pearl millet by 39.66 and 32.65% over weedy check, respectively. In cluster bean, increment in straw yield due to hand weeding and chemical method was 47.37 and 34.89% over weedy check, respectively. It was observed that in groundnut, two hand weeding and chemical method increased the grain yield to the tune of 53.81 and 44.72% over weedy check, respectively.

Conclusion

Based on the two years of study it was recommended that application of atrazine 0.5 kg/ha in pearl millet and pendimethalin at 1.0 kg/ha in cluster bean and groundnut significantly reduced density and dry weight of weeds except that of *Digera arvensis* which was not significantly controlled by pendimethalin in both cluster bean and groundnut. In pearl millet, cluster bean and groundnut, two hand weeding and chemical method increased the grain and straw yield over weedy check.

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Performance of new herbicides in groundnut and their carryover effect on fodder sorghum

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ABSTRACT

Field experiments were conducted during winter, 2018-19 and summer, 2019 in groundnut and fodder sorghum, respectively at S.V. Agricultural College, Tirupati, Andhra Pradesh, India to know the performance of pre-emergence (pendimethalin 38.7% CS 725 g/ha and diclosulam 84% WDG 20 g/ha) and post-emergence (haloxyfop-p-ethyl 10.5% EC 135 g/ha and cycloxydim 20% EC 100 g/ha) herbicides on weed growth and yield of groundnut and their carryover effect on fodder sorghum. Significantly lower density and dry weight of weeds with higher WCE were recorded with pre-emergence application of diclosulam 20 g/ha + HW at 40 DAS and it was closely followed by pre-emergence application of diclosulam 20 g/ha *fb* cycloxydim 100 g/ha applied at 20 DAS in groundnut. The highest pod yield and benefit-cost ratio were registered with former weed management practice. All the herbicides tried did not show any inhibitory effect on germination, growth parameters and dry fodder yield of residual crop of fodder sorghum. Pre-emergence application of diclosulam 20 g/ha *fb* cycloxydim 100 g/ha applied at 20 DAS in groundnut showed its superiority in supressing weed growth at early stages of fodder sorghum due to extended herbicidal activity of diclosulam and reduced weed seed bank.

Groundnut (*Arachis hypogaea* L.) is important oil, food and forage crop of the country. India is the second largest producer of groundnut in the world. Among different constraints that limit the productivity of groundnut, weed menace is one of the serious bottlenecks (Chaitanya *et al.*2012). Season long weed competition in groundnut reduced the pod yield to the tune of 40% on sandy loam soils (Clewis *et al.* 2007). Pre-emergence application of herbicides is more common method for weed control in groundnut as it gives the crop a good start, by eliminating early weed competition. Pendimethalin is the commonly used dinitroaniline herbicide for control of annual grasses and some of the broad-leaved weeds, but less effective against perennial sedge, *Cyperus rotundu*s as it is less mobile and lower half-life period. Ideally, the herbicides should have reasonably acceptable residual activity during crop growing season for effective and season long weed control without affecting the succeeding crops. Some herbicides such as imazethapyr or atrazine persist in the soil for long time and showed their residual effect on succeeding susceptible crop. Post-emergence application of imazethapyr 75 g/ha is recommended for control of weeds in groundnut, but the choice of succeeding crops is limited because of its persistence in soil and plant for longer time with a half-life period of 33 months (Sondhia *et al.* 2015). However, persistence of imazethapyr depends upon soil type and its half-life which is 24 and 5 months in clay and sandy soils, respectively (Hollaway *et al.* 2006). There is need to evaluate alternate pre-and post-emergence herbicides for broad-spectrum weed control in groundnut and their residual effect on succeeding rotational crops. In recent years, new generation low- dose and high potent herbicides are available for control of mixed weed flora with reasonably good residual activity and low mammalian toxicity. Fodder sorghum cultivation is emphasized owing of its drought-tolerant characteristics and high production potential to meet the fodder requirement during dry periods after harvesting of groundnut in Southern Agroclimatic Zone of Andhra Pradesh. Therefore, the present investigation was undertaken with an objective to assess the performance of low dose high efficacy pre-and post-emergence herbicides and their carryover effect on succeeding fodder sorghum.

Field experiments were conducted during *Rabi* (winter) 2018-19 in groundnut and summer 2019 in fodder sorghum on sandy loam soil of dryland farm of S.V. Agricultural College, Tirupati, Andhra Pradesh India with eleven weed management practices consisted of pre-emergence (PE) application of diclosulam 84% WDG 20 g/ha alone and followed by HW at 40 DAS and sequential post-emergence (PoE) application of haloxyfop-p-ethyl 10.5% EC 135 g/ha or cycloxydim 20% EC 100 g/ha at 20 DAS, PE application of pendimethalin38.7% CS 725 g/ha alone and supplemented with HW at 40 DAS or sequential post-emergence application of haloxyfop-p-ethyl 135 g/ha or cycloxydim 100 g/ha at 20 DAS along with PE application of pendimethalin 30% EC 1000 g/ha, two HW at 20 and 40 DAS and unweeded check, which were laid out in a randomized block design with three replications. The soil was low in organic matter content, available nitrogen and phosphorous and medium in available potassium. Pre-and post-emergence herbicides were applied to groundnut '*Kadiri-6'* at one and 20 DAS by using power operated knapsack sprayer fitted with flat-fan nozzle with spray fluid of 500 L/ha. The crop was supplied with recommended fertilizer dose of 20 kg N, 40 kg P and 50 kg K/ha through urea, single super phosphate and muriate of potash, respectively to all the plots as basal. Top dressing of 10 kg of N in the form of urea was applied at 25 DAS. Data on weeds were recorded at harvest in each plot with the help of quadrat measuring 50 x 50 cm. Weed samples were sun dried at 70^0C until constant weight was attained. The succeeding fodder sorghum '*Co FS-29'* was sown in undisturbed layout of experiment field, immediately after harvest of groundnut. Density and dry weight of weeds in groundnut were recorded at 60 DAS and the data on weeds and growth parameters of fodder sorghum were recorded at 15 and 30 DAS. Weed data in both crops was transformed to square root transformation ($\sqrt{X+0.5}$) to normalize their distribution. Weed control efficiency of each treatment was calculated (Mani *et al.* 1973). The data on both crops were analysed by the analysis of variance and means were separated with least significant difference at 5% level of probability.

Effect on groundnut

The predominant weed flora associated with groundnut was *Cyperus rotundus* L. (42%), *Boerhavia erecta* L. (15%), *Dactyloctenium aegyptium* (L.) Willd. (11%), *Commelina benghalensis* L. (10%), *Digitaria sanguinalis* (L.) Scop. (8%), *Cleome viscosa* L.(6%), *Phyllanthus niruri* L. (4%) and others (4%). Significantly lower density and dry weight of total weeds was recorded with PE application of diclosulam 20 g/ha +HW at 40 DAS followed by PE application of diclosulam 20 g/ ha *fb* cycloxydim 100 g/ha applied at 20 DAS in groundnut **(Table 1)**. Similar trend of influence was noticed with respect to grasses, sedges and broad-leaved weeds due to above said treatments. Diclosulam inhibits the ace to lactate synthase (ALS) enzyme activity in target plants, a key enzyme responsible for biosynthesis of branched chain amino acids in target weeds. Diclosulam might have increased its concentration at deeper layers of the soil as a soluble herbicide due to higher half-life period coupled with higher leaching potential index and lower sorption coefficient (Hornsby *et al.*1986) lead to increased control of purplenut sedge and broad-leaved weeds. Grichar *et al* (1999) also stated that diclosulam 10 g/ha in combination with ethalfluralin 840 g/ha found to be effective against broad-leaved weeds and perennial sedges in groundnut on sandy soils. Significantly higher pod and haulm yield was registered with PE application of diclosulam 20 g/ha supplemented with HW at 40 DAS, however which was at par with sequential application of diclosulam 20 g/ha as PE *fb* cycloxydim 100 g/ha. Aruna and Sagar (2018) also concluded that PE application of pendimethalin 1.5 kg/ha followed by post-emergence application of imazethapyr 75 g/ha at 18-20 DAS was effective in controlling both broad-leaved weeds and grasses in groundnut. Both the formulations of pendimethalin were found to be inferior in controlling density and dry weight of sedges and broad-leaved weeds, but effective in controlling grassy weeds compared to diclosulam 20g/ha (data not presented). The highest benefit-cost ratio was computed with PE application of diclosulam 20 g/ha supplemented with HW at 40 DAS followed by PE application of diclosulam 20 g/ha *fb* cycloxydim 100 g/ha due to reduced cost of weeding and increased pod as well as haulm yield. Punia *et al.* (2016) also stated that higher net returns and benefit-cost ratio were obtained with sequential application of pendimethalin as PE and imazethapyr 75 g/ha as post-emergence in groundnut.

Carryover effect of herbicides on fodder sorghum

The major weeds associated with fodder sorghum consisted of *Cyperus rotundus* L. (38%), *Cleome viscosa* L. (27%), *Boerhavia erecta* L. (13%), *Dactyloctenium aegyptium* (L.) Willd. (8%), *Commelina benghalensis* L. (4%), *Digitaria sanguinalis* (L.) Scop. (4%), *Phyllanthus niruri* L. (3%) and other weeds (3%). There is a shift in weed flora from groundnut to succeeding fodder sorghum due to carryover effect of herbicidal treatments applied to groundnut. The relative densities of weeds in groundnut and fodder sorghum clearly shows that sedges and grasses were reduced and broad-leaved weeds like *Cleome viscosa* was increased in fodder sorghum compared to groundnut. All the weed management practices imposed to preceding groundnut significantly influenced the growth character like germination per cent, root and shoot length, dry matter production and green fodder yield of succeeding fodder sorghum (**Table 2**). The lowest density of total weeds in fodder sorghum was recorded with PE application of diclosulam 20 g/ha *fb* cycloxydim 100 g/ha applied to groundnut and it was at par with PE application of diclosulam 20 g/ha supplemented with HW at 40 DAS. The later weed management practice recorded significantly lower weed dry weight than former treatment in fodder sorghum. Both the weed management practices were significantly superior in reducing density and dry weight of total weeds in fodder sorghum due to effective control of all the categories of weeds in groundnut, which in turn produced lesser weed seed bank deposition in succeeding fodder sorghum. Further, diclosulam might have extended its herbicidal activity due to its favourable physico-chemical properties like higher half-life period (87 days) and leaching potential index (129) with lower sorption coefficient (0.22 L/kg) resulted in more quantity of diclosulam as a free herbicide available at deep layers of soil (Hornsby *et al.*1986). Pre-emergence application of both the formulations (CS and EC) of pendimethalin applied to groundnut registered higher density and dry weight of weeds in succeeding fodder sorghum might be due to lower half-life period (40 days) and leaching potential index (5) with higher sorption coefficient (25.55 L/kg).

All the herbicides applied to groundnut did not show any inhibitory effect on growth and yield of succeeding fodder sorghum. Germination percentage of fodder sorghum did not influenced due to different herbicides applied to groundnut. Diclosulam applied plots recorded significantly higher stature of growth parameters and dry fodder yield than rest of the treatments **(Table 2)**. Pre-emergence application of diclosulam 20 g/ha *fb* cycloxydim 100 g/ha applied to groundnut produced significantly higher root length, shoot length and dry matter production of succeeding fodder sorghum. This might be due to maintenance of weed free environment as a result of carryover effect of diclosulam up to early stages of fodder sorghum because of its longer half-life period. The highest green fodder yield of succeeding fodder sorghum was obtained with pre-emergence application of diclosulam 20 g/ha *fb* cycloxydim 100 g/ha at 20 DAS, which was closely followed by sequential application of diclosulam 20 g/ha supplemented with HW at 40 DAS imposed in preceding groundnut. This might be due to extended herbicidal activity diclosulam even after harvest of groundnut.

On basis of the above study, it can be concluded that pre-emergence application of diclosulam 20 g/ha supplemented with HW at 40 DAS provided excellent control weeds, which resulted in higher pod yield and benefit:cost ratio, which was at par with sequential application of diclosulam 20 g/ha and cycloxydim 100 g/ha applied at 20 DAS in groundnut. Diclosulam 20 g/ha, pendimethalin 1000 g/ha, cycloxydim 100 g/ha and haloxyfop 135 g/ha applied to groundnut did not show any inhibitory effect on succeeding fodder sorghum. However, pre-emergence application of diclosulam 20 g/ha *fb* cycloxydim 100 g/ha applied at

Table 1. Effect of different weed management practices on weed growth, WCE, yield and economics of groundnut during winter 2018-19

Treatment	Dose (g/ha)	Time of application (DAS)	Weed density (no./m^2)	Weed dry weight (g/m^2)	WCE (%)	Pod yield (t/ha)	Haulm yield (t/ha)	Shelling (%)	B:C ratio
Pendimethalin (CS)	725	1	6.37(39.7)	5.02(24.3)	63.69	1.56	2.57	68.43	2.04
Diclosulam	20	1	3.63(12.3)	2.58(5.7)	91.45	1.71	2.74	71.16	2.29
Pendimethalin *fb* hand weeding	725	1 *fb* 40	5.19(26.0)	3.81(13.6)	79.67	1.60	2.61	69.05	1.97
Diclosulam *fb* hand weeding	20	1 *fb* 40	2.07(3.3)	1.61(1.6)	97.57	2.10	3.05	73.87	2.62
Pendimethalin *fb* haloxyfop-p-ethyl	725 *fb*135	1 *fb* 20	6.60(42.7)	5.10(25.1)	62.49	1.65	2.68	70.10	2.02
Diclosulam *fb* haloxyfop-P-ethyl	20 *fb*135	1 *fb* 20	3.35(10.3)	2.50(5.3)	92.09	1.86	2.85	71.89	2.32
Pendimethalin *fb* cycloxydim	725 *fb*100	1 *fb* 20	6.26(38.3)	4.91(23.7)	64.58	1.70	2.73	70.61	2.14
Diclosulam *fb* cycloxydim	20 *fb*100	1 *fb* 20	3.03(8.3)	2.13(3.6)	94.67	1.93	2.91	72.43	2.47
Pendimethalin (EC)	1000	1	8.05(64.3)	5.15(26.0)	61.06	1.62	2.62	69.47	2.12
Hand weedings	-	20 *fb* 40	4.19(16.7)	2.88(7.3)	89.05	1.81	2.81	73.21	2.10
Unweeded check (control)	-	-	13.22(174.3)	8.21(66.9)	-	1.08	1.95	62.85	1.50
LSD (p=0.05)	-	-	0.56	0.39	-	0.24	0.32	2.46	0.14

CS: Capsulated suspension, EC: Emulsifiable concentrate, *fb*: followed by, WCE: Weed control efficiency, Data on weed density and dry weight are subjected to square root transformation: Data given in parentheses are original values

Table 2. Carryover effect of different herbicides applied to groundnut on weed parameters, growth and green fodder yield of succeeding fodder sorghum during summer, 2019

Treatment	Dose (g/ha)	Time of application (DAS)	Weed density (no./m^2)	Weed dry weight (g/m^2)	Germination (%)	30 DAS Shoot length (cm)	Root length (cm)	DMP (kg/ha)	Dry fodder yield (t/ha)
Pendimethalin (CS)	725	1	9.34(94.7)	6.09(36.2)	90.91	106	9.9	5812	1.8
Diclosulam	20	1	6.01(42.3)	4.20(16.6)	90.50	125	13.0	6788	2.3
Pendimethalin *fb* hand weeding	725	1 *fb* 40	8.73(81.9)	5.88(33.6)	92.97	106	10.9	5892	2.0
Diclosulam *fb* hand weeding	20	1 *fb* 40	6.11(42.3)	4.30(17.5)	94.45	128	13.2	6816	2.7
Pendimethalin *fb* haloxyfop-p-ethyl	725 *fb* 135	1 *fb* 20	9.03(87.0)	5.92(34.1)	92.42	109	10.4	6005	2.1
Diclosulam *fb* haloxyfop-p-ethyl	20 *fb* 135	1 *fb* 20	6.32(47.3)	4.47(19.1)	91.12	121	13.2	6746	2.5
Pendimethalin *fb* cycloxydim	725 *fb* 100	1 *fb* 20	8.63(81.0)	5.79(32.6)	93.94	115	11.5	6057	2.2
Diclosulam *fb* cycloxydim	20 *fb* 100	1 *fb* 20	5.77(39.7)	4.42(18.6)	92.91	140	13.3	6982	2.9
Pendimethalin (EC)	1000	1	8.81(84.7)	5.79(32.6)	91.45	118	12.3	6298	1.9
Hand weedings	-	20 *fb* 40	9.02(83.0)	5.85(33.3)	94.48	121	11.2	6458	2.2
Unweeded check (control)	-	-	11.11(141.7)	7.26(51.8)	90.05	99	9.8	5096	1.6
LSD (p=0.05)	-	-	0.57	0.38	NS	14.6	1.5	769	0.2

CS: Capsulated Suspension, EC: Emulsifiable Concentrate, *fb*: Followed by, DMP: Dry matter production, Data on weed density and dry weight are subjected to square root transformation: Data given in parentheses are original values

20 DAS in groundnut showed its superiority in supressing weed growth at early stages of fodder sorghum due to extended herbicidal activity of diclosulam.

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Allelopathic effect of *Lantana* and *Parthenium* on germination and growth of *Thespesia* tree species

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ABSTRACT

A pot culture experiment was conducted in the nursery of Department of Silviculture, Forest College and Research Institute, Tamil Nadu Agricultural University, Mettupalayam, Tamil Nadu during summer season (February - April) 2016, to study the allelopathic effect of *Lantana camara* (L.) and *Parthenium hysterophorus* (L.) on germination and growth of *Thespesia populnea* (L.) tree species under greenhouse condition. Aqueous extracts of *L. camara* and *P. hysterophorus* at four concentration levels *viz*. 10, 20, 30 and 40% with absolute control (distilled water) were assigned as experimental treatments under completely randomized design and replicated thrice. Application of whole plant aqueous extract of *P. hysterophorus* and *L. camara* at 40% concentration recorded lower seed germination of 26.7% and 36.7% and germination value of 3.0 and 5.2 respectively than application of aqueous extracts of the weeds at 30, 20 and 10% concentration levels. Application of *P. hysterophorus* weed extract at 40% concentration recorded higher inhibition of shoot growth, root growth, total length and dry matter production of *T. populnea* seedlings than its application at lower concentrations and over *L. camara* weed extract at all concentrations.

Allelopathy is a phenomenon of involving either direct or indirect and either beneficial or adverse effects of a plant (including microorganisms) on another plant through the release of chemicals in the environment. Many weeds, specifically invasive weeds pose an important biological constraint to crop and tree productivity in agricultural and natural forest ecosystems (Devi and Dutta 2012). Invasion of native plant communities by exotic species has been among the most intractable ecological problems of recent years. It is a global scale problem experienced by the natural ecosystems especially forest ecosystems and is considered as the second largest threat to the global biodiversity (Ashok Kumar *et al.* 2012). The invasion of exotic species affects the native flora and reduces the regeneration ability and diversity of native species in forest ecosystems through their allelopathy and competitive interference.

Lantana camara and *Parthenium hysterophorus* are the America originated weeds and have spread to the other regions of world including India, threatens ecological biodiversity in forest ecosystems by their huge proliferation in any place at any time thus it exerts negative effects on agriculture, animal husbandry, ecology and environment in natural and managed ecosystems (Ahmed *et al*. 2007). These weeds possess the ability to suppress other plants through the release of allelochemicals from living plants or decomposing plant materials into the environment, which allows these weeds to compete more effectively with crop or tree or pasture species. Though, several researchers have worked on the invasion and allelopathic effects of *L. camara* and *P. hysterophorus* on various agricultural crops throughout the world, but such scientific experiments are scarce in the context of tree crops in India. With this background, the present investigation was undertaken to study the allelopathic effect of *L. camara* and *P. hysterophorus* weeds on germination and growth behaviour of *Thespesia populnea* tree species.

A pot culture experiment was conducted during summer season (February - April 2016), under greenhouse in the Nursery of Department of Silviculture, Forest College and Research Institute, Tamil Nadu Agricultural University, Mettupalayam, located at 11°20' North latitude and 76°56' East longitude with an altitude of about 320 m above mean sea level. Weed species namely *L. camara* and *P. hysterophorus* were selected to study their allelopathic potential on *T. populnea*. The collected weeds were cut into 5-10 cm pieces for preparation of aqueous extract. The extract of 100% concentration was prepared by soaking 1000 g chopped plant material in 1000 ml distilled water (1:1 weight/volume basis) at room temperature (22-26°C) for 72 hours and ground with mixer grinder. The extract was filtered through muslin cloth and the volume of the filtrate was made to 1000 ml with distilled water. The extract was considered as stock solution and a series of solution with different concentration, *viz*. 10, 20, 30 and 40% aqueous extract were prepared by dilution and stored for pot culture experiment.

Pot culture soil media was prepared with soil, sand and farmyard manure in the ratio of 2:1:1 and was filled in pot for sowing of *T. populnea* tree seeds 10 Nos. per poly bag. To obtain uniform germination under normal condition, the seeds were pre-treated with cold water for 24 hours and dried in shade for half an hour and used for sowing. The trial was laid out in completely randomized design (CRD) with the 9 treatments given in **Table 1** and replicated thrice. A 250 ml aqueous extract was applied immediately after sowing in each treatment. Thereafter, equal quantity (100 ml) of aqueous extract was added to the respective treatment on daily basis to keep the pot mixture soil moist enough to get favourable condition for seed germination and seedlings growth. The control treatment was maintained with distilled water. The pot culture experiment was maintained up to 60 days under greenhouse condition.

Data on germinated seeds were counted and recorded on daily basis from 4th to 20th days after sowing in all the treatments. The germination per cent was calculated by using the formula proposed by Jacob *et al.* (2011) and expressed in percentage. Seeds were considered as germinated when the radicle emerged. The observation on germination inhibition percentage was estimated by the formula suggested by Wakjira *et al.* (2009).

$$G_T = \frac{(N_C - N_T)}{N_C} \times 100$$

Where, G_T - Germination inhibition %, N_C - Number of germinated seeds in control at the end of 10th day and N_T - Number of germinated seeds in treatment at the end of 20th day. Germination value (GV) can be calculated from the following formula (Prasad and Kandya 1992).

$$GV = \frac{DGS}{N} \times \frac{GP}{100}$$

Where, GV - Germination value, DGS - Daily germination speed, obtained by dividing the cumulative germination % by the number of days since sowing, GP - Germination % at the end of the 20th days after sowing and N - Number of daily counts, starting from the date of first germination. With respect to biometric observation, *viz*. seedlings shoot length, root length and total length was measured (cm) following the International Seed Testing Association (ISTA) rules (Anonymous 1999) at 30, 45 and 60 days after sowing. Seedlings sampled for measurement of shoot length, root length and total length were partitioned in to the respective plant parts and oven dried at 70°C for 24 hours to a constant weight and dry matter of each part was weighed separately using sensitive electronic balance and expressed in mg/plant. Seedling vigour index I, based on total seedling length was estimated by the methodology of Bhattacharya *et al.* (1991)

Vigour Index I = Germination (%) x Total seedling length (cm)

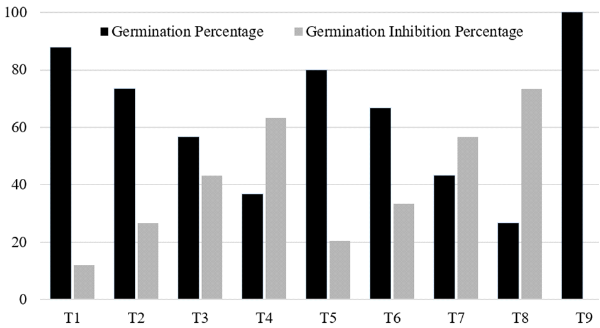
Vigour index II, based on seedling dry weight was measured by the methodology proposed by Abdul Baki and Anderson (1973)

Vigour Index II = Germination (%) x Seedling dry weight (mg/plant)

Significance of the difference in germination percentage, germination inhibition, germination value, germination index, seedling growth, seedling biomass production, and chlorophyll content of seedlings under different treatments were tested and compared using Analysis of Variance (ANOVA) and homogeneity test as suggested by Gomez and Gomez (1984). Wherever the treatments difference was found significant, the critical differences were worked out at 5% probability and values were furnished.

Total germination, germination inhibition and germination value

Seed germination is the best indicator of seed viability under biotic or abiotic stressed condition. The result of allelopathic effect of *L. camara* and *P. hysterophorus* weeds at different concentration on total germination and germination inhibition percentage of *T. populnea* is depicted in **Figure 1** and germination value presented in **Table 1**. Germination percentage, germination value and germination inhibition percentage varied from 26.7 to 100%, 3.0 to 29.3 and 0 to 73.3%, respectively. With the increase of aqueous extract concentration levels, the germination percentage and germination values progressively decreased, whereas germination inhibition percentage linearly increased. Among the two weed species and four concentration levels studied, application of aqueous extract of *L. camara* at 10% concentration recorded the maximum seed germination (87.9%), germination value (25.6) and minimum germination inhibition (12.1%) followed by aqueous extract of *P. hysterophorus* at 10%. This was significantly higher than the application of aqueous extract of *L. camara* and *P. hysterophorus* weeds at 20, 30 and 40% concentration levels. Whereas, the lowest seed germination (26.7%) and germination value (3.0) and the highest germination inhibition of 73.3% was recorded in application of 40% aqueous extract of *P. hysterophorus* followed by 40% aqueous extract of *L. camara*. Similar research findings were reported in an experiment conducted in *Eragrostis tef*



T_1- *L. camara* extract 10%; T_2- *L. camara* extract 20%; T_3- *L. camara* extract 30%; T_4- *L. camara* extract 40%; T_5- *P. hysterophorus* extract 10%; T_6- *P. hysterophorus* extract 20%; T_7- *P. hysterophorus* extract 30%; T_8- *P. hysterophorus* extract 40%; T_9- Control/distilled water

Figure 1. Effect of *L. camara* and *P. hysterophorus* aqueous extracts on total germination percentage of *T. populnea*

(Tefera 2002), cultivated and wild herbaceous species (Maharajan *et al*. 2007), sunflower (Kumar and Gautam 2008) and wheat (Gella *et al*. 2013). The higher inhibitory effect of *Parthenium* is due to presence of large amount of allelochemicals, which inhibit the process of seed germination and relevant parameters of many plants in nurseries and plantations.

Shoot length, root length and total length

The results of allelopathic effect of *L. camara* and *P. hysterophorus* and distilled water on shoot length, root length and total length of *T. populnea* varied from 6.8 to 23.5 cm, 9.6 to 29.6 cm and 12.6 to 36.4 cm, 4.7 to 12.5 cm, 6.6 to 16.8 cm and 9.2 to 21.6 cm, 11.6 to 36.0 cm, 16.2 to 46.4 cm and 21.8 to 58.0 cm at 30, 45 and 60 DAS, respectively (**Table 1**). Irrespective of the stages of observation, the lowest shoot length of 6.8, 9.6 and 12.6 cm, root length of 4.7, 6.6 and 9.2 cm, and total length 11.6, 16.2 and 21.8 cm was recorded in application of 40% aqueous extract of *P. hysterophorus* at 30, 45 and 60 DAS, respectively followed by application of 40% aqueous extract of *L. camara*. This was significantly lower than application of aqueous extract of *L. camara* and *P. hysterophorus* weeds at 30, 20 and 10% concentration levels. The highest inhibiting effect on shoot length, root length and total length with application of 40% aqueous extract of *P. hysterophorus* could be attributed mainly due to the release of different kinds of phytotoxic compounds, *viz*. phenolics, sesquiterpenes and lactones from root and vegetative part of the weed and its accumulation in shoot and root meristem of the plants (Gella *et al.* 2013). These chemicals are capable of suppressing the growth of receptor crops and can have multiple phytotoxic effects *viz*. reduction in plant hormone synthesis, inhibition on nutrient and ion absorption. Earlier works have also reported that aqueous leachates of *P. hysterophorus* reduced the shoot and root elongation of *Oryza sativa* and *Triticum aestivum*

Table 1. Germination value, shoot length, root length, total length of *T. populnea* as affected by concentration of aqueous extracts of *L. camara* and *P. hysterophorus*

Treatment	Germination value	Shoot length (cm)			Root length (cm)			Total length (cm)		
		30 DAS	45 DAS	60 DAS	30 DAS	45 DAS	60 DAS	30 DAS	45 DAS	60 DAS
L. camara extract 10%	25.6	20.4	11.3	31.7	15.2	25.2	40.4	30.7	19.5	50.2
L. camara extract 20%	19.0	17.6	9.9	27.5	21.8	13.3	35.2	26.6	17.2	43.8
L. camara extract 30%	11.8	14.7	8.0	22.7	18.5	10.9	29.4	22.8	14.3	37.1
L. camara extract 40%	5.2	10.0	6.5	17.3	12.9	8.9	21.8	16.6	11.7	28.4
P. hysterophorus extract 10%	22.6	16.2	9.9	26.2	20.7	13.2	33.9	25.5	17.1	42.7
P. hysterophorus extract 20%	16.4	12.6	8.2	20.8	16.8	11.1	27.8	21.1	14.8	35.9
P. hysterophorus extract 30%	7.3	10.5	6.8	16.7	13.9	9.2	23.1	17.6	12.4	30.1
P. hysterophorus extract 40%	3.0	6.8	4.7	11.6	9.6	6.6	16.2	12.6	9.2	21.8
Control/distilled water	31.3	23.5	12.5	36.0	29.6	16.8	46.4	36.4	21.6	58.0
LSD (p=0.05)	5.4	2.5	1.4	4.0	2.7	1.7	3.0	3.5	1.4	4.5

(Singh and Sangeeta 1991), *Zea mays* (Maharajan *et al*. 2007), *Helianthus annuus* (Kumar and Gautam 2008), *Glycine max* (Netsere and Mendesil 2011), *Brassica* species (Singh *et al*. 2005).

Dry matter and chlorophyll content

Among the levels of aqueous extract of *L. camara* and *P. hysterophorus* weeds, the maximum reduction in dry matter production and chlorophyll content was found in 40% concentration of *P. hysterophorus,* which registered the dry matter of 4.9, 8.6 and 12.6 mg/plant and chlorophyll content of 13.9, 14.4 and 15.7 µmol chlorophyll/m^2 of leaf at 30, 45 and 60 DAS respectively (**Table 2**). At all the stages of observation, dry weight and chlorophyll content of *T. populnea* in control (distilled water) treatment was significantly higher than application of various concentration of aqueous extract of *L. camara* and *P. hysterophorus* weeds, which registered the dry matter of 12.3, 17.9 and 24.2 mg/plant and chlorophyll content of 32.6, 36.8 and 43.4 µmol chlorophyll/m of leaf at 30, 45 and 60 DAS respectively followed by application of aqueous extract of *L. camara* at 10 and 20% concentration level. The survived *T. populnea* seedlings exhibited varying degree of necrosis and chlorosis in their leaves, stunted growth and development and many seedlings lost their ability to develop normally as a result of reduced plume elongation, radicle elongation, shoot necrosis and root necrosis. Changes in leaf chlorophyll content provide an indicator of maximum photosynthetic capacity, leaf developmental stage, productivity and stress. In stressed vegetation, leaf chlorophyll content decrease, thereby changing the proportion of light absorbing pigments and leading to less overall absorption (Zarco-Tejada *et al*. 2000). Allelochemicals may reduce chlorophyll accumulation in three ways, *viz*. the inhibition of chlorophyll synthesis, the stimulation of chlorophyll degradation, and both (Djurdjevic *et al*. 2008).

Table 2. Effect of *L. camara* and *P. hysterophorus* weeds aqueous extracts concentration on dry matter and chlorophyll content of *T. populnea*

Treatment	Dry matter (mg/plant)			Chlorophyll content (µmol chlorophyll/m^2 of leaf)		
	30 DAS	45 DAS	30 DAS	45 DAS	30 DAS	45 DAS
L. camara extract 10%	11.2	16.4	22.3	30.4	33.9	39.8
L. camara extract 20%	9.9	14.5	20.1	27.7	30.3	35.2
L. camara extract 30%	8.4	12.6	17.8	24.2	26.0	29.3
L. camara extract 40%	6.8	10.3	15.1	19.2	19.8	21.4
P. hysterophorus extract 10%	10.3	15.1	20.6	29.2	32.8	38.9
P. hysterophorus extract 20%	8.8	13.3	18.5	25.1	28.2	33.3
P. hysterophorus extract 30%	7.1	11.2	15.7	20.2	22.3	25.8
P. hysterophorus extract 40%	4.9	8.6	12.6	13.9	14.4	15.7
Control/distilled water	12.3	17.9	24.2	32.6	36.8	43.4
LSD (p=0.05)	1.5	2.0	3.4	1.6	1.9	2.0

Vigour index I and II

Vigour index of the *T. populnea* seedlings was significantly influenced by the application of aqueous extract of *L. camara* and *P. hysterophorus*. The results of allelopathic effect on vigour index I and II are varied from 308 to 3600, 433 to 4640, and 582 to 5800 and 131 to 1230, 230 to 1790 and 336 to 2420 at 30, 45 and 60 DAS respectively **(Figure 2)**. Based on seed germination percentage and seedling total length, the highest vigour index of 3600, 4640 and 5800 was observed in distilled water at 30, 45 and 60 DAS respectively. Similarly, based on seed germination percentage and dry weight, the highest vigour index of 1230, 1790 and 2420 was also recorded in distilled water at 30, 45 and 60 DAS respectively. This was significantly higher than application of whole plant aqueous extract of *L. camara* and *P. hysterophorus* weeds at all the concentration levels. The maximum inhibitory effect on growth potential of *T. populnea* was observed in application of 40% aqueous extract of *P. hysterophorus*, which recorded vigour index I of 308, 433 and 582 and vigour index II of 131, 230 and 336 at 30, 45 and 60 DAS, respectively followed by 40% aqueous extract of *L. camara*. Reduction in seedling growth, dry matter production and subsequently in vigour index, might be due to the results of the presence of allelochemicals in the aqueous extracts of weeds that were able to inhibit the synthesis of growth hormones which in turn prevented cell division and cell differentiation to promote the shoot and root length and dry matter production (Bhadoria 2011, Kanchan and Jayachandra

Table 3. Allelopathic inhibitory potential of *L. camara* and *P. hysterophorus* weeds aqueous extracts on *T. populnea* vigour index I and II

Treatment	Vigour index I			Vigour index II		
	30 DAS	45 DAS	30 DAS	45 DAS	30 DAS	45 DAS
L. camara extract 10%	2786	3551	4413	978	1418	1939
L. camara extract 20%	2016	2580	3211	728	1063	1473
L. camara extract 30%	1287	1667	2104	474	717	1003
L. camara extract 40%	635	800	1042	251	375	547
P. hysterophorus extract 10%	2096	2712	3416	821	1205	1660
P. hysterophorus extract 20%	1387	1854	2395	588	888	1245
P. hysterophorus extract 30%	723	1000	1303	309	490	693
P. hysterophorus extract 40%	308	433	582	131	228	338
Control/distilled water	3600	4640	5800	1150	1670	2260
LSD (p=0.05)	382	476	557	181	243	377

1980). Different allelochemicals have different sites of action in plant. Thus, the sensitivity to allelochemicals and the extent of growth inhibition varied with species and organs (Maharajan *et al.* 2007).

It was concluded that application of aqueous extract of *P. hysterophorus* at 40% concentration had strong allelopathic inhibitory effect on germination, seedling growth and dry matter production of *T. populnea* than *L. camara*. Allelopathic potential of *P. hysterophorus* may be an important mechanism involved in invasive success of this weed in natural ecosystems.

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Invasion status of alien weeds in the historical Chobhar area of Kathmandu valley, Nepal

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ABSTRACT

Invasive alien weeds in Nepal have become a great problem. Many of them have been naturalized and threatening native ecosystems and biodiversity. This assessment was carried out to measure the density, frequency and coverage of four major invasive weeds in a historical place, Chobhar of Kathmandu, Nepal. It was found that *Ageratina adenophora* had the highest density, frequency, and cover in the Pine forest. Similarly, *Ageratum conyzoides, Bidens pilosa,* and *Parthenium hysterophorus* were dense and frequent with high cover along the roadside. The frequency of *B. pilosa* and *P. hysterophorus* was comparatively high in the fallow land. It shows that the ecological parameters of the particular invasive alien weeds vary with land-use types and aspects. These weeds should be regularly monitored and appropriate methods of controlling them should be implemented in the study area.

The invasion of alien species has been challenging the conservation of biodiversity and natural resources (Maèiæ *et al.* 2018). The invasive alien plant species (IAPS) compete with native plants for nutrients, water and light (Vilà *et al.* 2011). They can change the native ecosystems and diversity which is irreversible (Barton *et al.* 2007).

With the increasing globalization, trade and human movement the number of IAPS has been increasing in all climatic regions and continents from tropics to high mountains (Seebens *et al.* 2017). Nepal's physiographic and climatic diversity are suitable for alien plant species introduction and establishment. The number of highly problematic IAPS in Nepal has reached up to 26 which are mostly native of tropical Americas (Shrestha *et al.* 2016). These species are distributed in various habitats such as roadsides, fallow lands, agroecosystems, and even in the forests throughout Nepal (Thapa *et al.* 2015, 2016, 2017, Shrestha *et al.* 2016). In addition, the natural beauty of many historical places has been also destroyed by the invasion of such alien species but the community people, governmental and non-governmental authorities are unaware on these issues. This study aims to highlight the status of invasion of major problematic invasive weeds in a famous historical place, the Chobhar area of Kathmandu valley, Nepal.

The Chobhar area lies in Kirtipur municipality of the valley (27°27' N and 85°28' E and elevation ranges from 1310 to 1346 m above the sea level). The area is famous for the Chobhar Gorge cut by Manjushree, Chobhar caves, Jal Binayak and Adinath Lokeshwar temples. The area is surrounded by beautiful herbs, shrubs, and a patch of Pine forest patches. Kathmandu-Dakshinkali road makes a half-circle to the Chobhar area and there is another road running up to the hill through Pine forest towards the North aspect. The roadsides, fallow land, and forest patches of Chobhar are invaded by mainly four invasive weeds named *Ageratina adenophora* (Spreng.) King and H.Rob., *Ageratum conyzoides* L., *Bidens pilosa* L. and *Parthenium hysterophorus* L.

A field survey was conducted from September to November 2018. A total of 100 quadrats of size 1×1 m^2 were sampled in 3 sites (forest, fallow land, and road sides of North and South aspects) in the study area. There were 25 quadrates at each site. In the forest and fallow land, five transects were made having a distance about 20 m apart and in each transect 5 quadrats were sampled. The distance between the two quadrates was at least 10 m. The remaining 25 quadrats were sampled along the roadside towards each North and South aspect of Chobhar. Density and cover of the weeds were measured in each quadrat. The number of each weeds per plot was counted as the density and cover estimation was done by visual observation method starting from >5, 5, 10, 15, 20%, and so on. The frequency was calculated using the following formula:

$$\text{Frequency (\%)} = \frac{\text{No. of quadrats in which selected invasive plant species occurred}}{\text{Total no. of quadrats studied}} \times 100$$

Density, frequency, and coverage of the weeds among the forest, fallow land, and roadsides were compared using a non-parametric Kruskal-Wallis test as the data were not normal.

Density, frequency and cover of weeds

Ageratina adenophora had the highest density in the forest (27 plants per plot) and the lowest in the fallow land. In the case of *A. conyzoides,* the highest density was found along the roadside towards the North aspect while it was absent in the fallow-land (**Figure 1a, Table 1**). The density of *B. pilosa* was the highest in the roadside (28 plants per plot) towards the North aspect followed by the roadside towards the South aspect. Fallow land was the site where the density of *B. pilosa* was the least *i.e.* 4 plants per plot. The density of *P. hysterophorus* was the highest in the road towards the South aspect. The least density of *P. hysterophorus* was measured in the forests and roadside towards the North aspect (**Figure 1a, Table 1**).

The highest cover of *A. adenophora* was found in the forest (38%) and the least in the fallow land (**Figure 1b, Table 1**). Similarly, *A. conyzoides* had the maximum coverage in the forest and roadside towards the North aspect in comparison to the fallow land and roadside towards the South aspect. *B. pilosa* had maximum cover in the road towards North aspect (34%) followed by road towards South aspect (31%) and the minimum cover was found in the forest. The highest cover of *P. hysterophorus* was found on the roadside towards South aspect (18%) followed by fallow land and the least in the roadside towards North aspect (**Figure 1b, Table 1**).

Table 1. Kruskal-Wallis test result for density and frequency of IAPS in different sites

	IAPS density			
	Forest	FA	RTNA	RTSA
Chi-square	51.45	57.27	42.38	55.68
P value	<0.001	<0.001	<0.001	<0.001
	IAPS cover			
Chi-Square	61.113	41.302	47.112	46.730
P value	<0.001	<0.001	<0.001	<0.001

FA: Fallow land; RTNA: Roadside towards the North aspect; RTSA: Roadside towards the South aspect

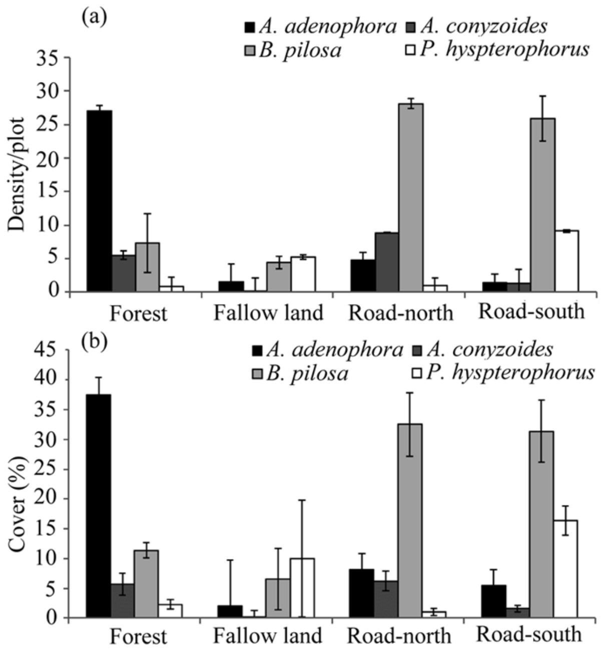

Figure 1. Density (a) and cover (b) of IAPS in different sites

All the weeds were present in all the sampling sites in the study area. In the case of *A. adenophora,* the highest frequency was found in the forest (100%) followed by the roadside towards the North and South aspects and the fallow land (**Figure 2**). Similarly, the highest frequency of *A. conyzoides* was found in the road towards the North aspect and the lowest in the fallow land. In the case of *B. pilosa*, the maximum frequency was found in the road towards the North aspect (100%) and forest (100%) followed by the road towards the South aspect (95%) and fallow land (91%). The frequency of *P. hysterophorus* was the highest in the road towards the South aspect (85%) and the least in the road towards the North aspect (18%) **(Figure 2)**.

The results show that the fallow land had a low density of weeds than the forest and roadsides might be due to high disturbance. In the Pine forest, there was high density, frequency, and cover of *A. adenophora* comparing to the other weeds. Its high density inside the forest may affect native species and seedling regenerations (Thapa *et al.* 2020a, 2020b). *B. pilosa* showed the highest density and cover in the roadsides towards both North and South aspect whereas it was the most frequent species in all sites although the density and cover were low in the forest and fallow land. It indicates that this species is one of the highly invading species in all types of habitats. Regarding the ecological impacts, this species is also responsible to reduce native diversity, alters soil characteristics, and inhibits plant growth and development (Khanh *et al.* 2009). It can be expected

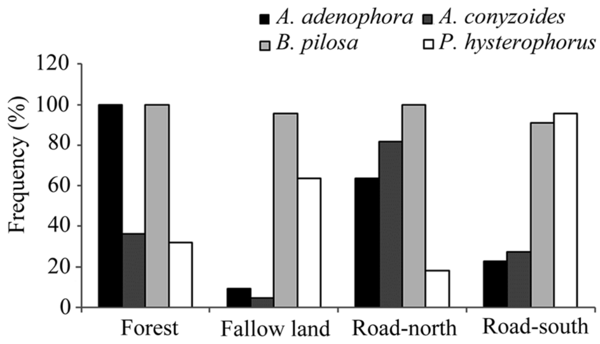

Figure 2. Frequency of IAPS in different sites

that the native species of the area might have negatively impacted by this weed.

Ageratum conyzoides is also known as a troublesome species having an adverse ecological, economic and social impact (Kohli *et al.* 2006). It was denser, more frequent with high cover in the forest and roadside towards the North aspect comparing to the fallow land and roadside towards South aspect but this weed is not a severer one in terms of its abundance in the Chobhar area. As the *P. hysterophorus* was abundant along the roadside (South aspect) and fallow land than the forest and roadside towards North aspect indicating the effect of aspect on its frequency and cover.

In conclusion, *A. adenophora, A. conyzoides, B. pilosa,* and *P. hysterophorus* were the major invasive alien weeds in the historical Chobhar area of Kathmandu valley, Nepal. Forest patches were heavily invaded by *A. adenophora* and *B. pilosa* showing their ability to invade under the tree canopies. Invasion of these weeds is deteriorating the natural beauty of the historical place and the native species diversity might have severely impacted. Hence, regular monitoring and appropriate methods of controlling these weeds should be implemented.

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