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Volume 55 Number 1 January–March, 2023

Analysis article

Research articles

Research notes

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ANALYSIS ARTICLE

Bibliographic analysis of modelling weed distribution and invasion with global perspective

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ABSTRACT

Invasive alien weeds are of great concern because of their capability of spreading fast, their high competitiveness and ability to settle in new areas within short period of time. Thus, they are the second biggest threat to biodiversity after habitat destruction. It is therefore necessary to prevent the introduction, establishment, and spread of these invasive alien weeds (IAWs) into newer areas. Ecological niche modelling (ENMs) and species distribution modelling (SDMs) are two commonly used approaches in theoretical and applied studies in ecology to study the species behavior in future climatic conditions. In this study, we undertook a bibliographic analysis of scholarly articles on the modelling studies on species invasion under current and future climatic scenarios. In addition, results of different studies on modelling and prediction on distribution of IAWs on global as well as India level were also discussed. Study revealed that researchers started getting interest and published more work in the subject between 2015 and 2020. The greater number of related articles were published in the subjects such as ecology, biology, habitat and climate change and published mostly by Wiley, Elsevier and Springer publishers. Further, the shortcomings of species distribution modelling and future prospects were also discussed.

Keywords: Bibliographic analysis, Invasive alien weeds, Modelling, Species distribution modelling

INTRODUCTION

Invasive organism is defined as a non-native organism whose introduction causes, or is likely to cause, economic or environmental harm, or harm to human, animal, or plant health (Reaser *et al.* 2020). The invasive alien species are those that are introduced into places outside their natural range, adversely impacting native biodiversity, ecosystem or human well-being. According to Convention on Biological Diversity (2005), invasive alien species are introduced purposefully or accidentally outside their natural habitat, where they exhibit the ability to establish themselves, invade, out-compete native weeds and take over the new environment within short period of time. Thus, they have the potential to harm the biodiversity, ecosystem and human well-being (Ansong and Pickering 2015; Beaumont *et al.* 2014; Kleunen *et al.* 2015). They put significant social, ecological and economic impacts on the invaded environment (Gharde *et al.* 2018). The nature and severity of the impacts of these weeds on society, environment, health and national heritage are of great concern (McNeely *et al.* 2001). They are also highly tolerant to climatic and edaphic changes and have ability to compete and drive off other species from their habitat. Thus, they are the second biggest threat to biodiversity after habitat destruction. They reduce agricultural yields, and interfere with crop lands, grazing areas, water availability, and contribute to spread of many diseases (Essa *et al.* 2006). Further, their uncontrolled expansion in agriculture ecosystem may cause huge crop yield losses (Chauhan *et al.* 2011; Fahad *et al.* 2015; Parker 2012).

In the era of globalization, it is necessary to prevent the introduction, establishment, and spread of these invasive alien weeds (IAWs) into newer areas (Rao *et al.* 2017). It is usually accepted that prevention before the establishment of the invasive weeds is a much better economic strategy than control or eradication (Seebens *et al.* 2017) after the establishment (Jarnevich *et al.* 2010; Braun *et al.* 2016). Moreover, management of invasive species relies on information about their expected distributional potential and relative abundance under current and future climate scenarios. Therefore, it is important to know the areas which are favorable for occurrence of these species so that planning can be done for appropriate long-term management strategies for the control of these species before its invasion in the new areas. Further, how species will respond to projected future climate change is of fundamental importance for effective management

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and conservation of biodiversity (Hannah *et al.* 2002; Hijmans and Graham 2006). It is reported that some extreme weather events such as droughts and floods may increase due to climate change and can cause huge impacts on the global ecosystem, including rise in sea levels (Lee 2010), change in areas of crop production and spread of species (Kwak *et al.* 2008; Pearson and Dawson 2003). As per estimate reported by Intergovernmental Panel on Climate Change (IPCC), the earth temperature is estimated to increase by about 1.4–5.8°C from 1990 to 2100, whereas precipitation is estimated to increase by up to 1.0% for the mid- and high-latitude regions and 0.3% for the tropical zones (IPCC 2014). It was also confirmed that South Asia will experience a substantial change in its climate during the 21st century. It is established that climate change has already changed many species' behaviors, biodiversity, their distribution and habitat substantially. As the climate is known to be the most significant factor affecting the growth and development (Rosenzweig *et al.* 2001), invasive weeds are heavily influenced by climate change and can extend their range, thereby causing increased damage to ecosystem and agricultural production.

However, the relationship between IAW and climate change is complex (Hellmann *et al.* 2008). Climatic factors are considered as one of the main factors determining the overall distribution of invasive species due to their synergistic effects (Guisan and Thuiller 2005; Bai *et al.* 2013; Gharde *et al.* 2019). However, Sathischandra *et al.* (2014) reported the absence of a linear correlation between the occurrence of weeds and insect pests with climate variables. Hence, with such complexities, there is need for precise prediction on dynamics of IAW under future climate change scenarios in order to manage such weeds (Kariyawasam *et al.* 2019).

To address these questions, we undertook a bibliographic analysis of scholarly articles on the modelling studies on species invasion under current and future climatic scenarios. Specifically, two approaches used for modelling, *viz.* ecological niche modelling and species distribution modelling along with different commonly used algorithms were discussed. Results of different studies on modelling and prediction on distribution of IAWs on global as well as India level were also discussed. Further, this article summarizes shortcomings of species distribution modelling (SDM) and future prospects.

Ecological niche modelling and species distribution modelling

Ecological niche modelling (ENMs) and SDM are two commonly used approaches in theoretical and applied studies in ecology (Peterson *et al.* 2015). Most common applications of these models are finding suitable sites for species (Guisan and Zimmermann 2000), predicting the impacts of future climate change on species' distributions (Pearson and Dawson 2003), assessing the invasive potential of alien species (Jiménez-Valverde *et al.* 2011), and subsequently the conservation planning (Guisan *et al.* 2013).

However, there is considerable difference between these two approaches. SDM refers to the approach for modelling the objects in G-space (the geographical space occupied by the species), on the other hand, ENM refers to approach for modelling the objects in E-space (all the environmental combinations available in the study region) (Soberón *et al.* 2017). ENM requires an overt estimation of the fundamental niche of the species, and are envisioned to model the processes that defined the area of distribution of the species (Peterson and Soberón 2012). Usually SDM can only target the species' distribution, and preferably must restrict model calibration to accessible areas of the study region, account for true absences and integrate dispersal and colonization abilities (Peterson and Soberón 2012). Three main classes of models are recognized in this field: correlative models, the most commonly used models found in the literature, which estimate the ecological requirements of species by relating their known spatial distributions to a set of environmental/climatic variables (Araújo and Guisan 2006; Franklin 2010); mechanistic models which use exhaustive physiological information and first principles of biophysics (Kearney and Porter 2009); and process-oriented models, which estimate species' distributions in terms of processes, including dispersal capability and biotic interactions (Peterson *et al.* 2015).

Use of ecological niche models (ENMs) plays important role in early detection of IAWs and to identify the ecologically sensitive areas for further monitoring and making necessary control measures (Srivastava *et al.* 2019; Yan *et al.* 2020; Marambe and Wijesundara, 2021). Species distribution modelling makes use of point-occurrence data and raster data layers summarizing environmental information (**Figure 1**). These species distribution models thus infer species' environmental requirements, and have been used to anticipate the geographic potential of species (Wisz *et al.* 2008). These models have become the extensively useful tool to determine the relationships between species and their environments and are used to predict extreme impacts of climate change, biogeographic studies, improve species management and answer conservation biology questions.

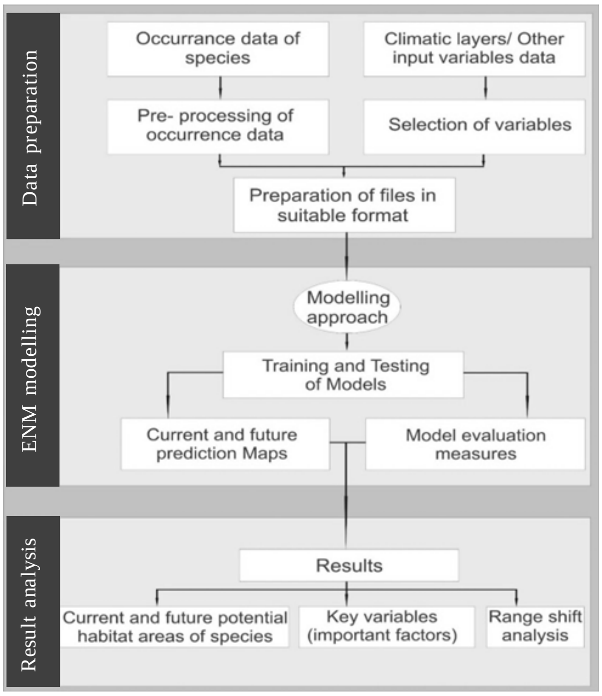

Figure 1. Steps used in species distribution modelling

BIOCLIM, DOMAIN, and Maxent are the frequently used ENMs known for their simplicity and the data accessibility (Elith *et al.* 2011; Katz and Zellmer 2018; Srivastava *et al.* 2019). However, compared to BIOCLIM and DOMAIN, Maxent exhibited much higher predictive performance (Phillips *et al.* 2006; Peterson and Anamza 2015), and it can generate much more robust results especially when applied to small sample sizes (Phillips *et al.* 2006; Elith and Leathwick 2009) when most of the technique fail to produce the adequate results. Thus, Maxent has been successfully applied to model the distributions of invasive species (Srivastava *et al.* 2019).

Additionally, several researchers have used remote sensing data to map the distribution of IAWs using phenology-based approaches (Ishii and Washitani 2013; Bradley *et al.* 2018; Huang and Geiger 2008). Remote detection of IAWs based on their distinct biochemical, physiological and structural traits are important in cases where IAWs and native species have similar phenology (Glenn *et al.* 2005; Mitchell and Glenn 2009; Yang and Everitt 2010). However, success of these approaches depends on the availability of hyperspectral data (Gholizadeh *et al.* 2022).

Species invasion under climate change scenarios

Several studies have been conducted to investigate the potential impact of global climate change on the geographic distribution of IAWs, but the results are somewhat different in each case (Buckley and Csergo 2017; Merow *et al.* 2017). Some studies reported that climate change may favour the expansion of geographic distribution of these species (Priyanka and Joshi 2013; Banerjee *et al.* 2017; Wei *et al.* 2017; Shrestha *et al.* 2018; Thapa *et al.* 2018); whereas, others have reported that climate change may constrain the geographic distribution of some IAW species (**Table 1** and **2**) (Bradley 2009; Taylor and Kumar 2013; Roger *et al.* 2015; Allen and Bradley 2016; Manzoor *et al.* 2018). Hence, prediction on areas of high/low invasion risk or varied invasion impact for the future is full of uncertainties and mainly depends upon the invasive species or biome type (Buckley and Csergo 2017).

Bibliographic analysis of articles on weeds distribution modelling

Bibliographic analysis is defined as the evaluation of published scientific literature including articles, books, book chapter and provide a way to measure the impact of publication among the scientific community. Research in SDMs in predicting the future distribution of IAW has expanded significantly over the past few decades with evolution of different algorithms. Hence, the present bibliographic analysis, study was done using the literatures available in the area of modelling of IAW distribution. For this purpose, published research articles were accessed and analysis was done with the help of LENS.ORG free access database. It is meant for search, analyze and manage patent as well as Scholarly data. Here, scholarly data was used for the purpose, and keywords, *viz*. invasive alien plant species climate change future distribution and modelling were used for selection of the articles out of total 252,116,476 scholarly literature available in the LENS.ORG. Using these keywords, 3244 articles have been filtered out. Results were also shown as the impact of the scholarly articles present in the area searched. These includes active author information; citation of the scholarly works; classification of articles based on their research area as well as institution where the work was conducted and publication trend of the documents over the years. These results are presented through **Figure 2** to **Figure 6**.

Figure 2 revealed that researchers started getting interest and published more work between 2015 and 2020. Many documents were published during these years with maximum observed during 2017 with more than 270 articles. These articles were more related to ecology (1360), biology (1218), geography (813), biodiversity (513), introduced species (406), invasive species (398), habitat (343), Climate change (325), ecosystem (302) and rest with other areas of interest (**Figure 3**). Most of the research were published by Spanish National

Table 1. The global prediction of species invasion under future climate scenario using distribution modelling

Weeds	Region	Contraction/expansion in areas	Reference	Weed type
Ageratina adenophora (Spreng.) R. M. King et H. Rob., *Alternanthera philoxeroides* (Mart.) Griseb., *Ambrosia artemisiifolia* L. *Mikania micrantha* Kunth	China	Expansion	Tu *et al.* 2021	Terrestrial
Parthenium hysterophorus L.	World and Oman	Contraction in areas in 2081–2100 at global level. Expansion during 2021-40 and a decrease during 2081–2100	Amna *et al.* 2022	Terrestrial
Cynodon dactylon, Cyperus rotundus, Echinochloa colona, Echinochloa crus-galli, Eichhornia crassipes, Eleusine indica, Imperata cylindrica, Lantana camara, Panicum maximum, and *Sorghum halepense*	World	Expansion	Wan and Wang 2019	Terrestrial and agro-ecosystem
Parthenium hysterophorus L.	Bangladesh	Expansion	Masum *et al.* 2022	Terrestrial
Ageratina adenophora	China	Expansion of the dispersal zone towards the northeast and coastal areas, and a slight contraction in the Yunnan–Guizhou plateau	Zhang *et al.* 2022	Terrestrial
Ageratina adenophora	Global	Contraction in potential suitable area globally and range expansion in six biodiversity hotspot regions	Changjun *et al.* 2021	Terrestrial
Ambrosia artemisiifolia, Ambrosia trifida, Symphyotrichum pilosum, Ageratina altissima, Hypochaeris radicata, Lactuca serriola, Paspalum dilatatum, Paspalum distichum, Rumex acetosella, Sicyos angulatus, Solanum carolinense, Solidago altissima	South Korea	Expansion	Adhikari *et al.* 2022	Terrestrial
Spartina alterniflora Loisel	China	Expansion	Yuan *et al.* 2021	Terrestrial
Verbesina encelioides (Cav.) Benth. & Hook. Fil ex Gray	South Africa	Expansion	Moshobane *et al.* 2022	Terrestrial
Ageratina adenophora (Sprengel) R. King and H. Robinson	Chitwan–Annapurna Landscape (CHAL) of Nepal	Expansion	Poudel *et al* 2020	Terrestrial
Parthenium Hysterophorus L.	Bhutan	Expansion	Dorji *et al.* 2022	Terrestrial
Apium leptophyllum, Astragalus sinicus, Bromus unioloides, Chenopodium ambrosioides, Coronopus didymus, Gnaphalium calviceps, Lolium multiflorum, Modiola caroliniana, Oenothera laciniata, Paspalum dilatatum, Sida rhombifolia, Silene gallica, Sisymbrium officinale, Sisyrinchium angustifolium, Spergularia rubra, Malva parviflora	South Korea	Expansion	Hong *et al.* 2021	Terrestrial
Urochloa panicoides P. Beauv.	World	Reductions in climate suitability in Brazil, Australia, India, and Africa, and an increase in suitability in Mexico, the United States, European countries, and China	Duque *et al.* 2022	Terrestrial
Amaranthus palmeri	USA	Northward range expansion and significantly increased suitability across large portions of the U.S. Overall	Runquist *et al.* 2019	Terrestrial
Parthenium hysterophorus	Chitwan Annapurna Landscape, Nepal	Expansion in the suitable habitat under RCP 4.5 scenario in 2050 and 2070, however decrease in suitable areas under RCP 8.5 scenario in 2050 and 2070	Maharjan *et al.* 2019	Terrestrial
Alstonia macrophylla Wall., *Annona glabra* L., *Austroeupatorium inulifolium* (H.B.K.) R. M. King & H. Rob, *Clidemia hirta* (L.) D. Don, *Dillenia suffruticosa* (Griff ex Hook.f. & Thomson) Martelli, *Lantana camara* L., *Leucaena leucocephala* (Lam.) de Wit, *Mimosa pigra* L., *Opuntia dillenii* (Ker-Gawl.) Haw, *Panicum maximum* Jacq., *Parthenium hysterophorus* L., *Prosopis juliflora* (Sw.) DC., *Sphagneticola trilobata* (L.) Pruski, *Ulex europaeus* L.	Sri Lanka	Contraction of the very low class and expansion of the moderate class of suitability.	Kariyawasam *et al.* 2019	Terrestrial
Myriophyllum aquaticum, Pistia stratiotes, Azolla filiculoides,, Eichhornia crassipes, Salvinia molesta	South Africa	Contraction in *Myriophyllum aquaticum* and *Pistia stratiotes* suitable areas and expansion in rest three areas	Hoveka *et al.* 2016	Freshwater weeds
Nitellopsis obtusa	United States	Decrease of the species' suitable range	Romero-Alvarez *et al.* 2017	Aquatic weed

Weeds	Region	Contraction/expansion in areas	Reference	Weed type
Alternanthera philoxeroides, Ceratophyllum demersum, Crassula helmsii, Elodea canadensis, Hydrilla verticillata, Ludwigia peruviana, Najas minor, Pistia stratiotes, Potamogeton crispus, Sagittaria platyphylla	World	Significantly higher climatic suitability for temperate coastal rivers and temperate floodplain rivers	Wang *et al.* 2017	Freshwater weeds
Lantana camara L.	World	Climatically suitable areas globally will contract. However, some areas in North Africa, Europe and Australia may become climatically suitable. In South Africa and China, its potential distribution could expand further inland.	Taylor *et al.* 2012	Terrestrial
Butomus umbellatus	North America	Decrease of suitable areas, though two of three global circulation models predict range expansion across gas emission scenarios	Banerjee *et al.* 2020	Terrestrial
Ageratum conyzoides, Praxelis clematidea, Solidago canadensis, Anredera cordifolia, Lantana camara, Conyza sumatrensis, Chenopodium ambrosioides, Parthenium hysterophorus, Avena fatua, Pharbitis purpurea, Aster subulatus	China	Species will expand northward	Guan *et al.* 2020	Terrestrial
Mikania micrantha	South and Southeast Asia, Australia, Oceania and parts of the USA	Predicted to expand toward cold and dry areas of the invasive range	Banerjee *et al.* 2019	Terrestrial
Lonicera japonica	Forests of the Cumberland Plateau and Mountain Region in the southeast of USA	Expansion	Lemke *et al.* 2011	Forest land
Chromolaena odorata	World	Expansion	Kriticos *et al.* 2004	Terrestrial
Amaranthus retroflexus, Amaranthus spinosus, Amaranthus viridis, Bidens pilosa, Conyza bonariensis, Conyza canadensis, Galinsoga parviflora, Physalis angulata	China	Expansion	Wan *et al.* 2017	Terrestrial
Lantana camara L.	Queensland, Australia	Reduction in climatic suitability	Taylor and Kumar 2013	Terrestrial

Table 2. The prediction of a few weed species invasion in India under future climate scenarios

Weeds	Region	Contraction/expansion in areas	Reference	Weed type
Lantana camara	Jharkhand, eastern India	Expansion up to 20–26% by 2050	Tiwari *et al.* 2022	Terrestrial
Parthenium hysterophorus	India	Overall decrease in habitat suitability with some highly vulnerable (Western Himalaya) region to its invasion under future climate	Ahmad *et al.* 2019	Terrestrial
Chromolaena odorata L. (King) & H.E. Robins	India	Higher suitability for species in northeastern states, the central Himalayan provinces and the Western Ghats and Eastern Ghats	Barik and Adhikari 2012	Terrestrial
Ageratina adenophora L., *Ageratum conyzoides* L., *Ageratum houstonianum* Mill., *Amaranthus spinosus* L., *Bidens pilosa* L., *Erigeron karvinskianus* DC., *Lantana camara* L., *Parthenium hysterophorus* L., *Senna occidentalis* (L.) Link., *Senna tora* (L.) Roxb., *Xanthium strumarium* L.	Western Himalaya, India	Most of these invasive plants are expected to expand under future climatic scenarios	Thapa *et al.* 2018	Terrestrial
Cassia tora and Lantana camara	India	Distribution ranges of both species could shift in the northern and north-eastern directions in India	Panda *et al.* 2018	Terrestrial
Chromolaena odorata and *Tridax procumbens*	India	Both are likely to reduce their potential distribution areas in the future climate	Panda and Behera 2019	Terrestrial

Research Council in all major areas and it was followed by Stellenbosch University in case of Ecology, Biology and Introduced Species. PloS one, PloS biology, PloS neglected tropical diseases are some of the leading free access journals who published the work related to modelling IAW invasion. The Wiley, Elsevier, Springer and Wiley-Blackwell are the leading publishers of research results on these areas (**Figure 5** and **6**).

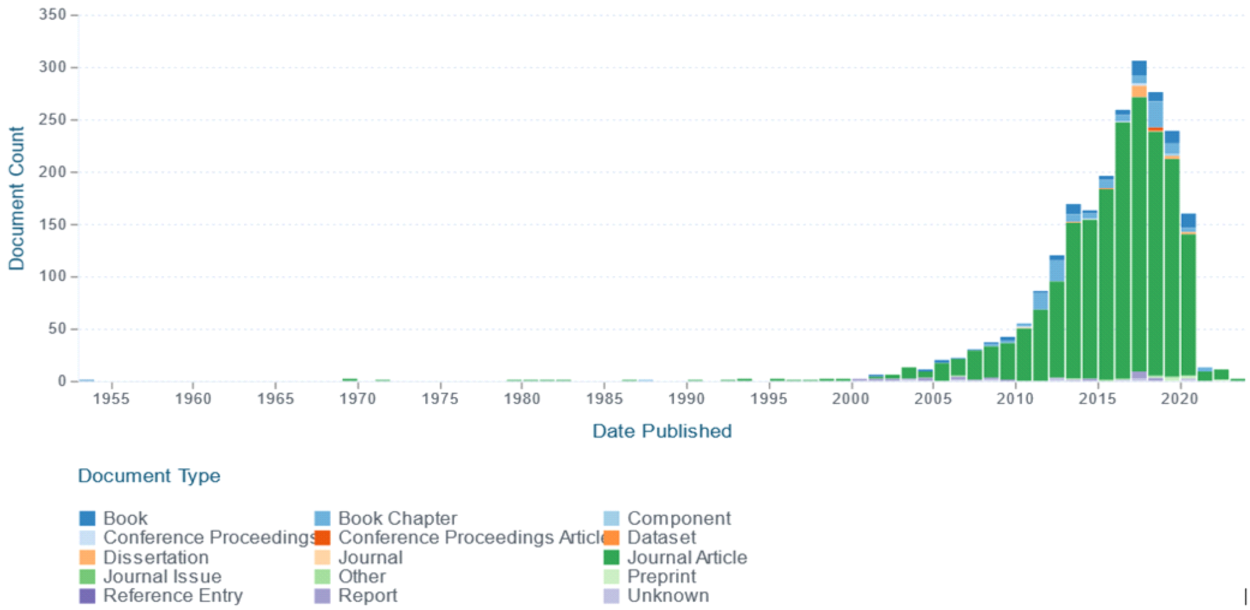

Figure 2. Published literature on modelling weed invasion over the years (from 1955-2022)

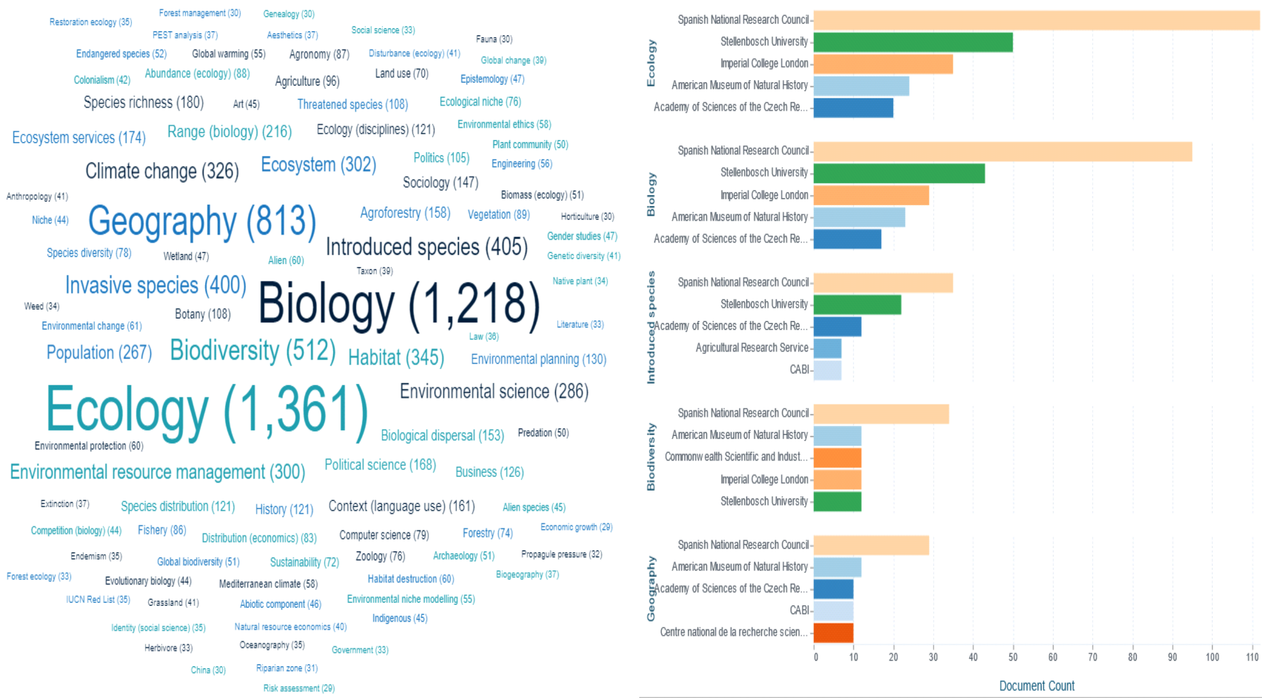

Figure 3. Classification of articles according to the research areas and research institutions

Implications of future climate on invasive alien weeds

The predicted distributional maps, based on the results of many studies, showed that climate change would significantly affect the global distribution of IAWs (Ahmad *et al.* 2019; Guan *et al.* 2020). Many studies have reported a range expansion for invasive species under climate change (Taylor *et al.* 2012, Cunze *et al.* 2013, Buczkowski and Bertelsmeier 2017, Kadioglu and Farooq 2017, Wei *et al.* 2017, Trethowan *et al.* 2011, Bradley BA *et al.* 2012, Bellard 2013, Priyanka and Joshi 2013). The possible reason may be that these species incline to expand their ranges with increasing temperature under climate change scenarios (Ju *et al.* 2015). In particular, the areas adjacent to the current distribution range of the species fall under high risk of invasion (Ahmad *et al.* 2019). However, many researchers reported that climate change may constrain the geographic range of some IAW species (Bradley 2009, Taylor and Kumar 2013, Roger *et al.* 2015, Allen and Bradley 2016, Manzoor *et al.* 2018).

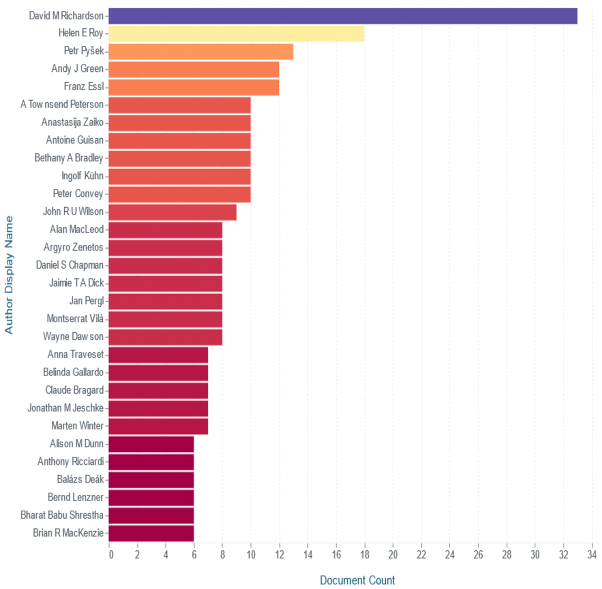

Figure 4. Leading authors who have contributed more to studies on the weed invasion in future climatic conditions

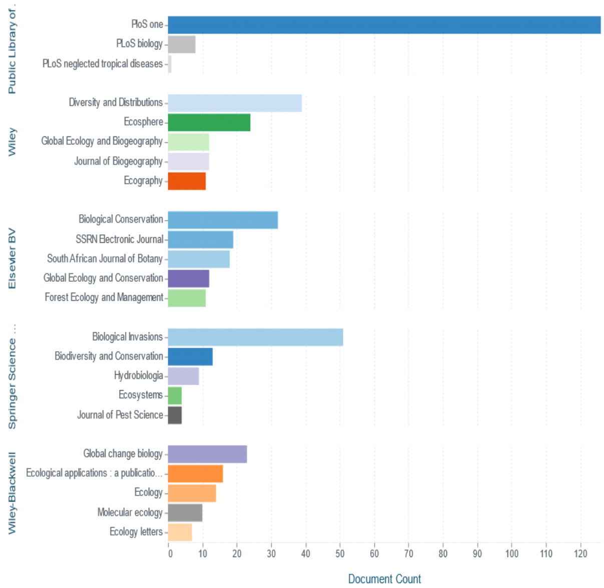

Figure 5. The leading journals which published work on weed invasion under future climatic scenarios

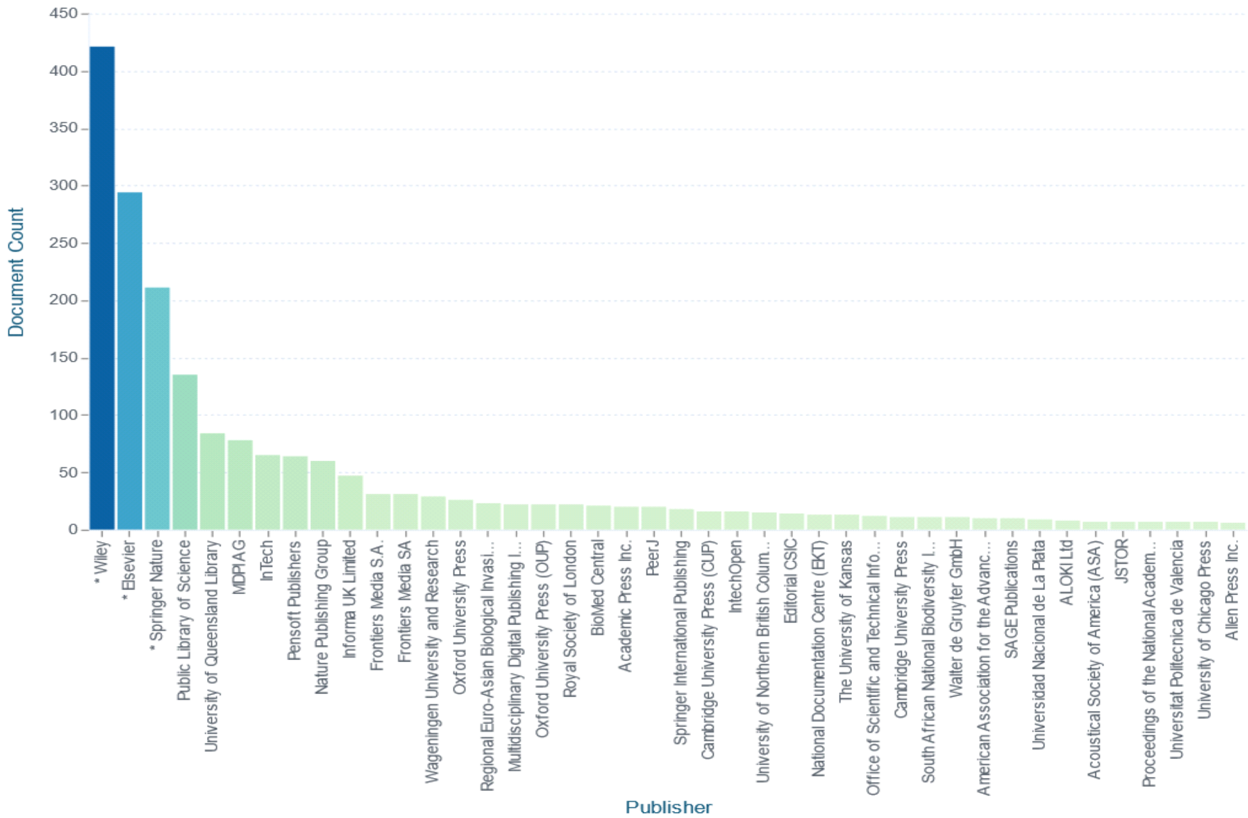

Figure 6. Leading publishers of the work on future distribution of invasive alien weeds

As far as high-risk regions are concerned, alarming situation will put forth the challenges for the policy makers, land resource managers and for other stakeholders to develop effective management plans in order to prevent the introduction, and further if it fails, then to control the further spread of this invasive species in High-Risk zones.

Limitations of SDM and future prospects

Many studies suggest that invasive alien species conquers climatic niches similar to those of its native places in some regions and such a resemblance in the climatic space between the native regions and invaded areas is considered to be critical factor for successful invasion in the non-native places (Becerra Lopez *et al.*

2017; Ficetola *et al.* 2007; Ahmad *et al.* 2019; Banerjee *et al.* 2019). Whereas, in some of the studies it is evident that the species when introduced into a new area, can simultaneously occupy climatic niches different from its native range, thereby it is necessary to reaffirm the fact that same species can exhibit variable invasion niche dynamics in an invaded regions (Wei *et al.* 2017; Becerra Lopez *et al.* 2017; Goncalves *et al.* 2014).

Many studies have successfully identified the invaded/hotspot areas and also determined the effect factors for the spreading of the invasive plants using climate factors (Welk *et al.* 2002; Kriticos *et al.* 2003; Tu *et al.* 2021), while others projected distribution scenarios and invasion trends of the plants in future (Van Wilgen *et al.* 2016; Tu *et al.* 2021). Although species distribution modelling plays a vital role in predicting the future potential distribution range of species under different climatic scenarios, such models are still relied on mainly abiotic factors. But, there are many other essential factors that affect the introduction and invasion process of invasive alien plant species and need to be considered in prediction (Coulin *et al.* 2019), for example, soil type, land use and biotic pressure, and especially anthropogenic factor (Zhu *et al.* 2017). Some biotic factors, such as competition, dispersal ability along with abiotic factors, also affect the potential distribution of species in future (Wisz *et al.* 2013*)*. Therefore, the future research challenge is to incorporate the biotic factors along with other factors such as land use and land cover changes in the SDMs to have a more sophisticated representation of the species distributions under changing climate (Bellard *et al.* 2016).

Currently, species distribution models (SDMs) are being widely used to predict distribution of IAWs at global (Guisan & Zimmermann 2000; Guisan and Thuiller 2005) as well as regional level. Though, one main challenge with the use of these SDMs is the selection of the most appropriate algorithm and suitable methodology among all available large number of modelling algorithms which are increasing at a rapid pace too (Elith *et al.* 2010). Recent studies revealed the difficulties in making the choice of the appropriate modelling algorithm due to varied performance of different algorithm. To avoid such situation, there is an emerging scientific trend to use several algorithms concurrently [*e.g.* ensemble modelling (Araujo and New 2007; Thuiller *et al.* 2009)] within a consensus modelling framework (Thuiller 2004, Marmion *et al.* 2009). By combining different algorithms for predictions, these ensemble modelling approaches accounts for uncertainties of using single algorithm (Buisson *et al.* 2010, Grenouillet *et al.* 2011) and hence increasing the predictive power of distribution modelling and projection (Marmion *et al.* 2009).

CONCLUSION

Climate change can cause huge impacts on the global ecosystem, change in areas of crop production and spread of weed species. An understanding the impact of climate change on weed species' future invasion is important for sustainable biodiversity conservation. This study summarized the important issues related to modelling weed invasion in future along with bibliographic analysis of the literatures related to weed invasion in future climate scenarios. The positive and negative economic and ecological consequences of species invasion everywhere are important concerns to all stakeholders of the society. The identification of areas where policies could benefit from synergies between climate, land use change and invasive species management is of prime relevance.

REFERENCES

Ansong M and Pickering C. 2015. What's a weed? Knowledge, attitude and behaviour of park visitors about weeds. *PLoS One* **10**(8): e0135026.

Adhikari P, Lee YH, Adhikari P, Hong SH and Park Y-S. 2022. Climate change-induced invasion risk of ecosystem disturbing alien plant species: An evaluation using species distribution modeling. *Frontiers in Ecology and Evolution* 10:880987.

Ahmad R, Khuroo AA, Hamid M, Charles B and Rashid I. 2019. Predicting invasion potential and niche dynamics of *Parthenium hysterophorus* (Congress grass) in India under projected climate change. *Biodiversity and Conservation* **28**: 2319–2344.

Allen J M and Bradley BA. 2016. Out of the weeds? Reduced plant invasion risk with climate change in the continental United States. *Biological Conservation* **203**: 306–312.

Amna M Al Ruheili, Thurya Al Sariri, Ali M. Al Subhi. 2022. Predicting the potential habitat distribution of parthenium weed (*Parthenium hysterophorus*) globally and in Oman under projected climate change. *Journal of the Saudi Society of Agricultural Sciences* **21**(7): 469–478.

Araujo MB and Guisan A. 2006. Five (or so) challenges for species distribution modelling. *Journal of biogeography* **33**(10): 1677–1688.

Araújo MB and New M. 2007. Ensemble forecasting of species distributions. *Trends in Ecology and Evolution* **22**(1): 42–47.

Bai F, Chisholm R, Sang W and Dong M. 2013. Spatial risk assessment of alien invasive plants in China. *Environmental Science & Technology* **47**(14): 7624–7632.

Banerjee AK, Mukherjee A and Dewanji A. 2017. Potential distribution of *Mikania micrantha* Kunth in India - evidence of climatic niche and biome shifts. *Flora* **234**: 215–223.

Banerjee AK, Mukherjee A, Guo W, Liu Y and Huang Y. 2019. Spatio-temporal patterns of climatic niche dynamics of an invasive plant *Mikania micrantha* Kunth and its potential distribution under projected climate change. *Frontiers in Ecology and Evolution* **7**: 291

Banerjee AK, Harms NE, Mukherjee A and Gaskin JF. 2020. Niche dynamics and potential distribution of *Butomus umbellatus* under current and future climate scenarios in North America. *Hydrobiologia* **847**(6): 1505–1520.

Barik SK and Adhikari D. 2012. Predicting geographic distribution of an invasive species (*Chromolaena odorata* L King & HE Robins) in Indian subcontinent under climate change scenarios. pp. 77–88. In: *Invasive Alien Plants: An Ecological Appraisal for the Indian subcontinent.* (Eds. Bhatt JR, Singh JS, Singh SP, Tripathi RS, Kohli RK), CABI, CPI Group (UK) Ltd, Croydon, UK.

Beaumont, LJ, Gallagher RV, Leishman MR, Hughes L and Downey PO. 2014. How can knowledge of the climate niche inform the weed risk assessment process? A case study of *Chrysanthemoides monilifera* in Australia. *Diversity and Distributions* **20**(6): 613–625.

Becerra Lopez JL, Esparza Estrada CE, Romero Mendez U, Sigala Rodriguez JJ, Mayer Goyenechea IG and Castillo Ceron JM. 2017. Evidence of niche shift and invasion potential of *Lithobatescatesbeianus* in the habitat of Mexican endemic frogs. *Plos One* **12**(9): e0185086. https://doi.org/10.1371/journal.pone.0185086

Bellard C, Thuiller W, Leroy B, Genovesi P, Bakkenes M and Courchamp F. 2013. Will climate change promote future invasions? *Global Change Biology* **19**(12): 3740–3748.

Bellard C, Leroy B, Thuiller W, Rysman JF and Courchamp F. 2016. Major drivers of invasion risks throughout the world. *Ecosphere* **7**(3): e01241.

Bradley BA. 2009. Regional analysis of the impacts of climate change on cheatgrass invasion shows potential risk and opportunity. *Global Change Biology* **15**(1): 196–208.

Bradley BA, Blumenthal DM, Early R, Grosholz ED, Lawler JJ, Miller LP, Sorte CJ, D'Antonio CM, Diez JM, Dukes JS and Ibanez I.. 2012. Global change, global trade, and the next wave of plant invasions. *Frontiers in Ecology and the Environment* **10**(1): 20–28.

Bradley BA, Curtis CA, Fusco EJ, Abatzoglou JT, Balch JK, Dadashi S and Tuanmu M-N. 2018. Cheatgrass (*Bromus tectorum*) distribution in the intermountain Western United States and its relationship to fire frequency, seasonality, and ignitions. *Biological Invasions* **20**(6): 1493–1506.

Braun M, Schindler S and Essl F. 2016. Distribution and management of invasive alien plant species in protected areas in Central Europe. *Journal for Nature Conservation* **33**: 48–57.

Buckley YM and Csergo AM. 2017. Predicting invasion winners and losers under climate change. *Proceedings of the National Academy of Sciences* **114**(16): 4040–4041.

Buczkowski G and Bertelsmeier C. 2017. Invasive termites in a changing climate: A global perspective. *Ecology and Evolution* **7**(3): 974–985.

Buisson L, Thuiller W, Casajus N, Lek S and Grenouillet G. 2010. Uncertainty in ensemble forecasting of species distribution. *Global Change Biology* **16**(4): 1145–1157.

Changjun G, Yanli T, Linshan L, Bo W, Yili Z, Haibin Y, Xilong W, Zhuoga Y, Binghua Z and Bohao C. 2021. Predicting the potential global distribution of *Ageratina adenophora* under current and future climate change scenarios. *Ecology and Evolution* **11**(17): 12092–12113.

Chauhan B and Johnson D. 2011. Growth Response of Direct-Seeded Rice to Oxadiazon and Bispyribac-Sodium in Aerobic and Saturated Soils. *Weed Science* **59**(1): 119–122.

Coulin C, de la Vega GJ, Chifflet L, Calcaterra LA and Schilman PE. 2019. Linking thermo-tolerances of the highly invasive ant, *Wasmannia auropunctata*, to its current and potential distribution. *Biological Invasions* **21**(12): 3491–3504.

Cunze Sarah, Leiblein MC and Tackenberg O. 2013. Range Expansion of *Ambrosia artemisiifolia* in Europe Is Promoted by Climate Change. *ISRN Ecology* **2013**: 1–9.

Dorji S, Lakey L, Wangchen T and Adkins S. 2022. Predicting the distribution of Parthenium weed (*Parthenium hysterophorus* L.) under current and future climatic conditions in Bhutan. *Journal of Environmental and Occupational Health* **12**(4): 169–181.

Duque TS, da Silva RS, Maciel JC, Silva DV, Fernandes BCC, Junior APB and Santos JBD. 2022. Potential Distribution of and Sensitivity Analysis for *Urochloa panicoides* Weed Using Modeling: An Implication of Invasion Risk Analysis for China and Europe. *Plants* **11**(13): 1761.

Elith J and Leathwick JR. 2009. Species distribution models ecological explanation and prediction across space and time. *Annual Review of Ecology, Evolution and Systematics* **40**(1): 677–697.

Elith J, Kearney M and Phillips S. 2010. The art of modelling range shifting species. *Methods in Ecology and Evolution* **1**(4): 330–342.

Elith J, Phillips SJ, Hastie T, Dudik M, Chee YE and Yates CJ. 2011. A statistical explanation of MaxEnt for ecologists. *Diversity and Distributions* **17**(1): 43–57.

Essa S, Dohai B and Ksiksi T. 2006. Mapping dynamics of invasive *Prosopis juliflora* in the Northern Emirates of the UAE: An application of remote sensing and GIS. In *ISPRS Commision VII Mid-term Symposium "Remote Sensing: From Pixels to Processes". Enschede, The Netherlands* (pp. 459-465): 24–29.

Fahad S, Hussain S, Chauhan BS, Saud S, Wu C, Hassan S, Tanveer M, Jan A and Huang J. 2015. Weed growth and crop yield loss in wheat as influenced by row spacing and weed emergence times. *Crop Protection* **71**: 101–108.

Ficetola GF, Thuiller W and Miaud C. 2007. Prediction and validation of the potential global distribution of a problematic alien invasive species-the American bullfrog. *Diversity and Distributions* **13**(4): 476–485.

Franklin J. 2010. *Mapping species distributions: spatial inference and prediction*. Cambridge University Press. **32**(6): 536–542.

Gharde Y, Kumar S and Sharma AR. 2019. Exploring models to predict the establishment of leaf-feeding beetle *Zygogramma bicolorata* (Coleoptera: Chrysomelidae) for the management of *Parthenium hysterophorus* (Asteraceae: Heliantheae) in India. *Crop Protection* **122:** 57–62.

Gharde Y, Singh PK, Dubey RP and Gupta PK. 2018. Assessment of yield and economic losses in agriculture due to weeds in India. *Crop Protection* **107:** 12–18.

Gholizadeh H, Friedman MS, McMillan NA, Hammond WM, Hassani K, Sams AV, Charles MD, Garrett DR, Joshi O, Hamilton RG, Fuhlendorf SD, Trowbridge AM and Adams

HD. 2022. Mapping invasive alien species in grassland ecosystems using air borne imaging spectroscopy and remotely observable vegetation functional traits. *Remote Sensing of Environment.* **271**: 112887.

Glenn NF, Mundt JT, Weber KT, Prather TS, Lass LW and Pettingill J. 2005. Hyperspectral Data Processing for Repeat Detection of Small Infestations of Leafy Spurge. *Remote Sensing of Environment* **95**(3): 399–412.

Goncalves E, Herrera I, Duarte M, Bustamante RO, Lampo M, Velasquez G, Sharma GP and Garcia-Rangel S. 2014. Global invasion of *Lantana camara*: has the climatic niche been conserved across continents? *PLoS One* **9**(10): e111468.

Grenouillet G, Buisson L, Casajus N and Lek S. 2011. Ensemble modelling of species distribution: the effects of geographical and environmental ranges. *Ecography* **34**(1): 9–17.

Guan BC, Guo HJ, Chen SS, Li DM, Liu X, Gong XI and Ge G. 2020. Shifting ranges of eleven invasive alien plants in China in the face of climate change. *Ecological Informatics* **55**: 101024.

Guisan A and Zimmermann NE. 2000. Predictive habitat distribution models in ecology. *Ecological Modelling* **135**(2-3): 147–186.

Guisan A and Thuiller W. 2005. Predicting species distribution: offering more than simple habitat models. *Ecology Letters* **8**(9): 993–1009.

Guisan A, Tingley R, Baumgartner JB, Naujokaitis Lewis I, Sutcliffe PR, Tulloch AIT, Regan TJ, Brotons L, McDonald Madden E, Mantyka Pringle C and Martin TG, Rhodes JR, Magini R, Setterfield SA, Elith J, Schwartz MW, Wintle BA, Broennimann O, Austin M, Ferrier S, Kearney MR, Possingham HP and Buckley YM. 2013. Predicting species distributions for conservation decisions. *Ecology letters* **16**(12): 1424–1435.

Hannah L, Midgley GF, Lovejoy T, Bond WJ, Bush MLJC, Lovett JC, Scott D and Woodward FI. 2002. Conservation of biodiversity in a changing climate. *Conservation Biology* **16**(1): 264–268. jstor.org/stable/3061423

Hellmann JJ, Byers JE, Bierwagen BG and Dukes JS. 2008. Five potential consequences of climate change for invasive species. *Conservation Biology* **22**(3): 534–543.

Hijmans RJ and Graham CH. 2006. The ability of climate envelope models to predict the effect of climate change on species distributions. *Global Change Biology* **12**(12): 2272–2281.

Hong SH, Lee YH, Lee G, Lee DH and Adhikari P. 2021. Predicting Impacts of Climate Change on Northward Range Expansion of Invasive Weeds in South Korea. *Plants* **10**(8): 1604.

Hoveka LN, Bezeng BS, Yessoufou K, Boatwright JS, Van der Bank M.2016. Effects of climate change on the future distributions of the top five freshwater invasive plants in South Africa. *South African Journal of Botany* **102**: 33–38.

Huang CY and Geiger EL.2008. Climate anomalies provide opportunities for large-scale mapping of non-native plant abundance in desert grasslands. *Diversity and Distributions* **14**(5): 875–884.

IPCC. 2014. Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assesment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, RK Pachauri and LA Meyer (eds).] IPCC, Geneva, Switzerland, 151 pp.

Ishii J and Washitani I. 2013. Early detection of the invasive alien plant *Solidago altissima* in moist tall grassland using hyperspectral imagery. *International Journal of Remote Sensing* **34**(16): 5926–5936.

Jarnevich CS, Holcombe TR, Barnett DT, Stohlgren TJ and Kartesz JT. 2010. Forecasting weed distributions using climate data a GIS early warning tool. *Invasive Plant Science and Management* **3**(4): 365–375.

Jimenez-Valverde A, Peterson AT, Soberon J, Overton JM, Aragon P and Lobo JM. 2011. Use of niche models in invasive species risk assessments. *Biological Invasions* **13**(12): 2785–2797.

Ju RT, Zhu HY, Gao L, Zhou XH and Li B. 2015. Increases in both temperatures means and extremes likely facilitate invasive herbivore outbreaks. *Scientific Reports* **5**(1): 1–10.

Kadioglu I and Farooq S. 2017. Potential Distribution of Sterile Oat (*Avena sterilis* L.) in Turkey under Changing Climate. *Turkish Journal of Weed Science* **20**(2): 1–13.

Kariyawasam CS, Kumar L and Ratnayake SS. 2019. Invasive Plants Distribution Modeling: A Tool for Tropical Biodiversity Conservation with Special Reference to Sri Lanka. *Tropical Conservation Science* **12**: 1–12.

Kariyawasam CS, Kumar L, Ratnayake SS. 2019. Invasive Plant Species Establishment and Range Dynamics in Sri Lanka under Climate Change. *Entropy* **21**(6): 571.

Katz TS and Zellmer AJ. 2018. Comparison of model selection technique performance in predicting the spread of newly invasive species: a case study with *Batrachochytrium salamandrivorans*. *Biological Invasions* **20**(8): 2107–2119.

Kearney M and Porter W. 2009. Mechanistic niche modeling combining physiological and spatial data to predict species ranges. *Ecology Letters* **12**(4): 334–350.

Kleunen van M, Dawson W, Essl F, Pergl J, Winter M, Weber E, Kreft H, Weigelt P, Kartesz J, Nishino M, Antonova LA, Barcelona JF, Cabezas FJ, Cardenas D, Cardenas Toro J, Castano N, Chacon E, Chatelain C, Ebel AL, Figueiredo E, Fuentes N, Groom QJ, Henderson L, Singh I, Kupriyanov A, Masciadri S, Meerman J, Morozova O, Moser D, Nickrent DL, Patzelt A, Pelser PB, Baptiste MP, Poopath M, Schulze M, Seebens H, Shu WS, Thomas J, Velayos M, Wieringa JJ and Pyšek P. 2015. Global exchange and accumulation of non-native plants. *Nature* **525**: 100–103.

Kriticos DJ, Sutherst RW, Brown JR, Adkins SW, Maywald GF. 2003. Climate change and the potential distribution of an invasive alien plant: Acacia nilotica ssp. indica in Australia. *Journal of Applied Ecology* **40**(1): 111–124.

Kriticos, D J, Yonow T and Mcfadyen R E. 2004. The potential distribution of *Chromolaena odorata* (Siam weed) in relation to climate. *Weed Research* **45**(4): 246–254.

Kwak TS, Ki JH, Kim YE, Jeon HM and Kim SJ. 2008. A study of GIS prediction model of domestic fruit cultivation location changes by the global warming-six tropical and sub-tropical fruits. *Journal of Korea Spatial Information System Society* **10**(3): 93-106.

Lee H.W. 2010. A study of methodologies assessing species susceptibility to climate change. *Issue studies of Korea Environment Institute* **13**(10): 1559.

Lemke D, Hulme PE, Brown JA and Tadesse W. 2011. Distribution modelling of Japanese honeysuckle (*Lonicera japonica*) invasion in the Cumberland Plateau and Mountain Region, USA. *Forest Ecology and Management* **262**(2): 139–149.

Manzoor SA, Grifths G, Iizuka K and Lukac M. 2018. Land cover and climate change may limit invasiveness of *Rhododendron ponticum* in Wales. *Frontiers in Plant Science* **9**: 664.

Marambe B and Wijesundara S. 2021. Effects of Climate Change on Weeds and Invasive Alien Plants in Sri Lankan Agro-Ecosystems: Policy and Management Implications. *Frontiers in Agronomy* **3**: 641006.

Maharjan S, Shrestha BB, Joshi MD, Devkota A, Muniappan R, Adiga A and Jha PK. 2019. Predicting suitable habitat of an invasive weed *Parthenium hysterophorus* under future climate scenarios in Chitwan Annapurna Landscape, Nepal. *Journal of Mountain Science* **16**: 2243–2256.

Marmion M, Parviainen M, Luoto M, Heikkinen RK and Thuiller W. 2009. Evaluation of consensus methods in predictive species distribution modelling. *Diversity and Distribution* **15**(1): 59–69.

Masum SM, Halim A, Mandal MSH, Asaduzzaman M and Adkins S. 2022. Predicting Current and Future Potential Distributions of *Parthenium hysterophorus* in Bangladesh Using Maximum Entropy Ecological Niche Modelling. *Agronomy* **12**(7): 1592.

McNeeley JA, Mooney HA, Neville LE, Schei PJ and Waage JK. 2001. Global Strategy on Invasive Alien Species. *IUCN: International Union for Conservation of Nature* **19**(3): 523–527.

Merow C, Bois ST, Allen JM, Xie Y and Silander Jr JA. 2017. Climate change both facilitates and inhibits invasive plant ranges in New England. *Proceedings of the National Academy of Sciences of the United States of America* **114**(16): 3276–3284.

Mitchell JJ and Glenn NF. 2009. Leafy spurge (*Euphorbia esula*) classification performance using hyperspectral and multispectral sensors. *Rangeland Ecology and Management* **62**: 16–27.

Moshobane MC and Esser LF. 2022. Ensemble modeling for the potential distribution of invasive weed *Verbesina encelioides* in South Africa from 2020 to 2090. *Management of Biological Invasions* **13**(4): 833-844.

Panda RM, Behera MD, Roy PS. 2018. Assessing distributions of two invasive species of contrasting habits in future climate. *Journal of Environmental Management* **213**: 478–488.

Panda RM and Behera MD. 2019. Assessing harmony in distribution patterns of plant invasions: a case study of two invasive alien species in India. *Biodiversity and Conservation* **28**(1): 2245–2258.

Parker C. 2012. Parasitic Weeds: A World Challenge. *Weed Science* **60**(2): 269–276.

Pearson RG and Dawson TP. 2003. Predicting the impacts of climate change on the distribution of species are bioclimate envelope models useful? *Global Ecology and Biogeography* **12**(5): 361–371.

Peterson AT and Anamza T. 2015. Ecological niches and present and historical geographic distributions of species: a 15-year review of frameworks, results, pitfalls, and promises. *Journal of Vertebrate Biology* **64**(3): 207–217.

Peterson AT, Papes M and Soberon J. 2015. Mechanistic and correlative models of ecological niches. *European Journal of Ecology* **1**(2): 28–38.

Peterson AT and Soberón J. 2012. Species distribution modeling and ecological niche modeling: getting the concepts right. *Natureza and Conservação* **10**(2): 102–107.

Phillips SJ, Anderso RP and Schapire RE. 2006. Maximum entropy modeling of species geographic distributions. *Ecological modelling* **190**(3-4): 231–259.

Poudel AS, Shrestha BB, Joshi MD, Muniappan R, Adiga A, Venkatramanan S and Jha PK. 2020. Predicting the Current and Future Distribution of the Invasive Weed *Ageratina adenophora* in the Chitwan–Annapurna Landscape, Nepal. *Mountain Research and Development* **40**(2): R61–R71.

Priyanka N and Joshi PK. 2013. Effects of climate change on invasion potential distribution of *Lantana camara*. *Journal of Earth Science and Climatic Change* **4**(6): 1000164.

Rao AN, Brainard DC, Kumar V, Ladha JK and Johnson DE. 2017. Preventive weed management in direct-Seeded Rice: Targeting the weed seedbank. *Advances in Agronomy* **144**: 45–142.

Reaser JK, Burgiel SW, Kirkey J, Brantley KA, Veatch SD and Burgos RJ. 2020. The early detection of and rapid response (EDRR) to invasive species: a conceptual framework and federal capacities assessment. *Biological Invasions* **22** (1): 1–19.

Roger E, Duursma DE, Downey PO, Gallagher RV, Hughes L, Steel J, Johnson SB and Leishman MR. 2015. A tool to assess potential for alien plant establishment and expansion under climate change. *Journal of Environmental Management* **159**: 121–127.

Romero-Alvarez D, Escobar LE, Varela S, Larkin DJ, Phelps NBD. 2017. Forecasting distributions of an aquatic invasive species (*Nitellopsis obtusa*) under future climate scenarios. *PLoS ONE* **12**(7): e0180930.

Rosenzweig C, Iglesius A, Yang XB, Epstein PR and Chivian E. 2001. Climate change and extreme weather events-Implications for food production, plant diseases, and pests. *Global Change and Human Health* **2**(2): 90–104.

Runquist Briscoe RD, Lake T, Tiffin P and Moeller DA. 2019. Species distribution models throughout the invasion history of Palmer amaranth predict regions at risk of future invasion and reveal challenges with modeling rapidly shifting geographic ranges. *Scientific Reports* **9**(1): 2426.

Sathischandra HGAS, Marambe B and Punyawardena R. 2014. Seasonal changes in temperature and rainfall and its relationship with the incidence of weeds and insect pests in rice (*Oryza sativa* L) cultivation in Sri Lanka. *Climate Change and Environment Sustainability* **2**(2): 105–115.

Seebens H, Blackburn TM, Dyer EE, Genovesi P, Hulme PE, Jeschke JM, Pagad S, Pysek P, Winter M, Arianoutsou M, Bachler S, Blasius B, Brundu G, Capinha C, Celesti-Grapow L, Dawson W, Dullinger S, Fuentes N, Jager H, Kartesz J, Kenis M, Kreft H, Kuhn I, Lenzner B, Liebhold A, Mosena A, Moser D, Nishino M, Pearman D, Pergl J, Rabitsch W, Rojas-Sandoval J, Roques A, Rorke S, Rossinelli S, Roy HE, Scalera R, Schindler S, Štajerova K, Tokarska-Guzik B, van Kleunen M, Walker K, Weigelt P, Yamanaka T and Essl F. 2017. No saturation in the accumulation of alien species worldwide. *Nature Communications* **8**(1): 14435.

Shrestha UB, Sharma KP, Devkota A, Siwakoti M and Shrestha BB. 2018. Potential impact of climate change on the distribution of six invasive alien plants in Nepal. *Ecological Indicators* **95**(1): 99–107.

Soberon J, Osorio-Olvera L and Peterson T. 2017. Conceptual differences between ecological niche modeling and species distribution modeling. *Revista Mexicana de Biodiversidad* **88**(2): 437–441.

Srivastava V, Lafond V and Griess VC. 2019. Species distribution models (SDM): applications, benefits and challenges in invasive species management. *CABI Reviews* **14**(20): 1–13.

Taylor S, Kumar L, Reid N and Kriticos DJ. 2012. Climate change and the potential distribution of an invasive shrub, *Lantana camara* L. *PloS one* **7**(4): e35565.

Taylor S. and Kumar L. 2013. Potential distribution of an invasive species under climate change scenarios using CLIMEX and soil drainage: a case study of *Lantana camara* L. in Queensland, Australia. *Journal of Environmental Management* **114**: 414–422.

Taylor S and Kumar L. 2012. Climate change and invasive weeds-Modeling distribution of *Lantana camara* (L.). The GSTF *Journal of Engineering Technology (JET)* **1**(1):56–60.

Thapa S, Chilate V, Rijal SJ, Bisht N and Shrestha BB. 2018. Underlying the dynamics in distribution of invasive alien plant species under predicted climate change in Western Himalaya. *PloS one* **13**(4): e0195752.

Thuiller W. 2004. Patterns and uncertainties of species' range shifts under climate change. *Global Change Biology* **10**(12): 2020–2027.

Thuiller W, Lafourcade B, Engler R and Araujo MB. 2009. BIOMOD–a platform for ensemble forecasting of species distributions. *Ecography* **32**(3): 369–373.

Tiwari S, Mishra SN, Kumar D, Kumar B, Vaidya SN, Ghosh BG, Rahaman SkM, Khatun M, Garai S and Kumar A. 2022 Modelling the potential risk zone of *Lantana camara* invasion and response to climate change in eastern India. *Ecological Processes* **11**.

Trethowan PD, Robertson MP and McConnachie AJ. 2011. Ecological niche modelling of an invasive alien plant and its potential biological control agents. *South African Journal of Botany* **77**(1): 137–146.

Tu W, Xiong Q, Qiu X and Zhang Y. 2021. Dynamics of invasive alien plant species in China under climate change scenarios *Ecological Indicators* **129**: 107919.

Van Wilgen BW, Fill JM, Baard J, Cheney C, Forsyth AT and Kraaij T. 2016. Historical costs and projected future scenarios for the management of invasive alien plants in protected areas in the Cape Floristic Region. *Biological Conservation* **200**: 168–177.

Wan JZ and Wang CJ, Tan JF and Yu FH. 2017. Climatic niche divergence and habitat suitability of eight alien invasive weeds in China under climate change. *Ecology and Evolution* **7**(5): 1541–1552.

Wan JZ and Wang CJ. 2019. Contribution of environmental factors toward distribution of ten most dangerous weed species globally. *Applied Ecology and Environmental Research* **17**(6): 14835-14846.

Wang CJ, Wan JZ, Qu H and Zhang ZX. 2017. Modelling plant invasion pathways in protected areas under climate change: implication for invasion management. *Web Ecology* **17**: 69-77.

Wei J, Zhang H, Zhao W and Zhao Q. 2017. Niche shifts and the potential distribution of *Phenacoccus solenopsis* (Hemiptera: Pseudococcidae) under climate change. *PloS one* **12**(7): e0180913.

Welk E, Schubert K and Hoffmann MH. 2002. Present and potential distribution of invasive garlic mustard (*Alliaria petiolata*) in North America. *Diversity and Distributions* **8**(4): 219–233.

Wisz MS, Pottier J, Kissling WD, Pellissier L, Lenoir J, Damgaard CF, Dormann CF, Forchhammer MC, Grytnes JA, Guisan A, Heikkinen RK, Hoye TT, Kuhn I, Luoto M, Maiorano L, Nilsson M-C, Normand S, Ockinger E, Schmidt NM, Termansen M, Timmermann A, Wardle DA, Aastrup P and Svenning J-C. 2013. The role of biotic interactions in shaping distributions and realised assemblages of species: implications for species distribution modelling. *Biological Reviews* **88**(1): 15–30.

Wisz MS, Hijmans RJ, Li J, Peterson AT, Graham CH, Guisan A and NCEAS Predicting Species Distributions Working Group. 2008. Effects of sample size on the performance of species distribution models. *Diversity and Distributions* **14**(5): 763–773.

Yan H, Feng L, Zhao Y, Feng L, Zhu C, Qu Y and Wang H. 2020. Predicting the potential distribution of an invasive species, *Erigeron canadensis* L. in China with a maximum entropy model. *Global Ecology and Conservation* **21**: e00822.

Yang C and Everitt JH. 2010. Comparison of hyperspectral imagery with aerial photography and multispectral imagery for mapping broom snakeweed. *International Journal of Remote Sensing* **31**(20): 5423–5438.

Yuan Y, Tang X, Liu M, Liu X and Tao J. 2021. Species Distribution Models of the *Spartina alterniflora* Loisel in Its Origin and Invasive Country Reveal an Ecological Niche Shift. *Frontiers in Plant Science* **12**: 738769.

Zhang X, Wang Y, Peng P, Wang G, Zhao G, Zhou Y and Tang Z. 2022. Mapping the Distribution and Dispersal Risks of the Alien Invasive Plant *Ageratina adenophora* in China. *Diversity* **14**(11): 915.

Zhu G, Li H and Zhao L. 2017. Incorporating anthropogenic variables into ecological niche modeling to predict areas of invasion of *Popillia japonica*. *Journal of Pesticide Sciences* **90**(1): 151–160.

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RESEARCH ARTICLE

Weed competitive ability and productivity of transplanted rice cultivars as influenced by weed management practices

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ABSTRACT

Weed competitive ability of six rice cultivars including three hybrids [Arize 6129 (short duration); Arize 6444 (medium duration), Arize Dhani (long duration)] and three varieties [Swarna Shreya (short duration); Rajendra Sweta (medium duration); MTU 7029 (long duration)] was evaluated under three weed pressures *i.e.* low weed pressure [pre-emergence application (PE) of pretilachlor 0.60 kg/ha at 2 days after transplanting (DAT) followed by *(fb)* post-emergence application (PoE) of bispyribac-sodium 30 g/ha at 20 DAT *fb* 1 hand weeding (HW) at 35 DAT; medium weed pressure (pretilachlor PE at 2 DAT *fb* bispyribac-sodium PoE at 20 DAT) and high weed pressure (weedy check)]. Experiment was conducted during rainy seasons of 2018 and 2019 at the ICAR-Research Complex for Eastern Region Patna, Bihar. The major weeds recorded with transplanted rice were *Brachariaria ramosa, Trianthema portulacastrum, Cyperus rotundus, Echinochloa colona, Caesulia axillaris* and *Physalis minima*. Rice hybrids, *viz.* Arize 6444 and Arize Dhani, and rice variety Swarna Shreya recorded significantly lower weed biomass compared to other varieties. Weeds reduced rice grain yield by 31.37%. Long-duration and short statured rice variety MTU 7029 was more susceptible to weed competition compared to other varieties and hybrids. Early duration hybrid Arize 6129 recorded low weed pressure, maximum rice grain yield (6.57 t/ha) and economic returns.

Keywords: Cultivars competitiveness, Hybrids, Rice, Varieties, Weed management

INTRODUCTION

Weeds are one of the major constraints in transplanted rice in drought-prone environments. Weeds compete with rice for moisture, nutrients, light, and space, and as a consequence result in yield loss ranging from 20-60% depending on the nature and density of weed species, and management practices (Rao *et al*. 2017). Farmers do follow certain weed management practices (manual, mechanical, herbicides, *etc*.) to minimise the weed infestation in crop fields. However, weeds are so complex and diverse in rice fields that no single method can control them effectively. Manual weeding is the most common method to suppress weeds in rice but scarcity of labour for timely weeding and high labour cost are major limitations (Mishra *et al.* 2022). The herbicidal weed management offers better weed control, but it may lead to environmental hazards. Moreover, weeds germinate in several flushes especially during rainy season, and may not be controlled satisfactorily using only herbicides. In such conditions, use of weed competitive cultivars as a component of integrated weed management system would be highly economical and eco-friendly. Rice verities vary in their weed competitive ability due to their diverse morphological traits, *viz*. plant height, tillering ability, canopy structure and relative growth rate, *etc*. (Ramesh *et al*. 2017; Kumar *et al.* 2020). Weed competitive cultivars are characterized by higher early vigour, higher leaf-area and biomass accumulation, rapid ground cover by canopy, deep and prolific roots, more tillering ability, taller plant, early maturity and allelopathy (Caton *et al*. 2003; Dhillon *et al*. 2021). A quick growing and early canopy cover enables a cultivar to compete better against weeds. Tall cultivars of rice exert effective smothering effect on weeds. Duration of the rice varieties also influences the crop-weed competition. Early maturing rice cultivars and hybrids have smothering effect on weeds due to improved vigour and having the tendency of early canopy cover (Mandal *et al.* 2011). In drought-prone environments,

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short duration rice cultivars may have high weed competitive ability over longer duration cultivars. However, the weed suppressing ability of rice cultivars may vary under different weed management practices. Therefore, the present study evaluated the weed competitive ability of rice cultivars under different levels of weed management in transplanted rice in the middle Indo-Gangetic Plains (IGP).

MATERIALS AND METHODS

The present study was carried out at the ICAR-Research Complex for Eastern Region, Patna, Bihar (25°30'N, 85°15'E, 52 m above mean sea levels) during 2018 and 2019. Total rainfall received during cropping season (June–October) was 715.7 and 911.5 mm in 2018 and 2019, respectively. Soil was clay loam (42% sand, 35% silt and 23% clay), low in organic carbon (0.46%), and N (212 kg/ha), and medium in available phosphorus (26 kg P/ha) and potassium (215 kg K/ha). Experiment was laid out in a split-plot design with three replications. The main plot consisted of three weed pressure maintenance treatments includes low weed pressure maintained with pre-emergence application (PE) of pretilachlor 0.60 kg/ha at 2 days after transplanting (DAT) followed by (*fb*) post-emergence application (PoE) of bispyribac-sodium 30 g/ha at 20 DAT followed by (*fb*) hand weeding (HW) at 35 DAT; medium weed pressure maintained with pretilachlor 0.60 kg/ha PE at 2 DAT *fb* bispyribac-sodium 30 g/ha PoE at 4-6 leaf stage *i.e.* 20 DAT, and high weed pressure maintained as weed check. Six high yielding rice cultivars including 3 hybrids [Arize 6129 (short duration: 115-120 days), Arize 6444 (medium duration: 130-135), Arize Dhani (long duration: 150-155)] and three varieties [Swarna Shreya (short duration: 115-120 days), Rajendra Sweta (medium duration: 130-135), MTU 7029 (long duration: 145-150)], were kept in sub plots. Herbicides were sprayed with knap-sack sprayer fitted with flat-fan nozzle using 500 litres/ha spray volume. Recommended dose of fertilizer (120, 60, 40 and 5 kg/ha N, P, K and Zn) was applied. Total quantity of P, K and Zn was applied as basal, whereas nitrogen was applied in 3-equal split-each at basal, maximum tillering and panicle initiation. There were large variations in rainfall intensity and distribution patterns during the experimentation. Average of mean rainfall during rice season (June–October) was 715.7 mm and 911.5 mm in 2018 and 2019, respectively. During 2018, crop faced early and late-season drought during cropping periods, but during 2019, rainfall was distributed quite uniformly. Mean monthly maximum and minimum temperature ranged between 28.7-37.4 and 16.1-28.2°C during 2018 and 2019, respectively. Leaf-area index (LAI) was measured at 60 DAS by removing all the leaves from each of 5 randomly selected plants from each plot and passing them individually through a stationary leaf area meter (Model: LI-COR 310).

Weed density and biomass were recorded at 60 DAT using a quadrat (0.5 × 0.5 m) placed randomly at 4 places in each plot. Weeds within each quadrat were uprooted, separated species wise and counted. Weed samples were oven dried before weighing at 70°C till constant weight was achieved. Data on weed density were subjected to square root transformation ($\sqrt{x+0.5}$) before statistical analysis to normalize their distribution. Data were analyzed statistically as per standard method (Panse and Sukhatme 1978). Test of significance of treatment differences was done on the basis of t-test. Significant difference between treatments mean was compared with critical differences at 5% levels of probability.

RESULTS AND DISCUSSION

Effect on weeds

The experimental field was infested with grasses (19.8%), broad-leaved weeds (67.26%) and sedges (12.93%). Among grassy weeds, *Brachiaria ramosa* (10.44%) was dominant followed by *Echinochloa colona* (8.63%). *Trianthema portulacastrum* (58.02%) was the major broad-leaved weed and *Cyperus rotundus* (8.9%), the major sedge. Other weeds contributed 3.69%.

Weed management practices and rice cultivars significantly influenced the weed flora density and biomass (**Table 1** and **2**). Irrespective of the weed species, pretilachlor *fb* bispyribac-sodium *fb* 1 HW at 35 DAT resulted in significantly lower total weed density and biomass. In general, hybrids were more competitive against weeds than the varieties, but the response varied with weed species. The density and biomass of *B. ramosa* was significantly lower in association with Arize 6444 than in Rajendra Sweta. Among rice varieties, Swarna Shreya was more competitive than the other two varieties. The density of *T. portulacastrum* was significantly lower in 'Arize 6444' as compared to long duration rice variety MTU 7029 (56.65/m^2). The density and biomass of *C. rotundus*, *E. colona* and *C. axillaris* did not vary significantly due to rice cultivars. Total weed density and biomass was significantly lower with rice hybrid Arize 6444 compared to long duration rice variety MTU 7029. Among hybrids, Arize Dhani being on a par with Arize 6444 and among varieties, Swarna Shreya registered the lowest weed biomass. This might be due to taller plant height and higher leaf area index resulting in better weed suppression. Kumar (2018) and Kumar *et al.* (2016) also reported that tall statured genotypes with drooped leaves were found to be more competitive than short and erect leaved genotypes. Better weed suppressing ability of hybrid rice over open-pollinated varieties was also reported by Awan *et al.* (2018).

Effect on rice

Crop growth, yield attributes and grain yield were significantly influenced by weed management practices and cultivars (**Table 3**). In general, higher grain yield of rice was recorded during 2019 as compared to 2018 due to sufficient and evenly distributed rainfall during 2019 (911.5 mm) compared to 2018 (715.7 mm). Uncontrolled weeds (high weed pressure) reduced rice grain yield by 31.37% as compared to low weed pressure. Maintaining low weed pressure with pretilachlor PE *fb* bispyribac-sodium PoE *fb* 1 HW at 35 DAT recorded significantly higher growth and yield attributes and grain yield of rice due to lesser crop-weed competition, followed by medium and high weed pressure treatments which can be attributed to lesser crop-weed competition for nutrients and moisture supply, resulting in maximum use of inputs for crop growth, yield attributes and yield. Maximum plant height, leaf area index, dry matter/hill was recorded with rice hybrid Arize 6444 but number of tillers/m^2 was higher with Arize 6129. Panicle length in all the 3 hybrids (24.3-24.9 cm) was at par with rice variety Swarna Shreya (24.6 cm), but significantly higher than Rajendra Sweta (20.6 cm) and MTU 7029 (22.5

Table 1. Weed density (no./m^2) at 60 DAT as influenced by rice cultivars and weed management treatments in transplanted rice (pooled data of 2 years)

Treatment	*Brachariaria ramosa*	*Trianthema portulacastrum*	*Cyperus rotundus*	*Echinochloa colona*	*Caesulia axillaris*	*Physalis minima*	Others weeds	Total weed density
Weed management practices								
Low weed pressure	2.63 (6.4)	4.82 (22.9)	3.00 (8.7)	1.45 (1.6)	1.49 (1.8)	0.92 (0.3)	2.79 (7.4)	7.10 (50.0)
Medium weed pressure	3.30 (10.4)	6.35 (39.8)	3.64 (12.9)	1.92 (3.2)	1.70 (2.4)	1.81 (2.8)	2.84 (7.6)	8.99 (80.9)
High weed pressure	4.67 (21.5)	10.95 (119.6)	5.18 (26.6)	4.20 (17.2)	2.99 (8.5)	2.31 (5.0)	2.84 (7.6)	14.37 (206.1)
LSD (p=0.05)	0.36	0.47	0.29	0.35	0.38	0.38	NS	0.43
Cultivars								
Arize 6129	3.62 (12.6)	7.37 (53.8)	4.06 (16.0)	2.50 (5.7)	2.16 (4.2)	1.77 (1.6)	2.84 (7.6)	10.25 (103.7)
Arize 6444	3.21 (9.8)	6.98 (48.2)	3.98 (15.3)	2.66 (6.6)	2.12 (4.0)	1.59 (2.0)	2.79 (7.3)	9.80 (95.2)
Arize Dhani	3.24 (10.0)	7.53 (56.2)	4.02 (15.7)	2.30 (4.8)	1.92 (3.2)	1.62 (2.2)	2.76 (7.2)	10.08 (101.2)
Swarna Shreya	3.61 (12.5)	7.65 (58.0)	3.73 (13.4)	2.32 (4.9)	1.85 (2.9)	1.70 (2.4)	2.89 (7.9)	10.26 (104.4)
Rajendra Sweta	3.82 (14.1)	7.14 (50.5)	4.04 (15.8)	2.74 (7.0)	2.01 (3.5)	1.54 (1.9)	2.80 (7.4)	10.13 (102.1)
MTU 7029	3.72 (13.3)	7.56 (56.6)	3.80 (13.9)	2.60 (6.3)	2.30 (4.8)	1.88 (3.1)	2.86 (7.7)	10.40 (107.5)
LSD (p=0.05)	0.45	0.40	NS	NS	NS	0.26	NS	0.40

Low weed pressure: pre-emergence application (PE) of pretilachlor 2 DAT *fb* post-emergence application (PoE) of bispyribac-sodium at 20 DAT *fb* 1 HW at 35 days after transplanting (DAT); Medium weed pressure: pretilachlor PE at 2 DAT *fb* bispyribac- sodium PoE at 20 DAT; High weed pressure: weedy check

Table 2. Weed biomass (g/m^2) at 60 DAT as influenced by rice cultivars and weed management practices (pooled data of 2 years)

Treatment	*Brachariaria ramosa*	*Trianthema portulacastrum*	*Cyperus rotundus*	*Echinochloa colona*	*Caesulia axillaris*	*Physalis minima*	Other weeds	Total biomass
Weed management practices								
Low weed pressure	1.68 (2.32)	2.56 (6.05)	1.76 (2.59)	1.38 (1.40)	1.15 (0.82)	0.80 (0.14)	1.93 (3.22)	4.23 (17.39)
Medium weed pressure	1.93 (3.22)	3.31 (10.46)	1.98 (3.42)	1.59 (2.03)	1.30 (1.22)	1.26 (1.09)	1.89 (3.09)	5.07 (25.20)
High weed pressure	2.44 (5.45)	4.63 (20.94)	2.54 (5.95)	3.54 (12.03)	2.29 (4.74)	1.49 (1.72)	2.13 (4.04)	7.50 (55.75)
LSD (p=0.05)	0.15	0.20	0.11	0.33	0.27	0.24	0.30	0.24
Cultivars								
Arize 6129	1.90 (3.11)	3.62 (12.60)	2.18 (4.44)	2.17 (4.21)	1.71 (2.42)	1.31 (1.22)	2.02 (3.58)	5.73 (32.33)
Arize 6444	1.78 (2.67)	3.47 (11.54)	2.08 (3.98)	2.24 (4.52)	1.65 (2.22)	1.20 (0.94)	1.91 (3.15)	5.49 (29.64)
Arize Dhani	1.73 (2.50)	3.55 (12.10)	2.15 (4.12)	1.84 (2.89)	1.55 (1.90)	1.02 (0.54)	1.93 (3.22)	5.35 (28.12)
Swarna Shreya	1.99 (3.46)	3.40 (11.60)	2.13 (4.04)	2.03 (3.62)	1.41 (1.59)	1.15 (0.82)	1.89 (3.10)	5.40 (28.66)
Rajendra Sweta	2.34 (4.98)	3.42 (11.20)	2.11 (3.99)	2.39 (5.21)	1.47 (1.66)	1.09 (0.69)	1.92 (3.19)	5.72 (32.22)
MTU 7029	2.35 (5.02)	3.53 (11.96)	1.92 (3.19)	2.35 (5.02)	1.70 (2.39)	1.33 (1.27)	2.23 (4.47)	5.91 (34.43)
LSD (p=0.05)	0.28	NS	NS	NS	0.19	0.18	NS	0.26

Low weed pressure: pre-emergence application (PE) of pretilachlor 2 DAT *fb* post-emergence application (PoE) of bispyribac-sodium at 20 DAT *fb* 1 HW at 35 days after transplanting (DAT); Medium weed pressure: pretilachlor PE at 2 DAT *fb* bispyribac- sodium PoE at 20 DAT; High weed pressure: weedy check cm). Number of filled grains/panicle were significantly lower in MTU 7029 (123.1) compared to other varieties (164.5-169.7) and hybrids (156.7-163.9). Early duration rice produced higher grain yields due to early completion of maturity without facing post-flowering drought during October month.

Interaction effect between weed management and rice cultivars for grain yield was significant. Grain yield decreased with increasing levels of weed pressure. However, the rate of reduction due to high weed pressure was maximum with long-duration rice variety MTU 7029 (46.63%) compared to other varieties (35%) and hybrids (20.93-27.42%) (**Table 4**). This might be due to less weed suppression due to shorter height of the variety, and longer duration of maturity (153 days) resulting in higher weed biomass and setback of post-flowering drought stress (Kumar *et al.* 2016). Hybrids produced higher grain yield compared to varieties even under high weed pressure. In the present study, higher net returns and B:C were obtained with rice hybrids compared to varieties. Arize 6129 (among hybrids) and Swarna Shreya (among varieties) had significantly higher net returns of ₹ 83,895 and ₹ 55,201/ha due to better crop productivity. In spite of higher cost of cultivation, net returns (₹ 66,763/ha) and B:C (2.22) were significantly higher with low weed pressure compared to medium and high weed pressures due to higher grain yield (**Table 5**).

It may be concluded that hybrids have better weed competitive ability than the varieties. Growing of high yielding rice hybrids Arize 6129, Arize 6444 or Arize Dhani and cultivar Swarna Shreya with adequate weed management by using pretilachlor

Table 3. Growth attributes and crop phenology as influenced by rice cultivars and weed management treatments (pooled data of 2 years)

Treatment	Plant height (cm)	Leaf area index	Dry matter/ hill (g)	Tillers / m^2 (no.)	Days to 50% flowering	Days to maturity (no.)	Panicle length (cm)	Grains/ panicle (no.)	Filled grains/ panicle (no.)	Chaffy grains/ panicle (no.)	1000-grain weight (g)	Grain yield (t/ha) 2018	Grain yield (t/ha) 2019
Weed management practices													
Low weed pressure	103.3	11.08	97.9	238.4	96.1	137	24.9	215.2	189.4	25.8	23.2	5.11	6.11
Medium weed pressure	101.3	8.26	88.8	191.1	91.1	134	23.8	198.8	161.1	37.7	21.7	4.44	5.38
High weed pressure	103.6	2.79	90.2	124.5	89.2	132	22.1	170.8	117.8	53.0	20.5	3.04	4.66
LSD (p=0.05)	1.7	0.91	1.7	15.7	1.7	2.0	0.9	18.1	18.4	7.1	0.7	0.16	0.34
Cultivars													
Arize 6129 (SD)	106.1	7.17	109.4	199.1	79.1	112	24.8	183.3	158.8	24.4	23.9	5.25	6.10
Arize 6444 (MD)	107.4	8.71	110.1	187.8	83.2	122	24.9	203.7	163.9	39.9	24.5	4.74	5.73
Arize Dhani (LD)	101.9	8.57	104.5	163.9	93.1	137	24.3	198.3	156.7	41.6	22.0	4.64	5.56
Swarna Shreya (SD)	103.6	5.39	106.2	169.8	78.4	136	24.6	203.7	164.5	39.3	22.8	3.82	5.25
Rajendra Sweta (MD)	103.1	6.79	105.8	197.7	88.1	145	20.6	213.2	169.7	43.6	14.2	3.35	4.98
MTU 7029 (LD)	94.6	7.62	18.0	189.8	119.6	153	22.5	167.3	123.1	44.3	23.6	3.39	4.68
LSD (p=0.05)	2.8	1.76	2.5	20.0	2.5	3	1.7	27.6	23.1	13.0	0.9	0.23	0.28

Low weed pressure: pre-emergence application (PE) of pretilachlor 2 DAT *fb* post-emergence application (PoE) of bispyribac-sodium at 20 DAT *fb* 1 HW at 35 days after transplanting (DAT); Medium weed pressure: pretilachlor PE at 2 DAT *fb* bispyribac- sodium PoE at 20 DAT; High weed pressure: weedy check

Table 4. Interaction effect of grain yield as influenced by rice cultivars and weed management treatments in transplanted rice (pooled data of 2 years)

Cultivars (V)	Weed management treatments (W): Low weed pressure	Medium weed pressure	High weed pressure	Mean	Reduction in yield due to high weed pressure compared to low weed pressure (%)
Arize 6129	6.57	5.62	4.85	5.68	26.18
Arize 6444	5.83	5.27	4.61	5.23	20.93
Arize Dhani	5.98	4.99	4.34	5.10	27.42
Swarna Shreya	5.40	4.73	3.49	4.54	35.37
Rajendra Sweta	4.86	4.50	3.14	4.16	35.40
MTU 7029	5.04	4.39	2.69	4.04	46.63
Mean	5.61	4.91	3.85		
LSD (*p*=0.05)	V	W	V×W		
	0.26	0.25	0.62		

Low weed pressure: pre-emergence application (PE) of pretilachlor 2 DAT *fb* post-emergence application (PoE) of bispyribac-sodium at 20 DAT *fb* 1 HW at 35 days after transplanting (DAT); Medium weed pressure: pretilachlor PE at 2 DAT *fb* bispyribac- sodium PoE at 20 DAT; High weed pressure: weedy check

Table 5. Economics as influenced by rice cultivars and weed management treatments (pooled data of 2 years)

Treatment	Cost of cultivation (x10^3 ₹/ha)	Gross returns (x10^3 ₹/ha)	Net returns (x10^3 ₹/ha)	B:C
Weed management practices				
Low weed pressure	54.60	121.37	66.76	2.22
Medium weed pressure	52.26	111.84	59.58	2.14
High weed pressure	50.24	101.38	51.14	2.02
LSD (p=0.05)		3.91	3.91	0.08
Cultivars				
Arize 6129	52.54	136.14	83.59	2.59
Arize 6444	53.19	118.75	65.56	2.24
Arize Dhani	51.94	119.25	67.30	2.30
Swarna Shreya	52.59	107.79	55.20	2.05
Rajendra Sweta	51.65	101.89	50.24	1.97
MTU 7029	52.30	75.37	23.07	1.42
LSD (p=0.05)		5.11	5.11	0.10

Low weed pressure: pre-emergence application (PE) of pretilachlor 2 DAT *fb* post-emergence application (PoE) of bispyribac-sodium at 20 DAT *fb* 1 HW at 35 days after transplanting (DAT); Medium weed pressure: pretilachlor PE at 2 DAT *fb* bispyribac- sodium PoE at 20 DAT; High weed pressure: weedy check

0.60 kg/ha PE fb bispyribac-sodium PoE 30 g/ha at 20 DAT *fb* one manual weeding at 25 DAT is a better option to manage the weeds and improve the transplanted rice productivity and profitability under rainfed ecosystem of middle Indo-Gangetic plains.

REFERENCES

Awan TH, Ahmed S and Chauhan BS. 2018. Weed competitive ability of a hybrid and an inbred rice cultivar in managing *Ischaemum rugosum* in dry-seeded rice. *Pakistan Journal of Agricultural Research* **55**(4): 739–748.

Caton BP, Cope AE and Mortimer M. 2003. Growth traits of diverse rice cultivars under severe competition: Implications for screening for competitiveness. *Field Crops Research* **83**(2): 157–172.

Kumar R, Mishra JS, Kumar S, Rao KK, Hans H, Bhatt BP, Srivastava AK and Singh S. 2020. Evaluation of weed competitiveness of direct-seeded rice (*Oryza sativa*) genotypes under different weed management practices. *Indian Journal of Agricultural Science* **90**(5): 914–918.

Kumar S, Mishra JS, Singh AK, Dwivedi SK, Singh SK, Singh SS, Haris AA, Mondal S, Bhatt BP, Singh S and Yadav A. 2016. Response of rice (*Oryza sativa*) genotypes to weed management in rainfed ecosystems of eastern India. *Indian Journal of Agronomy* **61**(1): 37–44.

Kumar S. 2018. Weed management practices in direct-seeded rice (*Oryza sativa* L.): A review. *Journal of Pharmacognosy and Phytochemistry* **7**(3): 2356–2362.

Mandal D, Singh D, Kumar R, Kumari A, Kumar V.2011. Effects on production potential and economics of direct seeded rice sowing dates and weed management techniques. *Indian Journal of Weed Science* **43**(3&4):139–144.

Mishra JS, Kumar R, Mondal S, Poonia SP, Rao KK, Dubey R, Raman RK, Dwivedi SK, Kumar R, Saurabh K, Monobrullah M, Kumar S, Bhatt BP, Malik RK, Kumar V, McDonald A and Bhaskar S. 2022.Tillage and crop establishment effects on weeds and productivity of a rice-wheat-mungbean rotation. *Field Crops Research* **284**: 108577.

Panse VG and Sukhatme PV.1978. *Statistical Methods for Agricultural Workers*, p.152.ICAR, New Delhi.

Ramesh K, Rao AN and Chauhan BS. 2017. Role of crop competition in managing weeds in rice, wheat, and maize in India: A review. *Crop Protection*. **97**: 14–21

Rao AN, Wani SP, Ahmed S, Ali H and Marambe B. 2017. An overview of weeds and weed management in rice of South Asia. In: Rao AN. and Matsumoto H. (Eds.). 2017. *Weed management in rice in the Asian-Pacific region*. pp. 247 to 281. Asian-Pacific Weed Science Society (APWSS); The Weed Science Society of Japan, Japan and Indian Society of Weed Science, India

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RESEARCH ARTICLE

Bio-efficacy of herbicide mixtures on weed dynamics in direct wet-seeded rice

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ABSTRACT

Weed infestation is the major yield limiting factor in direct wet-seeded rice (WSR). Herbicides use is gaining acceptance among the farmers as it is easy, economical, time saving, and efficient to manage weeds. The herbicide mixtures with different modes of action are preferable to use in rotation. An experiment was conducted to evaluate and identify a suitable pre-mix herbicide mixture and its dosage rate to get optimum weed management and rice yield in WSR during wet seasons of 2017 and 2018 at research farm of ICAR–National Rice Research Institute, Cuttack, Odisha, India using randomized complete block design with three replications. Nine treatments were tested including: *viz.* post-emergence application (PoE) of florpyrauxifen-benzyl + cyhalofop-butyl at 120, 150, 180 and 360 g/ha; florpyrauxifen-benzyl at 25 and 30 g/ha PoE; bispyribac-sodium 30 g/ha PoE; weed free and weedy check. Among the herbicide treatments, florpyrauxifen-benzyl + cyhalofop-butyl 150 g/ha PoE was most effective to control weeds with the lowest weed density, biomass, and weed index, lower weed persistence index and highest weed control index, weed control efficiency, crop resistance index, treatment efficiency index and weed management index at 60 days after sowing in WSR with higher rice grain yield, and was at par with the weed free. In weedy check, 40% rice yield loss was recorded. Thus, florpyrauxifen-benzyl + cyhalofop-butyl 150 g/ha PoE may be recommended for effective weed control in direct wet-seeded rice.

Keywords: Direct-seeded rice, Florpyrauxifen-benzyl + cyhalofop-butyl, Herbicide, Weed management, Wet-seeded rice

INTRODUCTION

Rice cultivation is an integral part of Indian agricultural economy being the second largest rice producer in the world. The average rice yield in India was 2.7 t/ha with total rice production of 116.42 Mt from an area of 43 Mha (Shahbandeh 2021). The lower rice productivity in India is due to different biotic and abiotic constraints. Among different biotic stresses, weed infestation is responsible for 40-60% yield loss (Dass *et al*. 2017) which accounts for about $4.42 billion every year in India (Gharde *et al.* 2018).

With the growing water and labour scarcity, farmers are adopting direct-seeded rice (DSR) as the method of crop establishment instead of the conventional puddled transplanted rice (PTR) (Rao *et al*. 2007). DSR is advantageous over transplanting due to faster and easier planting, reduced labour and drudgery, earlier crop maturity by 7-10 days, more efficient water use, higher tolerance of water deficit, lower methane emission and often higher profit in areas with an assured water supply (Balasubramanian and Hill 2002, Rao *et al.* 2007, Chauhan 2012).

Direct wet-seeded rice (WSR) is the method, where pre-germinated rice seeds are sown or broadcasted in puddled soil (Rao *et al.* 2017). The rainfed lowland ecosystem occupies nearly 35% (14.8 Mha) of total rice planted area in India *i.e.* 43 m ha, where, there is a possibility of puddling and sowing of pre-germinated rice seeds (Subbaiah and Balasubramanian 2000). However, WSR is very prone to weed infestation (Saha and Munda 2018) as the weed seeds emerge and grow along with the crop right from the beginning; especially the early emerging grassy weeds only are capable of reducing the grain yield even up to 50-91% (Rao *et al.* 2007 and Saha *et al*. 2021). Among different weed management methods, chemical method is easy, economical, efficient and effective way to suppress weeds (Bhurer *et al*. 2013). But the continuous use of same herbicide with same mode of action leads to weed flora shift and development of herbicide resistance in weeds. Therefore, herbicide mixtures with different spectrum of weed control that are more effective are essential to manage weeds in DSR. This

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study was conducted to evaluate and identify a suitable pre-mix herbicide mixture and its dosage rate to get optimum weed management and rice yield in WSR.

MATERIALS AND METHODS

The experiment was conducted at Institute Research Farm of ICAR-National Rice Research Institute, Cuttack (Odisha) (20°272 102 2 N, 85°562 92 2 E; 24 m above mean sea level) during wet seasons of 2017 and 2018. The experiment soil was sandy clay loam with pH 7.8 with low available N (215.4 kg/ha), medium available P (48 kg/ha), high available P (322.8 kg/ha) and medium organic carbon (0.52%). The experiment was laid out in Randomized Complete Block Design with nine treatments and three replications. The treatments include: post-emergence application (PoE) of florpyrauxifen-benzyl + cyhalofop-butyl 12% EC (w/v) 120 (20+100) g/ha, 150 (25+125) g/ha, 180 (30+150) g/ha and 360 (60+300) g/ha; florpyrauxifen-benzyl 2.5% EC (w/v) 25 g/ha, 30 g/ha; bispyribac-sodium at 30 g/ha; weed free and weedy check.

The field was prepared by mould board plough followed by puddling using a disc harrow. The gross and net plot size were 6.0 m x 5.0 m and 5.1 m x 4.0 m, respectively. The test variety *'Naveen'* (115 days duration, Indica type) was sown manually at 20 cm apart rows with a seed rate of 40 kg/ha on 13^{th} and 11^{th} June during 2017 and 2018 respectively. Light irrigation was given and the field was kept saturated during the first 10 days. Thereafter thin layer of standing water (1-2 cm) was maintained for 21 days after rice emergence. Afterward, 2-3 cm depth of irrigation water was applied after disappearance of water in the field till 15 days before maturity. Bispyribac-sodium was sprayed 10 days after seeding (DAS) at 2-3 leaf stage of weeds and all the other herbicides were sprayed at 15 DAS on saturated soil (after draining out water) using a knapsack sprayer fitted with flat fan nozzle with spray volume 300 l/ha and spray pressure 200 kPa. The field was irrigated 48 hours after spraying. The untreated weedy check (control) was kept undisturbed and the weed free plots were kept weed free during the entire cropping period. Recommended fertilizer application (N:P:K: : 100:60:40 kg/ha) was followed, with full dose of P and K application as basal during final land preparation and the N fertilizer application in four equal splits at 15, 30, 45 and 60 DAS. The crop was harvested on 6^{th} and 3^{rd} October 2017 and 2018, respectively.

The data on associated weeds was recorded at 30 and 60 DAS. Weed count was done randomly from three spots by placing quadrat of 50 cm x 50 cm (0.25 m^2) in each plot. Weeds present in quadrat were uprooted carefully along with roots. The root portion was cleaned thoroughly so that the attached soil would be detached. Then the weeds were oven dried at 60^oC for 36 to 48 hours. After complete oven drying, the dry matter of weeds (biomass) were recorded. Similarly, five random rice plants were selected from each plot and their biomass was measured and computed to per meter square values at 30 and 60 DAS. The weed density and biomass data were computed to per meter square values and were subjected to square root of transformation *i.e.* $\sqrt{x+0.5}$ for statistical analysis. Yields from different plots were recorded at harvest. Different weed indices *viz.* weed control index (WCI), weed control efficiency (WCE), weed index (WI), weed persistence index (WPI), crop resistance index (CRI), treatment efficiency index (TEI) and weed management index (WMI) (Sarma 2016); and summed dominance ratio (SDR) (Kim *et al.* 1983) were calculated using the following equations.

$$WCI = \frac{\text{Weed biomass in control (weedy) plot} - \text{Weed biomass in treated plot}}{\text{Weed biomass in control (weedy) plot}} \times 100$$

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

$$WI = \frac{\text{Yield from weed free plot} - \text{Yield from treated plot}}{\text{Yield from weed free plot}} \times 100$$

$$WPI = \frac{\text{Weed biomass in treated plot}}{\text{Weed biomass in control plot}} \times \frac{\text{Weed density in control plot}}{\text{Weed density in treated plot}}$$

$$CRI = \frac{\text{Dry weight produced by the crop in treated plot}}{\text{Dry weight produced by the crop in control plot}} \times \frac{\text{Weed biomass in control plot}}{\text{Weed biomass in treated plot}}$$

$$TEI = \frac{(\text{Yield from treated plot} - \text{Yield from control plot})/\text{Yield from control plot}}{\text{Weed biomass in treated plot}/\text{Weed biomass in control plot}}$$

$$WMI = \frac{(\text{Yield from treated plot} - \text{Yield from control plot})/\text{Yield from control plot}}{(\text{Weed biomass in control plot} - \text{Weed biomass in treated plot})/\text{Weed biomass in control plot}}$$

$$SDR = \frac{\left[\frac{\text{Weed density of a given species}}{\text{Total weed density}} \times 100\right] + \left[\frac{\text{Weed dry weight of a given species}}{\text{Total weed dry weight}} \times 100\right]}{2}$$

The data were subjected to the Analysis of Variance using the Statistical Analysis System (SAS) and significant differences among the treatment means tested Fisher's protected Least Significant Difference (LSD) test at $\sqrt{x+0.5}$.

RESULTS AND DISCUSSION

Effect on weeds

The weed flora in the experimental field was dominated by grasses *viz. Echinochloa colona, Leptochloa chinensis*; sedges *viz. Cyperus difformis, Cyperus iria, Fimbristylis mileacea* and broad-leaved weeds (BLWs) *viz. Sphenoclea zeylanica, Marsilia quadrifolia* during both the years. Other weeds observed in lower density were *Panicum repens, Alternanthera sessilis, Eclipta alba,* and *Ludwigia octovalvis*. In the control (weedy) plots, density of sedges was the highest at all stages of the crop, though the biomass of grasses was the highest at 30 DAS. Similar findings were also reported in direct-seeded rice (Saha and Munda 2018). Among the weeds appeared in the weedy plot, the density of sedges was the highest (42 and 37%), followed by grasses (35 and 27%); and BLWs (23 and 36% at 30 and 60 DAS, respectively). The weed biomass of grasses, sedges and BLWs were 58, 23 and 19% at 30 DAS and 34, 46 and 20% at 60 DAS, respectively among the weeds that occurred in the weedy check.

All the treatments significantly influenced the weed density at both 30 and 60 DAS (**Table 1**). Except *E. colona*, the density of all other weeds increased from 30 to 60 DAS. *E. colona* and *C. difformis* were the early competitors under grasses and sedges, respectively and their density decreased gradually due to their shorter (50-60 days) lifespan. Among the grasses, *L. chinensis* continued to compete with the crop during entire crop period. Among the sedges, *C. iria* and *F. miliacea* posed maximum competition during 30-60 DAS and the major broad-leaved weeds *i.e. S. zeylanica* and *Marsilea quadrifolia* competed moderately throughout the crop growing period. The treatment, florpyrauxifen-benzyl + cyhalofop-butyl at 360 g/ha PoE, recorded the lowest total weed density at 30 DAS, but at high dose it caused rice phyto-toxicity that caused emergence and growth of new flushes of weeds that led to higher total weed density at 60 DAS. Significantly the lowest total weed density was observed with florpyrauxifen-benzyl + cyhalofop-butyl 150 g/ha PoE which was at par with florpyrauxifen-benzyl at 30g/ha PoE as reported earlier in aerobic rice (Sreedevi *et al.* 2020).

All the weed control treatments affected weed biomass significantly (**Table 2**). Weed biomass followed similar trend as weed density. The density of sedges was the highest among the weed categories, but the grasses weed biomass was higher at 30 DAS. At 60 DAS, biomass of sedges was highest. florpyrauxifen-benzyl + cyhalofop-butyl at 150 g/ha PoE recorded lowest total weed biomass and at 60 DAS it was at par with florpyrauxifen-benzyl 30 g/ha PoE.

The highest WCI was observed under florpyrauxifen-benzyl + cyhalofop-butyl at 150 g/ha PoE followed by florpyrauxifen-benzyl at 30 g/ha PoE (**Table 3**). Florpyrauxifen-benzyl + cyhalofop-butyl at 360 g/ha PoE (85.90%) controlled the weed population at 30 DAS but it could not control weeds at 60 DAS (46.83%) due to phytotoxic effect caused by its higher dose on crop resulting in greater weed emergence at the cleared space which caused increased weed competition (Table 3). At 60 DAS, the highest WCI was observed under florpyrauxifen-benzyl + cyhalofop-butyl at 150 g/ha PoE (54.08%).

Florpyrauxifen-benzyl + cyhalofop-butyl at 360 resulted in higher WPI (1.11 and 0.65 at 30 and 60 DAS, respectively) which was followed by

Table 1. Effect of treatments on weed density (no./m^2) at 30 and 60 DAS in WSR (pooled data of 2 years)

Treatment	Grasses				Sedges						BLWs				Others		Total	
	E. colona		*L. chinensis*		*C. difformis*		*F. miliacea*		*C. iria*		*S. zeylanica*		*M. quadrifolia*					
	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS
FPB+CFB 120 g/ha	2.77^{b} (7.20)	1.92^{ab} (3.20)	3.29^{c} (10.30)	4.09^{c} (16.20)	2.63^{c} (6.40)	1.84^{b} (2.90)	2.83^{b} (7.50)	3.65^{b} (12.80)	2.95^{d} (8.20)	4.25^{bc} (17.60)	3.13^{b} (9.30)	3.87^{c} (14.50)	2.61^{cd} (6.30)	3.78^{b} (13.80)	4.35^{c} (18.40)	5.31^{b} (27.70)	8.61^{b} (73.60)	10.45^{bc} (108.70)
FPB+CFB 150 g/ha	2.19^{cd} (4.30)	1.76^{b} (2.60)	2.86^{e} (7.70)	3.44^{d} (11.30)	1.92^{e} (3.20)	1.34^{c} (1.30)	2.47^{c} (5.60)	2.95^{c} (8.20)	2.45^{e} (5.50)	4.05^{c} (15.90)	2.79^{c} (7.30)	3.27^{d} (10.20)	2.28^{d} (4.70)	2.86^{c} (7.70)	3.85^{d} (14.30)	4.32^{c} (18.20)	7.29^{d} (52.60)	8.71^{c} (75.40)
FPB+CFB 180 g/ha	2.02^{d} (3.60)	1.79^{b} (2.70)	2.81^{e} (7.40)	3.96^{c} (15.20)	1.73^{f} (2.50)	2.30^{a} (4.80)	1.95^{d} (3.30)	3.49^{bc} (11.70)	1.70^{f} (2.40)	3.86^{c} (14.40)	2.66^{c} (6.60)	4.38^{bc} (18.70)	0.71^{e} (0.00)	3.89^{b} (14.60)	3.33^{e} (10.60)	5.27^{b} (27.30)	6.07^{e} (36.40)	10.48^{b} (109.40)
FPB+CFB 360 g/ha	0.71^{e} (0.00)	1.55^{b} (1.90)	2.59^{f} (6.20)	3.55^{d} (12.10)	0.71^{g} (0.00)	1.97^{b} (3.40)	1.79^{d} (2.70)	3.13^{c} (9.30)	0.71^{g} (0.00)	3.49^{d} (11.70)	2.28^{d} (4.70)	4.09^{c} (16.20)	0.71^{e} (0.00)	3.55^{b} (12.10)	2.81^{f} (7.40)	4.59^{c} (20.60)	4.64^{f} (21.00)	9.37^{c} (87.30)
FPB 25 g/ha	2.83^{b} (7.50)	2.02^{a} (3.60)	3.55^{b} (12.10)	4.45^{b} (19.30)	2.97^{b} (8.30)	2.21^{ab} (4.40)	2.81^{bc} (7.40)	3.66^{b} (12.90)	3.70^{b} (13.20)	4.56^{b} (20.3)	3.18^{b} (9.60)	4.11^{c} (16.40)	2.77^{c} (7.20)	3.90^{b} (14.70)	4.72^{b} (21.80)	5.46^{b} (29.30)	9.36^{b} (87.10)	11.02^{b} (120.90)
FPB 30 g/ha	2.37^{c} (5.10)	1.82^{b} (2.80)	2.85^{e} (7.60)	3.65^{d} (12.80)	2.28^{d} (4.70)	1.76^{b} (2.60)	2.61^{c} (6.30)	3.18^{c} (9.60)	3.30^{c} (10.40)	4.09^{c} (16.20)	2.88^{c} (7.80)	3.44^{d} (11.30)	3.00^{bc} (8.50)	3.56^{b} (12.20)	4.24^{c} (17.50)	5.07^{b} (25.20)	8.27^{c} (67.90)	9.65^{c} (92.70)
BPS 30 g/ha	2.21^{c} (4.40)	1.48^{b} (1.70)	3.11^{d} (9.20)	4.69^{b} (21.50)	2.77^{c} (7.20)	2.37^{a} (5.10)	2.93^{b} (8.10)	3.70^{b} (13.20)	3.58^{b} (12.30)	4.68^{a} (21.40)	3.11^{b} (9.20)	4.51^{b} (19.80)	3.26^{b} (10.10)	3.96^{b} (15.20)	4.96^{b} (24.10)	5.81^{ab} (33.30)	9.22^{b} (84.60)	11.48^{b} (131.20)
Weed free	0.71^{e} (0.00)	0.71^{c} (0.00)	0.71^{g} (0.00)	0.71^{e} (0.00)	0.71^{g} (0.00)	0.71^{d} (0.00)	0.71^{e} (0.00)	0.71^{d} (0.00)	0.71^{g} (0.00)	0.71^{e} (0.00)	0.71^{e} (0.00)	0.71^{e} (0.00)	0.71^{e} (0.00)	0.71^{d} (0.00)	0.71^{g} (0.00)	0.71^{d} (0.00)	0.71^{g} (0.00)	0.71^{d} (0.00)
Weedy check	5.22^{a} (26.70)	2.39^{a} (5.20)	4.00^{a} (15.50)	5.36^{a} (28.20)	4.88^{a} (23.30)	2.17^{a} (4.20)	3.27^{a} (10.20)	4.36^{a} (18.50)	4.07^{a} (16.10)	5.01^{a} (24.60)	3.87^{a} (14.50)	5.10^{a} (25.50)	3.73^{a} (13.40)	4.55^{a} (20.20)	5.45^{a} (29.20)	6.19^{a} (37.80)	12.22^{a} (148.90)	12.83^{a} (164.20)
LSD (p=0.05)	0.19	0.47	0.12	0.31	0.14	0.29	0.20	0.45	0.17	0.37	0.18	0.39	0.40	0.45	0.35	0.58	0.87	1.04

BPS: bispyribac-sodium, BLWs: broad-leaved weeds, CFP: cyhalofop-butyl, DAS: days after sowing, FPB: florpyrauxifen-benzyl, LSD: least significant difference; Figures within and without parentheses indicate original and transformed values, respectively.

Table 2. Effect of different weed control treatments on weed biomass (g/m^2) at 30 and 60 DAS in WSR (pooled data of 2 years)

Treatment	Grasses				Sedges						BLWs				Others		Total	
	E. colona		*L. chinensis*		*C. difformis*		*F. miliacea*		*C. iria*		*S. zeylanica*		*M. quadrifolia*					
	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS
FPB+CFB	1.83^{b}	1.60^{b}	2.37^{bc}	2.72^{b}	1.23^{bc}	1.39^{c}	1.04^{b}	2.26^{bc}	1.82^{bc}	2.53^{b}	1.06^{bc}	1.51^{c}	1.57^{b}	1.71^{cd}	1.89^{c}	3.17^{b}	4.30^{c}	5.93^{b}
120 g/ha	(2.84)	(2.05)	(5.12)	(6.89)	(1.01)	(1.44)	(0.58)	(4.63)	(2.81)	(5.90)	(0.62)	(1.77)	(1.92)	(2.41)	(3.09)	(9.56)	(17.99)	(34.65)
FPB+CFB	1.48^{cd}	1.33^{c}	2.22^{c}	2.57^{b}	1.00^{c}	1.07^{d}	0.96^{bc}	1.76^{d}	1.55^{c}	2.42^{b}	0.99^{bc}	1.32^{d}	1.41^{b}	1.39^{d}	1.49^{d}	2.92^{b}	3.63^{d}	5.21^{c}
150 g/ha	(1.69)	(1.27)	(4.42)	(6.09)	(0.51)	(0.65)	(0.43)	(2.61)	(1.89)	(5.36)	(0.49)	(1.24)	(1.49)	(1.43)	(1.73)	(8.01)	(12.65)	(26.66)
FPB+CFB	1.39^{d}	1.49^{c}	2.76^{b}	2.89^{b}	0.95^{c}	1.70^{b}	0.87^{c}	2.38^{bc}	1.15^{d}	2.51^{b}	0.97^{bc}	1.67^{bc}	0.71^{c}	2.24^{b}	2.00^{cd}	3.37^{b}	3.80^{d}	6.41^{b}
180 g/ha	(1.42)	(1.73)	(7.13)	(7.85)	(0.40)	(2.39)	(0.25)	(5.15)	(0.82)	(5.82)	(0.44)	(2.28)	(0.00)	(4.50)	(3.51)	(10.85)	(13.97)	(40.57)
FPB+CFB	0.71^{e}	1.31^{d}	2.54^{bc}	2.79^{b}	0.71^{d}	1.48^{c}	0.84^{c}	2.14^{c}	0.71^{e}	2.39^{b}	0.90^{c}	1.57^{bc}	0.71^{c}	2.21^{b}	1.72^{d}	3.33^{b}	3.07^{e}	6.08^{bc}
360 g/ha	(0.00)	(1.22)	(5.97)	(7.30)	(0.00)	(1.69)	(0.21)	(4.09)	(0.00)	(5.23)	(0.31)	(1.98)	(0.00)	(4.38)	(2.45)	(10.60)	(8.94)	(36.49)
FPB 25 g/ha	1.86^{b}	1.68^{b}	2.67^{bc}	2.77^{b}	1.35^{bc}	1.64^{bc}	1.03^{b}	2.49^{b}	1.74^{bc}	2.64^{b}	1.07^{bc}	1.58^{bc}	1.57^{b}	1.74^{c}	2.78^{b}	3.29^{b}	4.93^{b}	6.26^{bc}
	(2.96)	(2.31)	(6.65)	(7.18)	(1.31)	(2.19)	(0.57)	(5.68)	(2.53)	(6.49)	(0.64)	(2.00)	(1.97)	(2.54)	(7.22)	(10.35)	(23.85)	(38.73)
FPB 30 g/ha	1.58^{c}	1.52^{b}	2.32^{c}	2.54^{b}	1.11^{c}	1.34^{c}	0.99^{bc}	2.17^{c}	1.75^{bc}	2.45^{b}	1.01^{bc}	1.37^{cd}	1.55^{b}	1.44^{d}	2.32^{c}	3.18^{b}	4.30^{c}	5.65^{c}
	(2.01)	(1.80)	(4.89)	(5.95)	(0.74)	(1.29)	(0.49)	(4.22)	(2.57)	(5.55)	(0.52)	(1.38)	(1.89)	(1.56)	(4.89)	(9.63)	(18.00)	(31.38)
BPS 30 g/ha	1.49^{cd}	1.26^{d}	2.52^{bc}	2.93^{b}	1.39^{b}	1.74^{b}	1.06^{b}	2.51^{b}	1.93^{b}	2.71^{b}	1.15^{b}	1.71^{b}	1.72^{b}	1.81^{c}	2.91^{b}	3.42^{b}	4.96^{b}	6.43^{b}
	(1.73)	(1.09)	(5.86)	(8.11)	(1.44)	(2.54)	(0.62)	(5.81)	(3.22)	(6.85)	(0.82)	(2.42)	(2.49)	(2.76)	(7.98)	(11.23)	(24.12)	(40.81)
Weed free	0.71^{e}	0.71^{e}	0.71^{d}	0.71^{c}	0.71^{d}	0.71^{e}	0.71^{d}	0.71^{e}	0.71^{e}	0.71^{c}	0.71^{d}	0.71^{e}	0.71^{c}	0.71^{e}	0.71^{e}	0.71^{c}	0.71^{f}	0.71^{d}
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Weedy check	3.32^{a}	1.96^{a}	3.93^{a}	4.81^{a}	2.04^{a}	2.14^{a}	1.14^{a}	2.94^{a}	2.45^{a}	4.91^{a}	2.11^{a}	2.57^{a}	2.18^{a}	3.08^{a}	3.76^{a}	5.43^{a}	7.61^{a}	10.31^{a}
	(10.52)	(3.34)	(14.93)	(22.64)	(3.68)	(4.09)	(0.79)	(8.14)	(5.52)	(23.62)	(3.97)	(6.11)	(4.26)	(8.99)	(13.67)	(28.95)	(57.34)	(105.88)
LSD(p=0.05)	0.18	0.16	0.42	0.49	0.26	0.17	0.12	0.31	0.31	0.59	0.24	0.16	0.33	0.29	0.53	0.57	0.46	0.64

BPS: bispyribac-sodium, BLWs: broad-leaved weeds, CFP: cyhalofop-butyl, DAS: days after sowing, FPB: florpyrauxifen-benzyl, LSD: least significant difference, WSR: wet-seeded rice
Figures within and without parentheses indicate original and transformed values, respectively.

Table 3. Effect of treatments on different crop and weed indices at 30 and 60 DAS in WSR (pooled data of two years)

Treatment	WCI		WCE (%)		WPI		CRI		TEI		WMI	
	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS
FPB+CFB 120 g/ha	68.63	67.27	50.57	33.80	0.63	0.49	4.50	4.23	1.56	1.50	0.71	0.73
FPB+CFB 150 g/ha	77.94	74.82	64.67	54.08	0.62	0.55	7.79	6.86	2.56	2.24	0.72	0.75
FPB+CFB 180 g/ha	75.64	61.68	75.55	33.37	1.00	0.58	4.02	2.75	1.35	0.86	0.43	0.53
FPB+CFB 360 g/ha	84.41	65.54	85.90	46.83	1.11	0.65	5.07	2.81	1.18	0.54	0.22	0.28
FPB 25 g/ha	58.41	63.42	41.50	26.37	0.71	0.50	2.89	3.25	1.01	1.15	0.72	0.66
FPB 30 g/ha	68.61	70.36	54.40	43.54	0.69	0.52	4.84	5.17	1.62	1.72	0.74	0.72
BPS 30 g/ha	57.94	61.46	43.18	20.10	0.74	0.48	2.50	2.94	0.92	1.01	0.67	0.63
Weed free	100.00	100.00	100.00	100.00	-	-	-	-	-	-	0.68	0.68
Weedy check	0.00	0.00	0.00	0.00	1.00	1.00	1.00	1.00	0.00	0.00	-	-

AMI: agronomic management index, BPS: bispyribac-sodium, BLWs: broad-leaved weeds, CRI: crop resistance index, CFP: cyhalofop-butyl, DAS: days after sowing, FPB: florpyrauxifen-benzyl, TEI: treatment efficiency index, WCE: weed control efficiency, WCI: weed control index, WI: weed index, WMI: weed management index, WPI: weed persistence index, WSR: wet-seeded rice

florpyrauxifen-benzyl + g/ha PoE cyhalofop-butyl at 180 g/ha PoE (0.58) and 150 g/ha PoE (0.55) (**Table 3**) indicating resistance of escaped weeds to control measures.

The crop resistance index (CRI) indicates increased vigour of crop plant due to weed control measures. Florpyrauxifen-benzyl + cyhalofop-butyl 150 g/ha PoE recorded maximum crop resistance to grow (7.79 and 6.86 at 30 and 60 DAS, respectively) followed by florpyrauxifen-benzyl 30 g/ha PoE (5.17) at 60 DAS (**Table 3**) indicating much less harmful effect of herbicides on crop as compared to other treatments.

Treatment efficiency index (TEI) indicates the weed killing potential of a particular herbicide treatment. Florpyrauxifen-benzyl + cyhalofop-butyl 150 g/ha PoE showed maximum TEI at both 30 (2.56) and 60 (2.24) DAS (**Table 3**) followed by florpyrauxifen-benzyl 30 g/ha PoE (1.62 and 1.72 at 30 and 60 DAS respectively).

Florpyrauxifen-benzyl + cyhalofop-butyl 150 g/ha PoE showed maximum weed management index (WMI) (0.75) closely followed by florpyrauxifen-benzyl + cyhalofop-butyl 120 g/ha PoE (0.73) and florpyrauxifen-benzyl 30 g/ha PoE (0.72) (**Table 3**). The lowest WMI was observed under florpyrauxifen-benzyl + cyhalofop-butyl 360 g/ha PoE due to its phyto-toxicity to rice.

Among the grasses, *L. chinensis* recorded highest SDR than *E. colona* at both 30 and 60 DAS

(**Table 4**). Whereas, among the sedges, *C. iria* and *F. miliacea* dominated over *C. difformis* at 60 DAS and among the BLWs both *S. zeylanica* and *M. quadrifolia* were moderately dominant at 60 DAS as reported in aerobic rice system (Rahman *et al.* 2012).

Effect on rice

The treatments didn't influence the crop biomass significantly at 30 DAS but at 60 DAS (**Table 5**) the highest crop growth was recorded under weed free plots followed by florpyrauxifen-benzyl + cyhalofop-butyl 150 g/ha PoE.

The highest grain yield was recorded in the weed free, which was at par with florpyrauxifen-benzyl + cyhalofop-butyl 150 g/ha PoE (**Table 5**). Florpyrauxifen-benzyl + cyhalofop-butyl 120 g/ha PoE, florpyrauxifen-benzyl 25 g/ha PoE and bispyribac-sodium 30 g/ha PoE recorded at par yield. The florpyrauxifen-benzyl + cyhalofop-butyl 150 g/ha PoE recorded 12.6% yield advantage over the recommended herbicide bispyribac-sodium 30 g/ha PoE supporting the findings of Meher *et al.* (2018) and Sreedevi *et al.* (2020). The uncontrolled weeds in the weedy check caused around 40% rice grain yield loss (**Table 5**). Florpyrauxifen-benzyl + cyhalofop-butyl 150 g/ha PoE restricted the yield loss at 6.83% showing 12.6% yield advantage over the recommended herbicide bispyribac-sodium due to broad spectrum weed control during the critical crop-weed competition period.

It may be concluded that florpyrauxifen-benzyl + cyhalofop-butyl 150 (25+125) g/ha PoE was the most effective herbicide mixture to control weeds in WSR as it recorded lowest weed density, biomass, weed index, weed persistence index and highest weed control index, weed control efficiency, crop resistance index, treatment efficiency index and weed management index and higher rice grain yield which was at par with the weed free.

Table 4. Effect of treatments on summed dominance ratio of different weed species at 30 and 60 DAS in WSR (pooled data of two years)

Treatment	Grasses				Sedges						BLWs				Others	
	E. colona		*L. chinensis*		*C. difformis*		*F. miliacea*		*C. iria*		*S. zeylanica*		*M. quadrifolia*			
	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS
FPB+CFB 120 g/ha	12.78	4.43	21.23	17.39	7.15	3.41	6.71	12.57	13.38	16.61	8.04	9.22	9.62	9.83	21.09	26.54
FPB+CFB 150 g/ha	10.77	4.11	24.79	18.91	5.06	2.08	7.02	10.33	12.70	20.60	8.88	9.09	10.36	7.79	20.43	27.09
FPB+CFB 180 g/ha	10.03	3.37	35.68	16.62	4.87	5.14	5.43	11.69	6.23	13.75	10.64	11.36	0.00	12.22	27.12	25.85
FPB+CFB 360 g/ha	0.00	2.76	48.15	16.93	0.00	4.26	7.60	10.93	0.00	13.87	12.92	11.99	0.00	12.93	31.32	26.32
FPB 25 g/ha	10.51	4.47	20.89	17.25	7.51	4.65	5.44	12.67	12.88	16.77	6.85	9.36	8.26	9.36	27.65	25.47
FPB 30 g/ha	9.34	4.38	19.18	16.38	5.52	3.46	6.00	11.90	14.80	17.58	7.19	8.29	11.51	9.07	26.47	28.94
BPS 30 g/ha	6.19	1.98	17.58	18.13	7.24	5.06	6.07	12.15	13.94	16.55	7.14	10.51	11.05	9.17	30.79	26.45
Weed free	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Weedy check	18.14	3.16	18.22	19.28	11.03	3.21	4.11	9.48	10.22	18.65	8.33	10.65	8.21	10.40	21.73	25.18

BPS: bispyribac-sodium, BLWs: broad-leaved weeds, CFP: cyhalofop-butyl, DAS: days after sowing, FPB: florpyrauxifen-benzyl, WSR: wet-seeded rice

Table 5. Effect of treatments on crop dry matter (at 30 and 60 DAS) and grain yield (at harvest) in WSR (pooled data of two years)

Treatment	Rice biomass (g/m^2)		Rice grain yield (t/ha)			Weed index
	30 DAS	60 DAS	2017	2018	Pooled	
FPB+CFB 120 g/ha	6.75	17.67^{d}	4.62bc	4.74b	4.68^{bc}	11.20
FPB+CFB 150 g/ha	8.21	22.04^{b}	4.88ab	4.94ab	4.91^{ab}	6.83
FPB+CFB 180 g/ha	4.68	13.45^{f}	4.12c	4.22c	4.17^{c}	20.87
FPB+CFB 360 g/ha	3.78	12.37^{f}	3.65c	3.79c	3.72^{c}	29.41
FPB 25 g/ha	5.74	15.15^{e}	4.42bc	4.50bc	4.46^{bc}	15.28
FPB 30 g/ha	7.27	19.56^{c}	4.70b	4.78b	4.74^{b}	10.06
BPS 30 g/ha	5.02	14.44^{ef}	4.30bc	4.42bc	4.36^{bc}	17.31
Weed free	8.60	26.35^{a}	5.24a	5.33a	5.27^{a}	-
Weedy check	4.78	12.76^{f}	3.08d	3.20d	3.14^{d}	40.42
LSD (p=0.05)	NS	1.10	0.53	0.49	0.52	-

BPS: bispyribac-sodium, CFP: cyhalofop-butyl, DAS: days after sowing, FPB: florpyrauxifen-benzyl, LSD: least significant difference, NS: not significant, WSR: wet-seeded rice

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REFERENCES

Balasubramanian V and Hill JE. 2002. Direct seeding of rice in Asia: emerging issues and strategic research needs for the 21st century, pp 15-39. In: *Direct seeding: research issues and opportunities. Proceedings of the International Workshop on Direct Seeding in Asian Rice Systems: Strategic Research Issues and Opportunities*. Eds. (Pandey S, Mortimer M, Wade L, Tuong TP, Lopez K, Hardy B, editors.), 25-28 January 2000, Bangkok, Thailand. Los Baños (Philippines): International Rice Research Institute.

Bhurer KP, Yadav DN, Ladha JK, Thapa RB and Pandey K. 2013. Effect of integrated weed management practices on performance of dry direct seeded rice (*Oryza sativa* L.). *Agronomy Journal of Nepal* **3**: 53–63.

Chauhan BS. 2012. Weed ecology and weed management strategies for dry-seeded rice in Asia. *Weed Technology* **26**: 1–13.

Dass A, Shekhawat K, Choudhary AK, Sepat S, Rathore SS, Mahajan G and Chauhan BS. 2017. Weed management in rice using crop competition-a review. *Crop Protection* **95**: 45–52.

Gharde Y, Singh PK, Dubey R P and Gupta, P. 2018. Assessment of yield and economic losses in agriculture due to weeds in India. *Crop Protection* **107**: 12–18. 10.1016/j.cropro. 2018.01.007.

Kim SC, Park RK and Moody K. 1983. Change in the weed flora in transplanted rice fields as affected by introduction of improved rice cultivars and the relationship between weed communities and soil chemical properties. *Research Reports of the Office of Rural Development (Korea R.)* **25** (c): 90–97.

Meher S, Tiwari N, Saha S, Mahapatra A and Jangde HK. 2018. Efficacy of Herbicide Mixtures on Yield and Yield Attributes in Wet Direct Seeded Rice. *International Journal of Current Microbiology and Applied Sciences* **7**: 4071–4076.

Rahman M, Juraimi AS, Suria J, Man AB and Anwar P. 2012. Response of weed flora to different herbicides in aerobic rice system. *Scientific Research and Essays* **7**(1): 12–23.

Rao AN, Wani SP, Ramesha MS and Ladha JK. 2017. Rice Production Systems. Chapter 8. Pp. 185-205, In: *Rice Production Worldwide*. (Eds. B.S. Chauhan e*t al.*), Springer International Publishing AG 2017 185.

Rao AN, Johnson DE, Sivaprasad B, Ladha JK and Mortimer AM. 2007. Weed management in direct-seeded rice. *Advances in Agronomy* **93**: 153–255.

Saha S and Munda S. 2018. Efficacy of Metamifop against grassy weeds in direct-sown rice (Oryza sativa) and its impact on succeeding crop. *Indian Journal of Agricultural Sciences* **88**: 41–46.

Saha S, Munda S, Singh S, Kumar V, Jangde HK, Mahapatra A and Chauhan BS. 2021. Crop establishment and weed control options for sustaining dry direct seeded rice production in Eastern India. *Agronomy* **11 (2)**: 389.

Sarma A. 2016. *Numerical Agronomy*. Kalyani Publishers, B-I/ 1292, Rajinder Nagar, Ludhiana – 141 008, India.

Shahbandeh S. 2021. Top countries based on production of milled rice | Statista. Statista. https://www.statista.com/ statistics/255945/top-countries-of-destination-for-us-rice-exports-2011/ (Accessed on 25 February 2022)

Sreedevi B, Singh A, Thakur C, Kumar MP, Mehra V, Mahenderkumar R and Srivastava GK. 2020. Weed Control by Single Post-emergence Combination Herbicide Florpyrauxifen-Benzyl Plus Cyhalofop-butyl in Aerobic Rice. *Current Journal of Applied Science and Technology* **39**: 109–122.

Subbaiah SV and Balasubramanian V. 2000. Wet seeding of rice in India. DRR (ICAR)-CREMNET (IRRI), Project Report, August 2000, DRR (ICAR), Hyderabad, India, and IRRI, Philippines.

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RESEARCH ARTICLE

Integration of allelopathic water extracts with cultural practices for weed management in organic wheat

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ABSTRACT

Weed management is a major constraint in organic wheat production systems and integration of non-herbicidal weed management practices is the only available option. The present study was conducted at two locations during 2019-20 to evaluate the efficiency of allelopathic water extracts coupled with cultural practices in managing the weeds in organic wheat. The treatments consisted of two wheat varieties (tall and dwarf) and seven weed management treatments. The taller wheat variety PBW 677 had significantly lower weed biomass (21.4 to 28.2%) at harvest and higher grain yield (7.4 to 15.4%) than the dwarf variety Unnat PBW 550 and recorded better net returns and B:C at both the locations. Among the weed management treatments, hand weeding twice recorded maximum reduction in weed density (44.6 to 46.2%), and weed dry biomass (44.6% to 58.2%) at 75 days after sowing (DAS). The next best treatment in reducing weed density (38.9 to 45.3%) and dry biomass (41.1 to 46.5%) was line sowing of pre-germinated wheat seeds + wheel hoeing. This was followed by line sowing of pre-germinated wheat seeds + plant extract spray. The corresponding increases in wheat grain yields with above mentioned treatments at location I and II, compared to weedy check, were 69.6 and 66%; 42.7 and 51.8%, and 17.7 and 30.7%, respectively. Under labour constrained situations, line sowing of pre-germinated wheat seeds followed by wheel hoeing or application of mixed plant extract of sorghum, sunflower and raya at 18 L/ha each at 25 and 50 DAS of wheat can provide effective weed management, higher grain yield and better economic returns in organic wheat production.

Keywords: Allelopathy, Cultural management, Organic wheat, Plant extract, Weed management

Wheat (*Triticum aestivum* L.), a staple food of most of the people, is one of the three important cereals (rice, wheat, maize) of world having major contribution in global food security, hence considered as economic backbone of global food security. In India, it is the major cereal after rice and grown on an area of 31.12 million hectare with production of 109.58 million tonnes and an average productivity of 3.52 t/ha during 2020-21 (Anonymous 2022).

Organic food is gaining popularity due to its health benefits *eg.* higher antioxidants concentration, omega 3 fatty acids *etc.* (Vigar *et al.* 2020) as against food grown using conventional agricultural practices and wheat is no-exception. Organic food contains lower amount of pesticide residues compared to conventional food (Singh 2021). Among the pests, weeds are the most problematic in nature as weeds cause the highest loss in wheat productivity (Jabran 2015). The weed menace is more under organic wheat production as the herbicides' usage is prohibited (Singh 2021). The herbicides use in conventional farming was proved to lead to environmental, human and animal health problems as well as resistance development in weeds (Głąb *et al.* 2017). Alternatively, the effectiveness of cultural practices and allelopathic extracts in managing weeds was reported (Aulakh *et al.* 2017, Jabran 2015, Farooq *et al.* 2020).

Allelopathy is a natural phenomenon in which different plants or organisms release chemical compounds (*i.e.* secondary metabolites/ allelochemicals) which influence the function of other plants or organisms in their vicinity in a positive or negative way (Ashraf *et al.* 2017). Rye (*Secale cereale*), sorghum (*Sorghum bicolor*), rapeseed-mustard (*Brassica* spp.), sunflower (*Helianthus annuus*), tobacco (*Nicotiana* spp.) and wheat (*Triticum aestivum*) have been reported to release allelochemicals (Jabran *et al.* 2015). Weeds (*Fumaria indica*, *Phalaris minor*, *Rumex dentatus* and *Chenopodium album*) growth suppression in wheat crop with allelopathic plant water extract of sorghum was reported (Cheema *et al.* 2000). However, crop cultivars, developmental stages of crops, and environmental conditions affect concentration and

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phytotoxicity of allelochemicals (Weston *et al.* 2013). Arif *et al.* (2015) reported reduction in total weed density and biomass and increase in wheat yield with two foliar sprays of mixture of sorghum, sunflower and brassica extracts at the rate of 18 L/ha each at 25 and 40 days after sowing (DAS) of wheat. Awan *et al.* (2012) also reported decreased weed infestation and increased wheat yield when mixture of sorghum, sunflower and brassica extracts at the rate of 4 L/ha each was sprayed at 30 and 60 DAS. The highest weed reduction was observed when sorghum, sunflower and *brassica* were applied in combination which might be due to interaction among allelochemicals to enhance overall phytotoxicity (Glab *et al.* 2017).

In organic wheat production, cultural practices or agronomic manipulations are done to provide initial start-up to the crop so that crop can smother weeds or can compete more efficiently with weeds (Bond *et al.* 2001; Bhullar *et al.* 2017). Use of crop competition is considered as a cost effective method of weed suppression and enhancing crop yields, particularly in cereals and so this method can be employed for future weed management research (Ramesh *et al.* 2017, Meulen and Chauhan 2017). This study was aimed at evaluating the integrated effect of cultural and allelopathic weed management practices on suppression of weeds and performance of wheat under organic management.

MATERIALS AND METHODS

This field experiment was carried out during *Rabi* 2019-20 at two locations [location I –Punjab Agricultural University, Ludhiana (30°54’ N latitude, 75°48’ E longitude), and location II – Grewal Natural Farm, Dheri (30°92’ N latitude, 75°88’ E longitude)] in Punjab. The climate at both the locations is subtropical and semi-arid having hot and dry summer (April to June), hot humid monsoon period (July to September), mild winter (October to November) and cold winter (December to February). During summer, temperature generally goes above 39°C and numerous frosty spells are observed during winters (December and January) when minimum temperature reaches below 0.5°C. Annual average rainfall in Punjab is 650 mm, from which nearly 75% is received during monsoon period (July to September). The experimental soil at location I was sandy loam having pH 6.24, electrical conductivity 0.18 dS/m, organic carbon 0.78%, available nitrogen 226 kg/ha, available phosphorus 30 kg/ha and available potassium 223 kg/ha, and at location II, it was silty loam having pH 6.71, electrical conductivity 0.20 dS/m, organic carbon 0.49%, available nitrogen 188 kg/ha, available phosphorus 20.6 kg/ha and available potassium 239 kg/ha. The cropping systems were moong-wheat and basmati rice-wheat at location I and II, respectively.

The treatments were replicated thrice in a randomized complete block design with combination of two wheat varieties [PBW 677 (tall) and Unnat PBW 550 (dwarf)] and seven weed management treatments – weedy check, hand weeding twice at 30 and 60 DAS, plant extract spray (PE), pre-germinated wheat seeds + broadcast sowing (PGS + broadcast), pre-germinated wheat seeds + broadcast sowing + plant extract spray (PGS + broadcast + PE), pre-germinated wheat seeds + plant extract spray (PGS + PE), and pre-germinated wheat seeds + wheel hoeing at 17 and 55 DAS (PGS + wheel hoe). Sorghum, sunflower and raya plant extract used was tank mix of their allelopathic crop water extracts in 1:1:1 ratio at 18 L/ha each and was sprayed at 25 and 50 DAS of wheat using 375 L/ha water. The stovers of sorghum, sunflower and raya varieties (S-898, PSH 1962 and PBR 357, respectively) were used for preparing the allelopathic crop water extract. The stover was cut into 2-3 cm pieces and were soaked separately in tap water in ratio of 1:10 (stover: water). After 24 hours, extract was filtered and boiled to concentrate the filtrate to reduce the volume by 95% (Cheema and Khaliq 2000). The extracts were prepared afresh for each spraying. Wheel hoeing was done before first irrigation (17 DAS) and afterwards (55 DAS), when soil was at moisture condition workable with wheel hoe after rains.

Pre-germination of wheat seeds was done by soaking seeds in water for 10 hours. After soaking, the seeds were sprouted by spreading on gunny bags as a thin layer and covering them with wet gunny bags for 24 hours. The wheat seeds in all the treatments were smeared with *beejamrit* before sowing. *Beejamrit*, a seed treatment concoction in natural farming, was prepared by hanging five kg fresh cow dung, in a cloth bag, in 20 L of water. Fifty gram lime in a cloth bag was put in one litre water separately. After 14 hours, the cloth bag containing cow dung was squeezed and to this solution 5 L cow urine, 50 g virgin soil and lime water were added. Farmyard manure (FYM) at 12.5 t/ha was applied at the time of seedbed preparation in all the treatments. Wheat varieties Unnat PBW 550 and PBW 677 were sown at seed rates of 112.5 and 100 kg/ha (recommended seed rates in Punjab for the respective variety characters), respectively at row spacing of 20 cm or broadcast as per the treatments. The crop was sown on 9th and 15th November, 2019 at location I and II, respectively. The crop received only one irrigation at location I and no irrigation at location II due to well distributed rainfall throughout the crop growth period. The crop was sprayed two times with Neemkavach (Azadirachtin 0.15% EC) at 2.5 L/ha in 250 L water at ear head stage for control of aphid. The crop was harvested manually in last week of April, 2020 at both the locations.

Weed density was recorded by using 0.6 x 0.6m quadrat and weed control efficiency was computed by taking dry weed biomass recorded at 75 DAS. Effective tillers of wheat were recorded from three random places from 50 cm row length in line sown plots and from 0.6 x 0.6 m quadrat in broadcast sown plots and were converted to number/m^2. Weed density and dry biomass data were subjected to square root transformation for statistical analysis as per factorial randomized complete block design using CPCS1 software developed by the Department of Mathematics and Statistics, PAU, Ludhiana. The economic analysis was done by considering variables costs and B:C by using gross returns to cost of cultivation.

RESULTS AND DISCUSSION

Effect on weeds

Major weed species included *Rumex dentatus, Medicago denticulata, Phalaris minor* at both the locations, *Anagallis arvensis* at location I and *Solanum nigrum* at location II. *Rumex dentatus* and *Medicago denticulata* were relatively more dominant at location I whereas *Phalaris minor* was dominant at location II. Other weed species were *Chenopodium album* and *Lepidium sativum*.

Weed density did not differ significantly with wheat varieties at both the locations (**Table 1**). Hand weeding caused significantly lower weed density at both the locations, compared to all the other treatments except PGS + wheel hoe at 75 DAS (**Table 1**). The lower weed density in hand weeding and PGS + wheel hoe treatments might be due to the weeding at 60 DAS and wheel hoeing at 55 DAS, respectively. At location I, significantly higher weed density was recorded in weedy check than all the other treatments except PGS + broadcast and PGS + broadcast + PE which were statistically at par with weedy check indicating ineffectiveness of these treatments in managing the weeds. However, at location II, only PGS + broadcast, and PE were statistically at par with weedy check indicating their inefficiency. Hussain (2015) and Awan *et al* (2012) also reported hand weeding as the most effective method of reducing weed density. At harvest, the differences in weed density became non-significant at both the locations. This might be due to the completion of life cycle of majority of the weeds till harvest of the wheat crop.

Wheat variety PBW 677 had significantly lowered weed biomass than Unnat PBW 550 (28.2, 21.4 % at location I and II, respectively) due to greater plant height of PBW 677 which suppressed the weeds leading to less accumulation of dry matter by weeds (**Table 1**). Korres and Froud-Williams (2002) also reported that diverse weed flora was reduced by winter wheat cultivars having greater crop height as well as rapid tillering capability. Greater the height of crop genotype, the higher was the weed suppression (Chokkar *et al* 2012, Sandhu *et al* 1981).

Hand weeding significantly lowered weed biomass than all the other treatments at 75 DAS at both the locations and it was followed by PGS + wheel hoe which had also significantly lower weed biomass than rest of the treatments (**Table 1**). The lower weed biomass in hand weeding and PGS + wheel hoe might be due to reduced weed density (**Table 1**) as well as small-sized weeds as a result of weeding at 60 DAS and wheel hoeing at 55 DAS, respectively. The higher weed biomass in PGS + wheel hoe than hand weeding might be due to comparatively more intra-row weeds. Among rest of the treatments, PGS+PE had significantly lower weed biomass than all the other treatments except PE. This can be attributed to the adverse effect of the plant extract on dry matter accumulation by weeds. Suppression of growth of weeds with allelopathic crop water extracts has also been reported by Cheema *et al* (2000a). Awan *et al* (2012) reported that multiple weed flora in wheat was comparatively better controlled than weedy check with mixture of aqueous extracts of sorghum, sunflower and brassica. The highest weed biomass was recorded in weedy check and it was statistically at par with PGS + broadcast, and PGS + broadcast + PE. At location II, hand weeding had the lowest weed biomass which was statistically at par with PGS + wheel hoe. Weedy check had the highest weed biomass and was statistically at par with other treatments except hand weeding and PGS + wheel hoe. The variation among the two locations might be due to different soil types *i.e.* sandy loam and silty loam at location I and II respectively which led to less or more resistance to growth of weeds from soil e.g. in sandy loam soils, in broadcast fields, early growth of different weeds due to less resistance by soil took place which led to higher biomass at later stages. It might also be due to different type of weed dominance and soil fertility at both the locations. In plant extract treatments, the reduction in weed biomass might be due to synergistic effect of allelochemicals which adversely affect the physiological and metabolic processes of weeds due to their phytotoxicity to weeds when applied in combination. Phytotoxic activity exhibited by extracts of sunflower and sorghum could be due to the presence of allelochemicals such as sorgoleone, heliannnone and leptocarpin (Bogatek *et al*. 2006). It might be possible that extracts had interfered with cell division, hormone biosynthesis, mineral uptake, stomatal oscillations, photosynthesis, respiration, protein metabolism and plant water relations that caused a reduction in weeds (Arif *et al.* 2015).

At harvest, there were non-significant differences among weed management practices at location I. However, at location II, the weedy check had the highest weed biomass and it was statistically at par with all the other treatments except PGS+wheel hoe and hand weeding (**Table 1**). Lesser weed biomass in PGS+wheel hoe and hand weeding might be due to comparatively lower weed density and small size of weeds in these treatments.

Among the varieties, Unnat PBW 550 recorded higher weed control efficiency than PBW 677 at 75 DAS (**Figure 1**). However, the situation reversed at harvest with better weed control efficiency with PBW 677 due to significantly lower weed biomass in PBW 677 than Unnat PBW 550 (**Table 1**). Unnat PBW 550 recorded higher weed index than PBW 677 at both the locations (**Figure 1**).

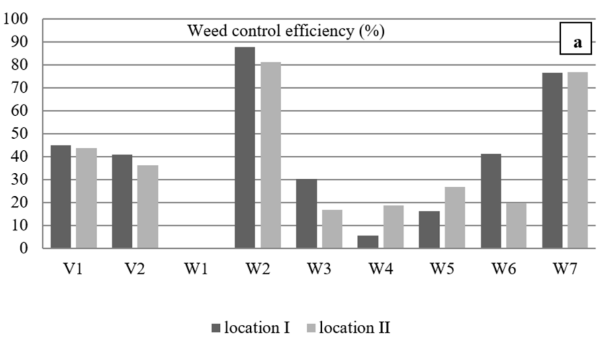
Higher weed index meant more yield loss which might have resulted due to more weed biomass at harvest of Unnat PBW 550 (**Table 1**) which adversely affected wheat grain yield (**Table 2**) of Unnat PBW 550.

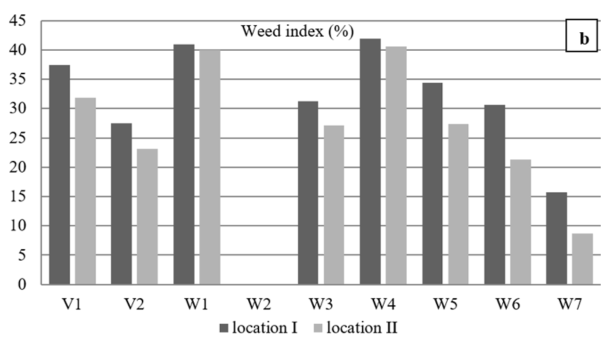
Among the weed management practices, hand weeding had the highest weed control efficiency followed by PGS + wheel hoe at both the locations. At location I, PGS + wheel hoe was followed by PGS+PE, PE, PGS + broadcast + PE, PGS + broadcast. At location II, PGS + wheel hoe was followed by PGS + broadcast + PE, PGS + PE, PGS + broadcast and PE and weedy check. The lowest weed index was recorded in hand weeding followed by PGS + wheel hoe, PGS+PE, PE, PGS + broadcast + PE, weedy check and PGS + broadcast. Compared to location I, better weed control efficiency at 75 DAS at location II in PGS + broadcast and PGS + broadcast + PE might be due to better emergence in these treatments. However, weed index was the highest in PGS + broadcast due to negative effect of broadcasting as a sowing method.

Effect on crop

The wheat varieties did not differ significantly in respect of ear length, number of grains per ear and effective tillers (**Table 2**). However, the thousand grain weight was significantly higher in PBW 677 than Unnat PBW 550. This might be due to less competition of weeds (**Table 1**) and higher plant height in PBW 677 as compared to Unnat PBW 550 which might have led to more accumulation of photosynthates to grains in PBW 677.

Among the weed management treatments at location I, hand weeding had the highest number of grains per ear, which was at par with PGS + wheel hoe. Among rest of the treatments, PE and PGS+PE, at par with each other, had significantly higher number of grains per ear than weedy check. At location II, hand weeding had the highest number of





*V1= Unnat PBW 550, V2= PBW677, W1= Weedy check, W2= Hand weeding, W3= PE, W4= PGS + broadcast, W5= PGS + broadcast + PE, W6= PGS + PE, W7= PGS + wheel hoe, PGS = pre-germinated wheat seeds, PE = plant extract spray

Figure 1. Effect of various treatments on a) weed control efficiency, b) weed index

grains per ear which was statistically at par with all the other treatments except weedy check. Reduction in weeds results in more photosynthates assimilation in wheat and subsequently their translocation towards grains (Borras *et al.* 2004) which could be the reason behind higher number of grains per ear. Hand weeding had the highest number of effective tillers which was statistically at par with all the other treatments except weedy check and PGS + broadcast. Lesser number of effective tillers in weedy check and PGS + broadcast could be attributed to more weed competition in these treatments. Arif *et al* (2015), Hussain (2015), Awan *et al* (2012) also had similar findings. At location I, hand weeding twice recorded the highest thousand grain weight which was statistically at par with all the other treatments except weedy check. More weed competition in weedy check (**Table 1**) might have resulted in lower thousand grain weight. The lesser number of effective tillers in PGS + broadcast might have resulted in statistically similar thousand-grain weight with hand weeding. At location II, hand weeding recorded the highest thousand grain weight which was statistically at par with PGS + wheel hoe. This could be attributed to lesser weed competition (**Table 1**) than other treatments. Among rest of the treatments, weedy check had the lowest thousand grain weight which was statistically at par with all the other treatments.

Plant extract application on crop improved yield attributes could be attributed to its negative effect on weeds and positive effect on crop. The increment in wheat yield can be attributed to less competition to crop because of good weed control or due to hormesis (Abbas *et al* 2017) which is the stimulatory effect of toxicants due to low dose (Calabrese 2005).

The wheat variety PBW 677 recorded significantly higher grain yield (4.06 and 3.88 t/ha at location I and II, respectively) than Unnat PBW 550 (3.78 and 3.36 t/ha at location I and II, respectively) (**Table 2**). The increase being 7.4 and 15.5% at location I and II, respectively. This might be due to significant lower weed biomass accumulation in the former variety due to suppression of weeds because of more plant height (**Table 1**). The lesser weed competition in PBW 677 might have contributed to better growth and yield attributes in this variety. Higher the height of genotype of a crop, the higher is the weed suppression (Sandhu *et al* 1981) which might have led to significantly better yield in PBW 677 than Unnat PBW 550. Kumar *et al* (2007) also reported enhanced grain yield of wheat and higher weed suppression in wheat cultivars, PBW 343, WH 542 and HD 2687, which was due to higher plant height and smothering potential compared to other cultivars.

Among the weed management practices, hand weeding recorded significantly higher grain yield (5.44 and 4.73 t/ha at location I and II, respectively) than all the other treatments at both the locations. The corresponding yield increases with respect to weedy check were 69.5 and 66%. The highest grain yield in hand weeding might be due to better removal of weeds which resulted in minimum weed competition to crop and influenced yield attributes positively. Among rest of the treatments, PGS + wheel hoe had significantly higher grain yield (4.58 and 4.32 t/ha at location I and II, respectively) than all the other

Table 1. Effect of wheat varieties and weed management treatments on weed density and biomass

Treatment	Location I				Location II			
	Weed density (no./m^2)		Weed biomass (g/m^2)		Weed density (no./m^2)		Weed biomass (g/m^2)	
	75 DAS	At harvest	75 DAS	At harvest	75 DAS	At harvest	75 DAS	At harvest
Variety								
Unnat PBW 550	17.7(290)	10.0(84)	7.1(41.22)	5.8(26.22)	15.0(209)	13.9(173)	4.2(11.0)	10.7(102)
PBW 677	17.8(298)	9.5(76)	7.2(43.04)	4.5(14.42)	14.5(195)	13.0(149)	3.8(8.7)	8.8(63)
LSD (p=0.05)	NS	NS	NS	0.95	NS	NS	NS	0.97
Weed management								
Weedy check	21.3(412)	10.0(85)	9.1(66.71)	5.2(18.95)	18.5(308)	15.6(215)	4.8(15.1)	11.2(123)
Hand weeding	11.8(117)	9.7(77)	3.8(8.11)	3.8(8.28)	10.0(82)	12.5(141)	2.7(2.9)	8.7(61.5)
PE	19.2(332)	9.0(65)	7.8(46.40)	4.3(13.29)	16.3(236)	13.9(171)	4.5(12.4)	10.1(86.0)
PGS + broadcast	20.9(401)	8.6(62)	8.9(63.00)	5.1(19.89)	16.6(249)	13.9(169)	4.4(12.0)	10.2(86.6)
PGS+ broadcast+ PE	19.9(358)	11.1(109)	8.4(55.91)	6.6(35.94)	15.7(219)	13.1(147)	4.3(10.9)	9.6(74.8)
PGS + PE	18.2(295)	10.0(85)	7.2(39.17)	5.3(21.35)	16.1(232)	13.7(175)	4.4(12.0)	10.1(92.7)
PGS + wheel hoe	13.0(145)	9.8(79)	4.9(15.61)	5.5(24.55)	10.1(86)	11.2(109)	2.8(3.5)	8.2(56.2)
LSD (p=0.05)	1.62	NS	0.82	NS	2.34	NS	0.72	1.82

*Data were subjected to square root transformation($\sqrt{x+1}$) Original values are in parentheses, Interaction LSD (p=0.05) = NS
PE=Plant extract, PGS=pre-germinated seeds, DAS=Days after sowing

treatments at both the locations. This could be attributed to lesser weed pressure (**Table 1**) because of removal of weeds with wheel hoe which resulted in an early suppression of weeds by crop and also influenced yield attributes and ultimately the yield positively. At location I, PGS+PE (3.77 t/ha) and PE (3.74 t/ha), statistically at par with each other; had significantly higher grain yield than PGS + broadcast (3.15 t/ha) and weedy check (3.21 t/ha). At location II, PGS+PE (3.72 t/ha), PE (3.45 t/ha), and PGS + broadcast + PE (3.44 t/ha), statistically at par with each other, had significantly higher grain yield than PGS + broadcast (2.82 t/ha) and weedy check (2.85 t/ha). The results indicated that though the PGS and plant extract combinations were inferior to hand weeding and PGS + wheel hoe but were significantly better than the weedy check indicating their potential in organic weed management programme particularly under labour constrained situations. PGS+PE resulted in an increase in grain yield by 17.66% at location I and 30.73% at location II compared to weedy check which can be attributed to negative effect of this treatment on weeds and positive on crop. Arif *et al* (2015) also reported improved wheat grain yield with water extract mixture of sorghum, sunflower and brassica. The comparatively better effect of plant extract at location II could be attributed to more grassy weeds which were suppressed better than broad-leaf weeds. The other reason could be the higher soil organic carbon content at location I which might have led to vigorous growth of weeds and thus comparatively their lesser suppression. PGS + broadcast recorded the lowest grain yield and it was statistically at par with weedy check and PGS + broadcast + PE at location I and with weedy check only at location II (**Table 2**). At location II, PGS + broadcast + PE was significantly better than weedy check. PGS + broadcast recorded the lower grain yield even than weedy check sown in lines and this might be due to more weed competition (**Table 1**) and less uniformly placed plants as compared to line sowing. Farooq and Cheema (2014) and Tomar *et al* (2020) also reported lower yield in broadcasting as a method of sowing compared to line sowing.

Both varieties had significant effect on harvest index at location II only where PBW 677 had significantly higher harvest index than Unnat PBW 550 (**Table 2**). Among the weed management practices, hand weeding recorded significantly higher harvest index than all the other treatments at both the locations. This could be attributed to higher grain yield in this treatment due to lesser weed competition (**Table 1, 2**). Better weed inhibition leads to better nutrient uptake by crop resulting in higher yield which ultimately enhances harvest index (Arif *et al* 2015). Among rest of the treatments at location I, PGS + wheel hoe had higher harvest index which was statistically at par with PGS + broadcast + PE and PGS+PE. Weedy check had significantly lower harvest index than all the other treatments except PE and PGS + broadcast. At location II, among rest of the treatments, PGS + wheel hoe had higher harvest index which was statistically at par with all the other treatments except weedy check and PGS + broadcast. Weedy check had significantly lower harvest index than all the other treatments except PE and PGS + broadcast. The lowest harvest index in weedy check and PGS + broadcast might be due to lesser grain yield (**Table 2**) due to more weed competition (**Table 1**). The lower harvest index in PE might be due to more straw yield compared to grain

Table 2. Effect of wheat varieties and weed management treatments on yield attributes, grain yield and harvest index of wheat

Treatment	Location I						Location II					
	Ear length (cm)	No. of grains per ear	Effective tillers (/m^2)	Thousand grain weight (g)	Grain yield (t/ha)	Harvest index (%)	Ear length (cm)	No. of grains per ear	Effective tillers (/m^2)	Thousand grain weight (g)	Grain yield (t/ha)	Harvest index (%)
Variety												
Unnat PBW 550	11.77	50.67	371.5	40.74	3.78	30.24	10.04	42.44	357.3	38.71	3.36	28.66
PBW 677	12.02	50.14	391.0	48.04	4.06	29.62	10.27	41.21	373.1	41.40	3.88	30.47
LSD (p=0.05)	NS	NS	NS	1.80	0.24	NS	NS	NS	NS	1.59	0.18	1.34
Weed management												
Weedy check	11.37	43.36	336.1	38.51	3.21	26.81	9.89	36.78	325.0	36.98	2.85	26.43
Hand weeding	12.10	58.00	432.8	46.13	5.44	35.87	10.49	44.92	412.8	44.34	4.73	34.08
PE	12.03	50.73	406.1	44.64	3.74	29.15	10.07	42.23	375.0	39.60	3.45	28.74
PGS + broadcast	12.00	46.76	308.8	43.83	3.15	27.36	10.00	40.82	304.7	37.69	2.82	27.06
PGS + broadcast + PE	11.73	47.57	350.7	46.18	3.56	29.59	10.10	41.72	367.7	38.90	3.44	29.59
PGS + PE	11.87	50.57	415.0	45.28	3.77	29.20	10.12	42.32	381.2	39.26	3.72	29.87
PGS + wheel hoe	12.17	55.83	419.4	46.13	4.58	31.53	10.44	44.00	390.2	43.61	4.32	31.21
LSD (p=0.05)	NS	6.99	83.1	3.36	0.44	2.35	NS	4.82	47.1	2.98	0.34	2.50

* PE=Plant extract, PGS=pre-germinated seeds, Interaction CD (p=0.05) = NS

Table 3. Effect of wheat varieties and weed management treatments on economics of wheat

Treatment	Economics							
	Location I				Location II			
	Cost of production (x10^3 `/ha)	Gross returns (x10^3 `/ha)**	Net returns (x10^3 `/ha)**	B : C ratio	Cost of production (x10^3 `/ha)	Gross returns (x10^3 `/ha)**	Net returns (x10^3 `/ha)**	B : C ratio
Variety								
Unnat PBW 550	32.25	105.04	72.79	3.23	32.25	93.59	61.34	2.89
PBW 677	31.87	112.49	80.62	3.53	31.87	107.62	75.75	3.38
Weed management								
Weedy check	29.60	89.51	59.91	3.03	29.60	79.82	50.21	2.70
Hand weedings	41.85	149.74	107.89	3.58	41.85	130.54	88.69	3.12
PE	31.35	103.84	72.48	3.31	31.35	96.16	64.80	3.07
PGS + broadcast	28.57	87.94	59.36	3.08	28.57	78.99	50.42	2.77
PGS + broadcast + PE	30.32	99.12	68.80	3.27	30.32	95.74	65.42	3.16
PGS + PE	31.35	104.78	73.43	3.34	31.35	103.42	72.06	3.30
PGS + wheel hoe	31.35	126.43	95.08	4.03	31.35	119.58	88.22	3.82

*PE=Plant extract, PGS=Pre-germinated seeds, B: C ratio= Benefit-cost ratio.** Organic wheat produce price (₹ 26950/t) was subjected to 40% increase due to organic produce compared to wheat minimum support price (₹ 19250/t), *** Costs/prices= farm yard manure ₹ 1000/ton; seed ₹ 30/kg; seed treatment = beejamrit (₹ 415/ha seed); land preparation + sowing method = line sowing – drill (₹ 6250/ha), broadcast sowing (₹ 5220/ha); insecticide - neemkavach (₹ 350/L); Extract preparation (two times) = ₹ 1000/ha, labour ₹ 350/person/day, two wheel hoeing ₹ 1750/ha; two hand weedings (₹ 12250/ha) spray charges = ₹ 1/L, two sprays of plant extract ₹ 750, two sprays of neemkavach ₹ 500; harvesting ₹ 5000/ha, grains 26950/t, straw ₹ 3000/ha.

yield as plant extract application might have enhanced straw yield (**Table 2**) due to increased plant height.

Economic analysis

Economics plays an important role in final evaluation of a treatment. There was a slight higher cost of cultivation in Unnat PBW 550 due to more seed rate (112.5 kg/ha) compared to PBW 677 (100 kg/ha). However, the gross returns, net returns and B: C were higher in PBW 677 than Unnat PBW 550 (**Table 3**). This was due to higher grain yield and comparatively less cost of cultivation in PBW 677.

Among the weed management practices, the highest cost of cultivation was with hand weeding twice, at both the locations due to labour involved while the lowest cost was in PGS + broadcast. Hand weeding had the higher gross and net returns but the B : C was higher in PGS + wheel hoe. At location II, the B : C of PGS + PE and PGS + broadcast + PE was also higher than hand weeding.

It may be concluded that the taller wheat variety PBW 677 proved better than Unnat PBW 550 in respect of weed management, grain yield, net returns and B : C ratio. Hand weeding twice at 30 and 60 DAS provided the most effective management of weeds followed by line sowing of pre-germinated wheat seeds+ two wheel hoeing- one before first irrigation and second at about 55 DAS. Under labour constrained situations, line sowing of pre-germinated wheat seeds + foliar application of sorghum + sunflower + raya extract at 18 L/ha each at 25 and 50 DAS can be a viable option for weed management in organic wheat production.

REFERENCES

Anonymous 2022. https://www.indiastat.com/table/wheat/area-production-productivity-wheat-india-1949-1950/7400

Anonymous 2022a. *Package of Practices for Crops of Punjab – Rabi 2021-22*. Punjab Agricultural University, Ludhiana, Pp 2.

Abbas T, Nadeem MA, Tanveer A and Chauhan BS. 2017. Can hormesis of plant-released phytotoxins be used to boost and sustain crop production? *Crop Protection* **93**: 69–76.

Arif M, Cheema ZA, Khaliq A and Hassan A. 2015. Organic weed management in wheat through allelopathy. *International Journal of Agriculture and Biology* **17**: 127–134.

Ashraf R, Sultana B, Yaqoob S and Iqbal M. 2017. Allelochemicals and crop management: A review. *Current Science* **3**: 1–13.

Aulakh CS and Ravisankar N. 2017. Organic farming in Indian context: A perspective. *Agricultural Research Journal* **54** (2): 149–164.

Awan FK, Rasheed M, Ashraf M and Khurshid YM. 2012. Efficacy of brassica, sorghum and sunflower aqueous extracts to control wheat weeds under rainfed conditions of Pothwar, Pakistan. *Journal of Animal and Plant Sciences* **22**: 715–721.

Bhullar MS, Kaur N, Kaur P and Gill G. 2017. Herbicide resistance in weeds and its management. *Agricultural Research Journal* **54** (4): 436–444.

Bogatek R, Gniazdowska A, Zakrzewska W, Oracz K and Gawronski SW. 2006. Allelopathic effects of sunflower extracts on mustard seed germination and seedling growth. *Biologia Plantarum* **50**: 156–158.

Bond W and Grundy AC. 2001. Non-chemical weed management in organic farming systems. *Weed Research* **41**: 383–405.

Borras L, Slafer GA and Otegui ME. 2004. Seed dry weight response to source-sink manipulations in wheat, maize and soybean: a quantitative reappraisal. *Field Crop Research* **86**: 131–146.

Calabrese EJ. 2005. Paradigm lost, paradigm found: the re-emergence of hormesis as a fundamental dose response model in the toxicological sciences. *Environmental pollution* **138**: 378–411.

Cheema ZA and Khaliq A. 2000. Use of sorghum allelopathic properties to control weeds in irrigated wheat in a semi-arid region of Punjab. *Agriculture, Ecosystems and Environment* **79**: 105–112.

Cheema ZA, Sadiq HMI and Khaliq A. 2000a. Efficacy of *sorgaab* (sorghum water extract) as a natural weed inhibitor in wheat. *International Journal of Agriculture and Biology* **2**: 144–146.

Chhokar RS, Sharma RK and Sharma I. 2012. Weed management strategies in wheat-A review. *Journal of Wheat Research* **4**(2): 1–21.

Farooq N, Abbas T, Tanveer A and Jabran K. 2020. Allelopathy for Weed Management. In: Mérillon JM., Ramawat K. (eds) *Co-Evolution of Secondary Metabolites. Reference Series in Phytochemistry*. Springer, Cham.

Farooq O and Cheema ZA. 2014. Influence of sowing dates and planting methods on weed dynamics in wheat crop. *Pakistan Journal of Agricultural Sciences* **51**(4): 817–825.

Glab L, Sowiñski J, Bough R and Dayan FE. 2017. Allelopathic potential of sorghum (*Sorghum bicolor* (L.) Moench) in weed control: A comprehensive review. *Advances in Agronomy* **145**: 43–95.

Hussain S. 2015. *Effects of allelopathic crop water extracts with low doses of herbicides on weeds and yield of rainfed wheat and groundnut*. Dissertation, Pir Mehr Ali Shah Arid Agriculture University Rawalpindi, Pakistan.

Jabran K, Mahajan G, Sardana V and Chauhan BS. 2015. Allelopathy for weed control in agricultural systems. *Crop Protection* **72**: 57–65.

Korres NE and Froud-Williams RJ. 2002. Effects of winter wheat cultivars and seed rate on the biological characteristics of naturally occurring weed flora. *Weed Research* **42**: 417–428.

Kumar S, Malik RS, Yadav A and Malik RK. 2007. Performance of cultivars and sulfosulfuron against weeds in wheat. *Indian Journal of Weed Science* **39**: 44–47.

Meulen AV and Chauhan BS. 2017. A review of weed management in wheat using crop competition. *Crop Protection* **95**: 38–44.

Ramesh K, Rao AN and Chauhan BS. 2017. Role of crop competition in managing weeds in rice, wheat, and maize in India: A review. *Crop Protection*. **97**: 14–21.

Sandhu KS, Kolar JS and Singh G. 1981. Studies on cultural control of wild oats (*Avena ludoviciana* Dur.), a grassy weed in wheat. *Indian Journal of Weed Science* **13**(2): 146–149.

Singh M. 2021. Organic farming for sustainable agriculture. *Indian Journal of Organic Farming* **1**: 1–8.

Tomar V, Panotra N, Tomer R and Singh G. 2020. Effect of different herbicides and planting techniques on yield and yield components in late sown wheat (*Triticum aestivum* L.). *Journal of Pharmacognosy and Phytochemistry* **9**(2): 2044–2047.

Vigar V, Myers S, Oliver C, Arellano J, Robinson S and Leifert C. 2020. A Systematic Review of Organic Versus Conventional Food Consumption: Is There a Measurable Benefit on Human Health? *Nutrients* **12(1)**: 7.

Weston LA, Alsaadawi IS and Baerson SR. 2013. Sorghum allelopathy- from ecosystem to molecule. *Journal of Chemical Ecology* **39**: 142–153.

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RESEARCH ARTICLE

Weed management with pre- and post-emergence herbicides in *Kharif* maize in sub-mountainous area of Punjab, India

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ABSTRACT

A field experiment was conducted at Punjab Agricultural University, Krishi Vigyan Kendra, Pathankot, Punjab, India during *Kharif* 2016 and 2017 to identify the best herbicides-based weed management practices in maize (*Zea mays* L.). The treatments consisted of pre-emergence (PE) application of atrazine 1000 g/ha, pendimethalin 750 g/ha, pendimethalin 750 g/ha + atrazine 750 g/ha and post-emergence (PoE) application of tembotrione 110.2 g/ha, tembotrione 110.2 g/ha + atrazine 625 g/ha and 2,4-D amine salt 580 g/ha, hand weeding twice at 15 and 30 days after sowing (DAS) and weedy check. A randomized complete block design with three replications was used. The tembotrione 110.2 g/ha + atrazine 625 g/ha (tank mix) PoE at 25 DAS recorded the highest weed control efficiency (94.2%), maize grain yield (4.43 t/ha), net monetary returns (₹ 28047.3) and B:C (1.77).

Keywords: Atrazine, Economics, Maize, Tembotrione, Weed control efficiency, Weed management

INTRODUCTION

Maize (*Zea mays* L.) is one of the world's most important food crops. It serves as food to the human beings and feed to the cattle. In Punjab, it is grown on an area of 116 thousand hectares with a production of 423 thousand tones and an average grain yield of 3.71 t/ha (Anonymous 2018). The average maize yield is still far below than the achievable potential of hybrids in spite of availability of several high yielding hybrids. The potentiality of maize can be fully exploited by adopting suitable agronomic practices among which, weed management plays a significant role in enhancing the crop yield (Ramesh *et al.* 2017). Maize, being a rainy season and widely spaced crop, gets infested with variety of weeds and subjected to heavy weed competition, which often inflicts huge losses ranging from 28 to 100 per cent (Patel *et al.* 2006). The growth of maize in the first three to four weeks is rather slow and during this period weeds establish rapidly and take competitive advantage (Srividya *et al.* 2011). Management of weeds is considered to be an important factor for achieving higher productivity as weed problem is more severe during *Kharif* season due to continuous rains in early stages of maize growth.

Weeds in maize can be controlled by cultural and chemical measures to attain 77 to 96.7% higher yield than weedy check (Khan *et al.* 1998). Manual weeding is a common practice, but it is labour intensive, time consuming, costly and often not done by most of the farmers at critical period of crop-weed competition. Moreover, the labour problem is becoming acute day by day and it will not be possible and economical to stick the traditional cultural weed control practices (Oerke 2005). Thus, herbicides are preferred by farmers as they control the weeds timely and effectively and offer great scope for minimizing the cost of weed control irrespective of situation.

The use of pre-emergent and post-emergent herbicides would help effective weed management of weeds in maize during the critical period (Rao and Chauhan 2015). Usage of pre-emergence herbicides assumes greater importance in the view of their effectiveness from initial stages. As the weeds interfere during the harvesting of the crop, post-emergence herbicides at about 40-45 DAS may help in avoiding the problem of weeds at later stages. Thus, managing weeds using sequential application of pre- and post-emergence herbicides will be an ideal means for managing the weeds economically and effectively in maize. Hence, a study was carried out to quantify the effect of pre- and post-emergence herbicides in maize in managing weeds and improving the productivity economically.

MATERIALS AND METHODS

The experiment was carried out at Krishi Vigyan Kendra, Pathankot during 2016 and 2017. The experiment was laid out in randomized complete

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block design with three replications having a net plot size of 5 x 3 m. The soil was sandy loam with pH of 7.6, electrical conductivity of 2.5 dS/m, organic matter of soil 0.72%, available phosphorus 9.7 mg/kg and extractable potassium was 139 mg/kg. Maize hybrid PMH-1 was sown on 25th June, 2016 and on 2nd July, 2017 with single row hand drill using a seed rate of 20 kg/ha in 60 cm apart rows. Plant to plant distance of 20 cm was maintained by thinning at an early growth stage. Recommended dose of nitrogen (N), phosphorus (P) and potassium (K) at 160-80-50 kg/ha was applied through urea, di-ammonium phosphate (DAP) and muriate of potash (MOP), respectively. Fertilizers, P and K were applied as basal dose and half of the nitrogen was broadcasted and incorporated into soil at sowing while remaining half of the nitrogen was top dressed at knee high stage.

The treatments comprised of pre-emergence application (PE) of atrazine 1000 g/ha, pendimethalin 750 g/ha, pendimethalin 750 g/ha + atrazine 750 g/ha (tank-mix) and post-emergence application (PoE) of tembotrione 110.2 g/ha, tembotrione 110.2 g/ha + atrazine 625 g/ha and 2,4-D amine salt 580 g/ha, hand weeding twice at 15 and 30 days after sowing (DAS) and weedy check.

A knapsack sprayer fitted with flat-fan nozzle was used for pre-emergence herbicides application within two days after sowing using 500 litre/ha water and for post-emergence herbicides application at 25 DAS using 375 litre/ha water. Phytotoxic effect on crop was recorded at 3rd and 10th day after herbicides application. Weed density was recorded at 20 DAS and 40 DAS by using a quadrat of 100 x 100 cm (1 m^2) size from the center of the plot. 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 (biomass). The samples were first dried in sun and then kept in oven at 70 ± 2°C. The dried samples were weighed and expressed as dry biomass of weed (g/m^2). Cost of cultivation, gross returns, net monetary returns and benefit cost ratio for each treatment were calculated, using standard procedure, by taking into consideration of total costs incurred and returns obtained. Weed control efficiency (WCE) and weed index (WI) were calculated using formulae as suggested by Gill and Vijaya Kumar (1969).

RESULTS AND DISCUSSION

Weed flora

Among the weeds, sedges and broad-leaved weeds were dominant in the experimental site as compared to the grasses (**Table 1**). *Cyperus compressus* L. was the dominant weed followed by *Cyperus rotundus* L., *Trianthema portulacastrum* L. and *Commelina benghalensis* L., during both the years of study.

Effect on weeds

The total weed density was significantly lower with hand weeding done at 15 days after sowing (DAS) in which 82.5 per cent lower weeds were recorded than weedy check. Among the herbicide treatments, total weed density was significantly lower with pendimethalin 750 g/ha + atrazine 750 g/ha (tank mix) than other herbicide-based treatments and it was 18 per cent lesser than weedy check (**Table 1**). The density of *T. portulacastrum* at 20 DAS was significantly reduced by all the pre-emergence herbicides. However, emergence of *C. rotundus*, *C. compressus* and *C. benghalensis* were unaffected by any of the pre-emergence herbicides. *T. portulacastrum* was significantly controlled by pendimethalin 750 g/ha + atrazine 750 g/ha (tank mix) PE followed by atrazine 1000 g/ha PE and hand weeding at 15 DAS with the reduction of 67.5, 38.1 and 58.4 per cent over weedy check during both years, respectively. Similarly, weed biomass of *T. portulacastrum* was also reduced with pendimethalin 750 g/ha + atrazine at 750 g/ha (tank

Table 1. Effect of pre- and post-emergence herbicides on weed density at 20 and 40 days after sowing in maize (pooled mean)

Treatment	Weed density at 20 DAS (no./m^2)				Total weed density at 20 DAS (no./m^2)	Weed density at 40 DAS (no./m^2)				Total weed density at 40 DAS (no./m^2)
	TP	*CR*	*CC*	*CB*		*TP*	*CR*	*CC*	*CB*	
Weedy check	4.6(25)	5.5(29)	10.2(104)	3.3(11)	13.0(169)	6.8(47)	5.0(24)	10.0(100)	3.6(12)	13.5 (183)
Hand weeding twice	1.9(3)	1.3(1)	1.0(0)	1.1(1)	2.2(4)	1.5(1)	1.5(1)	1.2(1)	1.5(1)	2.3 (5)
Atrazine 1000 g/ha PE	1.9(3)	4.5(20)	10.0(99)	3.7(14)	11.6(135)	2.5(6)	5.2(27)	9.6(92)	3.4(11)	11.6 (135)
Pendimethalin 750 g/ha PE	2.9(8)	4.8(23)	10.1(102)	3.4(12)	12.0(145)	3.2(10)	5.3(28)	11.5(132)	3.6(13)	13.5 (182)
Pendimethalin + atrazine 750 + 750 g/ha PE	1.5(2)	4.5(20)	9.1(83)	2.8(7)	10.5(111)	2.2(4)	5.1(26)	10.2(104)	4.3(18)	12.3 (152)
Tembotrione 110.2 g/ha PoE	6.3(40)	4.5(19)	9.8(96)	3.8(14)	13.0(168)	1.6(2)	2.6(6)	3.3(11)	1.5(2)	4.5 (20)
Tembotrione+ atrazine 110.2 + 625 g/ha PoE	4.8(28)	5.0(24)	9.7(95)	4.3(18)	12.8(165)	1.7(2)	1.7(2)	1.4(1)	1.4(1)	2.7 (6)
2,4-D amine salt 580 g/ha PoE	6.8(45)	4.9(24)	9.7(95)	3.4(11)	13.2(175)	2.6(6)	3.0(8)	3.3(11)	3.1(9)	6.0 (34)
LSD (p=0.05)	2.54	0.57	1.30	1.13	0.89	0.61	0.47	0.67	0.81	0.61

*Data were square root transformed and values in parenthesis are actual mean values; PE = pre-emergence application; PoE = post-emergence application; *TP*: *T. portulacastrum; CR: C. rotundus; CC: C. compressus; CB: C. benghalensis* mix) PE as compared to other pre-emergence herbicides (**Table 2**). However, total weed biomass was not significantly reduced by any of the herbicide except hand weeding at 15 DAS. Deshmukh *et al.* (2009) also reported that the lowest weed density and biomass at 30 DAS with atrazine 1000 g/ha PE.

At 40 DAS, significantly the lowest weed density and biomass was recorded with tembotrione 110.2 g/ha + atrazine 625 g/ha PoE, followed by tembotrione at 110.2 g/ha PoE at 25 DAS (**Table 1** and **2**). The total weed density was 23.3 and 75.1% lower with tembotrione 110.2 g/ha + atrazine 625 g/ha PoE as compared to pendimethalin 750 g/ha + atrazine 750 g/ha (tank mix) PE and weedy check (**Table 1**). The pre-emergence herbicides were not effective on weeds in maize upto 40 DAS while post-emergence herbicide tembotrione at 110.2 g/ha as well as tembotrione 110.2 g/ha + atrazine 625 g/ha applied at 25 DAS significantly reduced the total weed density and biomass at 40 DAS. Arvadiya (2012) also reported that post-emergence herbicide control weeds very effectively in maize. The weed control efficiency at 40 DAS was significantly higher (94.2%) in tembotrione 110.2 g/ha+ atrazine 625 g/PoE followed by tembotrione at 110.2 g/ha PoE (85.6%) than other treatments and it was closely followed by hand weeding twice at 15 and 30 DAS (94.5%). Williams II *et al.* (2011) and Bollman *et al.* (2008) also reported the efficacy of tembotrione + atrazine 31 + 370 g/ha (tank mix) PoE in managing weeds in maize.

Weed index was lower with tembotrione 110.2 g/ha + atrazine 625 g/ha and tembotrione 110.2 g/ha (tank mix) PoE alone (**Table 3**) and was comparable to hand weeding as it gave complete control of all weeds till 40 DAS. Higher weed density and biomass in 2,4-D amine salt PoE at 25 DAS caused 28.8 per cent yield penalty compared to hand weeding.

Effect on crop

Maize plant height, cob length, grain and stover yields were significantly higher with hand weeding twice at 15 and 30 DAS (**Table 3**). Among the herbicides tested, tembotrione 110.2 g/ha + atrazine 625 g/ha (tank mix) PoE, significantly increased plant height and cob length during both the years, and it was statistically at par with tembotrione 110.2 g/ha alone as reported earlier by Williams II *et al.* (2011), Swetha (2015), Triveni *et al.* (2017). The increased plant height, cob length in effective treatments might be due to less degree of crop weed competition which increased the growth of maize. The stunted growth of crop in weedy check was due to higher weed density and competition (Shinde *et al.* 2018).

Grain yield and stover yield were significantly higher in hand weeding but it was at par with tembotrione 110.2 g/ha + atrazine 625 g/ha PoE and tembotrione 110.2 g/ha PoE. Sabiry and Babu (2019) also reported that the post-emergence herbicide mixtures were at par with hand weeding. The increase in grain yield was 88.5 per cent when tembotrione 110.2 g/ha + atrazine 625 g/ha was applied as compared to weedy check. After the first irrigation the re-emerged weeds in maize cannot be controlled with the pre-emergence herbicides resulting in yield reduction due to occurrence of higher weed density. There was a significant negative linear relationship between grain yield and weed biomass at 40 DAS (**Figure 1**). The least grain yield was recorded under control (weedy check) as reported by Rao *et al.* (2009).

Economics

The gross monetary returns, net monetary returns and benefit cost ration (B:C) in maize were significantly higher with tembotrione 110.2 g/ha + atrazine 625 g/ha PoE at 25 DAS (**Table 3**). The

Table 2. Effect of pre- and post-emergence herbicides on weed biomass at 20 and 40 days after sowing in maize (pooled mean)

Treatment	Weed biomass at 20 DAS (g/m^2)				Total weed biomass at 20 DAS (g/m^2)	Weed biomass at 40 DAS (g/m^2)				Total Weed biomass at 40 DAS (g/m^2)
	TP	*CR*	*CC*	*CB*		*TP*	*CR*	*CC*	*CB*	
Weedy check	5.4 (34)	6.2 (39)	3.4 (11)	4.7 (23)	10.2 (106)	8.8 (78)	6.3 (40)	4.2 (17)	3.8 (14)	12.2 (149)
Hand weeding twice	2.2 (4)	1.4 (1)	1.0 (0)	1.2 (1)	2.6 (6)	1.5 (2)	2.1 (3)	1.4 (1)	1.6 (2)	3.0 (8)
Atrazine 1000 g/ha PE	2.2 (4)	5.1 (26)	3.2 (10)	5.4 (30)	8.3 (69)	2.8 (7)	6.9 (48)	4.0 (15)	3.6 (12)	9.1 (83)
Pendimethalin 750 g/ha PE	3.3 (10)	5.6 (31)	3.3 (10)	4.7 (24)	8.7 (76)	3.7 (13)	7.1 (50)	4.8 (22)	3.9 (15)	10.0 (100)
Pendimethalin + atrazine 750 + 750 g/ha PE	1.6 (2)	5.4 (29)	3.0 (8)	3.0 (9)	6.9 (48)	2.6 (6)	6.8 (46)	4.3 (17)	4.6 (21)	9.5 (90)
Tembotrione 110.2 g/ha PoE	7.4 (54)	5.0 (24)	3.1 (9)	5.5 (30)	10.8 (117)	2.0 (3)	3.7 (13)	2.0 (3)	1.5 (2)	4.6 (21)
Tembotrione + atrazine 110.2 + 625 g/ha PoE	5.6 (39)	5.6 (31)	3.2 (10)	6.1 (37)	11.0 (118)	1.7 (2)	2.2 (4)	1.5 (1)	1.3 (1)	3.1 (9)
2,4-D amine salt 580 g/ha PoE	7.9 (62)	5.4 (29)	3.2 (9)	4.8 (23)	11.1 (123)	2.8 (9)	5.1 (25)	2.2 (4)	3.3 (10)	7.0 (49)
LSD (p=0.05)	3.04	0.89	0.46	1.74	1.70	0.71	0.61	0.47	0.85	0.69

*Data were square root transformed and values in parenthesis are actual mean values; PE = pre-emergence application; PoE = post-emergence application; *TP*: *T. portulacastrum; CR: C. rotundus; CC: C. compressus; CB: C. benghalensis*

Table 3. Effect of pre- and post-emergence herbicides on growth, yield attributes and yield of maize (pooled mean)

Treatment	Plant height (cm)	Cob length (cm)	Grain yield (t/ha)	Stover yield (t/ha)	Harvest index (%)	Weed index (%)	Weed control efficiency (%)	Net returns (Rs/ha)
Weedy check	170.3	14.3	2.35	3.44	40.6	46.0	-	2926.5
Hand weeding twice	211.0	15.2	4.47	5.81	43.5	-	94.52	24526.3
Atrazine 1000 g/ha PE	179.7	14.7	2.86	3.79	43.1	35.7	44.12	9287.7
Pendimethalin 750 g/ha PE	175.3	14.7	2.43	3.35	42.0	45.8	32.40	2624.5
Pendimethalin + atrazine 750 + 750 g/ha PE	182.0	14.8	3.24	4.42	42.4	27.8	38.87	13734.8
Tembotrione 110.2 g/ha PoE	209.6	15.1	4.26	5.68	42.9	4.6	85.65	26318.3
Tembotrione+ atrazine 110.2 + 625 g/ha PoE	210.6	15.0	4.43	5.85	43.0	1.7	94.24	28047.8
2,4-D amine salt 580 g/ha as PoE	181.0	15.0	3.18	4.24	43.1	27.4	66.90	14326.8
LSD (p=0.05)	8.4	0.5	1.03	1.50	1.4	24.6	-	-

PE = Pre-emergence application; PoE = Post-emergence application

highest B:C was obtained with tembotrione 110.2 g/ha + atrazine 625 g/ha (1.77) followed by tembotrione 110.2 g/ha (1.74). The weedy check and pendimethalin 750 g/ha PE recorded the lowest B: C (1.08 and 1.09, respectively). The results are in accordance with those reported by Triveni *et al* (2017).

It was concluded that the tembotrione 110.2 g/ha + atrazine 625 g/ha (tank mix) as PoE significantly decreased the weed density, weed biomass and enhanced the weed control efficiency up to 94% and hence it may be recommended to the maize growers to effectively and economically managing weeds and improve maize grain yield with higher net returns.

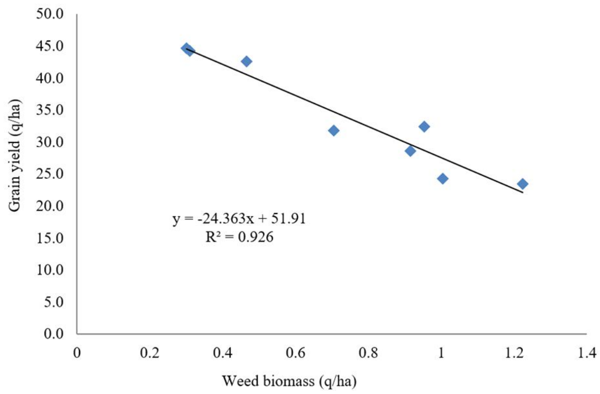

Figure 1. Relationship between weed biomass at 40 days after sowing and grain yield of maize

REFERENCES

Anonymous. 2018. Package and practices of Punjab Agricultural University Ludhiana pp 23.

Arvadiya LK, Raj VC, Patel TU, Arvadiya MK and Patel AM. 2012. Effect of plant population and weed management practices on productivity of sweet corn. *Indian Journal of Weed Science* **44**(3): 167–171.

Bollman JD, Boerboom BH, Becker RL and Fritz VA. 2008. Efficacy and tolerance to HPPD-inhibiting herbicides in sweet corn. *Weed Technology* **22**: 666–674.

Deshmukh LS, Jadhav AS, Jathure RS and Raskar SK. 2009. Effect of nutrient and weed management on weed growthand productivity of kharif maize under rainfed condition. *Karnataka Journal of Agricultural Sciences* **22**(4): 889–891.

Gill GS and K Vijaya. 1969. "Weed index" A new method for reporting weed control trials. *Indian Journal of Agronomy* **16**: 96–98.

Khan SA, Hussain N, Khan IA, Khan M and Iqbal M. 1998. Study on weed control in maize. *Sarhad Journal of Agriculture* **14**(6): 581–586.

Oerke E C. 2005. Crop losses to pest. *Journal of Agriculture Science* **143**: 1–13.

Patel VJ, Upadhyay PN, Patel JB and Meisuriya MI. 2006 Effect of herbicide mixture on weeds in *Kharif* maize (*Zea mays* L.) under middle Gujarat conditions. *Indian Journal of Weed science* **38**(1&2): 54–57.

Ramesh K, Rao AN and Chauhan BS. 2017. Role of crop competition in managing weeds in rice, wheat, and maize in India: A review. *Crop Protection* **97**: 14–21

Rao AN and Chauhan BS. 2015. Weeds and Weed Management in India - A Review. In: Weed Science in the Asian Pacific Region. Indian Society of Weed Science, Hyderabad, pp. 87–118.

Rao AS, Ratnam M and Reddy TY. 2009. Weed management in zero-till sown maize. *Indian Journal of Weed Science* **41**(1&2): 46–49.

Sabiry B and Babu R. 2019. Influence of early post emergent herbicide mixtures on weed control and gain yield of maize (Zea mays L.). *Acta Scientific Agriculture* **3**(5): 26–28.

Shinde SS, Pawar SU, Awasarmal VB and Narkhede WN. 2018. Studies on effect of different herbicides on weed control, yield and economics of maize. *International Journal of Current Microbiology and Applied Sciences* **6**: 951–955.

Srividya S, Chandrasekhar K and Veeraraghavaiah R. 2011. Effect of tillage and herbicide use on weed management in maize. *The Andhra Agricultural Journal* **58**(2): 123–126.

Swetha K. 2015.Weed management with new generation herbicides in *Kharif* maize *(Zea mays l.)*. M.Sc. thesis, Department of Agronomy, Professor Jayashankar Telangana State Agricultural University, Rajendranagar,

Triveni U, Rani Sandhya Y, Patro TSSK and Bharathalakshmi M. 2017. Effect of different pre- and post-emergence herbicides on weed control, productivity and economics of maize. *Indian Journal of Weed Science* **49**(3): 231–235.

Williams II MM, Boydston RA, Peachy R Ed and Robinson D. 2011. Significance of atrazine as a tank-mix partner with tembotrione. *Weed Technology* **25**: 299–302.

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RESEARCH ARTICLE

Effect of different combinations of herbicides and aqua-based plants extracts on weeds in sugarcane

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ABSTRACT

A field experiment was conducted during 2016-17 and 2017-18 at Agricultural Research Farm of Institute of Agricultural Sciences, BHU, Varanasi. The experiment was laid out in split plot design with five treatments in main plots and five treatments in sub plots. In main plots, there were five herbicide combinations, *viz.* pre-emergence application (PE) of atrazine 2 kg/ha at 3 days after planting (DAP) followed by (*fb*) post-emergence application (PoE) of halosulfuron-methyl 150 g/ha at 45 DAP, metribuzin 2 kg/ha *fb* halosulfuron-methyl 150 g/ha, triazinone 1.0 kg/ha *fb* halosulfuron-methyl 150 g/ha, weed free and weedy check. In sub-plots, five aqua based plant/allelopathic extracts were tested, *viz.* cow urine (500 L/ha), parthenium extract (15%), sunflower + sorghum + maize extract (15%), eucalyptus extract (15%) and water (600 L/ha). The lowest weed density and biomass, weed index (WI), NPK uptake by weeds and the highest weed control efficiency (WCE) were recorded with atrazine 2 kg/ha PE *fb* halosulfuron-methyl 150 g/ha PoE in combination with sorghum + sunflower + maize extract, while need based hand weeding recorded higher cane yield.

Keywords: Atrazine, Allelopathic water extracts, Herbicide combination, Halosulfuron-methyl, Sugarcane, Weed Management

INTRODUCTION

Sugarcane (*Saccharum officinarum* L.) is the most imperative sugar crop in the world which plays paramount role in Indian economy by contributing about 1% of national GDP (Venkatesh and Venkateswarlu 2017). Uttar Pradesh ranks first in both area (2.17 mha) and production (133.20 mt) of sugarcane; contributing 42.89 and 39.01%, respectively of the nation.

Various factors like small and marginal holdings, non-availability of quality inputs, weed competition caused losses, occurrence of various diseases, insect-pests and inevitable stresses during the crop growth period restrict the sugarcane yield particularly in the sub-tropical region of India (Choudhary and Singh 2016). Among them inadequate management of weeds by farmers is considered as the most important yield loss causing factor. Slow initial growth of crop and wide spacing between the rows, frequent and heavy irrigations, application of heavy doses of nutrients and warm-humid climate during a large part of the growing season of crop are responsible for high weed infestation. Weeds are fast growing and multiply at alarming rate and if allowed to grow unhindered, lead to severe competition for light, space, water, nutrients *etc.* (Singh *et al.* 2001).

Yield losses caused by weeds may be minimized by keeping weed growth under control by adopting mechanical, cultural and chemical methods. Cultural methods include crop rotation and good seedbed preparation, which may reduce this problem to some extent. The mechanical methods are most effective for control of weeds but are arduous with costly, time consuming and labour shortage at proper time make it difficult to adopt by the farmers. Hence, use of herbicides for weed control is gaining ground (Kumar *et al.* 2017). However, continuous use of same herbicide over the years has given rise to resistant biotypes of weeds (Le Baron 1992, Devedee *et al.* 2022) and many others environmental problems along with health issues due to continuous and non-judicious use of herbicides compelled the search for alternative weed control strategies (Jabran *et al.* 2010; Farooq *et al.* 2011). One of the conceivable strategies for reducing or minimizing the use of herbicides may be the use of natural products and allelopathic manipulation for crop improvement and environmental protection (Hussain *et al.* 2007, Farooq *et al.* 2008). It has been reported that allelopathic water extracts of different plants (crops as well as weeds) significantly reduced germination and growth of different weeds (Jabran *et al.* 2010).

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Allelopathic water extracts and herbicides applied in combination work synergistically, helping to reduce the dose of herbicide (Cheema *et al.* 2003).

The present study was under taken to identify the best combination of herbicides with allelopathic water extracts for controlling weeds in sugarcane.

MATERIALS AND METHODS

The present study was carried out during spring season of 2016 and 2017 at the Agricultural Research Farm, Department of Agronomy, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi, Uttar Pradesh, India. The cumulative rainfall during both the year of investigation was recorded 1229.2 mm in 2016 and 649.6 mm in 2017. Soil of the experimental field was sandy clay loam in texture and neutral in reaction with low in organic carbon, low in nitrogen and medium in available phosphorus and potassium.

The experiment was laid out in split plot design with five treatments in main plots and five treatments in sub-plots replicated three times. In main plots, there were five herbicide combinations *i.e.* pre-emergence application (PE) of atrazine 2 kg/ha followed by (*fb*) post-emergence application (PoE) of halosulfuron-methyl 150 g/ha, metribuzin 2 kg/ha PE *fb* halosulfuron-methyl 150 g/ha PE, triazinone 1.0 kg/ha PE *fb* halosulfuron-methyl 150 g/ha PoE, weed free (three hand weeding + hoeing) and weedy check plot. In the sub plots, five allelopathic extracts treatments *i.e.* cow urine (500 l/ha), parthenium extract (15%), sunflower + sorghum + maize extract (15%), eucalyptus extract (15%) and water (600 l/ha) were used.

Preparation of aqua-based plant extracts

Cut plant leaves into 2-3 cm small pieces

↓

Weight the plant on balance

↓

Measure the desirable quantity of water

↓

Pieces of leaves poured into water

↓

Soaked in water from 24 to 48 hours

↓

Filter it into another pot

↓

Heat this filtrate and reduce 25% of total amount

↓

Cool it and mix with herbicide as per treatment and spray

Pre-emergence application [at 3 days after planting (DAP)] and post-emergence application (PoE) (at 45 DAP) of herbicides was done with the help of a hand- operated knapsack sprayer fitted with flat-fan nozzle. Sugarcane variety (Co-0238) was planted in lines at the row spacing of 90 cm in spring season of 2016 and 2017. Planting date of sugarcane was 03/03/2016 in the first year and 01/03/2017 in second year of experimentation. Recommended dose of fertilizers *i.e*. 150 kg N, 80 kg P and 60 kg K/ha were applied to the crop. Urea, DAP and MOP were used for fertilization. Whole of phosphorus and potassium and half dose of nitrogen were applied at the time of planting. The remaining half-dose of nitrogen was applied in two equal split doses as per requirement. Cane was harvested 8 to 13 February, 2017 for first year crop and in second year sugarcane harvested in 13 to 19 February, 2018. Weed density was recorded species wise at 30, 60 and 90 days after planting (DAP). Weed density was recorded with the help of a quadrat (50 x 50 cm = 250 cm^2) placed randomly at two spots in each plot, and counting different weeds. Weeds occurring in a quadrat of 0.25 m^2 (50 x 50 cm) were cut at ground level and were separated individual species wise at 30, 60 and 90 DAP, washed under running of tap water, sun dried, oven dried at 70^0C for 48 hours and weighed. The values were converted to per square meter basis. Weed control efficiency (WCE) was calculated at 90 DAP by using the formula suggested by Mani *et al.* (1973) and weed Index (WI), a measure of reduction in crop yield was computed as per formula given by Gill and Kumar (1969). Nutrient (N, P and K) depletion by weeds at 90 DAP was calculated by the multiplication of percent NPK content with weed dry matter. For determining the significance of differences between the treatments and to draw valid conclusions, the data obtained were subjected to statistical analysis by 'Analysis of Variance' for split plot design and the significance was tested by ''Variance ratio'' *i.e.* 'F' value (Gomez and Gomez 1984).

Weed control efficiency (WCE)

$$\text{Weed control efficiency (\%)} = \frac{WDM_C - WDM_t}{WDM_C} \times 100$$

Where,

WDM_C = Weed dry matter in control plot

WDM_t = Weed dry weight in treated plot

Weed index (WI)

$$\text{Weed index (\%)} = \frac{X - Y}{X} \times 100$$

Where,

X = Yield from weed free plots (Three hoeing)

Y = Yield from treated plot

Nutrient (N, P, K) depletion by weeds (kg/ha)

$$\text{Nutrient depletion by weeds (kg/ha)} = \text{Per cent N/P/K in weed} \times \text{weed dry matter (kg/ha)}$$

RESULTS AND DISSCUSSION

Effect on weeds

The experimental field was infested with fifteen weed species of which eight belonged to grasses, six were broad-leaved weeds and one sedge. Among grasses: *Cynodon dactylon, Dactyloctenium aegyptium, Leptochloa chinensis, Eleusine indica, Cenchrus catharticus, Digitaria sanguinalis, Setaria glauca* and *Panicum repens,* and among broad-leaved weeds; *Parthenium hysterophorus, Trianthema monogyna, Solanum nigrum, Phyllanthus niruri, Euphorbia hirta* and *Commelina benghalensis* were noticed in the field. *Cyperus rotundus* was the only sedge. *Cyperus rotundus, Cynodon dactylon* and *Parthenium hysterophorus* were the dominant weed species.

Among the herbicides tested, atrazine 2 kg/ha PE at 3 DAP *fb* halosulfuron-methyl 150 g/ha PoE at 45 DAP were statistically superior than triazinone 1.0 kg/ha at 3 DAP *fb* halosulfuron-methyl 150 g/ha PoE at 45 DAP at all the weed growth stages during both the years (**Table 1**). Atrazine 2 kg/ha PE at 3 DAP *fb* halosulfuron-methyl 150 g/ha at 45 DAP and metribuzin 2 kg/ha at 3 DAP *fb* halosulfuron-methyl 150 g/ha at 45 DAP were equally effective in controlling weeds and attaining higher WCE. The sequential application of pre- and post-emergence herbicides was more effective in managing initial as well as later emerged flushes of total weeds as observed by Jayabal and Chockalingam (1990). Relative efficacy of different aqua-based plant extracts was at par with each other. The combined application of sunflower + sorghum + maize extract was significantly superior over rest of the plant extracts for the control of total weeds biomass reduction due to their effective management of all categories of weeds as observed by Cheema *et al.* (2003) and Razzaq *et al.* (2010).

Weed index of different treatments indicated that herbicide sequences and aqua-based plant extracts have significant influence on yield improvement by controlling weeds (**Table 4**). Among the herbicidal sequences, atrazine 2 kg/ha PE at 3 DAP *fb* halosulfuron-methyl 150 g/ha PoE at 45 DAP caused higher reduction of weeds resulting in minimum value of weed index. The main reason for its efficacy was the efficient control of grassy and broad-leaved weeds by atrazine and sedges by halosulfuron-methyl as also reported by Singh *et al.* (2008) and Mc Elroy and Martins (2013).

Among the different herbicide treatments tested, atrazine 2 kg/ha PE at 3 DAP *fb* halosulfuron-methyl 150 g/ha at 45 DAP has resulted in less depletion of nitrogen, phosphorus and potassium by weeds (**Table 3**) due to less infestation of weeds owing to the better efficacy of this combination. Aqua-based plant extracts and cow urine application significantly influenced the uptake of primary nutrients by weeds. Combined application of sunflower + sorghum + maize extract has resulted in lowest uptake thus saved

Table 1. Effect of herbicide sequences and aqua based plant extracts on weed density (no./m^2) in sugarcane

Treatment	Weed density (no./m^2)					
	30 DAP		60 DAP		90 DAP	
	2016-17	2017-18	2016-17	2017-18	2016-17	2017-18
Herbicides						
Atrazine 2 kg/ha PE *fb* halosulfuron-methyl 150 g/ha PoE	6.7(44)	7.5(55)	7.7(59)	8.3(69)	9.5(91)	10.2(105)
Metribuzin 2 kg/ha PE *fb* halosulfuron- methyl 150 g/ha PoE	7.0(49)	7.7(60)	8.0(65)	8.7(75)	9.8(96)	10.5(109)
Triazinone 1.0 kg/ha PE *fb* halosulfuron-methyl 150g/ha PoE	7.9(62)	8.5(72)	8.6(75)	9.3(86)	10.6(113)	11.1(124)
Weed free	11.5(130)	12.0(144)	5.1(27)	6.2(39)	5.0(25)	6.0(38)
Weedy check	11.5(132)	12.0(148)	15.6(243)	16.3(270)	18.1(338)	18.1(355)
LSD (p=0.05)	0.32	0.43	0.42	0.45	0.39	1.54
Aqua-based plant extracts						
Cow urine 500 l/ ha.	9.2(90)	9.9(103)	9.3(101)	10.0(114)	10.9(144)	11.7(162)
Parthenium extract 15%	9.0(83)	9.6(96)	9.1(95)	9.8(108)	10.8(135)	11.3(146)
Sunflower + sorghum + maize extract 15%	8.3(73)	9.0(85)	8.4(84)	9.2(98)	9.9(116)	10.2(121)
Eucalyptus extract 15%	8.9(82)	9.5(95)	9.0(92)	9.7(106)	10.6(132)	11.2(143)
Water 600 l/ha	9.2(88)	9.8(101)	9.2(97)	10.0(112)	10.8(136)	11.6(157)
LSD (p=0.05)	0.31	0.34	0.34	0.30	0.36	0.94

PE = pre-emergence application; PoE = post-emergence application; *fb* = followed by; DAP = days after planting

Original figures in parenthesis were subjected to square root transformation (Ö X+1) before statistical analysis

Table 2. Effect of herbicide sequences and aqua based plant extracts on weeds biomass (g/m^2) in sugarcane

Treatment	Weed biomass					
	30 DAP		60 DAP		90 DAP	
	2016-17	2017-18	2016-17	2017-18	2016-17	2017-18
Herbicides						
Atrazine 2 kg/ha PE *fb* halosulfuron-methyl 150 g/ha PoE	3.04(8.9)	3.43(11.4)	7.53(56.9)	8.10(65.6)	10.12(103.2)	11.03(122.0)
Metribuzin 2 kg/ha PE *fb* halosulfuron- methyl 150 g/ha PoE	3.23(10.1)	3.59(12.6)	7.80(61.1)	8.39(70.5)	10.61(112.9)	11.33(128.6)
Triazinone 1 kg/ha. *fb* halosulfuron-methyl 150g/ha PoE	3.66(13.2)	3.95(15.4)	8.54(73.5)	9.08(82.7)	11.63(135.7)	12.33(152.5)
Weed free	5.72(32.5)	6.15(37.7)	2.95(8.6)	3.73(13.7)	4.58(21.1)	4.09(16.7)
Weedy check	5.80(32.5)	6.19(38.1)	16.31(267.1)	17.18(296.0)	21.68(471.0)	22.85(523.2)
LSD (p=0.05)	0.21	0.17	0.32	0.40	0.50	0.36
Aqua-based plant extracts						
Cow urine 500 l/ ha	4.46(21.3)	4.81(24.7)	8.85(99.5)	9.54(111.7)	12.05(178.2)	12.60(199.1)
Parthenium extract 15%	4.36(20.3)	4.70(23.3)	8.65(93.5)	9.35107.9)	11.77(170.0)	12.42(190.3)
Sunflower + sorghum + maize extract 15%	3.94(16.6)	4.35(20.1)	8.22(86.1)	8.84(96.8)	11.11(154.7)	11.77 (174.7)
Eucalyptus extract 15%	4.29(19.3)	4.69(23.0)	8.62(91.9)	9.27(103.6)	11.70(167.4)	12.34(187.5)
Water 600 l/ha	4.42(20.7)	4.77(24.1)	8.79(96.2)	9.49(108.5)	11.98(173.5)	12.49(191.5)
LSD (p=0.05)	0.17	0.14	0.24	0.27	0.37	0.29

*Original figures in parenthesis were subjected to square root transformation (Ö X+1) before statistical analysis; PE = pre-emergence application; PoE = post-emergence application; *fb* = followed by; DAP = days after planting

Table 3. Effect of herbicide sequences and aqua based plant extracts on NPK depletion by weeds and sugarcane yield

Treatment	Nutrient depletion by weeds (kg/ha)							
	Nitrogen		Phosphorus		Potassium		Total sugarcane yield (t/ha)	
	2016-17	2017-18	2016-17	2017-18	2016-17	2017-18	2016-17	2017-18
Herbicides								
Atrazine 2 kg/ha PE *fb* halosulfuron-methyl 150 g/ha PoE	3.80	4.42	2.73	3.05	4.77	5.47	143.45	131.96
Metribuzin 2 kg/ha PE *fb* halosulfuron- methyl 150 g/ha PoE	4.09	4.63	2.83	3.33	5.00	5.59	129.31	117.94
Triazinone 1 kg/ha PE *fb* halosulfuron-methyl 150g/ha PoE	4.50	4.99	3.70	3.82	5.44	6.17	119.18	102.05
Weed free	3.18	3.73	2.35	2.61	4.29	4.78	171.92	152.32
Weedy check	5.28	5.43	4.48	4.40	6.49	6.81	68.31	60.99
LSD (p=0.05)	0.34	0.30	0.56	0.38	0.28	0.25	11.56	14.04
Aqua-based plant extracts								
Cow urine 500 l/ ha	4.45	4.88	3.56	3.66	5.41	5.94	105.29	93.36
Parthenium extract 15%	4.08	4.60	3.29	3.51	5.25	5.82	127.35	113.17
Sunflower + sorghum + maize extract 15%	3.67	4.25	2.59	3.07	4.79	5.41	152.68	139.68
Eucalyptus extract 15%	4.15	4.66	3.16	3.39	5.17	5.72	130.61	116.57
Water 600 l/ha.	4.49	4.81	3.50	3.58	5.38	5.92	116.23	102.48
LSD (p=0.05)	0.30	0.26	0.51	0.28	0.24	0.21	6.29	6.30

*PE = pre-emergence application; PoE = post-emergence application; *fb* = followed by; DAP = days after planting

Table 4. Effect of herbicide sequence on weed control efficiency and weed index of different weeds in sugarcane

Treatment	Weed control efficiency (%) at 90 DAP		Weed index (%) at harvest	
	2016-17	2017-18	2016-17	2017-18
Herbicides				
Atrazine 2 kg/ha PE *fb* halosulfuron-methyl 150 g/ha PoE	78.97	78.21	12.28	23.22
Metribuzin 2 kg/ha PE *fb* halosulfuron-methyl 150 g/ha PoE	76.98	77.04	16.70	29.89
Triazinone 1.0 kg/ha PE *fb* halosulfuron-methyl 150 g/ha PoE	72.30	72.80	24.91	36.98
Weed free	95.72	97.02	4.96	9.04
Weedy check	3.85	6.66	55.91	62.94
LSD (p=0.05)	3.78	3.07	7.30	7.06
Aqua-based plant extracts				
Cow urine 500 l/ha	63.63	64.50	25.71	34.97
Parthenium extract 15%	65.27	66.06	23.96	33.92
Sunflower + sorghum + maize extract 15%	68.46	68.81	18.02	26.32
Eucalyptus extract 15%	65.82	66.53	22.90	32.05
Water 600 l/ha	64.63	65.83	24.17	34.83
LSD (p=0.05)	1.97	1.42	3.31	3.75

*PE = pre-emergence application; PoE = post-emergence application; *fb* = followed by; DAP = days after planting soil NPK content. The highest uptake of nutrients by weeds was noticed with un-weeded check due to heavy weed infestation and increased weeds biomass (Tomar *et al.* 2002; Hatcher and Melander 2003; Boquet *et al.* 2004).

Sugarcane yield

Hoeing at 30, 60 and 90 DAP (weed free) was superior over the herbicidal treatment in increasing sugarcane yield (Rana and Singh 2004). Atrazine 2 kg/ha PE at 3 DAP *fb* halosulfuron-methyl 150 g/ha PoE at 45 DAP increased cane yield due to effective management of associated (**Table 5**). The aqua based plant extracts also caused significant increase in cane yield. Maximum sugarcane yield was recorded with combine application of sorghum + maize + sunflower leaf extracts which was significantly higher than with eucalypus leaf extracts, parthenium extracts, water as well as cow urine and these four extracts remained at par with each other during both the years of experimentation. The results are in conformity with those of Ameena *et al.* (2015).

Conclusion

Atrazine 2 kg/ha PE at 3 DAP followed by halosulfuron-methyl 150 g/ha PoE at 45 DAP and metribuzin 2 kg/ha PE at 3 DAP *fb* halosulfuron methyl 150 g/ha at 45 DAP were equally effective in reducing weeds and their nutrient uptake and increasing sugarcane yield. Among the aqua-based plant extracts, highest WCE and lowest WI, lower nutrient uptake by weeds was registered with combined application of sorghum + maize + sunflower extracts.

REFERENCES

Ameena M, Kumari VG and George S. 2015. Allelopathic effects of root exudates of purple nutsedge (*Cyperus rotundus* L.) on growth of field crops. *Journal of Crop and Weed* **11**: 142–145.

Boquet DJ, Hutchinson RL and Breitenbeck GA. 2004. Long-term tillage, cover crop and nitrogen rate effects on cotton. *Agronomy Journal* **96**: 1443–1452.

Table 5. Effect of herbicide sequences and aqua based plant extracts on cane yield, cane top yield and cane trash yield of sugarcane

Treatment	Cane yield (t/ha)		Cane top yield (t/ha)		Cane trash yield (t/ha)	
	2016-17	2017-18	2016-17	2017-18	2016-17	2017-18
Herbicides						
Atrazine 2 kg/ha PE *fb* halosulfuron-methyl 150 g/ha PoE	98.65	91.96	24.55	22.38	13.34	11.84
Metribuzin 2 kg/ha PE *fb* halosulfuron-methyl 150 g/ha PoE	89.51	82.94	23.78	20.70	13.23	11.36
Triazinone 1 kg/ha PE *fb* halosulfuron-methyl 150g/ha PoE	74.38	62.05	21.90	18.67	11.25	9.39
Weed free	127.12	112.32	30.05	27.61	16.40	14.75
Weedy check	48.51	45.99	13.39	10.78	8.09	6.11
LSD (p=0.05)	11.56	14.04	1.82	1.69	1.04	1.32
Aqua-based plant extracts						
Cow urine 500 l/ ha.	65.29	59.36	21.70	18.03	11.83	9.21
Parthenium extract 15%	87.35	79.17	22.87	20.23	12.56	11.41
Sunflower + Sorghum +Maize extract 15%	118.68	105.68	24.29	23.37	13.33	13.05
Eucalyptus extract 15%	90.61	82.57	22.92	20.41	12.64	10.56
Water 600 l/ha.	76.23	68.48	21.90	18.09	11.97	9.23
LSD (p=0.05)	6.29	6.30	0.96	1.27	0.63	1.19

Table 6. Effect of herbicide sequences and aqua based plant extracts on economics of sugarcane

Treatment	Cost of cultivation ($x10^3$ `/ha)		Gross returns ($x10^3$ `/ha)		Net returns ($x10^3$ `/ha)		B:C	
	2016-17	2017-18	2016-17	2017-18	2016-17	2017-18	2016-17	2017-18
Herbicides								
Atrazine 2 kg/ha PE *fb* halosulfuron-methyl 150g/ha PoE	80.17	96.03	251.55	234.50	171.38	138.47	2.14	1.44
Metribuzin 2 kg/ha PE *fb* halosulfuron-methyl 150g/ha PoE	88.26	104.12	228.24	211.50	139.98	107.37	1.59	1.03
Triazinone 1.0 kg/ha PE *fb* halosulfuron-methyl 150g/ha PoE	79.46	95.32	189.67	158.24	110.20	62.91	1.39	0.66
Weed free	110.55	126.40	324.16	286.42	213.61	160.01	1.93	1.27
Weedy check	78.73	94.58	123.69	117.27	44.96	22.68	0.57	0.24
Aqua-based plant extracts								
Cow urine 500 l/ ha.	87.43	103.29	166.50	151.37	79.06	48.07	0.90	0.47
Parthenium extract 15%	87.43	103.29	222.75	201.89	135.31	98.60	1.55	0.95
Sunflower + sorghum + maize extract 15%	87.43	103.29	302.63	269.48	215.20	166.19	2.46	1.61
Eucalyptus extract 15%	87.43	103.29	231.05	210.54	143.61	107.25	1.64	1.04
Water 600 l/ha	87.43	103.29	194.38	174.62	106.94	71.33	1.22	0.69

Cheema ZA, Hussain S and Khaliq A. 2003. Efficacy of sorgaab in combination with allelopathic water extracts and reduced rates of pendimethalin for weed control in Mungbean. *Indus Journal of Plant Science* **2**: 21–25.

Choudhary HR and Singh RK. 2016. Effect of sequential application of herbicides on weeds and productivity of spring planted sugarcane (*Saccharum officinarum* L.). *The Bioscan* **11**(1): 687–690.

Devedee AK, Singh RK, Meena RN, Choudhary K, Mahjabeen, Meena AK and Meena K. 2022. Effect of different allelopathic aqueous extracts combination with synthetic herbicide on weed dynamics yield attributing characters and soil microbial population in sugarcane. *Agricultural Mechanization in Asia* **53**(4): 7423–7431.

Farooq M, Jabran K, Cheema ZA, Wahid A and Siddique KHM. 2011. The role of allelopathy in agricultural pest manage-ment. *Pest Management Sciences* **67**(5): 493–506.

Farooq M, Jabran K, Rehman H and Hussain M. 2008. Allelopathic effects of rice on seedling development in wheat, oat, bar-ley and berseem. *Allelopathy Journal* **22**(2): 385–390.

Gill GS and Kumar KV. 1969. "Weed index" A new method for reporting weed control trial. *Indian Journal of Agronomy* **14**(2): 96–98.

Gomez KA and Gomez AA. 1984. Statistical Procedures in Agriculture Research. Wiley 2nd Edition, New York, Chichester.

Hatcher PE and Melander B. 2003. Combining physical, cultural and biological methods prospects for integrated non-chemical weed management strategies. *Weed Research* **43**: 303–322.

Hussain S, Siddiqui SU, Khalid S, Jamal A, Qayyum A and Ahmed Z. 2007. Allelopathic potential of senna on germi-nation and seedling characters of some major cereal crops and their associated grassy weeds. *Pakistan Journal of Botany* **39**(4): 1145–1153.

Jabran K, Farooq M, Hussain M, Rehman H and Ali MA. 2010. Wild oat (*Avena fatua* L.) and canary grass (*Phalaris minor* Ritz.) management through allelopathy. *Journal of Plant Protection and Research* **50** (1): 32–35.

Jayabal V and Chockalingam S. 1990. Effect of herbicides and cultural practices on yield and quality of sugarcane. *Bhartiya Sugar* **16**(1): 197–201.

Kumar V, Hooda VS, Nandal DP, Kumar S and Gupta G. 2017. Influence of weed management practices on nutrient uptake and productivity of basmati rice under different dates of transplanting. *Environment and Ecology* **35**(2A): 885–889.

Le Baron HM. 1992. Herbicide resistance in crops and weeds and its management. In: *Proceedings 3rd Tropical Weed Science Conference,* Kualalampur, Malaysia.

Mani VS, Mala ML, Gautam KC and Bhagavandas. 1973. Weed killing chemicals in potato cultivation. *Indian Farming* 23 (1): 17–18.

Mc Elroy JS and Martins D. 2013. Use of herbicides on turfgrass, *Planta Daninha*. *Vicosa –MG* **31**(2): 455–467.

Rana NS and Singh D. 2004. Studies on integrated weed management in spring planted sugarcane under Tarai conditions of Uttaranchal. *Indian Journal of Weed Science* **36**(1-2): 89–92.

Razzaq A, Cheema ZA, Jabran K, Farooq M, Khaliq A, Haider G and Basra SMA. 2010. Weed management in wheat through combination of allelopathic water extracts with reduced doses of herbicides. *Pakistan Journal of Weed Science Research* **16**(3): 247–256.

Singh A, Virk, AS, Singh J and Singh J. 2001. Comparison of pre- and post-emergence application of herbicides for the control of weeds in sugarcane. *Sugar Tech* **3**(3): 109–112.

Singh R, Radhey S, Tripathi, SS and Kumar S. 2008. Integrated weed management studies in spring planted sugarcane. *Indian Journal of Weed Science* **40**(1-2): 85–87.

Tomar PK, Om P and Singh D. 2002. Nutrient uptake (N, P and K) by weeds and crop as influenced by weed management practices in late-planted sugarcane. *Indian Journal of Sugarcane Technology* **17**(1-2): 72–74.

Venkatesh D and Venkateswarlu M. 2017. An overview of the Indian sugar industry, BIMS *International Journal of Social Science Research* **2**(1): 11–16.

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RESEARCH ARTICLE

Integrated weed management in irrigated cotton under high density planting system

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ABSTRACT

Field experiments were conducted under irrigated condition during winter seasons of 2020-21 and 2021-22 (September to February) at Cotton Research Station, Tamil Nadu Agricultural University, Srivilliputtur to study the comparative efficacy of mechanical and chemical weed management methods in cotton. Six treatments were evaluated in a randomized block design with four replications. The treatments consisted of control (no weeding), weed free check, pre-emergence application of (PE) pendimethalin at 1.0 kg/ha followed by (*fb)* one hoeing at 45 days after sowing (DAS), pendimethalin at 1.0 kg/ha *fb* post-emergence application (PoE) of pyrithiobac-sodium at 62.5 g/ha at 25 DAS *fb* one hoeing at 45 DAS, weeding by power tiller at 25 and 45 DAS, pendimethalin PE at 1.0 kg/ha *fb* weeding by power tiller on 25 and 45 DAS. Pendimethalin PE *fb* pyrithiobac-sodium PoE *fb* one hoeing recorded the higher cotton growth and yield attributes except boll weight along with lesser weed density and biomas and higher weed control efficiency. This was on par with that of pendimethalin PE *fb* weeding by power tiller at 25 and 45 DAS and pendimethalin PE *fb* one hoeing at 45 DAS and significantly superior than weeding by power tiller at 25 and 45 DAS. Application of PE *fb* PoE herbicide *fb* one hoeing also registered the highest seed cotton yield which were comparable with that of pendimethalin *fb* weeding by power tiller at 25 and 45 DAS. The cost of cultivation was drastically reduced by mechanical weeding. The economic analysis showed that higher net income and benefit cost ratio were associated with PE herbicide application *fb* weeding by power tiller at 25 and 45 DAS followed by weeding by power tiller at 25 and 45 DAS.

Keywords: Cotton, Economics, Mechanical weeding, Pendimethalin, Power tiller, Pyrithiobac-sodium, Weed management

INTRODUCTION

Cotton is the most important fibre and commercial crop of India with the largest area (41.3 per cent) of cotton in the world. However, due to its lower productivity, India's share to the total world cotton production is 25.4 per cent only. In Tamil Nadu, cotton is cultivated in an area of 1.55 lakh ha during 2020-21 with a production of 5.0 lakh bales and productivity of 548 kg/ha which is below the world average yield of 768 kg/ha (Anonymous 2021). Among the constraints of cotton production, the most troublesome is the weeds menace. Cotton is very sensitive to crop-weed competition due to slow growth during early stage and wider spacing resulting in reduction in yield of cotton of 50 to 85 per cent (Venugopalan *et al.* 2009). The labour scarcity and higher wages, are preventing farmers to timely manage weeds in cotton and hence, the chemical and mechanical weed management methods play important role. As pre-emergence herbicides effectively controlled the weeds of early stages of crop growth, post-emergence herbicides or mechanical weeding are needed to combat the weed growth at later stages to minimize the cost of cultivation. In this context, the present study was carried out to study the combined efficacy of chemical and mechanical weed management methods in irrigated cotton under high density planting system.

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MATERIALS AND METHODS

Field experiments were conducted under irrigated condition during winter seasons of 2020-21 and 2021-22 (September to February) at Cotton Research Station, Tamil Nadu Agricultural University, Srivilliputtur. Six treatments were evaluated in a randomized block design with four replications. The treatments consisted of control (no weeding), weed free check, pre-emergence application (PE) of pendimethalin at 1.0 kg/ha followed by one hoeing on 45 (DAS), pendimethalin at 1.0 kg/ha *fb* post-emergence application (PoE) of pyrithiobac - sodium at 62.5 g/ha on 25 days after seeding (DAS) *fb* one hoeing on 45 DAS, weeding by power tiller on 25 and 45 DAS, pendimethalin PE at

1.0 kg/ha *fb* weeding by power tiller on 25 and 45 DAS. The zero monopodial cotton variety CO 17 was used for the study. High density planting system was followed with a spacing of 100 x 10 cm with a fertilizer recommendation of 100:50:50 kg NPK/ha. The power tiller (model VST Sakthi 130 DI and width 80 cm) was used for weeding in the concerned mechanical weeding treatments.The data on weed density and biomass were recorded at 25 and 50 DAS. The weed control efficiency (WCE) and weed index (WI) were calculated as per standard formulae. The growth, yield attributes and seed cotton yield were recorded and economics was also worked out.

RESULTS AND DISCUSSION

Cotton growth and yield attributes

The weed control treatments caused significantly higher growth and yield attributes than control during both the years (**Table 1**). Among them, pendimethalin PE *fb* pyrithiobac-sodium PoE at 20 - 25 DAS *fb* one hoeing at 40-45 DAS recorded the highest plant height, number of monopodial branches and number of bolls per plant which were on par with that of pendimethalin PE *fb* weeding by power tiller at 25 and 45 DAS, pendimethalin PE application *fb* one hoeing at 40- 45 DAS and significantly higher than weeding by power tiller at 25 and 45 DAS. However there was no significant difference among the weed control treatments on boll weight. Favourable cotton growth and yield attributes due to weeding by power weeder was noticed by Malarkodi *et al.* (2017) and Bhoi *et al.* (2010).

Effect on weeds

The pre-emergence herbicide application treatments registered significantly lesser weed density and biomass than without pre-emergence herbicide application at 25 DAS (**Table 2**). However, at 50 DAS, the treatments which received hoeing recorded significantly lower weed densities than all other treatments. The effect of weeding by power tiller was sigficantly superior than control as evident from significantly lesser weed density with these treatments. The lower weed density under pre-emergence herbicides application followed by power tiller weeding twice might have been due to effective hindering the germination of weeds in the initial stages and reducing the density of grasses, sedges and broad-leaved weeds by pre-emergence herbicide and also by efficiently uprooting the weeds by power tiller. Similar results of lesser weed density with pre-emergence herbicide application and mechanical weeder were reported earlier by Kamble *et al.* (2017) and Hiremath *et al.* (2013). The beneficial effect of post-emergence herbicides in reducing the weed biomass in cotton was also reported by Veeraputhiran and Srinivasan (2015) and Mahar *et al.* (2007). The superiority of combination of chemical and mechanical weed management in Bt cotton was reported by Kamble *et al.* (2017), Nakala *et al.* (2019) and Patel *et al.* (2013).

The higher WCE and lesser weed index were observed with pendimethalin PE *fb* pyrithiobac-sodium PoE at 20-25 DAS *fb* one hoeing in both the time of observation (**Table 2**). The next higher WCE and lesser WI were recorded with pendimethalin PE *fb* weeding by power tiller at 25 and 45 DAS during both the years of study. Higher WCE in the above treatments was due to more effective controlling of weeds as result of lesser weed density and biomass. Beneficial effect of mechanical weeding with higher WCE was also registered by Nakala *et al.* (2019).

Seed cotton yield

The weed management had significant impact on seed cotton yield (**Table 1**). The pendimethalin PE *fb* pyrithiobac-sodium PoE at 25 DAS *fb* one hoeing

Table 1. Effect of weed management treatments on growth and yield of cotton

Treatment	Plant height at 120 DAS (cm)		No. of sympodia		No. of bolls/plant		Boll weight (g)		Seed cotton yield (kg/ha)		No. of labours used for weeding	
	2020-21	2021-22	2020-21	2021-22	2020-21	2021-22	2020-21	2021-22	2020-21	2021-22	2020-21	2021-22
Control (no weeding)	72.6	68.4	8.3	7.4	7.3	6.7	4.12	4.07	636	528	0	0
Weed free check	105.6	89.8	17.0	15.6	16.2	14.2	4.96	4.56	1989	1796	72	75
Pendimethalin 1.0 kg/ha PE *fb* one hoeing at 45 DAS	101.8	84.7	16.1	13.8	14.9	12.5	4.81	4.41	1897	1691	42	45
Pendimethalin1.0 kg/ha PE *fb* pyrithiobac-sodium 62.5 g/ha PoE at 25 DAS *fb* one hoeing on 45 DAS	105.1	89.2	17.6	15.4	15.9	13.9	4.95	4.54	1956	1753	46	49
Weeding by power tiller at 25 and 45 DAS	98.5	82.6	15.3	13.3	14.3	12.0	4.76	4.36	1788	1572	12	12
Pendimethalin1.0 kg/ha PE *fb* weeding by power tiller at 25 and 45 DAS	103.7	87.1	16.8	14.7	15.3	13.3	4.83	4.45	1908	1704	17	17
LSD (p=0.05)	10.5	9.46	2.01	1.78	1.51	1.40	0.30	0.26	135.2	115.9	-	-

PE: Pre-emergence application; PoE: Post-emergence application; DAS: Days after seeding; *fb*: Followed by registered the highest seed cotton yield of 1956 and 1753 kg/ha during 2020-21 and 2021-22, respectively which were comparable with that of pendimethalin PE *fb* weeding by power tiller at 25 and 45 DAS (1908 and 1704 kg/ha) and pendimethalin PE *fb* one hoeing at 45 DAS (1897 and 1691 kg/ha) and significantly higher than unweeded control (636 and 528 kg/ha) and weeding by power tiller at 25 and 45 DAS (1788 and 1572 kg/ha). The higher seed cotton yield under pre-emergence herbicide application followed by weeding twice by power tiller might be due to low weeds density during initial stage and also further control of later germinated weeds by the supplemented inter cultivation using power tiller. Similar results of higher yield with integrated management of weeds in cotton by pre-emergence herbicide and mechanical weeder was reported by Tanveer *et al.* (2003), Ali *et al.* (2013), Kamble *et al.* (2017) and Malarkodi *et al.* (2017)

Economics

The economic analysis (**Table 3**) revealed that higher gross income was noticed with pendimethalin PE *fb* pyrithiobac-sodium PoE at 20-25 DAS *fb* one hoeing during both the years of study. However, higher net income, benefit cost ratio and marginal benefit cost ratio were associated with pendimethalin PE *fb* weeding by power tiller at 25 and 45 DAS followed by weeding by power tiller at 25 and 45 DAS. The cost of cultivation has drastically reduced by mechanical weeding. As compared to pendimethalin PE *fb* one hoeing at 40- 45 DAS, reduction in cost of cultivation of Rs 6860 and Rs 7060/ha during 2020-21 and 2021-22 was observed by pendimethilin PE *fb* power tiller weeding at 25 and 45 DAS. Higher total income net income and B:C under the treatments were as a result of corresponding higher seed cotton yield confirming the reports by Kamble *et al.* (2017), Bhoi *et al.* (2010) and Malarkodi *et al.* (2017).

Table 2. Effect of weed management treatments on weed density and biomass, weed control efficiency and weed index of cotton

Treatment	Total weed density (no/m^2)				Total weed dry weight (g/m^2)				Weed control efficiency (WCE) (%)				Weed index	
	2020-21		2021-22		2020-21		2021-22		2020-21		2021-22		2020-21	2021-22
	25 DAS	50 DAS	25 DAS	50 DAS	25 DAS	50 DAS	25 DAS	50 DAS	25 DAS	50 DAS	25 DAS	50 DAS		
Control (no weeding)	504.7 (22.5)	509.6 (22.6)	410.2 (20.3)	131.5 (20.8)	92.2 (9.6)	130.5 (11.4)	80.6 (9.0)	110.7 (10.5)	0	0	0	0	68.02	70.60
Weed free check	0	0	0	0	0	0	0	0	100.0	100.0	100.0	100.0	0	0
Pendimethalin 1.0 kg/ha PE *fb* one hoeing at 45 DAS	96.0 (9.8)	46.9 (6.9)	990.3 (9.5)	40.2 (22.5)	9.6 (3.2)	5.8 (2.5)	7.7 (2.9)	5.1 (2.4)	89.58	95.56	90.45	95.39	4.62	5.84
Pendimethalin 1.0 kg/ha PE *fb* pyrithiobac-sodium 62.5 g/ha PoE on 25 DAS *fb* one hoeing at 45 DAS	90.5 (9.5)	29.6 (5.5)	85.4 (9.3)	26.8 (22.5)	9.8 (3.2)	4.1 (2.1)	6.5 (2.6)	4.2 (2.2)	92.62	96.86	91.93	96.20	1.66	2.44
Weeding by power tiller at 25 and 45 DAS	478.2 (2.9)	112.0 (10.6)	423.1 (20.6)	146.3 (22.5)	90.5 (9.5)	17.9 (4.3)	14.4 (3.9)	17.0 (4.2)	1.84	86.23	82.13	84.64	10.10	10.47
Pendimethalin1.0 kg/ha PE *fb* weeding by power tiller at 25 and 45 DAS	95.6 (9.8)	109.3 (10.5)	89.6 (9.5)	94.5 (22.5)	10.2 (3.3)	14.6 (3.9)	12.1 (3.5)	14.5 (3.9)	86.77	88.81	84.99	86.90	4.07	5.12
LSD(p=0.05)	20.74	19.22	19.47	17.69	6.26	6.74	5.27	5.78	-	-				

Figures in parentheses indicate $\sqrt{x+0.5}$ value; PE: Pre-emergence application; PoE: Post-emergence application; DAS: Days after seeding; *fb*: Followed by

Table 3. Effect of weed management treatments on economics of cotton cultivation

Treatment	Cost of cultivation (x10^3 `/ha)						Gross income (x10^3 `/ha)		Net income (x10^3 `/ha)		Benefit Cost ratio		Marginal Benefit Cost ratio	
	Common		Treatment		Total									
	2020-21	2021-22	2020-21	2021-22	2020-21	2021-22	2020-21	2021-22	2020-21	2021-22	2020-21	2021-22	2020-21	2021-22
Control (no weeding)	53.20	55.40	0	0	53.20	55.40	33.07	43.30	-20.13	-12.10	0.62	0.78	0	0
Weed free check	53.20	55.40	20.36	21.08	73.56	76.48	103.43	147.27	29.87	70.79	1.41	1.93	1.42	3.36
Pendimethalin 1.0 kg/ha PE *fb* one hoeing at 45 DAS	53.20	55.40	12.00	13.00	65.20	68.40	98.64	138.66	33.44	70.26	1.51	2.03	2.78	5.40
Pendimethalin 1.0 kg/ha PE *fb* pyrithiobac-sodium 62.5 g/ha PoE on 25 DAS *fb* one hoeing at 45 DAS	53.20	55.40	15.75	16.75	68.95	72.15	101.71	143.75	32.76	71.60	1.48	1.99	2.08	4.27
Weeding by power tiller at 25 and 45 DAS	53.20	55.40	5.25	6.05	58.45	61.45	92.98	128.90	34.53	67.45	1.59	2.10	6.58	11.15
Pendimethalin 1.0 kg/ha PE *fb* weeding by power tiller at 25 and 45 DAS	53.20	55.40	8.89	9.69	62.09	65.09	99.22	139.73	37.13	74.64	1.60	2.15	4.17	7.70

Thus, it may be concluded that economical weed management and higher cotton yield are obtainable with pre-emegence application of pendimethalin 1.0 kg/ha followed by weeding by power tiller at 25 and 45 DAS in winter irrigated cotton under high density planting system.

REFERENCES

Anonymous. 2021. Cotton Market Report News Letter XXXXIII (08):1–2 Published by Indian Cotton Federation, Coimbatore.

Ali H, Abid SA, Ahmad S, Sarwar N, Arooj M, Mahmood A and Shahzad AN. 2013. Integrated weed management in cotton cultivated in the alternate-furrow plantingsystem. *Journal of Food, Agriculture & Environment* **11**(3&4): 1664–1669.

Bhoi SK, Lakpale R, Jangre A and Mishra S. 2010. Studies on theffect of weed control methods on growth and yield attributes of hybrid cotton. *Research Journal of Agricultural Sciences* **1**(4): 434–437.

Hiremath R, Yadahalli GS, Chittapur BM, Siddapur AD, Yadahalli VG and Koppalkar BRG. 2013. Efficacy of chemical weed management in Bt cotton (*Gossypium hirsutum* L.) *Acta Biologica Indica* **2**(2): 425–429.

Kamble AB, Danawale NJ and Rajendrakumar 2017. Integrated weed management in Bt cotton. *Indian Journal of Weed Science* **49**(4): 405–408.

Malarkodi N, Balasubramanian R, Balakrishnan K, Krishnasamy S and Gopal. 2017. Integrated weed management in cotton. *Agriculture Update* **12**: 224–229.

Mahar GM, Oad FC, Buriro UA and Solangi GS, 2007.Effect of post-emergence herbicides on the yield of up- land cotton. *Asian Journal of Plant Sciences* **6**(8): 1282–1286.

Nakala V, Ramprakash T, Madhavi M and Devi KBS. 2019. Influence of weed control practices on nutrient uptake in cotton plant. *Journal of Research in Weed Science* (**2**)2: 115–126.

Patel JGM, Raj VC, Kumar V, Sutaria CM and Usadadiya VP. 2013. Integrated weed management in Bt cotton. *International Journal of Agriculture Innovations and Research* **2**(2): 149–151.

Tanveer A, Chaudhry NH, Ayub M and Ahmad R. 2003. Effect of cultural and chemical weed control methods on weed population andyield of cotton. *Pakistan Journal of Botany* **35 (2)**: 161–166.

Veeraputhiran R and Srinivasan G. 2015. Post-emergence herbicides effect on weeds, yield and economics of Bt cotton. *Indian Journal of Weed Science* **47**(4): 379–382.

Venugopalan MV, Sankaranarayanan K, Blaise D, Nalayini P, Prahraj CS and Gangaiah B. 2009. Bt cotton (*Gossypium* sp.) in India and its agronomic requirements: A review. *Indian Journal of Agronomy* **54**(4): 343–360.

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RESEARCH ARTICLE

Stale seed bed technique and leguminous cover crops as components of integrated weed management in irrigated cotton

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ABSTRACT

Integrated weed management approach is preferable to manage weeds effectively and economically. A study was carried out at Central Institute for Cotton Research, Regional station, Coimbatore to study the efficacy of stale seed bed technique (SSBT) in integration with weed smothering legumes as cover crops (CC) in managing weeds of irrigated cotton production system. The experiment was conducted during winter season of 2015-16 and 2016-17 cropping season in a randomized block design with four replications. Six weed control treatments viz., SSBT + CC - *Mimosa invisa*, SSBT + CC - *Crotalaria juncea*, SSBT + CC- *Sesbania aculeata*, SSBT + CC -*Vigna unguiculata* , SSBT + CC - *Desmanthus virgatus* along with one hand weeding (HW) at 30 days after seeding (DAS) was common to all cover crop treatments. They were compared against pre-emergence application (PE) of pendimethalin 1.0 kg/ha at 3 DAS followed by (*fb*) hand weeding twice at 30 and 60 DAS. The weed pressure was reduced significantly with SSBT integrated with leguminous cover crops when compared to currently recommended practice of pendimethalin PE *fb* hand weeding twice. The integration of SSBT to exhaust weed seed bank and growing of leguminous cover crops like *Crotalaria juncea* and *Vigna unguiculata* to smother weeds reduced weed pressure and hence recommended as an effective, sustainable weed management options in irrigated cotton production system

Keywords: Cotton, Stale seed bed technique (SSBT), Cover crops, Legumes, Weed management

INTRODUCTION

Cotton is cultivated at wider row spacing and the crop is slow growing during initial 45 days causing severe weed competition to the crop (Kalaichelvi 2008).Weed management is the most important component of irrigated cotton production system. The farmers are currently using inter-cultivation operations besides manual weeding to control weeds, while the technical recommendation is the pre-emergence (PE) herbicide application followed by (*fb*) two or three inter cultivations (Prabhu *et al.* 2010). However, as the inter-row cultivation operation is weather dependent, its timely adoption may not be possible. The pre-emergence herbicides are effective only for 2 - 4 weeks and hence late emerging weeds escape (Nalayini and Raju 2010). Repeated use of herbicides may be harmful to soil and environment. Hence, adoption of integrated weed management approach with minimum use of herbicides is suggested (Rao and Nagamani 2010). Thus, exploring other options like stale seed bed technique and targeting weeds in advance of cotton sowing to minimise weed pressure during actual cotton growing period and smothering of weeds by compatible leguminous cover crops may help in sustainably managing weeds of irrigated cotton. Cover crops play an important role in smothering the weeds and enclose the open land under vegetative cover until the main crop establishes so as to avoid late emerging weeds competing with main crop. In addition to weed control through physical obstruction and/or biochemical suppression, cover crops provide numerous environmental benefits that can promote long-term sustainability of farm lands. Leguminous covers such as hairy vetch (*Vicia villosa*) increase plant – accessible soil nitrogen leading to increase in growth and yield of cotton (Sainju *et al.* 2005). Cover crops also improve soil composition, conserve soil carbon, nitrogen and moisture content and enhance microbial activity (Hoffman and Regnier 2006). Thus, this study was conducted with the objective of quantifying the effect of integration of the stale seed bed technique with weed smothering leguminous cover crops on weeds and seed cotton yield.

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MATERIALS AND METHODS

Field experiments were conducted consecutively for two years during August – February 2015-16 and

2016-17 cropping season in the new area farm of the Regional station, ICAR - Central Institute for Cotton Research, Coimbatore (11^0N, 77^0E and 426.6 m MSL), Tamil Nadu. The total rainfall during the study period was (348.4 mm) in 2015-16 and (151 mm) in 2016-17. The experimental soil was low (161.2, 168.5 kg/ha) in soil available N, medium (13.5, 19.5 kg/ha) in phosphorus and high (680.5,720.2 kg/ha) in potash during 2015-16 and 2016-17 cropping season respectively.

The randomized block design with four replications was used. Six weed control treatments viz., stale seed bed technique (SSBT) + cover crop (CC) - *Mimosa invisa*; SSBT + CC-*Crotalaria juncea*; SSBT + CC - *Sesbania aculeata*; SSBT + CC - *Vigna unguiculata*; SSBT + CC - *Desmanthus virgatus*, and pendimethalin 1.0 kg /ha PE on 3 days after seeding (DAS) *fb* hand weeding twice at 30 and 60 DAS. All the treatments of SSBT + CC had received one hand weeding on 30 DAS. For the SSBT based treatments, the field was prepared one month in advance of cotton sowing by giving irrigation on 24 July and 5 August during 2015-16 and 2016-17 respectively. The germinated young weed seedlings were sprayed with mixture of pendimethalin 1.0 kg + glyphosate 1.0 kg two weeks after the irrigation on 7 August during 2015-16 and 19 August during and 2016-17. The germinated weeds were killed by the glyphosate and the weeds germinated after the herbicide spraying were killed by the residual action of pendimethalin. Two weeks after pre-sowing herbicidal spraying, the sowing of cotton crop cultivar RCH 20 Bt was taken up on one side of the ridges at 90 x 60 cm spacing on 21 August 2015-16 and 2 September 2016-17. The respective cover crops were sown on the other side of ridges. The pendimethalin PE was done on 24 August 2015 and 5 September 2016 during 2015-16 and 2016-17, respectively. The recommended dose of 90:45:45 kg/ha NPK were given to cotton crop in four equal splits of N and K at sowing, 30, 60 and 90 DAS while the entire P was applied as basal before cotton sowing. The weed density was recorded on 30 and 60 DAS *i.e.*, on 19 September 2015 and 19 October 2015 during 2015-2016 season and 1 October 2016 and 31 October 2016 during 2016-2017. The cover crops were allowed to smother weeds up to 45 DAS as living mulch and removed on 5 October and 17 October during 2015-16 and 2016-17, respectively and applied in the same sowing line of cover crops which added organics to the soil for sustainability of the system. Cotton was harvested (picked) on 28 December and 16 January during 2015-16 and 12 January and 27 January during 2016-17. The pooled data was subjected to ANOVA (Gomez and Gomez 1984) by using the randomized block design and analysed.

RESULTS AND DISCUSSION

Effect on weeds

The experimental field was infested with 15 broad-leaved weeds, six grassy weeds, one sedge weed. The broad-leaved weeds were**:** *Abutilon indicum, Amaranthus viridis, Argemone mexicana, Boerhaavia diffusa, Corchorus trilocularis, Celosia argentea, Datura metal, Digera arvensis, Euphorbia hirta, Gynandropis pentaphylla, Parthenium hysterophorus, Phyllanthus niruri, Portulaca oleracea, Trianthema portulacastrum* and *Tridax procumbens*. The grassy weeds *were: Chloris barbata, Cynodon dactylon, Dinebra arabica, Eleusine aegyptiaca, Panicum repens, Pennisetum cenchroides,* and the sedge *Cyperus rotundus*. Among the weed species, the carpet weed, *Trianthema portulacastrum* was the most dominant weed during initial stage of cotton growth.

The SSBT with cover crops caused significantly greater reduction in weed density and biomass (**Table 1**) on 30 and 60 DAS when compared to pendimethalin PE. The reduction in weed density in SSBT + cover crops might be due to exhausting weed seed bank by SSBT and better weed smothering by cover crops. Smothering effect of intercrop in Bt.

Table 1. Weed density and biomass as influenced by treatments in irrigated cotton

Treatment	Weed density (no./m^2) 30 DAS	Weed biomass (g/m^2) 30 DAS	Weed density (no./m^2) 60 DAS
SSBT + CC - *Mimosa invisa* followed by (*fb*) HW 30 DAS	67 (8.17)	74.5	174 (13.02)
SSBT + CC - *Crotalaria juncea fb* HW 30 DAS	63.0(7.91)	62.5	183.5 (13.54)
SSBT + CC - *Sesbania aculeata fb* HW 30 DAS	46.8 (6.79)	54.0	171.0 (12.69)
SSBT + CC - *Vigna unguiculata fb* HW 30 DAS	49.8 (7.04)	59.5	220.0 (14.7)
SSBT + CC - *Desmanthus virgatus fb* HW 30 DAS	74.0 (8.55)	76.5	158 (12.22)
Pendimethalin 1.0 kg PE *fb* HW twice 30 and 60 DAS	198.5(13.95)	212.5	372 (19.10)
LSD (p=0.05)	2.23	134.2	2.908

Figures in parentheses are square root transformed values for statistical analysis; HW: hand weeding; PE: Pre-emergence application; DAS: days after seeding cotton on weeds was also observed by Veeraputhiran and Sankaranarayanan (2021). Sun hemp grown as intercrop with cotton and later mulched into soil was reported to have lesser weeds (Blaise *et al.* 2020). Suppression of weeds by winter cover crops was attributed to allelopathy (Batish *et al.* 2006) and to physical blockage and shading (Teasdale and Mohler 2000).

Effect on cotton

The highest dry matter production of cotton was recorded with SSBT + *Crotalaria juncea* and it was on par with all other treatments except SSBT + *Sesbania aculeata* which recorded significantly lower cotton dry matter accumulation. The number of bolls/ plant was significantly higher with SSBT + *Vigna unguiculata* and SSBT + *Crotalaria juncea* and were on par and found superior to all other treatments. The differences in boll weight were not statistically significant, but all the SSBT + cover crops produced numerically higher boll weight and the boll weight was highest with SSBT + *Sesbania aculeata.* The seed cotton yield was significantly higher with SSBT with *Vigna unguiculata* + one HW and SSBT + *Crotalaria juncea* + one HW and the lowest (1959 kg/ ha) was recorded with no SSBT –pendimethalin PE + HW twice. The *Sesbania aculeata* which resulted in reduced dry matter accumulation which might be due to its competition with cotton crop for resources. However, all other SSBT + cover crops recorded higher dry matter accumulation by cotton due to lesser weed competition and lesser competition from cover crops for growth factors. Reduction in weed emergence and biomass due to cover crops was attributed earlier to release of allelo chemicals by living roots and residues (Macias et al. 2019) and /or physical interference to weed emergence (Teasdale *et al.* 2000). The fibre quality attributes were not influenced significantly by the weed control treatments.

Effect on sustainability

Inclusion of leguminous cover crops as intercrops with cotton not only for weed smothering but also aids in maintaining sustainability of the system due to legume effect. The fresh biomass added by various cover crops ranged from 1271 to 16238 kg/ha with the dry biomass worked out to about 329 - 3960 kg/ha. The ideal cover crops to be grown with cotton for weed smothering and significant yield improvement are *Vigna unguiculata* and *Crotalaria juncea* as they contributed dry matter of 1591 and 1574 kg/ha with nitrogen contribution of 45.07 and 56.56 kg/ha, respectively. The potential replacement of over 60% of the N fertilizer requirement for optimum cotton production by leguminous cover crop was reported with vetch which produced 225 kg N/ha under Australian condition (Robert *et al.* 2011). The post-harvest N status of the experimental soil revealed that all the cover crops treatments improved the available soil N status over no cover crop treatment. Among the cover crops, *Desmanthus virgatus* and *Crotalaria juncea* recorded significantly higher available soil N over other crops might be due to higher N fixation by

Table 2. Dry matter production of cotton, yield attributes, seed cotton yield and post-harvest soil available nitrogen status as influenced by treatments

Treatment	Dry matter of cotton (t/ha) at harvest	Bolls/ plant	Boll wt. (g/boll)	Seed cotton yield (t/ha)			Post-harvest soil available N (kg/ha)
				2015-16	2016-17	Pooled	
SSBT + CC - *Mimosa invisa fb* HW 30 DAS	4.50	28	6.15	3.24	1.17	2.20	172.9
SSBT + CC - *Crotalaria juncea fb* HW 30 DAS	4.78	33.4	6.08	3.41	1.52	2.46	182.0
SSBT + CC - *Sesbania aculeata fb* HW 30 DAS	3.84	24.8	6.28	3.16	1.13	2.14	172.2
SSBT + CC - *Vigna unguiculata fb* HW 30 DAS	4.23	34	6.03	3.58	1.41	2.49	172.9
SSBT + CC - *Desmanthus virgatus fb* HW 30 DAS	4.28	28.2	5.92	3.33	1.22	2.28	185.2
Pendimethalin 1.0 kg PE *fb* HW twice 30 and 60 DAS	4.15	24.9	5.82	2.86	1.06	1.96	168.0
LSD (p=0.05)	0.89	3.49	NS	0.44	0.17	0.22	7.71

Table 3. Fresh biomass production, dry matter accumulation and nitrogen contribution by leguminous cover crops as affected by different treatments

Treatment	Fresh wt. of cover crops (CC) (kg/ha)	Dry wt. of cover crops (kg/ha)	N contribution by cover crops (kg/ha)
SSBT + CC - Mimosa invisa followed by (*fb*) HW 30 DAS	1271	329	13.61
SSBT + CC - *Crotalaria juncea fb* HW 30 DAS	6664	1591	56.56
SSBT + CC - *Sesbania aculeata fb* HW 30 DAS	16238	3960	163.5
SSBT + CC - *Vigna unguiculata fb* HW 30 DAS	12219	1574	45.07
SSBT + CC - *Desmanthus virgatus fb* HW 30 DAS	3441	956	48.09
LSD (p=0.05)	2103	265.9	20.50

Table 4. Fibre quality attributes of cotton as influenced by stale seed bed technique and leguminous cover crops

Treatment	2.5 % Span length (mm)	Uniformity ratio	Micronaire	Tenacity 3.2 mm (g/tex)	Elongation (%)
SSBT + CC - Mimosa invisa followed by (*fb*) HW 30 DAS	31.0	46	4.3	21.1	6.9
SSBT + CC - *Crotalaria juncea fb* HW 30 DAS	30.5	47	4.3	20.2	6.8
SSBT + CC - *Sesbania aculeata fb* HW 30 DAS	30.2	46	4.1	21.0	6.8
SSBT + CC - *Vigna unguiculata fb* HW 30 DAS	31.1	46	4.1	20.9	6.6
SSBT + CC - *Desmanthus virgatus fb* HW 30 DAS	31.2	46	4.3	20.6	6.8
Pendimethalin 1.0 kg *fb* HW twice 30 and 60 DAS	30.9	46	4.3	20.7	6.8
LSD (p=0.05)	NS	NS	NS	NS	0.265

these crops. Similar finding of higher inorganic N with cover crop Vetch than other crops was reported by Sainju *et al*. (2006). Adusumilli and Fromme (2016) reported that introducing cover crop in an irrigated cotton system has a positive effect on cotton yield and soil organic matter.

It is concluded that integration of stale seed bed technique with leguminous cover crops like *Vigna unguiculata* or *Crotalaria juncea* results in efficient weed smothering and may be recommended as components of integrated weed management method in irrigated cotton production system for improving the sustainability.

REFERENCES

Adusumilli N and Fromme D. 2016. Evaluating benefits and costs of cover crops in cotton production system in Northwest Louisiana. Southern Agricultural Economics Association Annual Meeting, San Antonia, Texas, February 6-9, 2016.

Batish DR, Singh HP, Kohli R K and Dawra GP. 2006. Potential for allelopathy and allelochemicals for weed management. pp. 209–256. In: *Handbook of sustainable weed management*. (Eds. Singh HP, Batish DR and Kohli RK), Food Products Press, New York, NY.

Blaise D, Manikandan, Verma P**,** Nalayini P**,** Chakraborty M and Kranthi KR. 2020. Allelopathic Interactions and its mulch as an integrated weed management strategy for rainfed Bt transgenic cotton hybrids. *Crop Protection* **135**: 105214.

Gomez KA and Gomez AA. 1984. Statistical procedure for agricultural research, 2nd ed., New York (NY): Wiley.

Hoffman M L and Regnier E E. 2006. Contributions to weed suppression from cover crops. pp. 51–75. In: *Handbook of sustainable weed management*. (Eds. Singh HP, Batish DR and Kohli RK), Food Products Press, New York, NY.

Kalaichelvi K. 2008. Effect of planting geometry and fertilizer levels on weed density and biomass in Bt cotton. *Indian Journal of Weed Science* **40**(1&2): 66–68.

Macias FA, Mejias FR and Molinillo JMG. 2019. Recent advances in Allelopathy for weed control: from knowledge to applications.Pest management Science.**75**: 2413–2436.

Nalayini P and Raju R 2010. Recent advances in weed management. *Cotton Research Journal* **1**(1):18– 35.

Prabhu G, Halepyati A S and Pujari BT 2010.Weed Management Studies in Bt Cotton (*Gossypium hirsutum*) under irrigated conditions. pp: 263. In: *Proc. XIX National Symposium on Resource Management Approach Towards Livelihood Security*, 2-4 December, 2010, UAS, Bangalore.

Rao A N and Nagamani A. 2010. Integrated weed management in India- Revisited. *Indian Journal of Weed Science* **42**: 123–135.

Robert MZ, Krishna N R, Krutz, LJ, Gordon ER, Ryan E J and Price LD. 2011. Can leguminous Cover crops Partially replace Nitrogen fertilizer in Mississipi Delta Cotton Production?. *International Journal of Agronomy* **9**(4): 1–9.

Sainju UM, Singh BP and Whitehead WF. 2005. Tillage, cover crops, and nitrogen fertilization effects on cotton and sorghum root biomass, carbon, and nitrogen. *Agronomy J.* **97**: 1279–1290.

Sainju UM, Whitehead WF, Singh BP and Wang S. 2006. Tillage, Cover crops and nitrogen fertilization effects on soil nitrogen and cotton and sorghum yields. *European Journal of Agronomy* **25** :372–382.

Teasdale JR and Mohler CL. 2000. The quantitative relationship between weed emergences and the physical properties of mulches. *Weed Science* **48**: 385–392.

Veeraputhiran R and Sankaranarayanan K. 2021. Weed smothering efficiency and cotton equivalent productivity of Bt cotton based intercropping systems. *Indian Journal of Weed Science* **53**(4): 436–439.

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RESEARCH ARTICLE

Effect of sole and ready-mix herbicides on weeds and productivity of summer greengram in Odisha

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ABSTRACT

A field study was conducted to assess the effect of different sole and ready-mix herbicides on weeds and productivity of summer greengram in Odisha, during summer season of 2020 and 2021 at Agricultural Research Station, Chatabar, Faculty of Agricultural Sciences, IAS, SOADU, Bhubaneswar. Eight treatments *viz*. pre-emergence application (PE) of pendimethalin 0.75 kg/ha at 1 day after sowing (DAS), post-emergence application (PoE) of imazethapyr 75 g/ha at 20 DAS, pendimethalin + imazethapyr 0.75 kg/ha PE at 1 DAS, quizalofop-ethyl 50 g/ha PoE at 20 DAS, fenoxaprop-p-ethyl 50 g/ha PoE at 20 DAS, sodium-acifluorfen 16.5% + clodinafop-propargyl 8% 245 g/ha PoE at 20 DAS, hand weeding twice at 15 and 30 DAS and weedy check, were replicated thrice in the randomized block design. Hand weeding twice at 15 and 30 DAS registered significantly lowest density and biomass of all categories of weeds as well as total weeds and it was closely followed by pendimethalin + imazethapyr (ready-mix) 0.75 kg/ha PE. Pendimethalin PE and imazethapyr PoE recorded at par value of density and biomass of grasses, broad-leaved and total weeds. Hand weeding twice at 15 and 30 DAS registered the highest seed yield (1076 kg/ha) of greengram along with higher yield attributing characters like number of pods/plant (29.23), seeds/pod (7.90) and number of branches/plant (8.88) and it was closely followed by pendimethalin + imazethapyr (ready-mix) 0.75 kg/ha PoE. Highest net return (₹ 39,809/ha) and return per rupee invested (2.12) was registered with pendimethalin + imazethapyr (ready-mix) 0.75 kg/ha PE.

Keywords: Greengram, Herbicides, Pendimethalin + imazethapyr (ready-mix), Weed management

INTRODUCTION

Greengram [*Vigna radiata* (L.) Wilczek] is ranked third among the pulse crops cultivated in India. In eastern India, after the harvest of winter season crops fields remain fallow for 70–80 days during summer. As a measure to increase productivity and not to keep the land fallow during that time, inclusion of short-duration crops like greengram (60-70 days) in the summer season is gaining momentum. Weed competition is found to be a major constraint in achieving high yield. The yield loss in greengram due to weed competition ranged from 46 to 85% (Ali *et al*. 2013; Mirjha *et al*. 2012; Algotar *et al*. 2015) depending upon weed species, their densities and crop-weed competition period. Thus, it is essential to control the weed population in initial stage. About 70-80% of crop growth generally occurs during initial 20-40 days. The pre-emergence herbicide application (PE) suppresses the weed emergence, hence provides favourable environment to the crop during initial crop growth period with weed free condition. The weeds emerged later during critical growth period also require indispensable attention and can be controlled either by the use of post-emergence application (PoE) of herbicides or hand weeding or inter culture operations. Thus, weed management during all the growth stages ensures achievement of higher greengram yield. It is well known that weed management with manual hand weeding is most efficient and safe but it needs high physical energy and involves higher cost for its timely implementation in large area. Hence, chemical weed management is getting popularity amongst farmers. Pre- and post-emergence herbicides and some ready-mix formulations are available in the market to manage the emergence and growth of annual grasses and broad-leaved weeds and also to reduce the crop-weed competition. With this background, the present experiment was conducted to study the effect of sole and ready-mixed herbicides on weed dynamics and productivity of greengram.

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MATERIALS AND METHODS

A field study was carried out during summer seasons of 2020 and 2021 at Agricultural Research station, Binjhagiri, Chatabar, Faculty of Agricultural Sciences, IAS, SOADU, Bhubaneswar. The geographical location of research farm comes under the East and South Eastern Coastal Plain Agro climatic Zone of Odisha. It is situated between 20°26' N latitude and 85°67' E longitude at an altitude of 45 meters above mean sea-level. South-west monsoon period is the grant rainfall period of this zone. The soil of the experimental field was sandy loam in texture with acidic in reaction (pH 5.80), low in organic C (0.41%). Eight treatments *viz*. pendimethalin 0.75 kg/ha PE at 1 day after seeding (DAS), post-emergence application (PoE) of imazethapyr 75 g/ha at 20 DAS, pendimethalin + imazethapyr 0.75 kg/ha PE at 1 DAS, quizalofop ethyl 50 g/ha PoE at 20 DAS , fenoxaprop-p-ethyl 50 g/ha PoE at 20 DAS, sodium-acifluorfen Na 16.5% + clodinafop-propargyl 8% 245 g/ha PoE at 20 DAS, hand weeding twice at 15 and 30 DAS and weedy check, were replicated thrice in the randomized block design. Line to line spacing of 30 cm for greengram was maintained manually. Seed rate taken into account was 25 kg/ha for greengram. The greengram variety IPM-02-14 was used in this experiment. Recommended dose of nutrients N, P_2O_5 and K_2O at 20:40:20 kg/ha were applied. Full dose of nitrogen, phosphorus and potash was applied as basal. Hand operated knapsack sprayer fitted with a flat fan type nozzle was used for spraying the herbicides with a spray volume of 500 liters/ha. All other recommended agronomic practices were followed and plant protection measures were adopted as per need. Weed count was recorded at 45 DAS by placing 50 x 50 cm quadrat in the marked sampling area of 1.0 m^2 of each plot and after drying them in hot air oven at 70^o C, weed dry weight (biomass) was recorded. The data were subjected to a square root transformation to normalize their distribution. Yield attributes and seed yield of greengram was recorded at harvest and the data were statistically analyzed at 5% level of significance.

RESULTS AND DISCUSSION

Effect on weeds

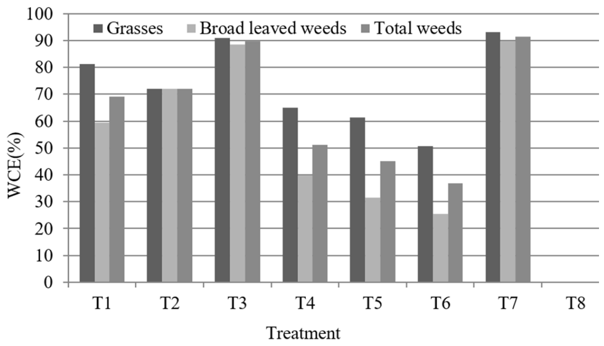
The dominance of weeds varied across different weed control treatments. The weedy check plots consisted of nine weed species. *Poa annua*, *Digitaria sanguinalis* and *Echinochloa colona* among the grasses and *Cleome viscosa* and *Melochia corchorifolia* among the broad-leaved weeds were observed dominating throughout the crop growing period. Similar weed flora in greengram was also reported by Aliveni *et al.* (2016), Kavad *et al.* (2016), Jinger *et al.* (2016) and Kundu *et al.* (2011).

The weed density and biomass at 45 DAS were highest under weedy check with dominance of grasses (53.82%), followed by broad-leaved weeds (46.18%). Among the different weed control treatments, hand weeding twice at 15 and 30 DAS was found to be significantly superior over others in reducing the density and biomass of grasses, broad-leaved and total weeds at 45 DAS and it was at par with pendimethalin + imazethapyr at 0.75 kg/ha PE (**Table 1**). The pendimethalin + imazethapyr (ready-mix) at 0.75 kg/ha PE, resulted in 91.04, 88.52 and 89.66% reduction of grasses, broad-leaved and total weed biomass as compared to weedy check. Imazethapyr at 75 g/ha PoE and pendimethalin 0.75 kg/ha PE recorded at par value of density and biomass of grasses, broad-leaved and total weeds at 45 DAS.

Pendimethalin + imazethapyr (ready-mix) at 0.75 kg/ha PE caused significant reduction of density and biomass of grasses, broad-leaved and total weeds in all the crop growth stages due to better weed control by two constituent herbicides. Singh *et al*. (2017) also reported similar observations. Hand weeding twice at 15 and 30 DAS recorded lowest density and biomass of grasses, broad-leaved and total weeds at all the crop growth stages over other treatments as also reported by Sultan and Baigh (2013) and Chhodavadia *et al.* (2014). Hand weeding twice at 15 and 30 DAS and pendimethalin + imazethapyr at 0.75 kg/ha PE were at par with each other in all the crop growth stages conforming the findings of Sing *et al*. (2017). Among the other treatments, pendimethalin and imazethapyr controlled the complex weed flora at all the crop growth stages. Chaudhari *et al.* (2016) reported that pendimethalin1.0 kg/ha PE recorded lowest weed density of monocot, dicot and sedge at 25, 50 DAS and at harvest of crop.

At the initial stage of crop growth, quizalofop-ethyl PoE and fenoxaprop-p-ethyl PoE registered lower density of grassy weeds, indicating the ability of these herbicides to control grassy weeds up to substantial period of time. But these herbicides were ineffective to control the broad-leaved weeds **(Table 1)** as reported earlier by Mundra and Maliwal (2012).

Amongst different weed control treatments, hand weeding twice at 15 and 30 DAS registered the highest WCE at 45 DAS against grasses (93.13%), broad-leaved (89.83%) and total weeds (91.32%) and was closely followed by pendimethalin + imazethapyr 0.75 kg/ha PE (**Figure 1**). Among the other herbicidal treatments, imazethapyr controlled the complex weed flora, registering higher WCE of



T_1: Pre-emergence application (PE) of pendimethalin 0.75 kg/ha at 1 day after sowing (DAS), T_2: post-emergence application (PoE) of imazethapyr 75 g/ha at 20 DAS, T_3: pendimethalin + imazethapyr 0.75 kg/ha PE at 1 DAS, T_4: quizalofop-ethyl 50 g/ha PoE at 20 DAS, T_5: fenoxaprop-p- ethyl 50 g/ha PoE at 20 DAS, T_6: Sodium-acifluorfen 16.5% + clodinafop-propargyl 8% 245 g/ha PoE at 20 DAS, T_7: hand weeding twice at 15 and 30 DAS and T_8: weedy check

Figure 1. Weed control efficiency (%) of different weed control treatments at 45 DAS in greengram

total weeds (72.06%) followed by pendimethalin (69.23%), quizalofop-ethyl (51.15%), fenoxaprop-p-ethyl (45.06%) and acifluorfen Na 16.5%+ clodinafop-propargyl 8% treatment (36.78%) at 45 DAS.

Effect on greengram

Hand weeding twice at 15 and 30 DAS registered higher number of pods/plant and seeds/pod than other treatments and it was at par with pendimethalin + imazethapyr 0.75 kg/ha PE. Among the other herbicidal treatments imazethapyr 75 g/ha recorded higher number of pods/plant and seeds/pod over others and it was closely followed by pendimethalin 0.75 kg/ha PE (**Table 2**). The crop under weedy check treatment faced severe weed competition for nutrient, light, water and space throughout the crop growth resulting in the lowest value of plant height, leaf area index and dry matter accumulation and ultimately recorded the lowest number of seeds/plant as also observed by Tagour *et al*. (2010). The pod length and test weight did not vary significantly among different weed control practices.

The highest seed yield was recorded with hand weeding twice during both the years and it was at par with pendimethalin + imazethapyr 0.75 kg/ha PE. Pendimethalin + imazethapyr PE recorded 13.26 and 18.97% higher seed yield than sole application of pendimethalin 0.75 kg/ha PE and imazethapyr 75 g/ha PoE (**Table 2**).When weeds were not controlled, yield was 450 kg/ha, whereas it was increased by 881 to 1048 kg/ha when weeds were controlled with different herbicide-based treatments (**Table 2**). Higher seed yield with hand weeding twice at 15 and 30 DAS and different herbicidal treatments was due to effective control of dominant weeds as evident from the lower weed density and biomass. The competition between greengram and weeds for nutrient, water, light and space was less under the above treatments, which facilitated greater utilization of sun light, higher synthesis of photosynthates and better partitioning towards seed formation and ultimately leading to higher seed yield. Gupta *et al.* (2019) reported that the combination of imazethapyr + imazamox (ready-mix) 80 g/ha PoE recorded highest seed yield (993 kg/ha), and was at par with hand weeding twice at 20 and 40 DAS and pendimethalin + imazethapyr 750 g/ha and 1000 g/ha PE. Weedy check recorded 58.17 and 57.07% lower seed yield of greengram as compared to hand weeding twice at 15 and 30 DAS and pendimethalin + imazethapyr 0.75 kg/ha PE, respectively. Yield reduction in greengram due to weed competition was 58.17%.

Table 1. Grasses, broad-leaved and total weed density and biomass at 45 DAS as influenced by different weed control practices in greengram (pooled mean)

Treatment	Weed density (no./m^2)			Weed biomass (g/m^2)		
	Grasses	Broad-leaved	Total	Grasses	Broad - leaved	Total
Pendimethalin 0.75 kg/ha PE at 1 DAS	3.75(13.7)	4.22(17.3)	5.40(31.0)	2.59(6.4)	4.15(16.8)	4.85(23.2)
Imazethapyr 75 g/ha PoE at 20 DAS	3.91(15.0)	3.66(13.0)	5.35(28.0)	3.14(9.5)	3.45(11.5)	4.62(21.1)
Pendimethalin + imazethapyr PE 0.75 kg/ha at 1 DAS	2.55(6.3)	2.73(7.0)	3.95(13.3)	1.88(3.0)	2.27(4.7)	2.87(7.8)
Quizalofop-ethyl 50 g/ha PoE at 20 DAS	4.49(19.7)	4.98(24.3)	6.84(44.0)	3.52(11.9)	5.03(24.9)	6.10(36.8)
Fenoxaprop-p-ethyl 50 g/ha PoE at 20 DAS	4.74(22.0)	5.19(26.7)	6.96(48.7)	3.68(13.1)	5.35(28.3)	6.47(41.4)
Acifluorfen Na 16.5% + clodinafop-propargyl 8% 245 g/ha PoE at 20 DAS	5.27(27.3)	5.49(29.7)	7.56(57.0)	4.16(16.8)	5.59(30.8)	6.94(47.6)
Hand weeding twice at 15 and 30 DAS	2.47(5.7)	2.64(6.7)	3.24(12.3)	1.67(2.3)	2.16(4.2)	2.64(6.5)
Weedy check	7.21(51.7)	6.67(44.3)	9.68(96.0)	5.87(34.7)	6.46(41.3)	8.71(75.4)
LSD (p=0.05)	0.69	0.79	0.75	0.64	0.65	0.63

Figures in parentheses are the original values. The data was transformed to SQRT ($\sqrt{x+0.5}$) before analysis; PE = pre-emergence application, PoE = post-emergence application

Table 2. Yield attributes, yield and economics of greengram as influenced by different weed control practices (pooled mean)

Treatment	Pod length (cm)	No. of pods/ plant	No. of seeds/ pod	Test weight (g)	Yield (kg/ha)	Weed index (%)	Net returns (x10^3 `/ha)	Returns per rupee invested
Pendimethalin 0.75 kg/ha PE at 1 DAS	6.10	25.92	6.25	36.25	881	18.12	28.46	1.81
Imazethapyr 75 g/ha PoE at 20 DAS	6.25	26.20	6.34	37.67	926	13.94	31.58	1.90
Pendimethalin + imazethapyr 0.75 kg/ha PE at 1 DAS	6.35	28.80	7.53	38.17	1048	2.60	39.81	2.12
Quizalofop ethyl 50 g/ha PoE at 20 DAS	6.02	23.57	5.07	37.73	761	29.27	18.54	1.51
Fenoxaprop-p-ethyl 50 g/ha PoE at 20 DAS	6.04	23.45	4.85	38.45	742	31.04	18.22	1.52
Acifluorfen Na 16.5% + clodinafop propargyl 8% 245 g/ha PoE at 20 DAS	5.68	23.12	4.79	35.12	712	33.83	15.08	1.42
Hand weeding twice at 15 and 30 DAS	6.50	29.23	7.90	38.23	1076	0.00	33.02	1.74
Weedy check	5.40	18.20	2.87	33.53	450	58.18	-0.94	0.97
LSD (p=0.05)	NS	2.49	0.85	NS	118	-	-	-

PE = pre-emergence application, PoE = post-emergence application

Weed index (%) was calculated on the basis of seed yield and all the weed control practices recorded lower WI over that of weedy check (**Table 2**). The lowest value of WI was recorded under pendimethalin + imazethapyr 0.75 kg/ha PE (2.60%), followed by imazethapyr 75 g/ha PoE (13.94%) and pendimethalin 0.75 kg/ha PE (18.12%). The highest weed index was recorded under weedy check (58.18%). Among the weed control practices, pendimethalin + imazethapyr (ready-mix) 0.75 kg/ha registered higher net returns (₹ 39809/ha) and returns/rupee invested (2.12) over other treatments **(Table 2)** as reported by Tamang *et al.* (2015). The lowest value of returns per rupee invested was recorded under weedy check.

It can be concluded that pendimethalin + imazethapyr (ready-mix) at 0.75 kg/ha PE may be advocated for effective weed control, higher productivity and profitability in summer greengram.

REFERENCES

Algotar SG, Raj VC, Pate DD and Patel DK. 2015. Integrated weed management in greengram, Paper presented at 25th Asian-Pacific Weed Science Society Conference on "*Weed Science for Sustainable Agriculture, Environment and Biodiversity*", Hyderabad, India during 13-16 October, 2015.

Ali S, Patel JC, Desai LJ and Singh J. 2013. Weed control in *Kharif* greengram (*Vigna radiata* L. Wilczek . *BIOINFOLET* **10**(2A): 458–461.

Aliveni A, Rao AS, Ramana AV and Jagannadham J. 2016. Management of common vetch and other weeds in relay crop of blackgram. *Indian Journal of Weed Science* **48**(3): 341–342.

Chaudhari VD, Desai LJ, Chaudhari SN and Chaudhari PR. 2016. Effect of weed management on weeds, growth and yield of summer greengram. *The Bioscan* **11**(1): 531–534.

Chhodavadia SK, Sagarka BK and Gohil BS. 2014. Integrated management for improved weed suppression in summer greengram. *The Bioscan* **9**(2): 1577–1580.

Gupta V, Sharma S, Sasode DS, Joshi E,Kasana BS and Joshi N. 2019. Efficacy of herbicides on weeds and yield of greengram. *Indian Journal of Weed Science* **51**(3): 262–265.

Kavad NB, Patel CK, Patel AR and Thumber BR. 2016. Integrated weed management in blackgram. *Indian Journal of Weed Science* **48**(2): 222–224.

Kundu R, Bera PS, Brahmachari K and Mallick R. 2011. Integrated weed management in greengram [*Vigna radiata* (L) Wilczek] under gangetic alluvial soil of West Bengal. *Journal Botanical Society of Bengal* **65**(1): 35–43.

Mirjha PR, Saroj KP, Manoj KS, and Chandra MD. 2012. Efficacy of different weed management strategies in mungbean. *International Agronomy Congress*, New Delhi, **2**(3): 130–131.

Mundra SL and Maliwal PL. 2012. Influence of quizalofop-ethyl on narrow-leaved weeds in blackgram and its residual effect on succeeding crops. *Indian Journal of Weed Science* **44**(4): 231–234

Singh UP, Mishra JS, Singh SP, Singh MK, Dahiphale AV, Kashyap SK and Kumar S. 2017. Viable weed management options for sustainable crop production p. 57. In: *Proceedings of Biennial Conference on "Doubling Farmers' Income by 2022: The Role of Weed Science"*, Udaipur, India during 1-3 March, 2017

Sultan T and Baigh MA. 2013. Weed control in summer moong (*Vigna radiata* L.), Shalimar moong-1. *Environment and Ecology* **31**(2A): 775–777.

Tamang D, Nath R and Sengupta K. 2015. Effect of herbicide application on weed management in greengram (*Vigna radiata). Advances in Crop Science and Technology* **3**: 163.

Indian Journal of Weed Science (2023) **55**(1): 54–57
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RESEARCH ARTICLE

Effect of haloxyfop on narrow-leaved weeds in blackgram and its residual effect on succeeding rice crop

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ABSTRACT

Blackgram (*Vigna mungo* (L.) Hepper) is one of the most remunerative legume crop which grown in *Kharif* or summer season. An experiment was conducted to evaluate the activity and selectivity of the post-emergence herbicide haloxyfop on weeds growth and blackgram productivity during *Kharif* season of 2015 and 2016 at N.E. Borlaug Crop Research Centre, G.B.P.U.A& T, Pantnagar, Uttarakhand. The grass weeds: *Echinochloa colona* (15.5 and 15.0%), *Eleusine indica* (48.6 and 32.3%), *Dactyloctenium aegyptium* (18.3 and 22.0%), *Digitaria sanguinalis* (3.5 and 6.4%), *Brachiaria* spp. (2.8 and 3.3%) and *Panicum maximum* (11.3 and 21.0%) dominated the field (during 2015 and 2016, respectively).The lowest weed density and biomass, and highest weed control efficiency and blackgram seed yield were recorded with post-emergence application (PoE) of haloxyfop 135 g/ha followed by and at par with its lower dose (108 g/ha) during both the years and statistically at par with standard check quizalofop-ethyl 50g/ha, only during 2015. No phytotoxicity occurred to blackgram on 1, 3, 5, 7, 10, 15 and 30 days after application at any of the tested haloxyfop doses and was found safe for growing succeeding transplanted rice as rice growth and yield were not affected by any of the doses of haloxyfop.

Keywords: Blackgram, Haloxyfop, Herbicides, Phytotoxicity, Rice, Weed management

INTRODUCTION

Blackgram is one of the important pulse crops cultivated worldwide in tropical and subtropical regions of the world. In *Kharif* 2021-22, blackgram production was 20.5 lakh tons in an area of 39.43 lakh hectares (agricoop.nic). Blackgram is not a very good competitor against weeds (Choudhary *et al.* 2012) and is mostly susceptible to weed infestation during the first four weeks of its growth period (Randhawa *et al.* 2002). Unchecked weeds have been reported to cause a considerable reduction in the grain yield of blackgram ranging from 35.2 to 87% (Sukumar *et al.* 2018) and critical period for crop weed competition is around 15 to 45 DAS (Khot *et al.* 2016). The majority of farmers use hand weeding, which requires a lot of labors, time and is also less cost effective under rainy days condition. Pre-emergence herbicides only control weeds for a short period and there after late-emerging weeds begin to compete with crops. Hence, in order to keep free from weed competition, the use of pre-emergence herbicides to manage early emerging weeds and post-emergence herbicides in sequence to manage late emerging weeds may be essential. Recently, haloxyfop-methyl and fluazifop-p-butyl have been reported as potential herbicides in controlling perennial grasses in most of the oilseeds and pulse crops. The aim of the present study was to evaluate the efficacy of haloxyfop in managing weeds and improving the productivity of blackgram while assessing its residual effect on rice grown in succession.

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MATERIALS AND METHODS

A field experiment was conducted during *Kharif* season of 2015 and 2016, at G.B. Pant University of Agriculture and Technology, Pantnagar, Uttarakhand. The experimental site was situated at 29^0N latitude, 27.3^0E longitude and at an altitude of 243.8 MSL in subtropical climatic condition of Himalaya foot hill of Uttarakhand at Norman E. Borlaug, Crop Research Center of G.B. Pant University of Agriculture and Technology, Pantnagar. The soil of the experimental area was loamy, medium in organic matter (0.67%), available nitrogen (210 kg/ha), phosphorus (17.5 kg/ha) and potassium (181.2 kg/ha) with a pH value of 7.5. During the growing period of the crop temperature ranged 22.4-33.8^0C and total rainfall was 1216 mm in *Kharif* 2015 and in *Kharif* 2016, the temperature range was 22-33.3^0C and the total rainfall 750.4 mm.

"*Pant Urd* - 31" variety was sown on April 9, 2015 and March 15, 2016 with seeding rate of 15 kg/ha. The experiment was laid out in a randomized block design with three replications. There were seven treatments consisting of post-emergence application (PoE) of haloxyfop 81, 108, 135 g/ha; fenoxaprop 67.5 g/ha, quizalofop-ethyl at 50 g/ha, hand weeding twice at 20 and 40 days after seeding (DAS) and weedy check. The haloxyfop dose of 270 g/ha was used for phytotoxic study. Post-emergence application of herbicides was done at 20 days after seeding and the residual effect of the herbicide was evaluated on succeeding transplanted rice crop variety Pant-12. Knapsack sprayer fitted with boom along with flat-fan nozzle was used to apply the herbicidal solution with spray volume of 400 l water per hectare.

The density and biomass of dominant weed species was recorded at 60 DAS. For recording both weed density and biomass a quadrat of 0.25 m^2 was placed randomly at four places per plot and the data was presented on per m^2 basis. The relative weed density and weed control efficiency were calculated according to the method given by Moinuddin *et al.* (2018).

The relative weed density of grassy weed flora was evaluated at 60 after herbicide application (DAA) in weedy plot during both the year by the following formula:

Visual scoring on control of weeds and phytotoxic symptoms (chlorosis/stunting/leaf tip injury/wilting/vein clearing/epinasty and hyponasty) in blackgram were recorded on 1, 3, 5, 7, 10, 15 and 30 days DAA. In the carry over study, the rice plant populations (2m row length) at 15 DAT and yield and yield attributes were recorded at harvest. The grain yield of succeeding crop (transplanted rice) was recorded separately for each plot and converted to per hectare.

RESULTS AND DISCUSSION

Effect on weeds

The major grassy weed flora in blackgram crop consisted of: *Echinochloa colona, Eleusine indica, Dactyloctenium aegyptium, Digitaria sanguinalis, Brachiaria* spp. and *Panicum maximum* with the relative weed density of 15.5%, 48.6%, 18.3%, 3.5%, 2.8% and 11.3% during 2015 and 15.0%, 32.3%, 22.0%, 6.4%, 3.3% and 21% during 2016, respectively. Similar findings were also reported by Punia (2014). At 60 DAA, hand weeding twice and haloxyfop 135 g/ha PoE were proved to be significantly superior to all the treatments in reducing the density of *E. colona* during *Kharif* 2015 and 2016. Haloxyfop 135 g/ha PoE recorded lowest density of *E. indica, D. aegyptium* and *D. sanguinalis* followed by haloxyfop108 g/ha PoE and quizalofop-ethyl 50 g/ha PoE. Lowest density of *E. colona* was recorded with haloxyfop 135 g/ha PoE and quizalofop-ethyl 50 g/ha PoE which were comparable with haloxyfop 108 g/ha PoE. All the treatments were equally effective and recorded lowest density of *Brachiaria* spp. All doses of haloxyfop as well as quizalofop-ethyl 50 g/ha PoE caused complete control of *P. maximum* during 2015. In 2016, complete control of *P. maximum* was observed with haloxyfop 135 g/ha PoE and quizalofop-ethyl 50 g/ha PoE (**Table 1**). Better response of haloxyfop in controlling grass weeds might be due to its ready absorption and translocation to meristematic region where it exerts herbicide activity (Burton 1997) and due to possession of a eukaryotic type ACCase in the chloroplasts which is sensitive to ACCase inhibitors like haloxyfop (Incledon and Hall 1997).

Among the treatments lowest total weed density (no./m^2) and total weed dry biomass (g/m^2) and highest weed control efficiency were recorded with haloxyfop at 135 g/ha PoE which was significantly at par to its lower dose of 108 g/ha during both the year 2015 and 2016 and with quizalofop-ethyl at 50 g/ha PoE only at 2015 (**Table 2**). Better response of quizalofop-ethyl in controlling narrow-leaved weeds might be due to the fact that aryloxyphenoxy-propionates (AOPP) class to which this herbicide belongs is readily absorbed and translocated to meristematic region and exert herbicide activity. Mundra and Maliwal (2012) also reported similar findings in terms of lowest weed density, weed dry biomass and highest weed control efficiency in blackgram.

Table 1. Effect of treatments on density of weeds at 60 days after seeding (DAS) in blackgram

Treatment	Dose g/ha	*E. colona*		*E. indica*		*D. aegyptium*		*D. sanguinalis*		*Brachiaria* spp.		*P. maximum*	
		2015	2016	2015	2016	2015	2016	2015	2016	2015	2016	2015	2016
Haloxyfop	81	15.5(17.3)	3.4(10.7)	6.2(40.0)	4.4(18.7)	4.3(17.3)	4.0(14.7)	1.9(2.7)	2.2(4.0)	1.7(2.0)	2.4(4.7)	1.0(0.0)	2.4(4.7)
Haloxyfop	108	3.6(12.0)	2.8(6.7)	3.9(14.0)	3.5(11.3)	2.2(4.0)	3.0(8.0)	1.3(0.7)	1.9(2.7)	1.5(1.3)	1.9(2.7)	1.0(0.0)	1.5(1.3)
Haloxyfop	135	3.2(9.3)	2.8(6.7)	3.8(13.3)	3.4(10.7)	2.2(4.0)	2.9(7.3)	1.0(0.0)	1.0(0.0)	1.5(1.3)	1.9(2.7)	1.0(0.0)	1.0(0.0)
Fenoxaprop-p	67.5	3.8(13.3)	3.2(9.3)	6.0(36.0)	4.0(14.7)	2.7(6.7)	4.0(14.7)	1.5(1.3)	2.4(4.7)	1.5(1.3)	1.9(2.7)	2.5(5.3)	1.9(2.7)
Quizalofop-ethyl	50.0	3.0(8.0)	2.9(7.3)	4.1(16.0)	3.6(12.0)	2.9(5.3)	3.5(11.3)	1.0(0.0)	2.2(4.0)	1.7(2.0)	1.9(2.7)	1.0(0.0)	1.0(0.0)
Hand weeding twice	20&40 DAS	2.5(5.3)	3.2(9.3)	5.2(26.7)	4.9(22.7)	3.0(8.0)	3.8(13.3)	2.2(4.0)	3.2(9.3)	1.5(1.3)	1.0(0.0)	1.9(2.7)	1.9(2.7)
Weedy check	-	5.5(29.3)	4.4(18.7)	9.6(92.0)	9.2(84.0)	5.9(34.7)	6.8(45.3)	2.8(6.7)	5.0(24.0)	2.5(5.3)	3.1(8.7)	4.7(21.3)	3.0(8.0)
LSD (p=0.05)	-	0.43	0.48	1.38	0.70	0.71	0.52	0.41	0.39	0.3	0.45	0.29	0.42

LSD: least significant difference at the 5% level of significance; Value in parentheses were original and transformed to square root $(\sqrt{x+1})$ for analysis

Effect on blackgram

All the yield attributing characters of blackgram were significantly influenced by weed control treatments during both the years, except number of plants/m^2 and 100 seed weight (g) during 2015. Haloxyfop 135 g/ha PoE recorded the highest plant height, number of plants/m^2, pods/plant, grains/pod and 100 seed weight followed by its lower dose at 108 g/ha and was found statistically at par to hand weeding twice (**Table 3**). These findings were corroborated with Singh *et al.* (2010), who reported similar results in case of soybean cop.

The highest grain yield was obtained with application of haloxyfop 135 g/ha PoE followed by haloxyfop 108 g/ha PoE which were at par to hand weeding twice, during both years. These findings are in agreement with those of Pankaj and Dewangan (2017). The blackgram yield was higher in *Kharif* 2015 than in *Kharif* 2016 due to favourable environmental conditions in *Kharif* 2015 leading to vigorous crop growth (**Table 3**).

Blackgram yield and weed biomass at 60 DAS were negatively correlated during both the years with R^2 of 0.80 in 2015 and 0.83 in 2016(**Figure 1a** and **1b**).

Economics

The highest net returns and B:C were observed with haloxyfop 135 g/ha PoE followed by haloxyfop108 g/ha during both the years (**Table 4**) due to higher seed yield with comparatively low cost of cultivation of blackgram in these treatments as reported by Karki *et al.* (2002), Rathore *et al.* (2014), Singh *et al.* (2016).

Phytotoxicity

No phytotoxic effect was observed on blackgram due to haloxyfop 135 g/ha PoE and 270 g/ha.

Carry over effect on succeeding crop

The transplanted rice yield attributing characters and yield were not affected significantly due to weed control treatments applied in blackgram. Hence haloxyfop use in blackgram during *Kharif* season was safe to transplanted rice crop grown after blackgram.

It was concluded that haloxyfop 135 g/ha PoE is economical and effective to manage weeds and economically improving blackgram productivity and it has no phytotoxic effect on blackgram or succeeding rice crop.

Table 2. Effect of treatments on dry biomass of weeds and weed control efficiency at 60 DAA in blackgram

Treatment	Dose (g/ha)	Total weed density (no./m^2)		Total weed biomass (g/m^2)		WCE (%)	
		2015	2016	2015	2016	2015	2016
Haloxyfop	81	8.9(79.3)	7.6(57.3)	13.9(191.9)	16.6(274.5)	74.2	54.3
Haloxyfop	108	5.7(32.0)	5.8(32.7)	10.2(103.6)	13.8(188.7)	86.1	68.6
Haloxyfop	135	5.4(28.0)	5.3(27.3)	9.6(91.3)	12.9(165.9)	87.7	72.4
Fenoxaprop	67.5	8.0(64.0)	7.0(48.7)	14.2(202.2)	16.2(260.9)	72.8	56.6
Quizalofop-ethyl	50.0	5.7(31.30	6.2(37.3)	10.5(109.7)	14.7(214.1)	85.2	64.4
Hand weeding twice	20 and 40 DAS	7.0(48.0)	7.6(57.3)	10.2(102.5)	16.1(257.5)	86.2	57.2
Weedy	-	13.8(189.3)	13.8(188.7)	27.3(743.1)	24.5(601.2)	-	-
LSD (p=0.05)	-	1.1	0.78	1.3	1.5	-	-

LSD, least significant difference at the 5% level of significance, Value in parentheses were original and transformed to square root $(\sqrt{x+1})$ for analysis, DAA: Days after herbicide application, DAS- days after sowing

Table 3. Effect of weed management treatments on blackgram yield attributing characters and yield

Treatment	Dose g/ha	Plant height (cm)		Plants (no./m^2)		Pods/plant		Grains/pod		100-seed weight (g)		Grain yield (kg/ha)	
		2015	2016	2015	2016	2015	2016	2015	2016	2015	2016	2015	2016
Haloxyfop	81	48.3	38.7	32.0	29.0	22.7	20.4	3.77	3.88	3.8	3.7	1033	933
Haloxyfop	108	49.8	39.8	33.8	32.5	29.1	25.7	3.93	3.93	4.0	4.0	1533	1300
Haloxyfop	135	50.4	41.4	34.0	33.0	29.0	24.7	3.93	4.02	4.1	3.9	1583	1308
Fenoxaprop	67.5	45.9	38.9	32.3	32.0	24.3	22.7	3.87	3.55	3.9	3.7	1200	967
Quizalofop-ethyl	50.0	49.7	39.0	33.5	32.5	24.7	23.0	3.87	3.67	4.0	3.8	1317	1050
Hand weeding twice	20 and 40 DAS	50.6	40.7	33.7	33.0	30.2	26.6	3.97	4.02	4.1	3.8	1650	1333
Weedy check	-	44.0	39.2	28.8	25.3	18.7	17.9	2.90	2.20	3.6	3.4	567	408
LSD (p=0.05)	-	2.92	2.9	NS	3.8	4.6	1.9	0.46	0.61	NS	0.40	151.8	108.4

LSD, least significant difference at the 5% level of significance, DAS- days after sowing, NS- non significant

Table 4. Effect of weed management treatments on cost of cultivation, gross return, net return and B:C ratio in blackgram

Treatment	Dose (g/ha)	Cost of cultivation (x10^3 `/ha)		Gross returns (x10^3 `/ha)		Net returns (x10^3 `/ha)		B:C	
		2015	2016	2015	2016	2015	2016	2015	2016
Haloxyfop	81	22.62	23.12	44.94	43.15	22.32	20.03	0.99	0.87
Haloxyfop	108	22.97	23.47	66.69	60.12	43.72	36.65	1.90	1.56
Haloxyfop	135	23.32	23.82	68.86	60.49	45.54	36.66	1.95	1.54
Fenoxaprop	67.5	22.95	23.45	52.20	44.72	29.25	21.27	1.27	0.91
Quizalofop-ethyl 5% EC	50.0	23.63	24.13	57.29	48.56	33.66	24.43	1.42	1.01
Hand weeding	20 & 40 DAS	33.00	33.50	71.77	61.65	38.77	28.15	1.18	0.84
Weedy check	-	21.00	21.50	24.66	18.87	3.66	-2.63	0.17	-0.12

MSP blackgram ₹: 43500/t (2015-16), ₹ 46250/t (2016-17), General cost of cultivation of blackgram: ₹ 21000/ha, Hand weeding (2 HW): ₹ 6000/ha

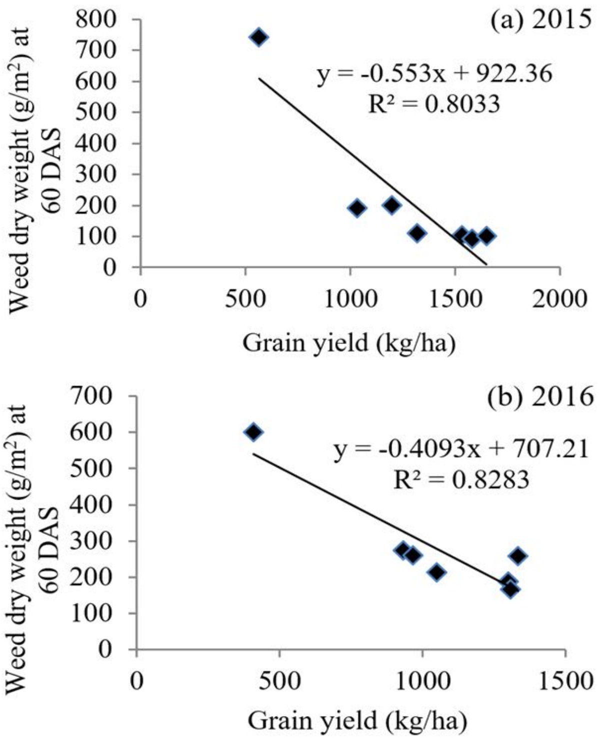

Figure 1. Correlation between grain yield and weed biomass at 60 DAS during (a) 2015 and (b) 2016

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REFERENCES

Burton JD. 1997. Acetyl–coenzyme A carboxylase inhibitors. pp.187-205. In: *Herbicide activity: Toxicology, Biochemistry and Molecular Biology*. (Eds Roe, RM, Burton RM and Kuhr RJ), Burke, VA: IOS.

Choudhary VK, Kumar SP and Bhagawati R. 2012. Integrated weed management in blackgram (*Vigna mungo*) under mid hills of Arunachal Pradesh. *Indian Journal of Agronomy* **57**: 382–385.

Incledon BJ and Hall JC. 1997. Acetyl–coenzyme A carboxylase: quaternary structure and inhibitition by graminicidal herbicides**.** *Pesticide Biochemistry and Physiology* **57**: 225–271.

Karki TB, Yadav YP and Pandit G. 2002. Raising blackgram productivity in the western hills through varietal and crop husbandary practice. *The Food and Agriculture Organization* pp. 130–135.

Khot AB, Sagvekar VV, Muthal YC, Panchal VV and Dhonde MB. 2016. Effect on summer blackgram (*Phaseolus mungo* L.) to different sowing time and weed management practices with respect to yield, quality and nutrient uptake. *International Journal of Tropical Agriculture* **34**(7): 2155–2161.

Moinuddin G, Kundu R, Jash S, Sarkar A and Soren C. 2018. Efficacy of Atrazine herbicide for maize weed control in new alluvial zone of West Bengal. *Journal of Experimental Biology and Agricultural Sciences* **6**(4):707–716.

Mundra SL and Maliwal PL. 2012. Influence of quizalofop-ethyl on narrow- leaved weeds in blackgram and its residual effect on succeeding crops. *Indian Journal of Weed Science* **44**(4): 231–234.

Pankaj SC and Dewangan PK 2017. A critical review on weed management in blackgram (*Vigna mungo* L.) and residual effect of herbicides on succeeding mustard (*Brasica juncea* L.) Crop. *International Journal of Current Microbiology and Applied Sciences* **6**(11): 865–881

Punia R. 2014. Evaluation of some herbicides in green gram (*Vigna radiata* L.) and their residual effect on succeeding mustard crop. M.Sc. (Ag) Thesis (Agronomy) College of Agriculture, Chaudhary Charan Singh Haryana Agricultural University, Hisar.

Randhawa JS, Deol JS, Sardana V and Singh J. 2002. Cropweed competition studies in summer blackgram (*Phaseolus mungo*). *Indian Journal of Weed Science* **34**(3&4): 299–300.

Rathore M, Singh R, Choudhary PP and Kumar B. 2014. Weed stress in plants. In: Approaches to plant stress and their management. Springer India. India, pp. 255–265.

Singh RK, Singh R, Sharma D, Saurabh S and Singh R. 2016. Intercropping system: an alternative pathway for sustainable productivity and economic viability. *International Journal of Agriculture Sciences* **8**(39): 1806–1808.

Singh VP, Singh SP, Kumar A, Tripathi N and Nainwal RC. 2010. Efficacy of Haloxyfop, a post-emergence herbicide on weeds and yield of soybean. *Indian Journal of Weed Science* **42**(1&2): 83–86.

Sukumar J, Pazhanivelan S and Kunjammal P. 2018. Effect of pre-emergence and post-emergence herbicides on weed control in irrigated blackgram. *Journal of Pharmacognosy and Phytochemistry* **1**: 3206–3209.

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RESEARCH ARTICLE

Molecular and morphological diagnosis of *Orobanche aegyptiaca Pers.* infestation in mustard fields

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ABSTRACT

Orobanche are the devastating holoparasitic weeds causing extensive damage to the mustard cultivation in India. Considering the tedious species identification from a single seed and seed longevity in the soil for years, the mitigation of this weed is difficult. Therefore, development of molecular diagnostic assay specific to *Orobanche aegyptiaca* is required for weed management. In this study, a polymerase chain reaction (PCR) based strategy was optimised using internal transcribed spacer (ITS) based markers to identify the *Orobanche* species predominant in the mustard fields. Genomic DNA was extracted from tissue and soil samples artificially inoculated with seeds of *Orobanche* spp. and subjected to PCR analysis. ITS primers amplified a 350bp PCR product specific to *O. aegyptiaca* confirming its dominance in mustard crop fields of India. Furthermore, soil and tissue samples were collected from the seven farmer fields of Rajasthan and subjected to PCR analysis using ITS-350 primers. ITS-350 primers amplified all the soil/tissue samples confirming the specificity of the method and markers applied. It was also found that one *Orobanche* plant could attach itself to the host plant through many haustoria and also many *Orobanche* plants could attach to the one mustard plant through individual haustorium. This assay can also be applied to identify seed contaminants in commercial seed lots. A small soil sample taken from the mustard field can provide clues about the infestation likely to affect crop yield and productivity. Based on diagnosis suitable recommendations for crop management and input on fertilizer doses can be provided to the farmers on timely basis.

Keywords: Internal Transcribed Spacer (ITS), Molecular diagnosis, *Orobanche aegyptiaca*, Parasitic plant, Rapeseed-Mustard, Soil testing

INTRODUCTION

Over 4000 species of parasitic weeds are major constraint to agricultural production causing heavy damage to various crops thereby reducing both crop yield and quality. Egyptian broomrape or *Orobanche* is an obligate, holoparasitic, phanerogamic, achlorophyllous root parasitic plant that lack chlorophyll and have wider host range including several members of the Solanaceae, Leguminaceae, and Brassicaceae families (Parker and Riches 1993, Wickett *et al*. 2011, Sheoran *et al*. 2014). It attaches itself to the root of mustard plant through haustorium and connects with the host vascular system to derive host water, carbon and nutrients (Schneeweiss 2007) (**Figure 1**). Rapeseed-Mustard is an oilseed crop with a wide range of food and industrial uses and with a major economic significance. In the major mustard cultivating regions of India *i.e*. Haryana, Punjab, northern Rajasthan, western UP and north-east Madhya Pradesh where *Orobanche* (*Orobanche* spp.) has caused enormous menace to mustard production. It is known by various local names such as 'Gudiya' 'margoja', 'khumbhi', 'gulli', 'rukhri', or 'bhuiphod' (Punia *et al*. 2012). Among *Orobanche* spp., *O. aegyptiaca* is dominant weed causing severe yield

Figure 1. ***Orobanche*** **attached through haustorium on the roots of Indian mustard plant**

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and quality reduction in rapeseed-mustard. The damage caused by *Orobanche* infestation is often devastating with reported losses up to 28.2% average reduction in Indian mustard yield (Shekhawat *et al.* 2012). It's underground development, miniscule seed size of approximately 180 to 300µm, single plant capacity to produce even over 5 million seeds (against 1,000-odd for mustard), seed longevity for 10-13 years in the soil and appearance of parasite shoots above the soil (70–90 days after sowing) makes its control and detection difficult in the soil and crop seed lot (Jat and Singh 2018). This parasite exerts the greatest damage in the standing crop prior to its emergence causing majority of field loss before diagnosis of infection (Aly 2007, Aly *et al*. 2012) Therefore, identification and classification of *Orobanche* species in a soil sample is very important (Joel *et al*. 1996). So far, the classification of parasitic by taxonomists has been carried out through the morphological features (Hebert and Gregory 2005). However, most of the *Orobanche* species have similar morphological characteristics which, differs in host preference which makes it difficult to classify. In addition, the conventional methods of detection in the soil employ tedious seed separation procedure, observation under binocular microscope and is time demanding (Portnoy *et al.* 1997).

Polymerase chain reaction (PCR) based assays which takes in use of unique DNA such as Internal transcribed sequences (ITS) which are conserved in nature can help in identifying and classifying the *Orobanche* species (Dongo *et al*. 2012). Presently, the tools of biotechnology and molecular biology have revolutionized the way of understanding the knowledge of taxonomy and anatomy to identify plant species with DNA-based marker techniques such as random amplified polymorphic DNA (RAPD) (Katzir *et al.* 1996; Portnoy *et al.* 1997), ITS (Schneeweiss *et al*. 2004; Agarwal *et al.* 2008; Park *et al.* 2008), Inter simple sequence repeat (ISSR) regions (Benharrat *et al.* 2002) and plastid DNA markers (Manen *et al.* 2004; Román *et al.* 2007). Efforts were also made to detect and quantify contamination of *O. aegyptiaca, O. ramosa* and *O. Cumana* in soil and crop seed lots of Israel (Dongo *et al*. 2012, Aly *et al*. 2012, Aly *et al*. 2019). Keeping this in view, *O. aegyptiaca* species specific primers were first tested on *Orobanche* spp. affecting the mustard crops cultivated in Rajasthan, India and then molecular diagnosis was performed on the soil collected from the various mustard infested farmers' fields to develop the soil-based diagnosis.

MATERIALS AND METHODS

Sample collection

Orobanche tubercles, shoots, inflorescences, seeds and soil samples used for the experimental purposes were collected from the infested fields of ICAR-Directorate of Rapeseed-Mustard Research in Sewar, Bharatpur, Rajasthan (India) (**Figure 2**) and seven farmers' fields in Bayana district, Rajasthan state, India (26° 54' 0" North, 77° 17' 0" East) *viz.* Seedpur, Bidyari, Nangla Andya, Nangla Jhamra, Sepoura, Vedpura, Bayana villages which represents a typical rainfed site of India. *O. cernua* and *O. ramosa* seeds were also procured for the experimental purposes. *Orobanche* tissue samples were harvested and stored at -80°C while seeds collected from fresh inflorescences were stored at room temperature in dark condition until used. The soil samples collected were taken from the top layer (0–15 cm) of experimental sites.

Soil Sampling and protocol for molecular diagnosis of *Orobanche*:

Sampling location: Soil was randomly collected from the rows within infested mustard field. Since *Orobanche* is attached on the roots of mustard plants,

Figure 2. *Orobanche* infested mustard fields of ICAR-DRMR, Sewar, Rajasthan

90% of seeds fall nearby to it. Therefore, surface and upto 0-8 cm deep soil was taken and pooled for analysis. Soil debris was removed during sampling.

Sampling volume: Around 200g soil was collected from the location and stored at -20ºC. However, 100 - 200mg soil sample is enough for DNA isolation and PCR analysis.

Molecular analysis: DNA based analysis to detect seeds of *Orobanche* in soil was performed using ITS-350 primers. Presence or absence of *Orobanche* in soil was confirmed on the basis of 350bp PCR amplification of bands in the samples.

DNA extraction

Genomic DNA extraction from fresh tissues of *Orobanche* spp. and mustard seeds and leaves of DRMR-IJ31 was carried out using modified cetyl trimethyl ammonium bromide (CTAB) method as described according to Doyle and Doyle (1987) with minor modifications. Total Genomic DNA from *Orobanche* soil samples was extracted using the UltraClean soil DNA isolation Kit (MoBio Laboratories, Inc., Solana Beach, CA) according to the manufacturer's instructions. DNA was quantified by analysing on 0.8% agarose gel with λ DNA as standard. The DNA stock solution was adjusted to a concentration of 80-100ng/µl with nuclease free sterile water as the working concentration for the polymerase chain reaction (PCR) and stored at -20º C.

PCR analysis

For PCR analysis ITS-350 primer directed to unique ITS regions corresponding to *O. aegyptiaca* were employed (Aly *et al.* 2012). As a control UCP-555, universal internal control primer was used which amplifies a region of the small subunit of nrDNA (555 bp) from a wide variety of microorganism such as protists, fungi, and plants (**Table 1**). PCR reactions were performed using thermocycler (Eppendorf) in a volume of 20µl PCR mixture containing 100 ng genomic DNA, 1 units of Taq DNA polymerase (G-BIOSCIENCES), 1X PCR Buffer (10mM Tris HCL), 1.mM $MgCl_2$, 100µM each of dNTPs and 10µM of each primer. ITS primers were amplified with following conditions: DNA was denatured at 95°C for 4 min, followed by 35 cycles of 94°C for 1 min each, 52°C for 1 min and 72°C for 1 min, followed by 7 min at 72°C. For amplification with UCP-555 primers, DNA was denatured at 94°C for 5 min, followed by 35 cycles of 94°C for 1 min each, 52.5°C for 1 min and 72°C for 1 min, followed by 7 min at 72°C. Multiplex PCR reaction was performed in 20-µL using the both ITS-350 primers and the universal internal control primers UCP-555. Each reaction tube contained 1X enzyme buffer, 1.5mM $MgCl_2$, 100µM dNTPs, and 0.5µM of the (ITS-350), 0.3µM of the UCP-555 primers, 1.0U *Taq* DNA polymerase, and 2µl (100ng) template (DNA). Amplification parameters were adjusted to 5 min at 94°C, followed by 35 cycles of 1 min at 94°C, 1 min at 52°C, and 1 min at 72°C, with a final extension step of 7 min at 72°C (**Table 2**). Amplification products were resolved on 1.5% (w/v) agarose gels in Tris-Borate-EDTA buffer (pH 8.3) and visualized with ethidium bromide under UV light.

Morphology of *Orobanche* plants

Orobanche samples collected from various locations were morphologically classified into length of stalk, number of *Orobanche* shoots attached to one mustard plant, length of haustorium, presence of scales, colour of scales and colour of flowers. Morphological characters of stem, leaf and flowers recorded during the investigation were compared with standard key given by Parker and Riches (1993).

RESULTS AND DISCUSSION

Morphological identification of *Orobanche* species

Morphology helps in the precise identification of species and its management thereafter. However, in case of *Orobanche* which is underground parasitic weed damage on the host plant occurs even before

Table 1. Molecular marker used for the diagnosis of *Orobanche aegyptiaca*

Gene	Primer name	Product sizes	Forward primer (5'-3')	Reverse Primer (5'-3')	References
Internal transcribed spacer	ITS-350	350 bp (+)	CATGGTGGG TGGGGCAACCC	ACGTGATGCGTGACGCCCAG	Aly *et al.* 2012
nrDNA	*UCP-555*	555 bp (+)	GTAGTCATATGCTTGTCTC	GGC TGCTGGCACCAGACTTGC	Aly *et al.* 2012

Table 2. PCR conditions for different primer used for molecular analysis

Primer name	PCR conditions
ITS-350	94° C- 4 min., 94° C- 1 min., 52° C- 1 min. for 35 cycles, 72° C- 1 min., 72° C- 10 min.
UCP-555	94° C- 5 min., 94° C- 1 min., 52.5° C- 2 min. for 40 cycles, 72° C- 1 min., 72° C- 7 min.
Multiplex reaction	94° C- 5 min., 94° C- 1 min., 52° C- 1 min. for 35 cycles, 72° C- 1 min., 72° C- 7 min.

precautionary measures can be taken. Morphological analysis of *Orobanche* samples collected from various mustard fields showed variation in shoot, root and haustoria length (**Figure 3**). It was observed that stem height of *Orobanche* plants ranged from 16-40 cm, mostly branched from the middle point, roundish, yellowish in colour and were thickened at the base. A globular tubercle like structure was present at the base of each stalk acting as reservoir of nutrients for growth and development. *Orobanche* is achlorophyllous plant due to which brown to dark drown scales were present in the raceme manner. Flowers were bisexual, alternate and axially attached to the stem. Cylindrical inflorescence was present; corolla was tubular-infundibuliform, blue-violet, and lighter at the base of tube covered with short hairs outside. Ovary was syncarpous and bicarpellary with terminal single style, 4 numbers of stamens were present in (2+2) manner. The morphological identification described here is in agreement with standard identification key for *Orobanche* species as suggested by Parker and Riches (1993). These findings are also supported by Punia *et al*. (2014) and Jat and Singh (2018) who reported that *O. aegyptiaca* is dominant species affecting mustard cultivation in India and has found similar morphological characteristics for *O. aegyptiaca*. Based on phyto-morphological characters Akhter *et al*. (2020) identified *Orobanche crenata* parasitizing *Cajanus cajan* crop in India. Al-Joboury and Aliwy (2021) also carried out similar morphological studies on *Orobanche* samples collected from Baghdad regions and stated that the average plant height and stem length for *O. aegyptiaca* Pers. is 27.5 and 19.0cm. *Orobanche* affected mustard plants showed shrunken siliquae wilting and yellowing and necrosis of leaves (**Figure 4b** and **c**). However, further studies are needed to assess the extent of damage on mustard plant. In Haryana, Mustard plants infested with *Orobanche* showed wilting symptoms, poor growth and yield (Jat and Singh 2018).

Variation in root architecture of mustard plants collected from farmer fields

Mustard plants attached with *Orobanche* plants collected from different locations showed differences in their root structure. Root architecture of mustard plants (var. DRMR-IJ31) collected from ICAR-Directorate of Rapeseed-Mustard Research, (ICAR-DRMR), Sewar showed well developed tap root system ranging from 25-30cm with non-fibrous adventitious roots while at the other locations root root length of mustard plants ranged from 10-20cm and exhibited well developed adventitious root system

Figure 3a. Showing tubercle, inflorescence, branched stem and root system of fully developed *Orobanche* plant b. brown to dark brown scales in racemose position c. bud stage of *Orobanche* plants d. purple colour tubular-infundibuliform flower e. syncarpus ovary with single style f. four stamens g. seeds forming stage h. roots architecture i. variation in stem length

Figure 4a. ***Orobanche*** **attached on the mustard plant through haustorium in mustard crop fields b. & c. silique and leaves of** ***Orobanche*** **affected mustard plants d.** ***Orobanche*** **and mustard seeds (1.5X)**

Table 3. The morphological characteristics of ***Orobanche plant*** **samples collected from various locations**

Name of the village	Length of flowering shoot (cm)	Presence and colour of scales	No. of *Orobanche* attached per plant	Colour of corolla	Haustorium length (cm) (Min-Max)	Root (cm) (Min-Max)
Sewar (ICAR-DRMR)	16±5.2	Present (Brown to dark brown)	1-2	violet	2.0-30.0	25.0-30.0
Seedpur	25±3.7	Present (Brown to dark brown)	2-3	violet	3.0-6.5	15.0-20.0
Bidyari	27±4.2	Present (Brown to dark brown)	4-5	violet	4.0-8.0	10.0-16.0
Nangla Andya	30±3.8	Present (Brown to dark brown)	4-5	violet	3.0-10.0	12.0-18.0
Nangla Jhamra	28±5.4	Present (Brown to dark brown)	3-4	violet	1.5-10.0	12.0-16.0
Sepoura	32±3.1	Present (Brown to dark brown)	4-5	violet	6.3-10.0	16.0-18.0
Vedpura	35±4.5	Present (Brown to dark brown)	5-6	violet	1.7-13.0	15.0-20.0
Bayana	28±4.3	Present (Brown to dark brown)	7-8	violet	5.0-10.0	12.0-16.0

in comparison to the main root system with lots of hairy and fibrous structure. In terms of attachment of *Orobanche* to the mustard plants, the length of haustorium was found higher while number of *Orobanche* per mustard plants was lesser in samples collected from Sewar region. In Farmers' field samples, a small haustorium connected *Orobanche* with mustard and higher numbers of *Orobanche* per mustard plants were present. Apart from that, it was found that one *Orobanche* plant can attach itself to the mustard plant through many haustoria and 3-4 *Orobanche* plants can attach to the one mustard plant through individual haustorium (**Figure 5, Table 3**). Soil samples collected from mustard fields of ICAR-DRMR is of clay loam in nature (Shekhawat *et al.* 2012). However, higher sandy and lighter texture was present in soil samples collected from farmers' villages. The soil texture may render it difficult for many *Orobanche* to connect to the host plant but still they were able to penetrate through the roots of host plant. Sandy loam soil is an important soil group of Bharatpur District of Rajasthan. Its texture varies from clays to sandy loam. It is reported that upper profile of sandy laom soil is often deficient in phosphate and calcium while its nitrogen contents vary (Sharma 2019). It is already reported that, *Orobanche* germinates and attaches after receiving certain germination stimulants or strigolactones released by host plant (Westwood *et al.* 2013). Phosphate (P) deficiency promotes strigolactone (SL) biosynthesis in the roots (Yoneyama *et al.* 2012). According to Andreo-Jimenez (2015), under P limiting conditions, SLs reduces primary root growth, inducing lateral root density and development, and stimulates root hair elongation and density. These modifications allow the plant to increase the exploratory capacity of the soil. This could be possibly one of the reasons why *Orobanche* has better penetration in sandy and clay loam soils. Sheoran *et al*. (2014) also supported the fact that most of the mustard cultivation in India is limited to light textured soil having inherent poor fertility status and water holding capacity which promotes higher germination of *Orobanche*.

Validation of ITS based markers on *Orobanche* samples

Genomic DNA was extracted from the *Orobanche* tissue samples collected from ICAR-DRMR, *O. ramosa* and *O. cernua* seed samples and mustard plants as previously described. Multiplex PCR reaction was carried out to validate the ITS-350 and UCP-555 primers. It was observed that ITS-350 did not amplify the DNA of *O. cernua*, *O. ramosa* and mustard samples. However, the expected 555bp amplicon from the universal primers UCP-555 was present for *O. cernua*, *O. ramosa* and mustard plants, indicating amplification did occur in these samples (**Figure 6**). Furthermore, ITS-350 and UCP-555 primer successfully amplified the 350bp and 555bp PCR product in *Orobanche* samples collected from ICAR-DRMR confirming the abundance of *O. aegyptiaca* in mustard fields of Bharatpur. In a similar study, *Orobanche* samples collected from the oilseed rape infested fields of Israel were confirmed as *O. aegyptiaca* using ITS based markers (Aly *et al*. (2012). In another instance, Osterbauer and Rehms (2002) developed a PCR based assay using ITS based

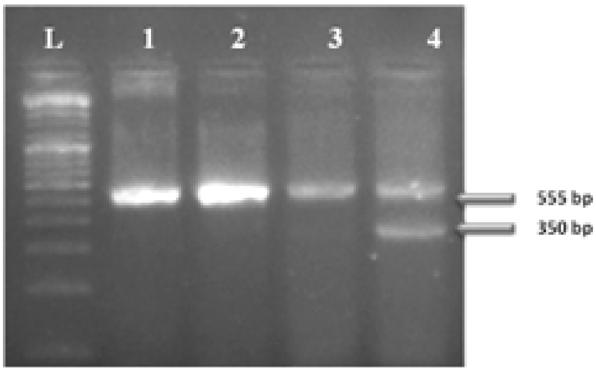

Figure 6. Multiplex PCR demonstrating the specificity of the *Orobanche*-specific primers (350 bp band) and the amplification of the internal control primers (555 bp band). 100bp ladder, Lane1: *Orobanche cernua*, Lane2: *Orobanche ramosa*, Lane 3: Mustard variety (DRMR-IJ31), Lane 4: *Orobanche aegyptiaca*

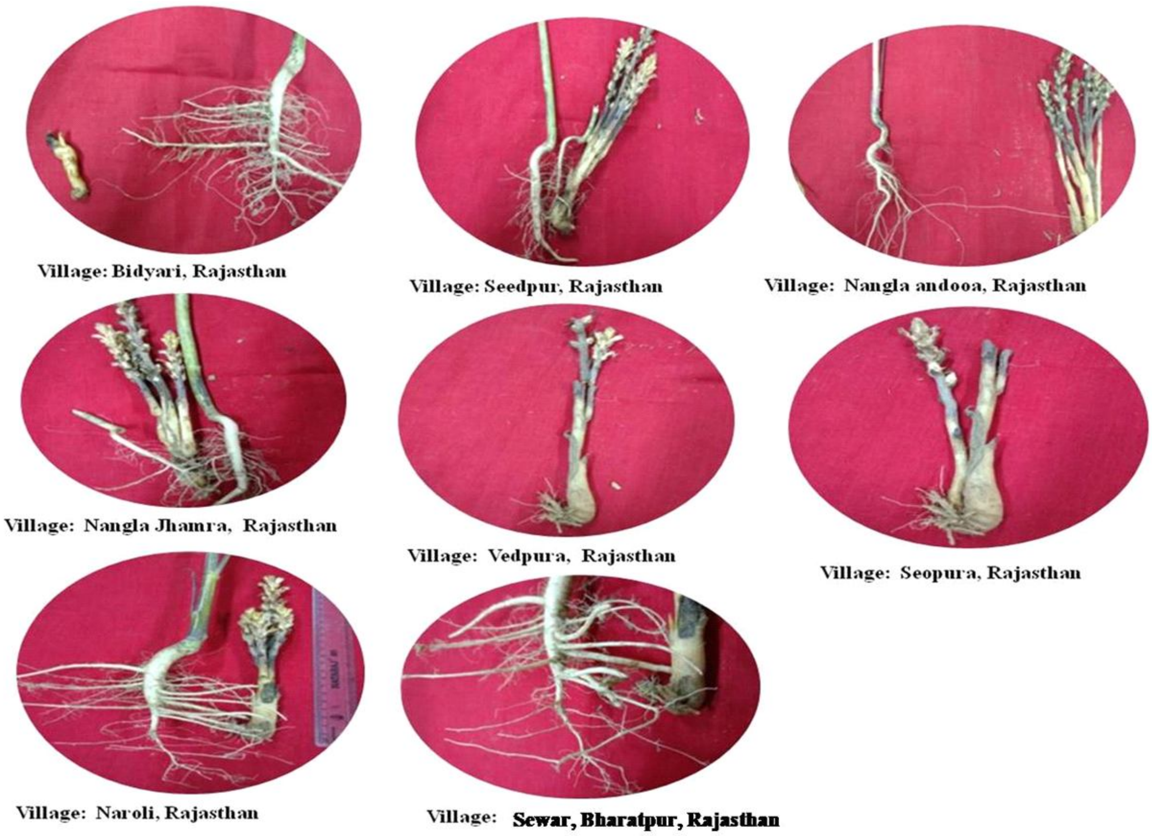

Figure 5. Variation in *Orobanche* plant samples collected from different mustard farmer fields infested with *Orobanche*

markers to detect *O. minor* seeds from Oregon regions. This assay is sensitive enough to detect a single *O. minor* seed and also not amplify the DNA of red and white clover (*Trifolium pratense* L. and *T. repens* L., respectively), two agricultural hosts for this parasite. Rolland *et al.* (2016) has also developed a high-resolution melting assay (HRM) using plastid markers to identify the eight broomrape species (*O. aegyptiaca*, *O. cernua*, *O. crenata*, *O. cumana*, *O. foetida*, *O. hederae*, *O. minor*, and *O. ramosa*) from a single seed allowing its subsequent use in quarantine purposes in commercial seed lots. Even though, the HRM assay successfully identifies mature plants from the field and seeds in commercial lots but cannot be used to differentiate from each other.

Developing soil-based diagnostic for *O. aegyptiaca*

Soil was collected from a non-infested field (wheat field) in ICAR-DRMR, Bharatpur to develop soil diagnostic assay for *Orobanche*. 200mg of this soil was split into eight samples and artificial infestation of 0, 10, 20, 30, 40, 50, 100, and 150 of *Orobanche* seeds was done. *Orobanche* seeds were collected from the mustard fields in the previous season and stored at room temperature. Total genomic DNA was extracted from the soil samples using DNA isolation kit (UltraClean Soil DNA Isolation Kit, MoBio Laboratories, Inc., Solana Beach, CA) and PCR amplification was carried out using the specific assay designed for this. In this multiplex reaction, ITS-350 and UCP-555 primers successfully amplified a (350bp) and (555bp) PCR product in all the soil samples (**Figure 7**). In Australia, DNA-based soil diagnostics provided assistance in predicting the likely extent of losses from various soilborne diseases caused by fungal and nematode pathogens in wheat and barley crops. Farmers, therefore, have the option of changing cultivars or modifying cropping programs in situations where the risk of crop loss is high (Ophel-Keller *et al.* 2008). In another instance, DNA based soil testing was successfully implemented for quantifying the presence of *P. brassicae* in oilseed rape fields (Wallenhammar *et al.* 2016).

Detecting *O. aegyptiaca* in farmer mustard fields

ITS-350 primers successfully amplified a (350bp) PCR product whereas as expected UCP-555 primers amplified a PCR product (555bp) in all of the soil samples collected from farmer fields. *O. aegyptiaca* infestation was detected in all the soil samples from all the locations which were reported to be infested (**Figure 8**). In one study, Pathak and Kannan (2014) collected soil samples from the tomato and mustard farmer fields of Gwalior regions of Madhya Pradesh and quantified *Orobanche* seed bank with viability on host crops such as mustard, brinjal and tomato. On the basis of morphological characters *Orobanche cernua* was identified as the invading species. The ITS region is conserved in nature and ITS markers has the potential to identity underground plants with greater accuracy (Linder *et al.* 2000). Therefore, molecular based assay has edge over the morphological identification for resolving the identity of closely linked species. Aly *et al.* (2019) quantified the number of *Orobanche* seeds present in a soil sample from a sunflower-infected field using ITS-100bp markers. Kirilova *et al.* (2019) also identified seeds of *O. ramosa*, *O. mutelii* and *O. cumana* in the soils collected from different farmer fields in Bulgaria by ITS based molecular markers.

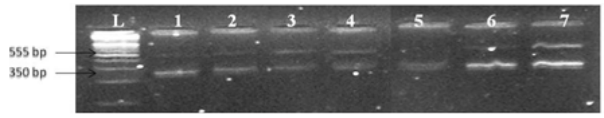

Figure 7. Multiplex PCR showing PCR amplification of *Orobanche* DNA isolated from soil containing *Orobanche* seeds. *Orobanche* specific primers amplified desired 350bp product whereas Universal primer gave 555bp product. 100 bp ladder, L: soil containing 10 seed of *Orobanche*, Lane 1: 20 seeds of *Orobanche*, Lane 2: 30 seeds of *Orobanche*, Lane 3: 40 seeds of *Orobanche*, Lane 4: 50 seeds of *Orobanche*, Lane 5: 100 seeds of *Orobanche*, Lane 6: 150 seeds of *Orobanche*, Lane 7

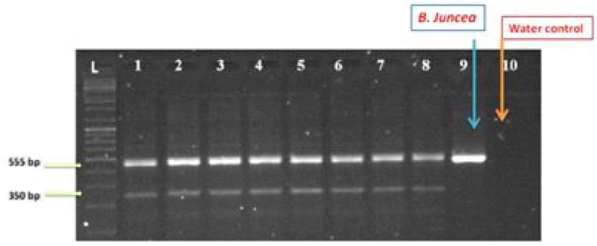

Figure 8. Multiplex PCR demonstrating the specificity of the *Orobanche aegyptiaca*-specific primers (350 bp band) and the amplification of the internal control primers (555 bp band). *Orobanche* samples from village: Bidyari, Seedpur, Nangla Andua, Seopura, Vedpura, Sewar, Bayana, Nangla Jhamra, Rajasthan, India (lanes 1 -8), *Brassica Juncea* (lane 9), and water control (lane 10) and 100 bp DNA ladder (L).

In this study, the molecular and morphological diagnosis of *Orobanche* was carried out to detect the prevalent species and presence of seeds in mustard fields. The use of this technique on soils collected from farmer's fields of Rajasthan showed that *O. aegyptiaca* is major dominant species affecting mustard crop as its DNA was detected in 100% of the eight fields sampled. Thus, a high risk of complete crop failures exists if a susceptible mustard cultivar is sown by farmers in Rajasthan, India. Jat and Meena (2018) reported control techniques for *Orobanche* infestation in mustard fields at Dausa district of Rajasthan which farmers can utilise.

In conclusion, DNA based soil testing can be applied for early detection of *Orobanche* seed bank in soil which can lower the risk of crop yield loss and helps in maintaining plant and soil health. Furthermore, identification of parasitic weed seeds in crop seed lot before a crop is planted can allow cultivators to take precautionary measures and prevent further spreading of this weed to parasite free fields.

REFERENCES

Agarwal M, Shrivastava N and Padh H. 2008. Advances in molecular marker techniques and their applications in plant sciences. *Plant Cell Reports* **27**: 617–631.

Akhter G, Hisamuddin and Khan TA. 2020. *Orobanche renata* destroying *renata* destroying *Cajanus cajan*: a new report from India. *Indian Phytopathology* **73**: 817–819.

Al-Joboury KR and Aliwy SA. 2021. Morphological and anatomical study in some species of Orobanche. *Journal of the American Research Center* **15**: 1815–1140.

Aly R 2007. Conventional and biotechnological approaches for control of parasitic weeds. *In Vitro Cellular and Developmental Biology-Plant* **43**: 304–317.

Aly R, Eizenberg H, Kocherman M, Abu-Nassar J, Taha L and Saadi I. 2012. Use of ITS nuclear sequences from Phelipanche aegyptiaca as a direct tool to detect single seeds of broomrape species in the soil. *European Journal of Plant Pathology* **133**: 523–526.

Aly R, Bari VK, Londner A, Nasser JA, Lati R, Taha-Salaime L and Eizenberg H. 2019. Development of specific molecular markers to distinguish and quantify broomrape species in a soil sample. *European Journal of Plant Pathology* **155**: 1367–1371.

Andreo-Jimenez B, Ruyter-Spira C, Bouwmeester HJ and Lopez-Raez JA. 2015. Ecological relevance of strigolactones in nutrient uptake and other abiotic stresses, and in plant-microbe interactions below-ground. *Plant Soil* **394**: 1–19.

Benharrat H, Veronesi C, Theodet C and Thalouarn P. 2002. Orobanche species and population discrimination using intersimple sequence repeat (ISSR). *Weed Research* **42**: 470–475.

Dongo A, Leflon M, Simier P and Delavault P. 2012. Development of a high-throughput real-time quantitative PCR method to detect and quantify contaminating seeds of Phelipanche ramosa and *Orobanche* cumana in crop seed lots. *Weed Research* **52**: 34–41.

Doyle JJ and Doyle JL 1987. A rapid DNA isolation procedure for small quantities of fresh leaf tissue. *Phytochemical Bulletin* **19**: 11–15.

Hebert PDN and Gregory TR. 2005. The Promise of DNA Barcoding for Taxonomy. *Systematic Biology* **54**: 852–859.

Jat BL and Meena RL. 2018. An Assessment of Orobanche in Mustard (Brassica juncea L. Czern and Coss) Control Techniques in Dausa District of Rajasthan. *International Journal of Agriculture Sciences* **10**: 5679–5681.

Jat RS and Singh D. 2018. Broomrape intimidation to rapeseed-mustard production in semi-arid regions. *Advances in Plants and Agriculture Research* **8**: 560 562.

Joel DM, Portnoy V and Katzir N. 1996. Identification of single tiny seeds of *Orobanche* using RAPD analysis. *Plant and Molecular Biology Reports* **14**: 243–248.

Katzir N, Portnoy V, Tzuri G, Joel DM and Castejon-Munoz M. 1996. Use of random amplified polymorphic DNA (RAPD) markers in the study of the parasitic weed *Orobanche*. *Theoretical and Applied Genetics* **93**: 367–372.

Kirilova I, Hristeva T and Denev I. 2019. Identification of seeds of *Phelipanche ramosa*, *Phelipanche mutelii* and *Orobanche cumana* in the soils from different agricultural regions in Bulgaria by molecular markers. *Biotechnology & Biotechnological Equipment* **33**: 520–528.

Linder CA, Moore IA and Jackson RB. 2000. A universal molecular method for identifying underground plant parts to species. *Molecular Ecology* **9**: 1549–1559.

Manen JF, Habashi C, Jeanmonod D, Park JM and Schneeweiss GM. 2004. Phylogeny and intraspecific variability of holoparasitic *Orobanche* (Orobanchaceae) inferred from plastid *rbcL* sequences. *Molecular Phylogenetics and Evolution* **33**: 482–500.

Ophel-Keller K, McKay A, Hartley D, Herdina and Curran J. 2008. Development of a routine DNA-based testing service for soilborne diseases in Australia. *Australasian Plant Pathology* **37**: 243–253.

Osterbauer NK and Rehms L. 2002. Detecting single seeds of small broomrape (*Orobanche minor*) with a polymerase chain reaction. Online. *Plant Health Progress* doi: 10.1094/PHP-2002-1111-01-RS.

Park JM, Manen JF, Colwell AE and Schneeweiss GM. 2008. A plastid gene phylogeny of the non-photosynthetic parasitic *Orobanche* (Orobanchaceae) and related genera. *Journal of Plant Research* **121**: 365–376.

Parker C and Riches CR. 1993. Orobanche species: The broomrapes. In: Parasitic Weeds of the World. *Biology and Control*, Wallingford, UK: CAB International, 111–164.

Pathak A and Kannan C. 2014. A new cost-effective method for quantification of seed bank of *Orobanche* in soil. *Indian Journal of Weed Science* **46**: 151–154.

Portnoy VH, Katzir N and Joel DM. 1997. Species identification of soil-borne *Orobanche* seeds by DNA fingerprinting. *Pesticide Biochemistry and Physiology* **58**: 49–54.

Punia SS, Yadav A, Singh S, Sheoran P, Yadav DB and Yadav B. 2012. Broomrape: A threat to mustard cultivation in Haryana and its control measures, pp. 105. In: Proceedings of 1st Brassica Conference "Production Barriers and Technological options in Oilseeds Brassica" March 2-3, 2012, CCS HAU, Hisar

Punia SS. 2014. Biology and control measures of Orobanche. *Indian Journal of Weed Science* **46**: 36–51.

Rolland M, Dupuy A, Pelleray A and Delavult P. 2016. Molecular Identification of Broomrape Species from a Single Seed by High Resolution Melting Analysis. *Frontier in Plant Sciences* https://doi.org/10.3389/fpls.2016.01838.

Román B, Gonzáles Verdejo CI, Satovic Z, Madrid MD, Cubero JI and Nadal S. 2007. Detecting *Orobanche* species by using cpDNA diagnostic markers. *Phytoparasitica* **35**: 129–135.

Schneeweiss GM, Colwell A, Park JM, Jang CG and Stuessy TF. 2004. Phylogeny of holoparasitic *Orobanche* (Orobanchaceae) inferred from nuclear ITS sequences. *Molecular and Phylogenetic Evolution* **30**: 465–478.

Schneeweiss GM. 2007. Correlated evolution of life history and host range in the non-photosynthetic parasitic flowering plants *Orobanche*and Phelipanche (*Orobanchaceae*). *Journal of Evolutionary Biology* **20**: 471–478.

Sharma N. 2019. *Geomorphology and Landuse Pattern & It's Impact on Agricultural Development*. Ph.D. thesis submitted to Kota University. A Case Study of Bharatpur District.

Shekhawat K, Rathore SS, Premi OP, Kandpal BK and Chauhan JS. 2012. Advances in Agronomic Management of Indian Mustard (*Brassica juncea* (L.) Czernj. Cosson): An Overview. *International Journal of Agronomy 14:* doi:10.1155/2012/408284.

Sheoran P, Punia SS, Singh S and Singh D. 2014. Orobanche weed management in mustard: Opportunities, possibilities and limitations. *Journal of Oilseed Brassica* **5**: 96–101.

Wallenhammar AC, Gunnarson A, Hansson F and Anders A. 2016. Quantification of Plasmodiophora brassicae using a DNA-Based soil test facilitates sustainable oilseed rape production. *Plants* **5**: 21.

Wickett NJ, Honaas LA, Wafula EK, Das M, Huang K, Wu B, Landherr L, Timko MP, Yoder J, Westwood JH and dePamphilis CW. 2011. Transcriptomes of the parasitic plant family Orobanchaceae reveal surprising conservation of chlorophyll synthesis. *Current Biology* **21**: 2098–2104.

Yoneyama K, Xie X, Kim HI, Kisugi T, Nomura T, Sekimoto H, Yokota T and Yoneyama K. 2012. How do nitrogen and phosphorus deficiencies affect strigolactone production and exudation? *Planta* **235**: 1197–1207.

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RESEARCH ARTICLE

Quality and profitability of sesame (*Sesamum indicum*) as influenced by weed management treatments in Kano, Sudan Savanna agro-ecological zone of Nigeria

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ABSTRACT

Weed control is an important component of crop management as it determines the crops productivity, quality and the profitability. A field trial was conducted in 2019 rainy season at Research and Training Farm of Centre for Dryland Agriculture, Bayero University Kano (BUK) (11°58'52.5" N and 008°24'48.6") and National Horticultural Research Institute at Bagauda, Kano (11°33'25.93" N and 008°23'11.97" E), Nigeria. The experiment was aimed at evaluating weed management strategies effect on quality and profitability of sesame production. Eleven weed management treatments were laid out in randomized complete block design replicated thrice. Weedy check recorded the largest number of broad-leaved, grasses and sedges weed species in both locations. The pre-emergence application (PE) of pendimethalin followed by (*fb*) a hoe weeding at 6 weeks after seeding (WAS) recorded the highest sesamum seed yield, seed oil contents and physical purity when compared to other weed control treatments at both locations. Hoe weeding twice at 3 and 6 WAS had the highest seed yield (1223 kg/ha and 1212 kg/ha), total variable cost ($973 and $963) and gross revenues ($1065 and $1056) than other weed control treatments, at both the locations. Hoe weeding twice at 3 and 6 WAS resulted into higher seed yield, but it is not economical due to labour cost involved. Pendimethalin 1.0kg/ha PE *fb* post-emergence application (PoE) of *Tithonia diversifolia* (Hemsl.) A. Gray leaf extract 5% w/v at 6 WAS had higher net return ($309 and $317) and benefit cost ratio (1.50 and 1.52) proving to be more economical and could therefore be recommended in the study area.

Keywords: Economics, Pendimethalin, Seed purity, Tithonia diversifolia, Sesame, Weed management

INTRODUCTION

Sesame (*Sesamum indicum* L.), is one of the most important oilseed crops due to its edible quality oil (Raikwar 2016). Apart from being an important oil seed source, sesame seed is a potential source of protein. It is rich in water soluble antioxidants such as sesamin, sesamol, sesamolin, and sesaminol glucosides which inhibit the development of rancidity in the oil (Langham 2008). The oil obtained from sesame is use in the industries as raw material for the production of detergent, scent, medications and edible oils (Yol *et al*. 2010).

The world's major sesame producing countries are China, India, Myanmar, Ethiopia and Nigeria. Worldwide, 6.55 million ton of sesame was produced in 2019 on an area of 12.82 million ha with an average yield of 510.8 kg/ha (FAOSTAT 2019) and Africa produced 4.00 million ton from 8.73 million ha with an average yield of 457.6 kg. Nigeria is the leading sesame producer in Africa, and the third major in the world, with about 0.48 million tons produced in 2019 and ranking third in the world.

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Weeds are one of the major constraints to sesame production. Weeds compete with sesame for resources leading to significant reduction (30%) in yield (Hossain *et al*. 2020, Babiker *et al*. 2014). Weed competition in sesame may reduce the size of sesame seeds and hence oil contents. Some weed seeds are morphologically similar with sesame seed and can adulterate sesame grains thereby decreasing its quality and oil contents. Sesame is now becoming an export crop and international market requires 99.99% purity (Vafaei *et al.* 2013) of sesame. To achieve this high percent purity, proper and efficient weed management is necessary and crucial.

To reduce the deleterious effect of unwanted plants on seed purity and oil content, farmers use varieties of weed control methods which may not necessarily be economical (Daramola *et al*. 2020). Previous studies were mostly aimed at identification of effective weed management strategies without considering their economic efficiency (Omovbude and Udensi 2012). Manual hoe weeding has been the traditional way of weed management in many crops production systems in Africa. Manual method is labour intensive, time consuming and became very expensive (Lins *et al.* 2021) in addition to non-availability of labour at time of critical needs due to shortage of labour during early crop growth stage when weeds must be controlled for higher quality and yield. The use of herbicide is the most cost effective compared to manual hoe weeding, but it may not control all weed species at the same time (Daramola *et al.* 2020), crop injury may occur and herbicide resistant weeds may emerge, if not properly used. If adulterated, herbicides may not provide efficient control. The use of *Tithonia diversifolia* (Hemsl.) A. Gray (*Tithonia*) leaf extract has been reported to be effective in weed control in many crops (Scavo and Mauromicale 2021). It is environmentally friendly and efficient in suppressing weed growth at relatively low cost. The plant is widely and freely available, and farmers may require lower technological and monitory input to prepare the extract and spray on their farms. The objective of this study was to evaluate the effect of using *Tithonia* leaf extract as a component of integrated weed management on quality and profitability of sesame production in Sudan savanna agro-ecological zone of Nigeria.

MATERIALS AND METHODS

Two experiments were conducted during 2019 cropping season at Research and Training Farm of Centre for Dryland Agriculture, Bayero University Kano (BUK) and National Horticultural Research Institute, Bagauda, both in the Sudan savanna zone of Nigeria. The soil textural class was sandy clay at BUK and sandy clay loam at Bagauda. Soil pH, available phosphorus and organic carbon were higher at BUK than Bagauda. The experimental sites have the same Nitrogen contents. The two sites have equal amount of calcium ion in their soils. Magnesium and potassium ions were higher in BUK than Bagauda while more sodium ion and higher CEC were reported in Bagauda than BUK.

The experiment consisted of eleven weed management treatments, *viz*. hoe weeding twice at 3 and 6 weeks after sowing (WAS), pre-emergence application (PE) of pendimethalin at 1.0 kg/ha, pendimethalin at 1.5 kg/ha PE, *Tithonia* leaves extract (*Tithonia* LE) at 5% weight by volume (W/V), *Tithonia* LE at 10% (W/V), combined use of *Tithonia* LE at 5% (W/V) PE followed by (*fb*) post-emergence application (PoE) of the *Tithonia* LE 5% (W/V) at 6 WAS, *Tithonia* LE at 5% (W/V) *fb Tithonia* LE 10% (W/V) PoE at 6 WAS, pendimethalin at 1kg/ha PE *fb Tithonia* LE 5% (W/V) PoE at 6 WAS, pendimethalin at 1 kg/ha PE *fb Tithonia* LE 10% (W/V) PoE at 6 WAS, pendimethalin at 1.0 kg/ha PE *fb* hoe weeding at 6 WAS and weedy check. The experiment was laid out in a Randomized Complete Block Design replicated thrice. X-Sudan variety of sesame, obtained from Jigawa State Research Institute, Kazaure, was used. The gross plots were six ridges each of 3 m long, spaced at 0.75 m apart. The net plot was 4.5 m² consisting of the two innermost ridges.

Sesame seeds were mixed with fine sands (1:1) and a finger pinch of sesame sand mixture were placed in hole when the rainy season was fully established at 75 cm inter rows and 20 cm intra rows spacing. Nitrogen was applied at the rate of 60 kg/ha, phosphorus (P) at 20 kg/ha and potassium (K) at 20 kg/ha using NPK 15:15:15 and urea. The NPK was applied at 3 WAS and the urea at 6 WAS. Weeding was done as par the treatment.

The shoots of *Tithonia* were collected from bushes of surrounding area and air dried for seven days. The dried shoots were chopped into pieces with fodder cutter and milled with A2 grinder into fine powder and sieved. The powder was soaked in a ratio of 1 kg of powder to 10 liters of distilled water (for 24 hrs) to obtain 10% (w/v) concentration. The mixture was filtered through four layers of muslin cloth to obtain the water extract. One liter of this was diluted to make 5% (w/v) concentrations by adding 1 liter of distilled water.

One m^2 quadrat was laid out randomly in each of the plot at harvest and weeds within the quadrat were identified in-situ using Akobundu *et al.* (2016). Weeds that could not be identified immediately in the field were taken to the herbarium unit of the Department of plant biology, Bayero University, Kano Nigeria for identification. Weed species noted were counted and classified morphologically into broad-leaved, grasses and sedges. The sesame was harvested at maturity when the capsules turned yellow and the basal leaves started dropping. The stems were cut from the ground level using sickle. Stems from each plot were tied together to make bundle which were raised up and allowed to dry before threshing and winnowing to obtain pure seeds. The grain yields per plot were weighed using electric balance and extrapolated to grain yield in kg per hectare. Seed oil content **(%)** was strong-minded by using the Soxhlet extraction procedure as defined by Malik *et al.* (2003). Seed physical purity (%) was determined using the equation below (FAO and Africa Seeds 2018).

The cost of production (land preparation, land rent, sowing, cost of treatments application, cost of herbicides and pesticides, cost of seeds and harvest, *etc*.) were used for computation. The gross revenue was computed based on the prevailing market price of sesame in Kano at the time of harvest ($0.870588/kg).

$$\text{Seeds physical purity (\%)} = \frac{\text{Weight of the pure sesame seeds}}{\text{Total weight of all components}} \times 100$$

Net returns was calculated as Gross revenue – Total cost while benefit cost ratio = Gross revenue / Total cost. Data generated on weed flora composition, oil content and seed purity were subjected to Analysis of variance using GENSTAT 17th edition. Significant means were compared using SNK at 5% level of probability.

RESULTS AND DISCUSSION

Effect on weeds

A total of 24 weed species were identified in the experimental sites. Of these, 12 were broad-leaved, 10 grasses and only 2 sedges. Further analysis showed that there were more broad-leaved and grass weed species at Bagauda than BUK (**Table 1**) hence higher level of infestations due to variations in weed seed bank at the two sites as reported in rice by Duary and Mukherjee (2013).

Weed control treatment significantly ($p<0.05$) affected the weed flora composition in sesame field at BUK and Bagauda (**Table 2**). Weedy check recorded the largest number of broad-leaved, grasses and sedges in both locations as the experimental sites were rich in weed species occurrence and no any weed control measure was applied. The weeds emerged and competed severely with sesame crop as reported by Milberg and Hallgren (2004) and Hamma and Ibrahim (2013) who observed that weeds may grow faster than crops and successfully compete for available nutrients, water, space and sunlight if no control measures were applied. The lowest density of broad-leaved weeds was recoded with pendimethalin at 1.0 kg/ha *fb* supplementary hoe weeding at 6 WAS in both locations. This implied that these categories of weed can be managed using this method and minimized competition for nutrients, moisture and space between weeds and sesame. This highlights the superiority of integrated methods of weed control over other methods as reported by Bhadauria *et al.* (2012). Manual hoe weeding twice at 3 and 6 WAS had lower density of narrow leaved weed species at both locations. Less number of sedges was observed with manual hoe weeding at BUK and with pre- and

Table 1. Weeds species associated with sesame at BUK and Bagauda in 2019 rainy season

Species	Level of Infestation	
	BUK	Bagauda
Broad-leaf		
Ageratum conyzoides Linn.	*	***
Amaranthus spinosus Linn.	-	**
Aspilia bussei O.	**	*
Gomphrena celosioides Mart.	**	**
Hyptis lanceolata Poir.	*	**
Leucas martinicensis (Jacq.) Ait.f.	**	***
Mitracarpus villosus (Sw.) DC.	**	***
Neptunia oleracea Lour.		**
Oldenlandia herbacea (Linn.) Roxb.	**	-
Portulaca quadrifida Linn.	*	*
Senna occidentalis (L.) Link	*	**
Sesamum datum Thonning	-	**
Grasses		
Cenchrus biflorus Roxb.	*	
Dactyloctenium aegyptium (Linn.)P. Beauv	**	***
Digitaria horizontalis Willd	**	***
Echinochloa stagnina Beauv.	*	***
Eragrostis tremula Hochst. Ex Steud	**	***
Oryza longistaminata A. Chev.	**	***
Panicum laxum Sw.	**	**
Pennisetum pedicellatum Trin.	***	***
Pennisetum violaceum (Lam.) L. Rich.	*	**
Setaria pumila (Poir.)	*	***
Sedges		
Kyllinga bulbosa Beauv.	*	-
Cyperus difformis Linn	-	*

***=high infestation, **=moderate infestation, *=low infestation

Table 2. Effect of weed control treatments on the number of broad-leaved, narrow-leaved and sedge weeds at sesame harvest in BUK and Bagauda during 2019 rainy season

Treatment	BUK			Bagauda		
	Broad-leaved	Grasses	Sedges	Broad-leaved	Grasses	Sedges
Manual hoe weeding twice at 3 & 6 WAS	23.33cde	31.33f	00b	23.33c	74.00c	1.667ab
Pendimethalin at 1 kg/ha PE	33.33b	80.67b	1.00b	34.00bc	151.00b	00b
Pendimethalin at 1.5 kg/ha PE	34.33b	66.00c	3.00b	58b	96.00bc	4.667ab
Tithonia leaves extract at 5% (W/V)	37.33b	87.00b	0.333b	48.67bc	97.3bc	1.667ab
Tithonia leaves extract at 10% (W/V)	32.33b	83.00b	5.00ab	47.33bc	116.3bc	0.667b
Tithonia leaves extract at 5% (W/V) PE *fb Tithonia* leaves extract at 5% (W/V) PoE	32.33b	66.33c	00b	27.67bc	86.3bc	0.333b
Tithonia leaves extract at 5% (W/V) *fb Tithonia* leaves extract at 10% (W/V)	34.00b	57.00d	2.00b	24.33c	122.3bc	00b
Pendimethalin at 1.0 kg/ha PE *fb Tithonia* leaves extract at 5% (W/V)	24.33cd	57.00cd	0.333b	30.33bc	110.3bc	00b
Pendimethalin at 1.0 kg/ha PE *fb Tithonia* leaves extract at 10% (W/V)	28.33bc	52.00d	0.667b	34.67bc	127bc	00b
Pendimethalin at 1.0 kg/ha PE *fb* SHW at 6 WAS	17.33d	43.33e	0.333b	24.00c	92.70bc	00b
Weedy check	79.00a	116.00a	7.00a	119.33a	219.70a	7.333a
Level of probability	< 0.001	< 0.001	0.002	<.001	< 0.001	0.052
SE±	1.997	2.517	1.103	6.89	13.98	1.572

Means followed by the same letter(s) in a column are not significantly different at 5% level of probability using Students-Newman-Keuls (SNK) Test. SE±= standard error of mean, SHW= Supplementary Hoe Weeding, WAS= Weeks After Sowing, *fb* = followed by post-emergence application of *Tithonia* LE at Bagauda.

Effect on seed yield, sesame oil yield and seed purity

The weed control treatment had significant influence on oil contents at BUK, while non-significant effect was observed at Bagauda (**Table 3**). Pendimethalin at 1.0 kg/ha PE *fb* hoe weeding at 6 WAS recorded higher oil contents than the other weed control methods. The lowest oil contents were obtained with weedy check due to severe competition between the crops and weeds which caused a reduction in photosynthetic processes and seed size as reported by Ahmed *et al.* (2014).

The highest physical purity of seeds was recorded with pendimethalin PE *fb* hoe weeding at 6 WAS, in both locations. Weedy check had the most contaminated sesame seeds in both locations. Weeds grow vegetatively faster than the crop and when dried their leaves contaminate the sesame seed resulting in lowest percent purity with crop in weedy check compared to weed controlled treated crop. Higher seed purity in plots with combined application of pendimethalin and hoe weeding could be ascribed to the lower weed density which might have reduced the contamination of sesame seeds with inert materials from weed. These finding support the observations of Farooq *et al.* (2011).

Total variable cost, gross profit, net profit and benefit cost ratio

The higher total variable cost and gross profit from plots were manual hoe weeding twice at 3 and 6 WAS as well as the combined use of pendimethalin at 1 kg/ha PE *fb* hoe weeding at 6 WAS (**Table 4**). However, higher net profit and cost-benefit ratio were observed with pendimethalin PE *fb Tithonia* LE PoE at various rates in both the locations. *Tithonia* LE at 5 and 10% w/v PE recorded higher gross and net profit as well as cost benefit ratio than pendimethalin at 1 and 1.5 kg/ha PE in both locations.

The manual hoe-weeding had resulted in higher yield, higher variable cost and lower profit compared to other weed management treatments due to higher cost of labour involved. The labor availability at the time of higher demand is also an issue of great concern as reported by Omovbude and Udensi (2012). The higher net profit and cost benefit ratio observed with pendimethalin at 1.0 kg/ha PE *fb Tithonia* LE at 5 and 10% w/v PoE at 6WAS was due to lower variable cost of these treatments combinations as reported by Daramola *et al.* (2020) in okra. The advantage of the use of the bio-herbicide may be in the unreported environmental cost benefit as the use of *Tithonia* LE in weed control is environmentally friendly because unlike synthetic herbicides, *Tithonia* LE is biodegradable (Scavo and Mauromicale 2021). This study also confirmed that the combined application of pendimethalin and *Tithonia* LE, at rate higher than 5% w/v may not be necessary because it reduces the net profit. This might possibly be associated with the fact that there may be an antagonistic effect at higher rate.

Manual hoe weeding twice adequately controlled weeds and produced higher sesame grain yield but it is not economical. The combined application of pendimethalin at 1.0 kg/ha PE *fb Tithonia* LE at 5 and 10% (w/v) PoE at 6WAS produces pure seeds with higher oil content and proved to be profitable than all other weed control measures studied and can therefore be recommended in sesame cultivated in the study area.

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Table 3. Effect of weed management treatments on sesame oil content and physical seed purity (%) at BUK and Bagauda during 2019 rainy season

Treatment	Oil content (%)		Physical seed purity (%)	
	BUK	Bagauda	BUK	Bagauda
Manual hoe weeding twice at 3 and 6 WAS	51.60a	52.28	98.73a	98.33a
Pendimethalin at 1 kg/ha PE	48.33a	47.80	95.87ab	96.33a
Pendimethalin at 1.5 kg/ha PE	47.75a	48.94	96.50ab	95.53ab
Tithonia leaves extract at 5% (W/V)	48.38a	48.53	96.95ab	94.29ab
Tithonia leaves extract at 10% (W/V)	47.35 a	49.45	97.00ab	95.44ab
Tithonia leaves extract at 5% (W/V) *fb Tithonia* leaves extract at 5% (W/V)	52.95a	51.15	97.89ab	97.67a
Tithonia leaves extract at 5% (W/V) *fb Tithonia* leaves extract at 10% (W/V)	49.21a	50.78	98.15a	98.27a
Pendimethalin at 1 kg/ha PE *fb Tithonia* leaves extract at 5% (W/V)	50.00a	51.74	98.33a	96.70a
Pendimethalin at 1 kg/ha PE *fb Tithonia* leaves extract at 10% (W/V)	49.10a	49.17	98.81a	96.46a
Pendimethalin at 1 kg/ha PE *fb* SHW at 6 WAS	53.82a	52.82	98.96a	98.67a
Weedy check	40.41b	47.35	94.85b	91.76b
Level of probability	< 0.001	0.681	0.006	0.005
SE±	1.454	2.151	0.691	1.036

Means followed by the same letter(s) in a column are not significantly different at 5% level of probability using Students-Newman-Keuls (SNK) Test. SE±= standard error of mean, SHW= Supplementary Hoe Weeding, WAS= Weeks After Sowing, *fb* = followed by

Table 4. Effect of weed management treatments in sesame on cost benefit and return at BUK and Bagauda during 2019 rainy season

Treatment	Total yield (kg/ha)	Total Variable cost ($)	Gross revenue ($)	Net revenue or loss ($)	Benefit cost ratio
BUK 2019					
Manual hoe weeding twice at 3 and 6 WAS	1224	973.16	1065.51	92.35	1.09
Pendimethalin at 1 kg/ha PE	739	575.42	643.28	67.85	1.12
Pendimethalin at 1.5 kg/ha PE	789	588.37	686.89	98.53	1.16
Tithonia leaves extract at 5% (W/V)	800	528.10	696.64	168.54	1.32
Tithonia leaves extract at 10% (W/V)	819	598.69	713.36	114.67	1.19
Tithonia leaves extract at 5% (W/V) *fb Tithonia* leaves extract at 5% (W/V)	871	598.69	758.63	159.94	1.27
Tithonia leaves extract at 5% (W/V) *fb Tithonia* leaves extract at 10% (WV)	920	645.75	800.94	155.19	1.24
Pendimethalin at 1 kg/ha PE *fb Tithonia* leaves extract at 5% (W/V)	1069	622.48	931.09	308.61	1.50
Pendimethalin at 1 kg/ha PE *fb Tithonia* leaves extract at 10% (W/V)	1121	669.28	976.10	306.82	1.46
Pendimethalin at 1 kg/ha PE *fb* SHW at 6 WAS	1160	782.65	1009.62	226.96	1.29
Weedy check	389	504.57	338.57	-166.00	0.67
Bagauda 2019					
Manual hoe weeding at 3 and 6 WAS	1213	962.64	1055.94	93.296	1.10
Pendimethalin at 1 kg/ha PE	736	563.59	641.01	77.423	1.14
Pendimethalin at 1.5 kg/ha PE	788	577.26	686.02	108.76	1.19
Tithonia leaves extract at 5% (W/V)	798	540.15	694.99	154.84	1.29
Tithonia leaves extract at 10% (W/V)	815	587.21	709.53	122.32	1.21
Tithonia leaves extract at 5% (W/V) fb *Tithonia* leaves extract at 5% (WV)	864	587.21	752.19	164.98	1.28
Tithonia leaves extract at 5% (W/V) fb *Tithonia* leaves extract at 10% (WV)	919	634.27	800.33	166.06	1.26
Pendimethalin at 1 kg/ha PE fb *Tithonia* leaves extract at 5% (W/V)	1066	610.65	927.96	317.31	1.52
Pendimethalin at 1 kg/ha PE fb *Tithonia* leaves extract at 10% (W/V)	1114	657.71	969.49	311.78	1.47
Pendimethalin at 1 kg/ha PE fb SHW at 6 WAS	1151	773.96	1002.13	228.17	1.29
Weedy check	375	493.09	326.73	-166.36	0.66

SHW= Supplementary Hoe Weeding, WAS= Weeks After Sowing, *fb* = followed by, PE = pre-emergence application; Price at time of harvest = $0.870588/kg

REFERENCES

Ahmed MS, Khaled AA and Mansour KE. 2014. Productivity of sesame as influenced by weeds competition and determination of critical period of weed control. *Alexandra Journal of Agricultural Research* **59** (3):179–187.

Akobundu IO, Ekeleme F, Agyakwa CW and Ogazie CA. 2016. *A hand book of West African Weeds,* IITA, Afkar printing and publishing company limited, Ibadan, Nigeria.

Babiker MM, Siraj OO and Salah AE. 2014. The critical period of weed control in sesame (*Sesamum orientale* L.). *Journal of Forest Products and Industries* **3**(1): 66–70.

Bhadauria N, Yadav KS, Rajput RL and Singh VB. 2012. Integrated Weed Management in Sesame. *Indian Journal of Weed Science* **44**(4): 235–237.

Daramola OS, Adiguun JA and Adeyemmi OR. 2020. Efficacy and economic of integrated weed management in okra (*Abelmoschus esculentus* (L.) Moench). *Agricultura Tropica Et Subtropica* **53**(4): 199–206.

Duary B and Mukherjee A. 2013. *Distribution Pattern of Predominant Weed in Wet Season and their Management in West Bengal, India*. (In) proceeding of the 24th Asian-Pacific Weed Science Society conference held during 22-25th October, 2013 at Bandung, Indonesia.

FAO and AfricaSeeds. 2018. *Seed quality assurance. Seeds toolit.* 126p.

FAOSTAT. 2019. htt://www.fao.org/faostat/fr/#data/QC

Farooq M, Jabran K, Cheema ZA, Wahid A and Siddique KHM. 2011. Exploiting allelopathy for sustainable agriculture. *Pest Management Science* **67**(5): 493–506. https://doi.org/10.1002/ps.2091.

Hamma IL and Ibrahim U. 2013. Weed Management Technique of Horticultural Crops in Nigeria. *American – Eurasian Journal of Agricultural and Environmental Science* **13**(3): 362–366.

Hossain J, Ali MO, Islam MA, Alam MS, Islam MR and Rahman J. 2020. Seed yield and yield components of sesame as affected by various weed control methods. *Bangladesh Agronomy Journal* **23**(1):107–116.

Langham DR. 2008. *Growth and development of sesame*. Sesaco Corporation, USA.

Lins H A, Dos santos MG, Junior APB, Mendonca V, Silva DV and Coelhod ED. 2021. Economic evaluation and effectiveness of herbicides applied in pre-emergency in the sesame. *Revista Caatinga* **34**(3): 621–630.

Malik AM, Farouk M, Akhatar M, Cheema ZA and Ahmed S. 2003. Influence of different nitrogen levels on productivity of sesame (*Sesamum indicum* L.) under varying planting patterns. *International Journal of Agriculture and Biology* **4**(1):490–492.

Milberg C and Hallgren A. 2004. Weed Control: Crop Yield Losses due to Weeds. *Field Crops Research*. **86**: 199–209.

Omovbude S and Udensi EU. 2012. Profitability of selected weed control methods in maize (*Zea mays* L.) in Nigeria. *Journal of Animal & Plant Sciences* **15**(1): 210–217

Raikwar RS. 2016. Stability for grain yield and its contributing traits in sesame (*Sesamum indicum* L.*). Electronic Journal of Plant Breeding* 7(4):1033–1039. DOI: 10.5958/0975-928X.2016.00141.1

Scavo A and Mauromicale G. 2021. Crop allelopathy for sustainable weed management in Agroecosystems: knowing the present with a view to the future. *Agronomy* **11**(11): 1–23. https://doi.org/10.3390/agronomy11112104.

Vafaei S, Razmjoo J and Karimmojeni H. 2013. Weed control in sesame (*Sesamum indicum* L.*)* using integrated soil applied herbicides and seed hydro-priming pre-treatment. *Journal of Agrobiology* **30**(1):1–8. DOI 10.2478/agro-2013-0001.

Yol E, Karaman E, Furat S and Uzun B. 2010. Assessment of selection criteria in sesame by using correlation coefficients, path and factor analyses. *Australian Journal of Crop Science* **4**(1): 598–602.

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RESEARCH ARTICLE

Cashew Orchards' weeds in high diseases and pests prevalence zone in Côte d'Ivoire

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ABSTRACT

The cashew orchards development and productivity faces several constraints, which include weeds. This study aims to assess the degree of infestation of weeds in cashew orchards by monitoring their density, richness and diversity in 108 cashew orchards in four regions of Côte d'Ivoire. In each plot of the 100 m² of each of the cashew orchards selected, weeds were identified and the individuals of herbaceous species were collected and counted whereas the trees and shrubs were counted without being up rooted. There were 295 weeds species belonging to 194 genera and 58 families of angiosperms. Regional data revealed 101 species and 50629 individuals in the Bounkani, 165 species and 70618 individuals in the Kabadougou, 156 species and 13597 individuals in the Gontougo and 164 species and 196257 individuals in Marahoué. A high negative relation was found between the orchards' age and the weeds infestation level in the cashew orchards.

Keywords: Cashew orchards, Cote D'Ivoire, Weeds survey, Weed diversity, Weed infestation

INTRODUCTION

Weeds have always been a major concern (Ipou 2005). Farmers maintain certain useful species for food, medicine, religious ceremonies, soil improvement (Ruthenberg 1976, Gliessman 1988) in association with the main crop in traditional agroecosystems (Altieri 1987; Konaté *et al.* 2021). Cashew is a tropical cash crop whose production in Africa increased very quickly during the current century (Bassett 2017, Firca 2018). Côte d'Ivoire became the leading African producer and exporter of raw cashew nuts (Diop 2016, Minagri 2016, Piperno 2011) with an estimated production of over 738,000 tons of raw cashew nuts in 2018 (Firca 2018). However, cashew nut yields in Ivorian orchards remain low, ranging from 350 to 500 kg/ha (Djaha *et al.* 2010), due to the climatic hazards, the agricultural techniques and the biotic factors (Link *et al.* 1984, Viana *et al.* 2007). Among these biotic factors, weeds are often cited to have a major impact on crop production and therefore cause a considerable decrease in yields (Mbaye 2013, Bassène *et al.* 2012, Noba 2002). This study aims to assess the weed flora, the floristic diversity and the degree of infestation of weeds in four cashew producing regions in Côte d'Ivoire.

MATERIALS AND METHODS

All the weeds including the herbaceous species, the woody species and the climbing species were inventoried in the cashew orchards. During this study which was carried out in the four regions known as of the highest prevalence of cashew diseases (Soro *et al.* 2017) and pests' attacks (N'Dépo *et al.* 2017) in Côte d'Ivoire (**Figure 1**). The monitoring was done during the raining season (July to October 2020) when all the weeds especially herbaceous species were alive and could be easily identified botanically.

The Kabadougou and Bounkani regions are characterized by a Sudanese climate with an average temperature of 30 °C with a Sudanian savannah

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vegetation (Monnier 1983). The annual rainfall of these regions ranged from 800 to 1 200 mm (Krogba *et al.* 2016). The Gontougo and Marahoué regions are in a forest-savannah mosaic vegetation (Monnier 1983) where the climatic regime was similar to the Guinean zone with an average annual rainfall between 1 200 and 1 500 mm; the annual average temperature is about 28.4 ° C (Krogba *et al.* 2016).

The survey was carried out in 108 cashew farms of age ranging from 5 to 48 years encompassing three villages in each region of Bounkani and Gontougo, and six villages in each region of Kabadougou and Marahoué (**Table 1**). Six cashew orchards were selected per village. Data was collected from 100 m^2 plot of 10 m x 10 m area. Weeds were recorded and assessed in 108 plots visited, *i.e.* one plot of 100 m^2 in each of the orchard. The herbaceous species that could have very high local densities and or be omitted when there are too short and rare, individuals were uprooted before being counted following methodology of Rew *et al.* (2000). But, the shrubs and trees individuals in plots except those of the cashew were counted without being uprooted. The observations were collected under three cashew tree crown configurations (Konaté *et al.* 2020).

The taxa were named in the field following methodology of Akobundu and Agyakwa (1989), Bourgeois and Merlier (1995), Arbonnier (2009) whereas the adopted nomenclature was the phylogenetic classification of APG (1998, 2003, 2009, 2016).

The floristical parameters were mainly the species richness (R), Simpson's diversity index (D), Shannon's diversity index (H), Piélou's equitability index (E) and Hill's equitability index (Na).

Simpson index (D) was calculated (Simpson 1949) by the following formula:

$$\boldsymbol{D = \sum(\frac{ni}{N})} \quad \text{Equation 1}$$

where ni = number of individuals/species and N = total number of individuals / survey; D varies from 0, for minimum diversity of taxa, to 1, for maximum diversity of taxa.

Shannon Index (H) was calculated according to Shannon (1948) as follows:

$$\boldsymbol{H' = -\sum i\,(\frac{ni}{N})\log_2(\frac{ni}{N})} \quad \text{Equation 2}$$

where ni = number of individuals/species and N = total number of individuals / survey; H' usually varies from 0, for dissimilar distribution of taxa, to $\log_2 S$, for similar distribution of all taxa.

Piélou equitability index (J') was calculated according to Pielou (1966) as follows:

$$\boldsymbol{J' = H'/log_2 H'max} \quad \text{Equation 3}$$

where H' = Shannon index and H'max = maximum diversity index. J' varies from 0, when the taxa show different abundances, to 1 when all taxa have the same abundance in the stand.

Hill's index was calculated according to Hill (1973) through the formula:

$$\boldsymbol{Hill = (\frac{1}{\sum i(\frac{ni}{N})^2}) \times 1/e^{[H']}} \quad \text{Equation 4}$$

where ni = number of individuals / species, N = total number of individuals/survey and H' = Shannon index. Hill varies from 1, for taxa single taxa stand, to ", for many taxa stand.

Density is always defined as the average of a taxa individuals' number on the sampled total area (Massenet 2010) and is expressed by the following formula:

$$\boldsymbol{Density = N/S} \quad \text{Equation 5}$$

with N = total number of individuals surveyed and S = total sampled area. The degree of infestation of the orchards by weeds was expressed according to the weeds density value to which this degree is positively correlated.

RESULTS AND DISCUSSION

A total of 295 species belonging to 194 genera and 58 families were recorded in 180 orchards. The dicotyledonous angiosperms were predominant (82%) than the monocotyledonous angiosperms (18%) (**Table 1**). The predominant families, to which recorded weeds belong, were Fabaceae (21%), Poaceae (10%), Rubiaceae (8%), Malvaceae (7%), Asteraceae (6%), Cyperaceae, Lamiaceae and Moraceae (4% each).

The total number of weeds species (weeds richness) recorded in each of the region was 101 species in Bounkani, 156 species / in Gontougo, 165 species in Kabadougou and 164 species in Marahoué. The majority (78-82%) of recorded species were dicots and 18-22% of them were monocots (**Table 1**).

The distribution of weeds' taxa varied amongst the regions and the cashew's crown types. Indeed, in Boukani region, weeds showed higher diversity and lower equitability under the juxtaposed cashew crown, and lower diversity and higher equitability under the separated cashew crown (**Table 2**). In Gontougo region, weeds showed higher diversity and lower equitability under the separated cashew crown,

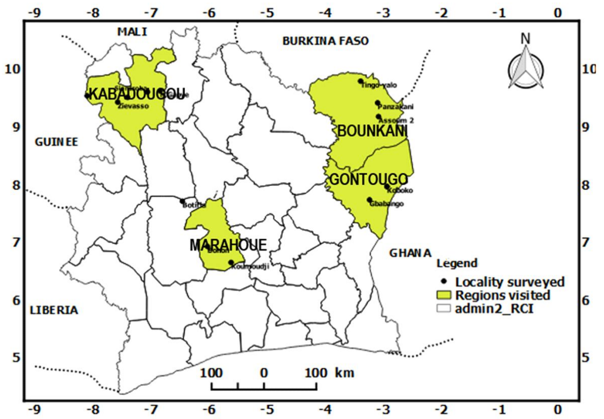

Figure 1. Map showing the studied regions in Côte d'Ivoire

Table 1. Weeds richness according to the regions

Regions	Plots number	Total number of weed species recorded	Dicots	Monocots
Bounkani	18	101	79 (78%)	22 (22%)
Gontougo	18	156	124 (79%)	32 (21%)
Kabadougou	36	164	135 (82%)	29 (18%)
Marahoué	36	165	134 (81%)	31 (19%)
Total	108	295	242 (82%)	53 (18%)

Values in (%) express the proportion of Angiosperm classes recorded by region

lower diversity under the closed cashew crown and higher equitability under the juxtaposed cashew crown (**Table 2**). In Kabadougou region, weeds showed higher diversity and lower equitability under the separated cashew crown, and lower diversity and higher equitability under the closed cashew crown (**Table 2**). In Marahoué region, weeds showed both higher diversity and equitability under the juxtaposed cashew crown, and both lower diversity and equitability under the separated cashew crown (**Table 2**). The overall highest weeds diversity was found under the juxtaposed cashew crown in Boukani region with 0.87 Simpson index, 1.06 Shannon-Weaver index and 53.13 Hill index while the lowest diversity was recorded under both separated cashew crown in Boukani region with 0.33 Simpson index, 1.46 Shannon-Weaver index and 10.26 Hill index, and closed cashew crown in Kabadougou region with 0.32 Simpson index, 1.46 Shannon-Weaver index and 10.13 Hill index (**Table 2**). The overall weeds' highest equitability was found under the juxtaposed cashew crown in Gontougo region with 0.62 Pielou index while the lowest equitability was experienced under the juxtaposed cashew crown in Boukani region with 0.31 Pielou index (**Table 2**).

The weeds flora of studied four regions is representative of the weeds national flora in cashew orchards of Côte d'Ivoire. It represents 67% of species, 70% of genera and 76% of families found in 261 cashew orchards spread in the production basin of cashew in Côte d'Ivoire (Konaté *et al.* 2020). However, it accounts for 54% of species, 58% of genera and 69% of families of the known cashew orchards weeds flora in the production basin of cashew in Côte d'Ivoire (Konaté 2021). It is far richer than the usual cashew orchards weeds flora in Côte d'Ivoire with 40,4% of species, 30,3% of genera and 17,6% of families (Konaté *et al.* 2021).

The highest value of dicotyledonous angiosperms and the predomination of Fabaceae family in the cashew orchards' floristic composition

Table 2. Variation in weeds' diversity indices in four study regions and under three cashew crown types

Study region	Diversity indices	Separated crowns**			Juxtaposed crowns***			Closed crowns****		
		Mini*	Max	Mean	Mini	Max	Mean	mini	Max	Mean
BOUNKANI	Simpson	0.17	0.69	0.33	0.17	0.87	0.87	0.09	0.65	0.45
	Shannon-Weaver	0.44	1.77	1.46	1.18	2.40	1.06	0.30	1.65	1.16
	Pielou	0.33	0.74	0.46	0.13	0.86	0.31	0.10	0.49	0.35
	Hill	1.52	17.08	10.26	1.75	82.86	53.13	1.48	15.01	6.12
GONTOUGO	Simpson	0.79	0.86	0.81	0.67	0.84	0.76	0.54	0.85	0.70
	Shannon-Weaver	1.01	1.42	1.36	1.49	2.28	1.90	2.39	2.50	2.90
	Pielou	0.43	0.71	0.39	0.46	0.76	0.62	0.43	0.79	0.58
	Hill	35.93	56.78	49.55	14.24	52.55	34.90	13.42	55.95	32.00
KABADOUGOU	Simpson	0.26	0.81	0.58	0.20	0.85	0.42	0.48	0.54	0.32
	Shannon-Weaver	0.71	1.94	1.35	0.51	2.09	1.03	0.94	1.72	1.46
	Pielou	0.24	0.63	0.33	0.17	0.66	0.47	0.36	0.58	0.49
	Hill	2.76	61.56	6.50	1.12	63.46	2.39	4.92	6.20	10.13
MARAHOUE	Simpson	0.52	0.81	0.37	0.03	0.73	0.55	0.34	0.63	0.49
	Shannon-Weaver	0.27	1.91	1.01	0.09	1.59	1.14	0.78	1.28	1.26
	Pielou	0.26	0.64	0.33	0.03	0.57	0.40	0.24	0.45	0.36
	Hill	12.1	36.05	3.57	1.12	20.94	12.37	3.28	19.68	7.11

*Mini: minimum, max: maximum indices' values; **Separate crowns: Cashew trees never touch each other; ***Juxtaposed crowns: All the cashew trees barely touch each other. all barely touch each other; ****Closed crowns: All the cashew trees overlap each other.

showed that these biotopes harbour a different flora in comparison to the local natural ecosystem which a Sudanian savannah or a Guinean savannah (Monnier 1983). Indeed, these savannahs were defined as a plant formation dominated by the Poaceae family (Trochain 1957). The higher weeds richness in Gontougo orchards than in Boukani orchards and the same weeds richness in both Kabadougou and Marahoué orchards, could be attributed to their savannah type and similar total plot area. In fact, the Guinean savannah in Gontougo region is naturally richer than Sudanian savannah in Boukani region due to the coexistence of wetter savannah and some islands of rainforests in Guinean savannah area while the Sudanian savannah is a mix of drier savannah and some islands of drier forests (Kouamé *et al.* 2021a, 2021b). This savannah type impact on the orchards' weed richness was more sighting in smaller total plot area of Boukani and Gontougo than in larger total plot area of Kabadougou and Marahoué.

The variation of the weeds' diversity according to both the region and the cashew crowns types could be attributed to the local farming practices. In all regions, cashew trees were planted at densities that varied from a farm to another and the clearing practices also vary from a farmer to another (Konaté *et al.* 2020, Konaté 2021, Ky 2021). And the variation in weed diversity according the cashew crowns type could be explained by the difference in the light availability for weeds under these crowns. Pioneer weeds that support full light intensity live and prosper under cashew separated crowns as in many crops lands like cotton (Aman e*t al.* 2004, Ipou 2005), rice (Kouamé *et al.* 2011, Konan *et al.* 2014, Touré 2014), pineapple (Mangara *et al.* 2010) and sugarcane (Traoré *et al.* 2019). Non-pioneer weeds hide under the cashew closed crowns like in some other crops lands such as rubber and cocoa (Kouamé and Koné 2021) while non-pioneer light-demanding weeds live as well under the cashew juxtaposed crowns as in some other crops like banana (Tano *et al.* 2016) and

Table 3. Total densities of the most invasive weeds in orchards by region

Taxa	Famillies	Total weed density (number/100 m²)			
		Bounkani	Gontougo	Kabadougou	Marahoue
Ageratum conyzoides L.	Asteraceae	102	614	6653	74070
Loudetia arundinacea (A. Rich) Hochst.	Poaceae	342	310	6276	6319
Mitracarpus scaber Urb.	Rubiaceae	17	35	24	1675
Croton hirtus L'Hér.	Euphorbiaceae	13914	439	2731	15221
Setaria barbata (Lam.) Kunth	Poaceae	6100	288	555	1201
Euphorbia heterophylla L.	Euphorbiaceae	27	501	429	24545
Desmodium triflorum (DC) L.	Fabaceae	3917	265	47	745
Talinum triangulare (Jacq.) Willd	Portulacaceae	234	356	46	4372
Imperata cylindrica (L.) Raeusch.	Poaceae	4912	74	9291	1016
Panicum brevifolium L.	Poaceae	816	45	172	4633
Indigofera hirsuta L.	Fabaceae	3	5	1232	345
Panicum laxum Sw	Poaceae	6356	1021	416	30
Phyllanthus amarus Schumach.	Phyllanthaceae	144	15	267	4069
Commelina diffusa Burm.f	Commelinaceae	14	4	45	5106
Synedrella nodiflora (L.) Gaertn.	Asteraceae	467	170	663	3814
Pouzolzia guineensis Benth.	Urticaceae	4	162	4	8704
Adenostemma perrottetii DC	Asteraceae	83	12	6276	2
Oplismenus burmannii (Retz.) P.Beauv	Poaceae	76	4945	1611	1610
Laportea aestuans (L.) Chew	Urticaceae	4	7	5	4888
Brachiaria lata (Schumach.)	Poaceae	6	2	1933	785
Pennisetum polystachion (L.) Schult	Poaceae	543	1	7159	5
Sida rhombifolia L.	Malvaceae	16	5	4074	3
Croton lobatus L.	Euphorbiaceae	10	2	1	2384
Hyptis suaveolens (L.) Poit	Lamiaceae	5103	3	3642	12
Mitracarpus villosus (Sw.) DC.	Rubiaceae	5074	3	100	45
Indigofera dendroides Jacq.	Fabaceae	2101	2	17	23
Spermacoce stachydea DC.	Rubiaceae	30	5	204	8829
Spigelia anthelmia L.	Loganiaceae	54	11	73	3440
Fimbristylis ferruginea (L.) Vahl	Cyperaceae	148	2	25	1234
Setaria pumila (Poir.) Roem.	Poaceae	342	3	5403	34
Aerva lanata (L.) Juss.	Amaranthaceae	3	1	3	534
Tridax procumbens L.	Asteraceae	745	10	276	3410
Paspalum conjugatum P.J.Bergius	Poaceae	77	6	1232	97
Justicia flava Forssk.) Vahl	Acanthaceae	12	2	1	1451
Cyperus rotundus L.	Cyperaceae	342	7	727	12

palm oil (Traoré *et al.* 2010). The dominance of the weeds depends on the cultural practices (Barralis *et al.* 1996) but also on the soil weed seedbank and the regrowth (Kouamé and Koné 2021).

Weeds density

The total weeds assessed in this study was about 333’377./10’800m² cashew orchards whereas the regional total density was respectively 50’629./ 1800m² in Bounkani, 13’597./1800m² in Gontougo, 70’618/3600m² in Kabadougou, and 196’257/3600m² in Marahoué.

Weeds with a total density higher than 100/100 m² in at least three regions belonged to the families Asteraceae (3 species), Poaceaes (6 species), Euphorbiaceae (2 species), and Fabaceae, Portulacaceae, Phyllanthaceae (1 species each) (**Table 3**). The less abundant species in the Boundani, Gontougo and Marahous regions are: *Mitracarpus* scaber, *Commelina diffusa*, *Laportea aestuans*, *Croton lobatus*, *Croton lobatus*, *Aerva lanata* and *Justicia flava* (**Table 3**). Of the four regions, Marahoué is the most weedy. Species such as *Ageratum conyzoides*, *Loudetia arundinacea*, *Croton hirtus*, *Euphorbia heterophylla*, *Panicum brevifolium*, *Phyllanthus amarus*, *Commelina diffusa*, *Pouzolzia guineensis*, *Laportea aestuans* and *Spermacoce stachydea* are abundant with more than 4000 individuals in the Marahoué plots while in the Gontaougo region they are less abundant with 100 individuals in the plots (**Table 3**). Weed density decreased with increasing orchard age (**Figure 2**).

The higher total weed density in the Bounkani region compared to the Gontougo region and those in the Marahoué region compared to the Kabadougou region, showed the absence of a link between local weed richness and local weed density in cashew orchards. Weed density depends mainly on their own ability to compete for nutrient resources (Delissio and Primack, 2003), spatial occupancy (Boyden *et al.* 2005; Brûmelis *et al.* 2009) and available sunlight (Poorter 2001, Baraloto 2003, Yedmel 2014) in the orchards.

A strong negative impact was found between orchard age and weed infestation level in cashew orchards (**Figure 2**). The impact of age on weed density found in this study is a combination of spatial occupancy and sunlight availability under cashew tree crowns. Indeed, these ecological parameters decrease from young to older cashew orchards. In this sense, Fenni (2003) and Traoré *et al.* (2019) evoked a progressive or regressive evolution of weed

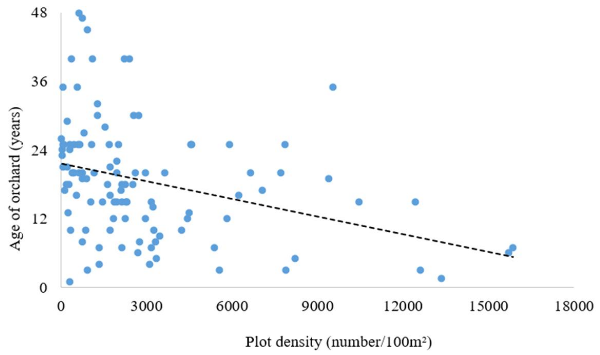

Figure 2. Evolution of weed density in the cashew orchards according to the orchards’ age

density through a series of successive stages in cultivated lands during their evolution and according to the capacity of the weeds to withstand or not the light intensity.

Most often, the youngest cashew orchards were colonised by highly invasive weeds corresponding to weeds with a density of 4000/100m² for each taxon and led by *Ageratum conyzoides* Sieber ex Steud. Orchards with a density higher than 16’000/100 m² are more observed in young orchards with separate cashew tree crowns and mostly hosting few but very invasive weed species such as *A. conyzoides*, *Loudetia arundinacea* Hochst. ex Steud. etc. between cashew trees. Over time, the open crowns of these cashew orchards successively juxtapose and close, while at the same time the density of pioneer and invasive weeds decreases to the benefit of non-pioneer and non-invasive weeds, which also increase slightly.

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REFERENCES

Akobundu IO and Agyakwa CW. 1989. *Guide des mauvaises herbes d’Afrique de l’Ouest. IITA*. 522 p.

Aman KG, Ipou IJ and Touré Y. 2004. La flore des mauvaises herbes des cultures cotonnières de la région du Worodougou, au nord-ouest de la Côte d’Ivoire. *Agronomie Africaine* **16**(1): 1–14.

APG. 1998. An ordinal classification for the families of flowering plants. APG I. *Annals of the Missouri Botanical Garden* **85**(4): 531–553.

APG. 2003. An update of the Angiosperm Phylogeny Group classification for the orders and families of flowering plants: APG II. *Botanical Journal of the Linnean Society* **141**: 399–436.

APG. 2009. An update of the Angiosperm Phylogeny Group classification for the orders and families of flowering plants: APG III. *Botanical Journal of the Linnean Society* **161**: 105–121.

APG. 2016. An update of the Angiosperm Phylogeny Group classification for the orders and families of flowering plants. APG IV. *Botanical Journal of the Linnean Society* **181**: 1–20.

Arbonnier M. 2009. *Arbres, arbustes et lianes des zones sèches d'Afrique de l'Ouest*. Quae, 3e édition, 576 p.

Baraloto C. 2003. Régénération forestière naturelle: de la graine à la jeune tige. *Revue Forestière de France LV (numéro spécial)* : 179–187.

Barralis G, Dessaint F and Chadeuf R. 1996. Relation flore potentielle – flore réelle de sol agricoles de Côte d'Or. *Agronomie* **16**: 453–463.

Bassène C, Mbaye MS, Kane A, Diangar S and Noba K. 2012. Flore adventice du maïs (*Zea mays* L.) dans le sud du Bassin arachidier (Sénégal) : structure et nuisibilité des espèces. *Journal of Applied Biosciences* **59**: 4307–4320.

Bassett T. 2017. Le boom de l'anacarde dans le bassin cotonnier du nord Ivoirien. Structures de marché et prix à la production**.** *Afrique Contemporaine* **263/264**: 59–83.

Bourgeois LT and Merlier H. 1995. *Adventrop. Les adventices d'Afrique soudano-sahélienne*. CIRAD, 637 p.

Boyden S, Binkle D and Shepperd W. 2005. Spatial and temporal patterns in structure, regeneration, and mortality of an old-growth ponderosa pine a forest in the Colorado Front Range. *Forest Ecology and Management* **219**: 43–55.

Brûmelis G, Strazds M and Eglava Z. 2009. *Stand structure and spatial pattern of regeneration of Pinus sylvestris in a natural treed mire in Latvia*. Silva Fennica **43**(5) : 767–781.

CIRAD-GRET. 2002. *Memento de l'Agronome*. Jouve, Paris, 1691 p.

Delissio LJ and Primack RB. 2003. The impact of drought on the population dynamics of canopy tree seed-lings in an aseasonal Malaysian rain forest. *Journal of Tropical Ecology* **19**: 489–500.

Djaha JBA, N'Guessan AK, Ballo CK and Aké S. 2010. Germination des semences de deux variétés d'anacardier (*Anacardium* L.) élites destinées à servir de porte-greffe en Côte d'Ivoire. *Journal of Applied Biosciences* **32***:* 1995–2001.

Fenni M. 2003. *Etude des mauvaises herbes des céréales d'hiver des hautes plaines*

constantinoises. Ecologie, dynamique, phénologie et biologie des bromes, Université de Sétif, 165 p.

Firca. 2018. La filière anacarde. firca.ci/wpcontent/uploads/2019/05/LaFiliereDuProgres20.pdf

Hill MO. 1973. Diversity and evenness: a unifying notation and its consequences. *Ecology* **54**: 427–432.

Ipou IJ. 2005**.** *Biologie et écologie* d'*Euphorbia heterophylla* L. (Euphorbiaceae) *en culture cotonnière. au nord de la Côte d'Ivoire*, l'Université de Cocody-Abidjan. UFR Biosciences 195 pp.

Konan Y, Akanvou L, N'Cho S, Arouna A, Eddy B and Kouakou CK. 2014. Analyse de l'éfficacité technique des riziculteurs face à l'infestation des cultures par les espèces parasites Striga en Côte d'Ivoire. *Revue Ivoirienne des Sciences et Technologie* **23**: 212–223.

Konaté ML, Kouamé FN, Abo K, Ipou Ipou J, Soro S, Traoré K and Koné D. 2020. Mauvaises herbes des vergers de l'anacardier en Côte d'Ivoire. *Agronomie Africaine* **32**(3): 277–295.

Konaté ML, Ouattara DN, Kouamé FN and Bakayoko A. 2021. Diversity and uses by farmers of cashew (*Anacardium occidentale* L.) orchards weeds in Côte d'Ivoire. *Ethnobotany Research and Applications* **21**(1): 1–14.

Konaté ML. 2021. *Caractérisation des adventices dans les vergers de l'anacardier (Anacardium occidentale L., Anacardiaceae) dans le bassin Anacardier de Côte d'Ivoire.*, Université Nangui Abrogoua, 201p.

Kouamé FN, Bakayoko A, Bah-Kouamé C, Téré HG and Dougouné Bi G. 2021a. Composition floristique des forêts denses en Côte d'Ivoire. *Afrique Science* **19**(4): 147–158.

Kouamé FN and Koné MLA. 2021. The effects of anthropogenic activities on the regeneration of flora in Duekoué and Scio forests in Southwestern Côte d'Ivoire. International Journal of Biodiversity and Conservation. **13**(1): 22–34.

Kouamé FN, Kouakou G, Bah-Kouamé C and Kouassi FL. 2021b. Structure et diversité floristique en forêt dense de la Côte d'Ivoire. *Afrique Science* **18**(6): 159–176.

Kouamé KF, Ipou IJ, Toure A and N'Guessan KE. 2011. Major weeds of rice agroecosystems in Côte d'Ivoire. *Agriculture and Biology Journal of North America* **2**(9): 1317–1325.

Krogba YN, Kouakou YKN, Gohi BZF, Rusu E and Yao KA. 2016. Distribution et comportement des éléments traces métalliques dans les cambisols manganésifères des sites volcano-sédimentaires de Côte d'Ivoire, *Lucrãrile Seminarului Geografic "Dimitrie Cantemir"* Nr. 43.

Ky ARF. 2021. *Pratiques paysannes de gestion des mauvaises herbes en culture de l'anacarde dans trois Régions en Côte d'Ivoire : Haut-Sassandra, Indénié-Djuablin et Poro*, Université Nangui Abrogoua, 33 p.

Link RJ and Mouch M. 1984. Contributions à la biologie, à la propagation et à la lutte contre les adventices au Maroc. *Deutsche Gesellschaft für Technische Zusammenarbeit.*

Mangara A, N'da AAA, Traoré K, Kéhé M, Soro K and Touré M. 2010. Etude phytoécologique des mauvaises herbes en cultures d'ananas (*Ananas comosus* (L.) Merr.) dans les localités de Bonoua et N'Douci en Basse Côte d'Ivoire. *Journal of Applied Biosciences* **36**: 2367–2382.

Massenet JY. 2010. Caractérisation et mesure des peuplements reguliers. 25 p.

Mbaye MS. 2013. *Association mil [Pennisetum glaucum (L.) R. Br] et niébé [Vigna unguiculata (L.) Walp.]: arrangement spatiotemporel des cultures. Structure, dynamique et concurrence de la ûore adventice et proposition d'un itinéraire technique*, UCAD (Sénégal), 236 p.

Monnier Y. 1983. Carte de la végétation de la Côte d'Ivoire. Pp. ***72.*** In: Vennetier P. & LaclavèreG. (eds) : Atlas de Côte d'Ivoire. 2e éd., *Jeune Afrique, Paris.*

N'Dépo OR, Chérif M, Johnson F, Kassi KFJM, N'Guessan AC, Silué N and N'Goran O.M. 2017. Inventaire des insectes ravageurs du verger anacardier dans les régions de Bounkani, Gontougo et Indénie-Djablun au Nord-Est en Côte d'Ivoire. *Afrique Science **13***(2): 333–343.

Noba K. 2002. *La ûore adventice dans le sud du bassin arachidier (Sénégal): Structure, dynamique et impact sur la production du mil et de l'arachide*, UCAD (Sénégal), 126p.

Pielou EC. 1966. The measurement of diversity in different types of biological collections. *Journal of theoretical Biology* **13**: 131–144.

Piperno DR. 2011. The Origins of plant cultivation and domestication in the New World Tropics patterns. Process and new developments. *Current Anthropology* **52**(4):ý S453–S470.

Poorter L. 2001. Growth responses of 15 rain-forest tree species to a light gradient: the relative importance of morphological and physiological traits. *Functional Ecology* **13**: 396–410.

Rew LJ, Alston CL, Harden S and Felton WL. 2000**.** Counts versus categories: Choosing the more appropriate weed scoring method. *Australian Journal of Experimental Agriculture* **40**: 1121–1129.

Shannon CE. 1948. The mathematical theory of communication. *The Bell System Technical Journal* **27**: 379–423 and 623–656.

Simpson EH. 1949. Measurement of diversity. Nature **163**: 688.

Soro S, Silué N, Ouattara GM, Chérif M, Camara B, Sorho F, Abo K, Koné M, Kouadio YJ and Koné D. 2017. Suivi effcient du verger anacardier à travers la veille sanitaire en Côte d'Ivoire. État sanitaire du verger anacardier ivoirien. *Colloque International d'Échanges Scientifques sur l'Anacarde* **2017**: 137–142.

Tano EJ, Kouadio YP, Gnonhouy GP and N'guessan KE. 2016. Inventaire floristique et effet de la densité de culture sur l'enherbement en bananeraie de type plantain (*Musa paradisiaca* L.) dans deux zones de production (Azaguié-abbè, région de l'Agnéby-tiassa et Éboissué, region de l'Indenié-djuablin) de la Côte d'Ivoire. *Agronomie africaine* **28**(3): 53–67.

Touré A, Adou LM, Kouamé FK and Ipou IJ. 2016. Dynamique d'infestation de la forêt classée de Sanaimbo par les mauvaises herbes à partir des agroécosystèmes environnants. *Tropicultura* **34**(4): 361–374.

Touré A. 2014. *Gestion agronomique et dynamique des mauvaises herbes dans les systèmes de riz de bas fond en Afrique de l'Ouest*, Université d'Abomey-Calavi, Bénin, 180 p.

Traoré K, Ouattara K, Sylla M and Coulibaly S. 2019**.** Dynamique des Mauvaises herbes dans la Culture de Canne À Sucre : Cas de l'Unité Agricole Intégrée de Zuénoula (Centre-Ouest de la Côte d'Ivoire). *European Scientific Journal* **15**(21): 1857–7881

Traoré K, Soro D, Péné CB and Aké S. 2010. Flore adventice sous palmeraie, dans la zone de savane incluse a dabou, basse Côte d'Ivoire. *Agronomie Africaine* **22**(1): 21–32

Trochain JL. 1957. Accord interafricain sur la définition des types de végétation de l'Afrique Tropicale. *Bulletin Institut Études Centrafricaines. Nouv. Sér.* **13**/**14**: 55–93.

Viana FMP, Cardoso JE and Suraiva HAO. 2007. First report of a bacterial leaf and fruit spot of cashew nut (*Anacardium occidentale* L.) caused by *Xanthomonas campestris* pv. *Mangiferae indicae* in Brazil. *The American Phytopatholo gical Society.* https://doi.org/10.1094/PDIS- 91-10-1361C.

Yedmel MSC. 2014. *Effets à long terme du feu en interaction avec les modalités sylvicoles dans le dispositif permanent de la forêt classée de la Téné (Côte d'Ivoire),* Université Félix Houphouët-Boigny, 152 p.

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RESEARCH ARTICLE

Tractor-drawn weeder to manage weeds in garlic grown on raised beds

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ABSTRACT

Currently, manual weeding is done in garlic, with hand tools like *Khurpi* or hand pulling which is a cumbersome operation. The cost of weeding by manual method alone accounts for more than one-fourth of the total cultivation cost in garlic. Tractor drawn mechanical weeding helps reduce time consumption and drudgery of manual weeding in non-herbicidal growing systems. A soil bin study with laboratory model weeder was carried out to investigate the effect of number of tines (soil working tool), depth of operation and forward speed of simulated weeds on weed control factor (WCF). The experimental study showed that the number of tines, depth of operation and forward speed significantly affected the WCF and it increased with an increase of all the three parameters. Three tines operated at 75 mm depth at 3 km/h speed gave the maximum value of WCF. Depth of operation of tine was the predominant factor influencing the WCF. Based on the soil bin investigation, tractor-drawn weeder was developed with multiple flexible round tines that vibrate perpendicular to the tractor direction to remove weeds from the soil. Developed weeder was evaluated for managing weeds in garlic crop grown on raised beds. The effective field capacity and field efficiency were observed as 0.18 ha/h and 76.62%, respectively, at forward speed of 2 km/h. The plant damage and weeding efficiency was observed as 1.61 and 68.64%, respectively. The cost saving due to usage of the developed weeder, in comparison with the existing manual weeding, was 51.3%. The machine has potential for adoption by farmers growing garlic on raised beds.

Keywords: Cost saving, Garlic, Narrow crop weeder, Raised beds, Weed control factor, Weed management

INTRODUCTION

In India, garlic (*Allium sativum*) is cultivated in an area of about 0.39 million hectares, with a production capacity of 31.9 lakh metric tons and a productivity of 8.1 t/ha (Indiastat 2022**)**. India is the second largest producer of garlic with 12% of global area. However, the garlic productivity in India is lowest in world. One of the major reasons of low productivity of garlic is weeds competition with garlic crop for different resources like sunlight, water soil nutrients etc. The garlic bulb yield loss due to weeds was estimated as 30-60% (Lawande *et al.* 2009). The common non-herbicide method of weed management used in garlic cultivation is manual weeding by hand pulling or using hand tools like *Khurpi*. Manual weeding generally requires about 50 to 60 man-days/ha. Moreover, manual weed control is the most laborious and tedious operations in garlic production. The non-availability of labour is high during peak time and labour scarcity due to industrialization delays the weeding operation in garlic crop resulting in reduced garlic bulb yield. Thus, farmers mostly prefer herbicides usage for weed management. Currently, government is encouraging organic cultivation in view of its benefit to human health, other organisms and non-target plants (Damalas and Koutroubas 2016). Mechanical inter-row weeding is the best option for weed management in organic food production systems (Pullen 1997).

Numerous active and passive mechanical weeders were developed, with manual, animal-drawn, tractor-drawn and self-propelled as power source, to control weed in wider row crops. These weeders could not be adopted in narrow row adopting crops like garlic, onion as it causes huge crop damage. In low-density crops, mechanical devices such as cultivators, finger-weeders, brush weeders, and torsion weeders are utilised, while spring-tine weeders are used mostly in narrow-row high-density crops (Peruzzi *et al.* 2017). Several researchers have developed ergonomically designed inter-row as well as intra-row weeders (Chethan and Krishnan 2017, Chethan *et al.* 2018, Kumar *et al.* 2019, Kumar *et al.* 2020, Tewari and Chethan 2018). There is a need for controlled and precision weeding tools which effectively control weeds while avoiding crop damage in garlic. Currently, raised bed cultivation is getting popular among the garlic

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growing farmers. Mechanization of weeding in garlic with modern appropriate technology is one of the essential tools to overcome the labour shortage for weed management and increase garlic productivity and farmer's income. This problem was addressed by development of tractor-drawn weeder for garlic grown on raised beds.

MATERIALS AND METHODS

The present study was undertaken to develop technically feasible and economical viable tractor-drawn garlic weeder with the help of optimized value in soil bin using laboratory model weeder. The fabrication and evaluation of the developed weeder was done at ICAR-Central Institute of Agricultural Engineering, Bhopal, Madhya Pradesh (MP).

Soil bin study for development of weeder

In the experimental study, the spring tine was used for mechanically uprooting the simulated weeds. A spring tine unit, made of 5 mm diameter stainless steel was attached on the rectangular main frame. The main frame was mounted on tool carriage of soil bin through free linked chain. The spring tines has vertical and angled segment of 200 and 100 mm respectively and the rake angle was 30°. The spring factor of the selected spring tine was 320 N/m. The experimental setup for soil bin study of garlic weeder is shown in **Figure 1**.

The soil bin consists of a stationary bin, tool carriage, soil processing trolley, load cell fixture and power transmission system. The soil bin was 16 m long, 2.5 m wide and 1.0 m deep. The bin was filled with vertisols soil up to a depth of 0.8 m. The clay, silt and sand content were 44, 34 and 24%. Before each experiment, water was sprayed for soil preparation and the soil was carefully prepared using soil processing unit (roto-tiller) and it is levelled by soil leveler. To achieve the resemblance of soil condition in actual field, uniform pressure is applied using the hydraulic roller attached in soil bin. The moisture content of soil during the tests was maintained in the range of 15-18% (db) (Yadav *et al.* 2005). The cone index and bulk density were maintained as 473.5±36.5 kPa and 1.47±0.01 kg/cm^3, respectively, for the study. It was tilled, levelled and compacted to achieve desired soil properties for each test run. The forward speed of the weeder was varied through the control panel, variable speed drive and linear distance sensor of the soil bin instrumentation system. The desired speed was set with the help of a speed control switch, which was calibrated with the frequency and displayed on the control panel.

Experimental procedure

Experiment was conducted in the soil bin of soil tillage laboratory to investigate the effect of number of tines (working tool), depth of operation and forward speed on weed control factor (WCF). WCF indicated the disturbance of simulated weeds due to the passes of tines. Wooden sticks were used to simulate the weed plants for the laboratory experiments because they are consistent, uniform and resemble the weed stems. They can be easily penetrated into the soil and their depth was easily adjusted. Wooden sticks were inserted into the soil to a depth of 50 mm in a row perpendicular to the direction of travel of the tine at a spacing of 12.5 mm between sticks for all selected level of treatment. Description of WCF with respect to position of wooden sticks as suggested by Jiken and Bin (2016) is given in **Table 1**. It was calculated by using following formula (Equation 1).

Table 1. Description of WCF with respect to position of wooden sticks

WCF	Description
90	The simulated weeds were removed fully out of the soil
60	The simulated weeds were dragged from its original position and angled
30	The simulated weeds were dragged from its original position but was still horizontally straight
10	The simulated weeds were on their original position but angled
0	No change in original position of sticks

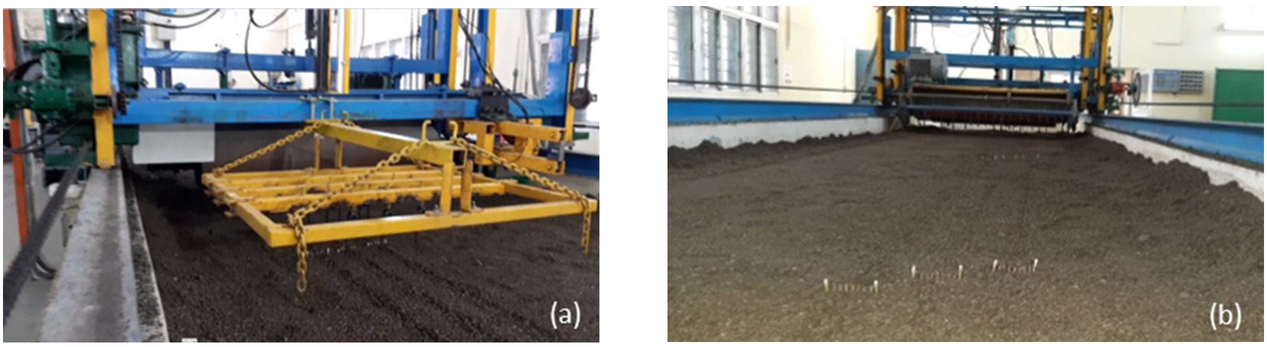

Figure 1. Experimental setup for soil bin study of garlic weeder (a) laboratory model weeder (b) soil bin

Table 2. Experimental parameters for the perfomance of spring tine in soil bin

Parameters		Level 1	Level 2	Level 3
Actual	Coded	(-1)	(0)	(+1)
Independent parameter				
Tine row numbers, no.	X_1	1	2	3
Forward speed, km/h	X_2	1	2	3
Depth of operation, mm	X_3	25	50	75
Dependent parameter				
Weed control factor (WCF)				

$$WCF = \frac{Sum\ of\ WCF\ of\ all\ the\ wood\ sticks}{Number\ of\ sticks} \quad (1)$$

Experimental parameters selected for the performance of spring tine in soil bin are given in **Table 2**. The experiment was designed as per face-centered central composite design (FCCCD) and was subjected to response surface methodology (RSM) (Myers 2002). RSM was also used by other researchers to optimize the operational parameters of the machine in the soil bin as well as in the field (Jat *et al.* 2020, Jat *et al.* 2022). Design expert software (Version 7.1.6. Stat-Ease, Inc., MN, USA) was used for the design of experiments. A total 20 runs were carried out with three replicates.

Second order polynomial regression model was developed for WCF in terms of the coded value of number of tines, depth of operation and forward speed. The adequacy of the models was tested using F-value, p-value and coefficient of determination (R^2). The second order polynomial model is given in Equation 2:

$$Y_i = \beta + \Sigma\beta_i X_i + \Sigma\beta_{ii} X_i^2 + \beta_{i\hat{j}} X_i X_{\hat{j}} \quad (2)$$

Where,

Y_i is the predicted response (*i.e.* Weed Control Factor), X_i, X_j are input variables (*i.e.* number of tine, depth of operation and forward speed); β_0 is the offset term; β_i is the linear coefficient; β_{ii} the i^{th} quadratic coefficient and $\beta_{i\hat{j}}$ is the $\hat{j}^{th}$ interaction coefficient (Myers *et al.* 2002).

Development of tractor-drawn garlic weeder

A tractor-drawn seven row weeder was developed for weeding in garlic crop grown on raised beds. The schematic diagram of the developed garlic weeder was shown in **Figure 2**. The technical specification of developed tractor-drawn garlic weeder was given in **Table 3**. The overall dimensions of machine were 1650×1430×1130 mm. It consists of main frame, tine frame, depth control wheel, link chain, spring tine and three-point hitching system. Main frame was made of mild steel square box of 50×50×5 mm size. Main frame was in T shape made by welding square box of 1500 mm length with square box of 1200 mm length. The developed weeder had passive type spring tines. The movement of spring tines strikes the weeds to uproot them from the soil. Spring tine was made of stainless-steel round bar of 5 mm diameter, 300 mm length and it had rake angle of 45° from the vertical plane in the direction of travel. The upper vertical segment and angled segment of spring tines was 200 mm and 100 mm. Each tine was mounted on perpendicular mounting bar member, adjustment was provided to move tine laterally in the members. The mounting bar members are increased or decreased to alter the intensity of weeding of the tines frame with the help of nuts and bolts. Tine frame was in rectangular shape made by welding two square boxes of 1200 mm length with two square boxes of 990 mm length.

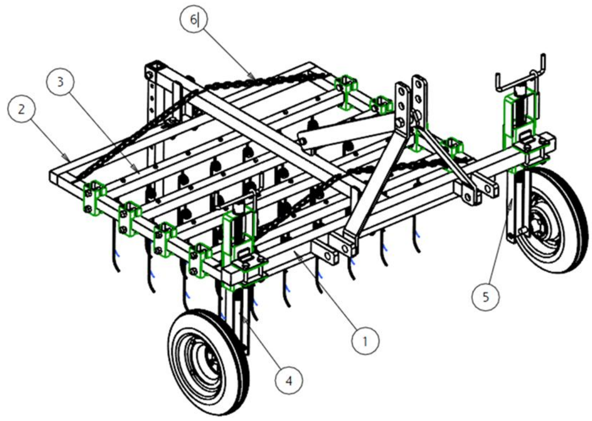

Figure 2. Drawing of garlic weeder for raised beds. (1) Main frame (2) tine frame (3) members (4) spring tine (5) depth control wheel and (6) link chain

Table 3. Technical specification of developed garlic weeder

Particulars	Specifications
Dimensions of weeder (L×W×T) (mm)	1650 × 1430 × 1130
Type of tine	Spring type, Ø 5 mm
Number of tines	28 (4 for each row for 150 mm R×R spacing) 30 (3 for each row for 100 mm R×R spacing)
Number of rows	7 and 10
Row spacing (mm)	100 and 150
Effective width of operation	1.1±0.1 m (excluding 0.3 m furrow width)
Provision for depth control	Two depth control wheels (Ø 400 mm)
Soil type	Black cotton soil
Soil moisture content	21±2.3% (dry basis)
Depth of operation	75 mm
Forward speed	1.0-3.0 km/h
Power source	Tractor (30 hp or above)

Field experiments

The developed weeder was evaluated in Vertisol soil in raised bed planted garlic at the ICAR-Central

Institute of Agricultural Engineering, Bhopal (23°182 36.693 N, 77°242 17.683 E). The weeder was evaluated with three different forward speeds, *viz.* 1, 2, 3 km/h with three tines at constant depth of operation of 75 mm. The experiment consisted of a randomized block design with nine replications. The performance of developed weeder was evaluated in the garlic sown on broad beds of 150 mm height and 1200 mm top width with 300 mm furrow width to the length of 20 m. The moisture content of the soil was 21±2.3% (dry basis) during operation. Machine performance parameters such as effective field capacity, field efficiency and weeding efficiency were measured. The speed of operation was measured by recording the time required to cover 10 m length of the experimental plot. Effective field capacity was calculated by dividing the actual area coverage during weeding by the total time taken to cover the area. Field efficiency was calculated by dividing the effective field capacity by the theoretical field capacity, and expressed in percentage. The weeding efficiency and plant damage were calculated based on the equations below (Chethan and Krishnan 2017).

Weeding efficiency was calculated by following formula (Equation 3)

$$\rho, \% = \frac{W1 - W2}{W1} \times 100 \quad (3)$$

Where,

W_1 – number of weeds before operation

W_2 – number of weeds after operation

The plant damage was calculated as follows (Equation 4):

$$Plant\ damage\ (PD), \% = \frac{P - Q}{P} \times 100 \quad (4)$$

Where,

P – number of plants in a 10 m crop row length before weeding

Q – number of plants in a 10 m crop row length after weeding

Cost of operation

The total cost of operation of garlic weeder was determined based on fixed cost and variable cost following the test code IS: 1964–1979 (Indian Standard 1979). The cost of operation of garlic weeder was compared with manual operation of weeding. The cost involved in the manual operation was calculated by considering man-hour required per hectare for weeding in garlic.

RESULTS AND DISCUSSION

Soil bin study

The analysis of variance (ANOVA) showed the significant effect of number of tines, forward speed and depth of operation on WCF (**Table 4**). The interaction effect of forward speed and depth of operation was also found to be significant. The model for WCF in coded terms was developed using the values of significant coefficients as follows (Equation 5):

$$WCF = 22.29+1.63A+3.34B+10.56C+1.83BC \quad (5)$$

The statistical significance of equation was evaluated via ANOVA. The F-value of 29.9 indicated that the model was highly significant (p<0.01). For the fitted model, the coefficient of determination was recorded as 0.96, which indicated the goodness of the model. The lack of fit was also not significant, which indicated the fitness of the model. The results of performance of laboratory model weeder in soil bin

Table 4. ANOVA for the response surface quadratic model of weed control factor

Source	Sum of squares	df	Mean square	F value	p-value	Test result
Model	1320.8	9	146.8	29.9	< 0.0001	S
A-Number of tines	26.6	1	26.6	5.4	0.0423	S
B-Forward speed	111.6	1	111.6	22.7	0.0008	S
C-Depth of operation	1115.1	1	1115.1	227.3	< 0.0001	S
AB	3.9	1	3.9	0.8	0.3924	NS
AC	18.6	1	18.6	3.8	0.0801	NS
BC	26.7	1	26.7	5.4	0.042	S
A^2	2.7	1	2.7	0.6	0.4753	NS
B^2	8.3	1	8.3	1.7	0.2217	NS
C^2	12.8	1	12.8	2.6	0.1371	NS
Residual	49.1	10	4.9			
Lack of fit	28.7	5	5.7	1.4	0.3579	NS
Pure error	20.37	5	4.1			
Corrected total	1369.8	19				
R^2						0.96

S: significant, NS: not significant, R^2: Coefficient of determination, df: degrees of freedom, is given in **Table 5**. Three numbers of tines operated at 75 mm depth at 3 km/h speed gave the maximum value of WCF.

Effect of forward speed and depth of operation on WCF

The effect of forward speed and depth of operation on WCF was presented in **Figure 3** as response surface graph. It was observed that, the WCF increased with increase in depth of operation and forward speed. Larger depth of operation yielded higher WCF values due to increase in soil depth increases penetration that removes the soil in excess amount. Hence, the width of soil failure increases in the direction perpendicular to the tine travel. Increase in forward speed increased the WCF of simulated weed. This is due to the tine move faster through the soil increased the acceleration of soil in front of the tine as observed by Zeng *et al.* (2020) and Gilandeh *et al.* (2020). It increases soil throw and soil disturbance on the soil surface and removes the simulated weeds. The effects of forward speed were found to be smaller than the effect of depth of operation on WCF as observed by Rahman *et al.* (2005) and Sahu and Raheman (2006). The maximum value of WCF observed with the combination of depth of operation 75 mm and forward speed of 3 km/h and minimum was with the combination of depth of operation 25 mm and forward speed 1 km/h.

Effect of no. of tines and forward speed on WCF

The mean WCF values were plotted against number of tines and forward speed in **Figure 4**. The increase in forward speed and number of tines increased the WCF values. Increasing forward speed has significant effect on soil disturbance. This was confirmed by many researchers (Hasimu and Chen 2014, Shinde *et al.* 2011). The number of tines had less effort at WCF compared to forward speed. This may be due to the tine arranged one behind another had less influence on soil disturbance and soil failure.

Table 5. Results of performance of laboratory model weeder in soil bin

Trials	Number of tines (Nos)	Forward speed (Km/h)	Depth of operation (mm)	Weed control factor (WCF)
1	3	1	25	12.2
2	2	2	50	20.0
3	2	2	50	20.0
4	2	2	50	24.4
5	2	2	50	23.3
6	1	1	75	24.4
7	3	1	75	33.3
8	1	3	75	35.6
9	1	2	50	24.4
10	2	2	25	11.1
11	2	2	50	24.4
12	2	2	75	28.9
13	1	3	25	13.3
14	2	3	50	27.8
15	3	2	50	21.9
16	3	3	75	42.2
17	1	1	25	8.9
18	3	3	25	13.3
19	2	2	50	22.2
20	2	1	50	20.0

The first tine sets creating more soil disturbance and WCF on simulated weeds than the other tine sets. The maximum values of WCF observed at combination of forward speed of 3 km/h and three numbers of tines set and minimum was at combination of single number of tines set and forward speed of 1 km/h.

Effect of depth of operation and no. of tines on WCF

The effect of depth of operation and number of tines on WCF is presented in **Figure 5** as response surface graph. The WCF of the simulated weeds increased with the higher values of depth of operations and number of tines. This pattern was expected as deeper depth of operations affects wider widths of soil. The increasing pattern of the WCF was also significant for depth of operation. The highest value of WCF was achieved at combination level of three numbers of tine set and depth of operation of 75 mm and the lowest value was obtained at single numbers of tine set and depth of operation of 25 mm.

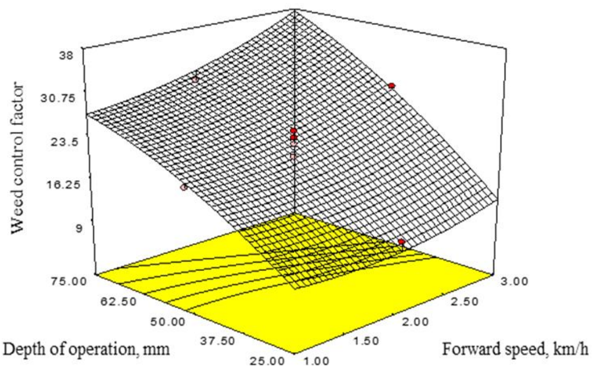

Figure 3. Response surface graph of effect of forward speed and depth of operation on WCF

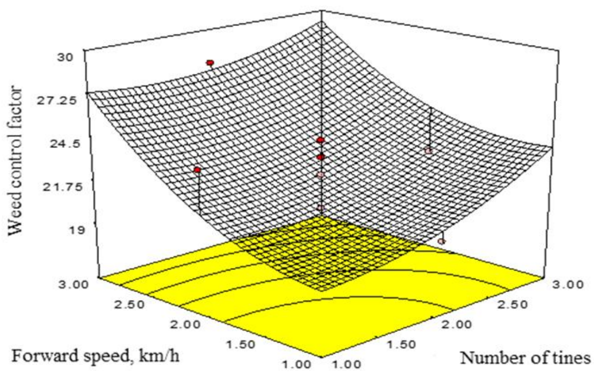

Figure 4. Response surface graph of effect of number of tines and forward speed on WCF

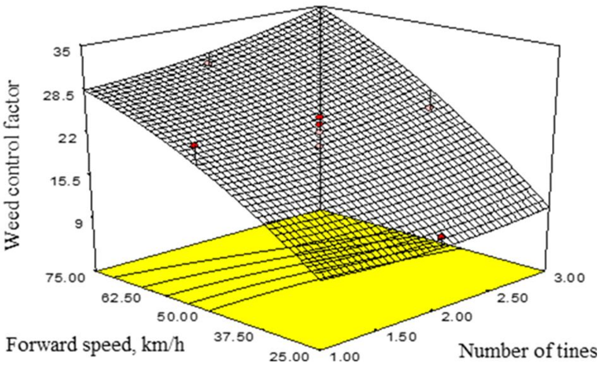

Figure 5. Response surface graph of effect of number of tines and depth of operation on WCF

Performance evaluation of garlic weeder in field

The performance evaluation of developed garlic weeder was done by operating it at a constant depth of operation of 75 mm (**Figure 6**). The weeding efficiency and plant damage increases with increase in forward speed. The weeding efficiency at 1, 2 and 3 km/h of forward speed was 63.42, 68.64 and 73.44% while the plant damages were observed at 0.74, 1.61 and 4.63% respectively (**Table 6**). The effective field capacity had significant difference

Figure 6. Garlic weeder during the operation in the garlic field

Table 6. Result of performance evaluation of garlic weeder in field

Forward speed (km/h)	Effective field capacity (ha/h)	Field efficiency (%)	Plant damage (%)	Weeding efficiency (%)
1	0.09[c]	75.65[a]	0.74[c]	63.42[c]
2	0.18[b]	76.62[a]	1.61[b]	68.64[b]
3	0.26[a]	73.44[b]	4.63[a]	73.44[a]

[a,b,c] means within the column followed by same letter has no significant difference ($p<0.05$)

Table 7. Cost analysis of operation of garlic weeder

Parameters		Tractor	Garlic weeder
(A) Fixed cost			
i.	Initial cost of tractor, `	450000	16000
ii.	Salvage value 10% of initial cost, `	45000	1600
iii.	Service life, years	15	10
iv.	Depreciation {(i-ii)/iii}, `/year	27000	1440
v.	Annual uses, h/year	1000	250
vi.	Interest on investment 8.8% per annum, `/year	39600	1408
vii.	Effective field capacity of machine, ha/h	-	0.18
viii.	Insurance, taxes and housing		
	2% of initial cost per annum, `/year	9000	320
ix.	Total fixed cost (iv+vi+viii), `/year	75600	3168
x.	Fixed cost of operation, `/h	75.6	12.7
xi.	Total fixed cost of operation, `/h	88.3	
(B) Variable cost			
i.	Repair and maintenance cost, `/h	22.5	3.2
ii.	Fuel required, l/h	3	-
iii.	Fuel cost ` 70/l, `/h	210	-
iv.	Cost of lubricant 20% of fuel cost, `/h	28	-
v.	Labour required with machine 8 h/day, no.	1	1
vi.	Labour cost (`/h) Rs. 50/h for skilled and ` 40/h for unskilled labour	50	40
vii.	Variable cost (i+iii+iv+vi), `/h	324.5	43.2
viii.	Total variable cost, `/h	367.7	
(C) Cost of operation			
i.	Total cost of operation (fixed cost + variable cost), `/h	456	
ii.	Effective field capacity of machine, `/h	0.18	
iii.	Cost of operation, `/ha		
	a) Cost of machine operation at 76.6% weeding efficiency	2533.3	
	b) Cost of manual operation for remaining 23.4% weeding (Considering cost of ` 10000/ha as given in D, ii)	2340	
	Total cost of operation for 100 % weeding	4873.3	
(D) Labour cost in manual weeding			
i.	Labour required, man-h/ha	250	
ii.	Cost of operation ` 40 per h for unskilled labour, `/ha	10000	
(E)	Saving in cost, %	51.3	

between forward speed of weeder and it increased with increase in the forward speed of the machine. It was observed that the average effective field capacity was 0.09, 0.18 and 0.26 ha/h at forward speed of 1, 2 and 3 km/h respectively. There was no significant effect observed at 1 and 2 km/h forward speed but 3 km/h had significant difference in field efficiency. The forward speed of 2 km/h had the highest field efficiency of 76.62% followed by 1 km/h of 75.65% and 3 km/h of 73.44% respectively.

Cost analysis

The cost analysis of tractor-drawn garlic weeder and manual operation is given in **Table 7**. The results showed that the fixed and variable costs of garlic weeder were ₹ 88.3 and ₹ 367.7/hour respectively which gave the total cost of operation as ₹ 456/hour. The operating cost of garlic weeder (₹ 3507.7/ha) was less as compared to manual weeding (₹ 8000/ha). A 51% saving in cost was observed with garlic weeder compared to manual operation.

Manual weed management in garlic is tedious and laborious work due to the frequent requirement of weeding. This problem could be addressed with the help of developed weeder. The lesser plant damage of 1.61% and its weeding efficiency of 68.64% were found best for weeding in raised bed condition. The field efficiency and effective field capacity at 2 km/h were 76.62% and 0.18 ha/h respectively. Also, 51.3% cost of weeding can be saved as compared to the traditional method of weeding. Thus, this study proved the potential of developed tractor-drawn weeder to complete the mechanization of weeding operation in raised bed narrow row spaced cultivation of garlic and onion.

REFERENCES

Chethan CR, Chander S and Kumar SP. 2018. Dynamic strength-based dryland weeders – Ergonomic and performance Evaluation. *Indian Journal of Weed Science* **50**(4): 382–387.

Chethan CR. and Krishnan DA. 2017. Dynamic push–pull strength data generation for agricultural workers to develop manual dryland weeders. *Current Science* **113**(8): 1601–1605.

Damalas C A. and Koutroubas SD. 2016. Farmers' exposure to pesticides: toxicity types and ways of prevention. *Toxics* **4**(1): 1. https://doi.org/10.3390/toxics4010001

Gilandeh YA, Fazeli M, Roshanianfard A, Hernández-Hernández JL, Fuentes Penna A and Herrera-Miranda I. 2020. Effect of different working and tool parameters on performance of several types of cultivators. *Agriculture* **10**(5): 145.

Hasimu A and Chen Y. 2014. Soil disturbance and draft force of selected seed openers. *Soil and Tillage Research* **140**: 48–54.

Indian Standard. 1979. Guide line for estimating cost of farm machinery operation, IS: 1964–1979. Bureau of Indian Standards, New Delhi, India.

Indiastat. 2022. Available from: https://www.indiastat.com/data/agriculture/garlic/data-year/all-years

Jat D, Chandel NS, Gurjar B and Jha A. 2020. Performance of pneumatic loader for loose straw handling on a farm yard. *Range Management and Agroforestry* **41**(1): 116–125.

Jat D, Singh KP and Mathur R. 2022. Optimization of tine spacing of seed drill for dual banding of fertilizer. *Journal of Scientific & Industrial Research* ***81***(10): 1073–1086.

Jiken JJ. 2016. *Experimental approach to determine the efficacy of a tine mechanism for auto weeding machine*. MSc thesis, Iowa State University, USA.

Kumar SP, Tewari VK, Chandel AK, Mehta CR, Nare B, Chethan CR, Mundhada K, Shrivastava P, Gupta C and Hota S. 2020. A fuzzy logic algorithm derived mechatronic concept prototype for crop damage avoidance during eco-friendly eradication of intra-row weeds. *Artificial intelligence in Agriculture* **4**: 116–126.

Kumar SP, Tewari VK, Chethan CR, Mehta CR, Nare B and Chandel AK. 2019. Development of non-powered self-propelling vertical axis inter row rotary weeder. *Indian Journal of Weed Science* **51**(3): 284–289.

Lawande KE, Khar A, Mahajan V, Srinivas P S, Sankar V and Singh RP. 2009. Onion and garlic research in India. *Journal of Horticultural Sciences* **4**(2): 91–119.

Myers RH, Montgomery DC and Anderson-Cook CM. 2002. *Response Surface Methodology*. Wiley, New York. USA.

Pullen DWM and Cowell PA. 1997. An evaluation of the performance of mechanical weeding mechanisms for use in high-speed inter-row weeding of arable crops. *Journal of Agricultural Engineering Research* **67**: 27–34.

Rahman S, Chen Y and Lobb D. 2005. Soil Movement resulting from Sweep Type Liquid Manure Injection Tools. *Biosystems Engineering* **91**(3): 379–392.

Sahu R and Raheman H. 2006. Draught Prediction of Agricultural Implements using reference Tillage Tools in Sandy Clay Loam Soil. *Biosystems Engineering* **88**(2): 275–284.

Shinde GU, Badgujar PD and Kajale SR. 2011. Experimental Analysis of Tillage Tool Shovel Geometry on Soil Disruption by Speed and depth of operation, IACSIT Press, Singapore: 65–70.

Tewari VK and Chethan CR. 2018. Mechanization in weed management: Global review. In: *Fifty Years of Weed Research in India* (Eds. Sushilkumar and Mishra JS). Indian Society of Weed Science, India, 215–237.

Yadav SN, Pandey MM and Saraswat DC. 2005. Effect of gang width and operating speed on specific draft and weeding efficiency of weeding sweep in vertisols. *Journal of Agricultural Engineering* **42**(3): 20–28.

Zeng Z, Martin A, Chen Y and Ma X. 2021. Weeding performance of a spring-tine harrow as affected by timing and operational parameters. *Weed Science* **69**: 247–256.

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RESEARCH ARTICLE

Effect of post-emergence herbicides on economic weed management and turfgrass quality characteristics of Bermuda grass Selection No. 1

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ABSTRACT

A field experiment was conducted to test the efficacy of different weed control treatments on control of turfgrass weeds in the established lawn of Bermuda grass 'Selection No. 1' at Punjab Agricultural University, Ludhiana during winter and summer seasons of 2021. The experiment was laid out in a randomized complete block design with 15 treatments *i.e.*, post-emergence application (PoE) of isoproturon 0.937 kg/ha, mesosulfuron + iodosulfuron 0.014 kg/ha, clodinafop + metribuzin 0.216 kg/ha, 2,4-D amine 0.50 kg/ha, bispyribac-sodium 0.025 kg/ha, metribuzin 0.120 kg/ha, metsulfuron 0.005 kg/ha, carfentrazone-ethyl 0.020 kg/ha, metsulfuron + carfentrazone-ethyl 0.025 kg/ha, metsulfuron-methyl + chlorimuron-ethyl 0.004 kg/ha, ethoxysulfuron 0.018 kg/ha, halosulfuron 0.050 kg/ha, atrazine 1.0 kg/ha, hand weeding twice at 15 days interval and weedy check. The PoE of isoproturon 0.937 kg/ha, mesosulfuron + iodosulfuron 0.014 kg/ha, clodinafop + metribuzin 0.216 kg/ha, bispyribac-sodium 0.025 kg/ha, metribuzin 0.120 kg/ha and ethoxysulfuron 0.018 kg/ha provided complete control of *Poa annua*, a winter season weed, which was at par with hand weeding twice, whereas, in summer season, clodinafop + metribuzin 0.216 kg/ha PoE reduced the density and biomass of *Digitaria sanguinalis* and *Dactyloctenium aegyptium*. Bispyribac-sodium 0.025 kg/ha was found effective against *Dicanthium annulatum*. Metsulfuron + carfentrazone-ethyl 0.025 kg/ha PoE provided complete control of broad-leaved weeds, *viz. Gnaphalium purpureum*, *Oxalis corniculata*, *Desmodium triflorum*, *Coronopus didymus* in winter season and *Boerhavia diffusa* and *Alysicarpus vaginalis* in summer season. Halosulfuron 0.050 kg/ha PoE effectively controlled *Cyperus rotundus* upto 45 days after spray (DAS) during winter season. Metsulfuron + carfentrazone-ethyl 0.025 kg/ha PoE recorded highest weed control efficiency (WCE) (72.9 %) during winter, whereas in summer clodinafop + metribuzin 0.216 kg/ha PoE recorded highest WCE. Sward height and dry biomass of turfgrass were found negatively correlated with the weed biomass in both of seasons. Phyto-toxicity was observed with clodinafop + metribuzin (0.216 kg/ha) PoE, however, the grass recovered after 35 DAS in winter season.

Keywords: Economics, Herbicides, Turfgrass, Weed management

INTRODUCTION

A lawn is an indispensable feature of a residential landscape with a considerably greater proportion of space relative to other garden features. A weed free lawn is valued for providing aesthetic and functional utility in a residential, institutional, public and several other amenity area. In India, the turfgrass industry is being regarded as a consolidated sector of ornamental horticulture, spanning more than 30,000 acres under different turf grasses at recreational facilities, residential colonies and sports grounds.

Bermuda grass [*Cynodon dactylon* (L.) Pers.] is the most widely planted amenity turfgrass appreciated for its several desirable traits, *viz.* drought resistance, trespassing tolerance, disease resistance and relatively better recuperative potential (Zhang *et al.* 2017). Lawns are generally mowed and maintained at short height (not more than 3-5 cm) to encourage dense growth of lateral stolons to form a lush green mat, that offers several recreational (adds aesthetics to a landscape and provide comfortable sitting) and ecological services (reduces rainwater runoff, prevents soil erosion, regulates temperature, sequesters carbon and trap particulate matter). However, it has become a common observation to sight weed encroachment in the improved strain (Selection No.1) of Bermuda grass, that considerably affects the aesthetics of lawn (Siddappa *et al.* 2016). Infestation of weeds in turfgrass not only competes for moisture, nutrients, sunlight and space but also harbor several insects and fungal pathogens rendering it unsuitable for active or passive recreation (Busey

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2003). It has also been observed that altering certain agronomic practices to reduce the competitiveness of one weed may cause other weed species to resurge or may exhibit a shift in weed flora due to periodic application of pre-emergence and post-emergence herbicide application (Ramachandra *et al.* 2014).

The weed management in lawn is being undertaken following physical or mechanical removal of weeds, spray of herbicides and adopting an integrated seasonal approach for holistic control of weed growth. Although the mechanical ways to manage the weeds from lawn is generally advocated, but it is labor-intensive, incur higher costs, cause soil compaction due to repeated trampling and trespassing and often a times unpractical to rough out weeds in extensively planted lawns. It is a mandatory cultural practice to undertake hand weeding 2-3 times in a newly planted lawn for its rapid establishment to encourage dense growth and suppress the weed emergence (Siddappa *et al.* 2015a). Turfgrass landscapes rely on application of different post-emergence herbicides and is believed to be a practically feasible alternative especially in extensively planted areas (Doughlas *et al.* 2005). These herbicides gradually percolate in the soil by rain or irrigation and thereafter uptake by the roots and shoots of weeds. The residual activity of herbicides in soil depends upon the herbicidal group and rate of application (Sondhia 2014). Depending upon the mode of action, post-emergence herbicides may act as a direct contact herbicide or may get translocated through conducting tissues of weed plants through the xylem and phloem and finally reach the target site where these interfere with plant physio-chemical processes, ultimately causing their mortality and suppress the weed density. Therefore, it is pertinent to address the issue of weed infestation in turfgrass to ensure a healthy, lush green and weed-free lawn. Due to the omnipresent nature of the weeds, an integrated approach to weed control along with application of herbicides is necessary to curtail the spread of weeds and maintain the quality of turfgrass (Uddin *et al.* 2012). The objective of this study was to test the efficacy of different weed control treatments on turfgrass weeds and to assess their potential effects on turfgrass quality in the established lawn of Bermuda grass ‘Selection no. 1.

MATERIALS AND METHODS

The experiment was conducted at Punjab Agricultural University, Ludhiana over well-established lawn of Bermuda grass var. ‘Selection no. 1’. The experimental site was selected based on the representation of maximum diversity of weed species in both winter and summer season. The site geographically tagged at 30°56' N latitude, 75°52' E longitude is a representive of the Indo-gangetic alluvial plain at an altitude of 247 m above mean sea. The climate of experimental site was sub-tropical characterized by semi-arid climate with hot summers and severe winters receiving mean annual rainfall of 700 mm. The mean maximum temperature above 45° C is common during summer months (May-June) and during winter months (December-January) the temperature falls below 4° C occasionally. The experiment was laid out in randomized complete block design (RBD) with 15 treatments replicated thrice. The treatments comprised of post-emergence application (PoE) of isoproturon 0.937 kg/ha, mesosulfuron + iodosulfuron 0.014 kg/ha, clodinafop + metribuzin 0.216 kg/ha, 2,4-D amine 0.50 kg/ha, bispyribac-sodium 0.025 kg/ha, metribuzin 0.120 kg/ha , metsulfuron 0.005 kg/ha, carfentrazone-ethyl 0.020 kg/ha, metsulfuron + carfentrazone-ethyl 0.025 kg/ha, metsulfuron-methyl + chlorimuron-ethyl 0.004 kg/ha, ethoxysulfuron 0.018 kg/ha, halosulfuron 0.050 kg/ha, atrazine 1.0 kg/ha, hand weeding twice (at 15 days interval) and weedy check. The soil texture of the experimental site was sandy loam, slightly alkaline in soil reaction (pH 8.0) and lower electrical conductivity (0.20 m mhos cm^{-1}). The chemical analysis of soil recorded lower organic carbon (0.21%), medium in available phosphorus (16.25 kg/ha) and available potash (172.5 kg/ha). Lawn was mowed mechanically with a lawn mower (12 inches reel width) one month before application of different weed control treatments and later plots were irrigated at fifteen days interval. The PoE herbicides were applied on clear, sunny and calm day using knapsack sprayer attached with flat fan nozzle. As per the treatments, the required quantity of herbicide was applied by dissolving in 375 litres water/ha. Care was taken that the mowing height of grass was never kept shorter than 3.0 cm. Urea was applied as drench application at the rate 0.5 per cent at 30 days after the herbicide sprays.

Cynodon dactylon cultivar ‘Selection No. 1’, a fine strain of bermuda grass was subjected to undertake the different weed control treatments. Different weed control treatments and record of observations were made during 1 March 2021 till 30 April 2021 (for winter weed flora) and same set of treatments were repeated during 1 August 2021 till 30 September 2021 (for summer season weed flora). The observation on weed density were recorded at 15, 30 and 45 days after spray (DAS) and weed biomass was computed at 30 and 45 DAS. The qualitative turfgrass characteristics were visually assessed at 60 DAS of different herbicides. The species-wise weed density was recorded from two fixed spots in each of the treatments and was expressed as number/m^2 whereas, for weed dry biomass recorded from two random spots which was expressed as g/m^2. The weed control efficiency (WCE) of different weed control treatments was calculated to determine the percentage of weed reduction (Mani *et al.* 1976).

The sward of turfgrass was measured before mowing with a 30 cm graduated scale at 60 DAS. The scale was aligned vertical and height was measured from ground level to the tip of grass leaf blade and was expressed in cm. The colour of the turf regarded as a qualitative attribute was observed visually. The scores (1-9) were used to distinguish various hues of green colour according to the fifth edition of royal horticultural society colour chart (RHSCC). Numerical values 1-9 were coded representing different hues of green *viz*., yellow green-1, olive green-2, light green-3, gray green-4, luscious green-5, green-6, grassy green-7, dirty green-8, emerald-9. The mowed grass clippings from each of the treatment plots were sun dried for 2-3 days prior to oven drying at 55°C till the constant dry weight (expressed in g/m^2) was achieved. Visual phyto-toxicity rating was recorded at 3, 7, 10, 15 and 25 DAS of herbicidal treatments to know the extent of toxicity on bermuda grass turf. The phyto-toxicity rating was adjudged on 0 to 10 scale (Rao 1986). The phyto-toxicity rating on turfgrass was designated as 0 (no injury), 1 (slight stunting injury or discoloration), 2 (some stand loss, stunting or discoloration), 3 (injury more pronounced but not persistent), 4 (moderate injury, recovery possible), 5 (injury more persistent, recovery possible), 6 (near severe injury, no recovery possible), 7 (sever injury, stand loss), 8 (almost destroyed, a few plants surviving), 9 (very few plants alive), 10 (complete destruction).

The economics of different weed control treatments was calculated on the basis of prevalent market price. Cost of different PoE herbicides in Indian Rupee per hectare (INR/ha) for isoproturon = 1250, mesosulfuron + iodosulfuron = 1625, clodinafop + metribuzin = 1875, 2,4-D amine = 435, bispyribac-sodium = 1500, metribuzin = 360, metsulfuron-methyl = 300, carfentrazone-ethyl = 625, metsulfuron + carfentrazone-ethyl = 925, metsulfuron-methyl + chlorimuron-ethyl = 500 ethoxysulfuron = 1080, halosulfuron = 2240, atrazine = 720. Cost of hand weeding twice was ₹ 14720/ha (40 man-days) and cost of manpower for herbicide application was ₹ 368/ha. Square root transformation was used to transform the data for statistical inferences and improve the interpretability of the plotted graphs. All the recorded data were analyzed statistically using SPSS (IBM) statistical software Ver. 22.

RESULTS AND DISCUSSION

Winter season

The observed major weed flora, in the established bermuda turfgrass var. Selection No. 1, during winter season include *Poa annua* among grasses; *Gnaphalium purpureum*, *Oxalis corniculata*, *Desmodium triflorum*, *Coronopus didymus* among broad-leaved weeds and *Cyperus rotundus*, the sedge weed. The weed flora of well-established lawn comprises of 26.6, 60.5 and 12.7 per cent of grasses, broad-leaved weeds and sedges, respectively (**Table 1**).

Effect on weed density

The weed mortality indicates the comparative efficacy of a particular herbicide. The complete control of *Poa annua* was provided by PoE of isoproturon 0.937 kg/ha, mesosulfuron + iodosulfuron 0.014 kg/ha, clodinafop + metribuzin 0.216 kg/ha, bispyribac- sodium 0.025 kg/ha and metribuzin 0.120 kg/ha. One hand weeding at 15 DAS recorded significantly lower *P. annua* density than all other herbicide treatments and weedy check (**Table 1**). The *P. annua* density in atrazine 1.0 kg/ha was significantly lower than metsulfuron 0.005 kg/ha, carfentrazone-ethyl 0.020 kg/ha, metsulfuron + carfentrazone-ethyl 0.025 kg/ha and metsulfuron + chlorimuron-ethyl 0.004 kg/ha and weedy check which were statistically found at par with each other at 15, 30 and 45 DAS (**Table 1, 2, 3**). All the post-emergence herbicides except halosulfuron 0.050 kg/ha showed reduction in *G. purpureum* density whereas, isoproturon 0.937 kg/ha, metsulfuron 0.005 kg/ha, metsulfuron + carfentrazone-ethyl 0.025 kg/ha and atrazine 1.0 kg/ha provided complete control at 30 and 45 DAS which was observed at par with hand weeding done twice at 15 days interval. The density of *G. purpureum* in mesosulfuron + iodosulfuron 0.014 kg/ha, clodinafop + metribuzin 0.216 kg/ha, metribuzin 0.120 g/ha, carfentrazone-ethyl 0.020 kg/ha, metsulfuron + chlorimuron-ethyl 0.004 kg/ha and ethoxysulfuron 0.018 kg/ha was recorded significantly lesser than the weedy check and halosulfuron 0.050 kg/ha at 30 and 45 DAS during the winter season. Clodinafop + metribuzin 0.216 kg/ha, metribuzin 0.120 kg/ha and metsulfuron + carfentrazone-ethyl 0.025 kg/ha provided complete control of *Oxalis corniculata* at 30 DAS and the density was recorded at par with hand weeding done twice. McCurdy *et al.* (2013) also reported that metsulfuron controlled *Oxalis* spp. Mesosulfuron + iodosulfuron 0.014 kg/ha, 2,4-D 0.50 kg/ha, bispyribac-sodium 0.025 kg/ha and halosulfuron 0.050 kg/ha did not have any significant effect in checking the density of *O. corniculata* and was found at par with weedy check. All the PoE except bispyribac-sodium 0.025 kg/ha recorded significantly lesser *Desmodium triflorum* density than weedy check at 15 DAS whereas, *D. triflorum* density in metsulfuron + carfentrazone-ethyl 0.025 kg/ha was significantly lower than all other PoE and at par with hand weeding twice and had provided complete control at 30 and 45 DAS. Similar results were observed in control of *Coronopus didymus* where all the post-emergence herbicides except bispyribac-sodium 0.025 kg/ha was found effective to control *C. didymus* and had also recorded significantly lesser weed density than weedy check at 15, 30 and 45 DAS (**Table 1, 2, 3**). Herbicides clodinafop + metribuzin 0.216 kg/ha, metribuzin 0.120 kg/ha and metsulfuron + carfentrazone-ethyl 0.025 kg/ha were found very effective and provided complete control of *Coronopus didymus* and *Cyperus rotundus,* whereas their density was observed significantly lower in halosulfuron 0.050 kg/ha, ethoxysulfuron 0.018 kg/ha and 2,4-D 0.50 kg/ha as compared to all the other post-emergence herbicides and weedy check. Danilo *et al.* (2016) reported similar findings on efficacy of ethoxysulfuron in controlling the *Cyperus rotundus*. All post-emergence herbicides tested recorded best efficacy at 30 DAS against different weed flora and were found effective to curtail the

Table 1. Effect of post-emergence herbicides on weed density at 15 DAS in bermuda grass

Treatment	Dose (kg/ha)	Weed density (no./m^2)										
		Winter season						Summer season				
		Poa annua	*Gnaphalium purpureum*	*Oxalis corniculata*	*Desmodium triflorum*	*Coronopus didymus*	*Cyperus rotundus*	*Digitaria sanguinalis*	*Dichanthium annulatum*	*Dactyloctenium aegyptium*	*Boerhavia diffusa*	*Alysicarpus vaginalis*
Isoproturon	0.937	1.00^{a*} (0)	4.16^{b} (17)	7.13^{b} (50)	7.13^{bc} (50)	7.88^{e} (61)	8.23^{bc} (67)	8.25^{cd} (67)	8.25^{d} (67)	6.71^{bc} (44)	3.46^{b} (11)	7.55^{bc} (56)
Mesosulfuron + iodosulfuron	0.014	1.00^{a} (0)	4.81^{bc} (22)	9.69^{c} (94)	7.13^{bc} (50)	5.85^{bcd} (33)	7.88^{bc} (61)	8.89^{cd} (78)	6.71^{bc} (44)	6.71^{bc} (44)	3.46^{b} (11)	8.89^{c} (78)
Clodinafop + metribuzin	0.216	1.00^{a} (0)	4.16^{b} (17)	5.34^{ab} (28)	6.31^{bc} (39)	1.00^{a} (0)	6.75^{b} (44)	5.83^{b} (33)	5.83^{b} (33)	3.94^{ab} (15)	4.80^{c} (22)	8.25^{c} (67)
2,4-D amine	0.500	9.17^{b} (83)	5.34^{bc} (28)	9.46^{c} (89)	6.71^{bc} (44)	6.30^{cde} (39)	4.17^{a} (16.6)	8.25^{cd} (67)	9.49^{d} (89)	7.55^{c} (56)	3.46^{b} (11)	8.25^{c} (67)
Bispyribac-sodium	0.025	1.00^{a} (0)	5.34^{bc} (28)	9.69^{c} (94)	7.88^{cd} (61)	9.48^{f} (89)	8.15^{bc} (67)	9.49^{d} (89)	1.00^{a} (0)	5.2^{bc} (26)	4.80^{c} (22)	8.00^{c} (63)
Metribuzin	0.120	1.00^{a} (0)	4.16^{b} (17)	5.34^{ab} (28)	6.31^{bc} (39)	1.00^{a} (0)	7.52^{bc} (56)	7.55^{bc} (56)	8.25^{d} (67)	5.83^{bc} (33)	4.80^{c} (22)	8.25^{c} (67)
Metsulfuron	0.005	10.31^{c} (106)	4.16^{b} (17)	4.16^{a} (17)	6.74^{bc} (44)	3.47^{ab} (11)	7.88^{bc} (61)	8.25^{cd} (67)	8.89^{d} (78)	7.55^{c} (56)	3.46^{b} (11)	1.00^{a} (0)
Carfentrazone-ethyl	0.020	10.34^{c} (108)	4.16^{b} (17)	4.81^{ab} (22)	6.74^{bc} (44)	4.19^{abc} (17)	7.88^{bc} (61)	8.25^{cd} (67)	8.89^{d} (78)	6.71^{bc} (44)	3.46^{b} (11)	5.48^{ab} (29)
Metsulfuron + Carfentrazone-ethyl	0.025	10.31^{c} (106)	4.16^{b} (17)	4.16^{a} (17)	6.31^{bc} (39)	1.00^{a} (0)	8.86^{c} (78)	9.49^{d} (89)	8.89^{d} (78)	5.83^{bc} (33)	1.00^{a} (0)	1.00^{a} (0)
Metsulfuron-methyl + chlorimuron-ethyl	0.004	10.31^{c} (106)	4.16^{b} (17)	4.81^{ab} (22)	6.31^{bc} (39)	5.35^{bc} (28)	7.88^{bc} (61)	8.89^{cd} (78)	9.49^{d} (89)	7.55^{c} (56)	3.46^{b} (11)	4.79^{ab} (22)
Ethoxysulfuron	0.018	1.00^{a} (0)	4.81^{bc} (22)	10.57^{c} (111)	7.13^{bc} (50)	7.88^{e} (61)	1.00^{a} (0)	8.89^{cd} (78)	8.89^{d} (78)	7.55^{c} (56)	3.46^{b} (11)	7.55^{bc} (56)
Halosulfuron	0.050	8.22^{b} (67)	5.85^{c} (33)	9.69^{c} (94)	6.75^{bc} (44)	7.51^{de} (56)	1.00^{a} (0)	9.49^{d} (89)	8.89^{d} (78)	6.71^{bc} (44)	4.80^{c} (22)	8.25^{c} (67)
Atrazine	1.000	9.17^{b} (83)	4.81^{bc} (22)	7.13^{b} (50)	6.31^{bc} (39)	4.19^{abc} (17)	6.75^{b} (44)	8.89^{cd} (78)	8.25^{d} (67)	7.55^{c} (56)	4.80^{c} (22)	8.25^{c} (67)
Hand weeding twice (15 days interval)	-	1.00^{a} (0)	1.00^{a} (0)	1.00^{a} (0)	1.00^{a} (0)	1.00^{a} (0)	1.00^{a} (0)	1.00^{a} (0)	1.00^{a} (0)	1.00^{a} (0)	1.00^{a} (0)	1.00^{a} (0)
Un-weeded (control)	-	10.31^{c} (105)	5.85^{c} (33)	9.69^{c} (94)	8.82^{d} (78)	9.48^{f} (89)	8.21^{bc} (67)	9.49^{d} (89)	9.49^{d} (89)	7.55^{c} (56)	4.80^{c} (22)	8.89^{c} (78)

*Values in the parentheses are original means. Data was subjected to square root transformation ($\sqrt{x+1}$). Different alphabets indicate significant differences ($p<0.05$) according to Duncan’s test.

weed resurgence upto 45 DAS (**Table 3**). Metsulfuron + carfentrazone-ethyl 0.025 kg/ha and metsulfuron 0.005 kg/ha alone recorded significantly lower weed density of all broad-leaved weeds compared to all other post-emergence herbicide treatments and were found as effective as hand weeding done twice at 15 days interval. Metsulfuron + carfentrazone-ethyl 0.025 kg/ha provided complete control of all broad-leaved weeds upto 45 DAS. Clodinafop + metribuzin 0.216 kg/ha followed by metribuzin 0.120 kg/ha and isoproturon 0.937 kg/ha provided effective control of grass and broad-leaved weeds and recorded significantly lower weed density compared to other post-emergence herbicide treatments.

Weed biomass

All post-emergence herbicides recorded significantly lesser total weed biomass than weedy check whereas, none of the herbicides were found as effective as hand weeding done twice at 30 and 45 DAS. Among post-emergence herbicides, the total weed biomass was weighed lowest in metsulfuron + carfentrazone-ethyl 0.025 kg/ha which was found at par with the isoproturon 0.937 kg/ha, clodinafop + metribuzin 0.216 kg/ha, metribuzin 0.120 kg/ha and atrazine 1.0 kg/ha at 45 DAS (**Table 4**).

WCE calculated at 30 and 45 DAS (**Table 4**) revealed that hand weeding twice at 15 days interval reported highest WCE (97-100%) providing complete control of all weeds except *C. rotundus*. The WCE of different post-emergence herbicides was lower than the hand weeding twice. Among the PoE herbicides, metsulfuron + carfentrazone-ethyl 0.025 kg/ha recorded highest WCE (67-72%) with 60 % of the weed density comprised of broad-leaved weeds during the winter season (**Table 1**). Metsulfuron + carfentrazone-ethyl 0.025 kg/ha showed effective control of broad-leaved weeds as reported by McAfee and Baumann (2007). The WCE of

Table 2. Effect of post-emergence herbicides on weed density at 30 DAS in bermuda grass

Treatment	Dose (kg/ha)	Weed density (no./m^2)										
		Winter season						Summer season				
		Poa annua	*Gnaphalium purpureum*	*Oxalis corniculata*	*Desmodium triflorum*	*Coronopus didymus*	*Cyperus rotundus*	*Digitaria sanguinalis*	*Dichanthium annulatum*	*Dactyloctenium aegyptium*	*Boerhavia diffusa*	*Alysicarpus vaginalis*
Isoproturon	0.937	1.00^{a*} (0)	1.00^{a} (0)	7.13^{b} (50)	7.74^{bc} (61)	5.85^{c} (33)	8.86^{bcd} (78)	8.25^{cd} (67)	9.17^{d} (83)	7.55^{bc} (56)	3.46^{b} (11)	8.25^{b} (67)
Mesosulfuron + iodosulfuron	0.014	1.00^{a} (0)	4.81^{bc} (22)	9.69^{c} (94)	7.13^{bc} (50)	5.85^{c} (33)	8.23^{bc} (67)	8.89^{cd} (78)	7.87^{bc} (61)	7.55^{bc} (56)	3.46^{b} (11)	9.49^{c} (89)
Clodinafop + metribuzin	0.216	1.00^{a} (0)	4.16^{b} (17)	1.00^{a} (0)	6.31^{b} (39)	1.00^{a} (0)	7.52^{b} (56)	5.83^{b} (33)	5.83^{b} (33)	3.94^{ab} (15)	4.80^{c} (22)	8.89^{c} (78)
2,4-D amine	0.500	9.17^{b} (83)	5.34^{cd} (28)	9.46^{c} (89)	6.71^{bc} (44)	3.47^{ab} (11)	4.17^{a} (17)	8.25^{cd} (67)	10.34^{d} (106)	8.25^{c} (67)	3.46^{b} (11)	8.89^{c} (78)
Bispyribac-sodium	0.025	1.00^{a} (0)	5.34^{cd} (28)	9.69^{c} (94)	7.88^{bc} (61)	9.48^{e} (89)	8.86^{bcd} (78)	9.49^{d} (89)	1.00^{a} (0)	6.16^{bc} (37)	4.80^{c} (22)	8.25^{b} (67)
Metribuzin	0.120	1.00^{a} (0)	4.16^{b} (17)	1.00^{a} (0)	6.31^{b} (39)	1.00^{a} (0)	8.23^{bc} (67)	7.55^{bc} (56)	9.17^{d} (83)	6.71^{bc} (44)	4.80^{c} (22)	8.89^{c} (78)
Metsulfuron	0.005	10.31^{c} 106)	1.00^{a} (0)	4.19^{ab} (17)	6.31^{b} (39)	3.47^{ab} (11)	9.15^{cd} (83)	8.25^{cd} (67)	9.75^{d} (94)	8.25^{c} (67)	3.46^{b} (11)	1.00^{a} (0)
Carfentrazone-ethyl	0.020	10.34^{c} (108)	4.16^{b} (17)	4.81^{ab} (22)	7.13^{bc} (50)	4.19^{abc} (17)	7.52^{b} (56)	8.25^{cd} (67)	9.17^{d} (83)	7.55^{bc} (56)	3.46^{b} (11)	1.00^{a} (0)
Metsulfuron + carfentrazone-ethyl	0.025	10.31^{c} (106)	1.00^{a} (0)	1.00^{a} (0)	1.00^{a} (0)	1.00^{a} (0)	9.15^{cd} (83)	9.49^{d} (89)	9.75^{d} (94)	6.71^{bc} (44)	1.00^{a} (0)	1.00^{a} (0)
Metsulfuron-methyl + chlorimuron-ethyl	0.004	10.31^{c} (106)	4.16^{b} (17)	4.81^{ab} (22)	6.31^{b} (39)	5.35^{bc} (28)	8.55^{bcd} (72)	8.89^{cd} (78)	10.34^{d} (106)	8.25^{c} (67)	3.46^{b} (11)	1.00^{a} (0)
Ethoxysulfuron	0.018	1.00^{a} (0)	4.81^{bc} (22)	10.57^{c} (111)	7.13^{bc} (50)	7.88^{d} (61)	1.00^{a} (0)	8.89^{cd} (78)	9.75^{d} (94)	8.25^{c} (67)	3.46^{b} (11)	8.25^{b} (67)
Halosulfuron	0.050	8.22^{b} (67)	5.85^{d} (33)	9.69^{c} (94)	6.75^{bc} (44)	7.51^{d} (56)	1.00^{a} (0)	9.49^{d} (89)	9.75^{d} (94)	7.55^{bc} (56)	4.80^{c} (22)	8.89^{c} (78)
Atrazine	1.000	9.17^{b} (83)	1.00^{a} (0)	7.13^{b} (50)	7.13^{bc} (50)	4.19^{abc} (17)	7.52^{b} (56)	8.89^{cd} (78)	9.17^{d} (83)	8.25^{c} (67)	4.80^{c} (22)	8.89^{c} (78)
Hand weeding twice (15 days interval)	-	1.00^{a} (0)	1.00^{a} (0)	1.00^{a} (0)	1.00^{a} (0)	1.00^{a} (0)	1.00^{a} (0)	1.00^{a} (0)	1.00^{a} (0)	1.00^{a} (0)	1.00^{a} (0)	1.00^{a} (0)
Un-weeded (control)	-	10.31^{c} (105)	5.85^{d} (33)	9.69^{c} (94)	8.82^{c} (78)	9.48^{e} (89)	9.77^{d} (94)	9.49^{d} (89)	10.34^{d} (106)	8.25^{c} (67)	4.80^{c} (22)	9.49^{c} (89)

*Values in the parentheses are original means. Data was subjected to square root transformation ($\sqrt{x+1}$). Different alphabets indicate significant differences (p<0.05) according to Duncan's test.

isoproturon 0.937 kg/ha, clodinafop + metribuzin 0.216 kg/ha and metribuzin0.120 kg/ha ranged 60-69% and these PoE herbicides effectively controlled the diverse weed flora except sedge weeds in the lawn during winter season.

Summer season

Major weed flora observed during summer season was *Digitaria sanguinalis*, *Dicanthium annulatum* and *Dactyloctenium aegyptium* among grasses; and *Boerhavia diffusa* and *Alysicarpus vaginalis* were observed among broad-leaved weeds. The density of grass and broad-leaved weeds was 70 and 30%, respectively in the well-established lawn.

Effect on weed density

Clodinafop + metribuzin 0.216 kg/ha recorded significantly lower *Digitaria sanguinalis* density as compared to other PoE herbicides and was at par with metribuzin 0.120 kg/ha (**Table 1,2** and **3**). Lowest *D. sanguinalis* density was recorded in hand weeding which was significantly lower than all the other weed control treatments. Bispyribac-sodium 0.025 kg/ha and hand weeding twice provided complete control of *Dicanthium annulatum* and its density was found significantly lower than other weed control treatments (**Table 1, 2** and **3**). Clodinafop + metribuzin 0.216 kg/ha and mesosulfuron + iodosulfuron 0.014 kg/ha were observed at par with each other and were found effective to reduce the *D. annulatum* density significantly as compared to isoproturon 0.937 kg/ha and weedy check. The lowest *Dactyloctenium aegyptium* density was recorded in hand weeding treatment which was found statistically at par with clodinafop + metribuzin 0.216 kg/ha and significantly lower than all other weed control treatments. The

Table 3. Effect of post-emergence herbicides on weed density at 45 DAS in bermuda grass

Treatment	Dose (kg/ha)	Weed density (no./m^2) – Winter season						Summer season				
		Poa annua	*Gnaphalium purpureum*	*Oxalis corniculata*	*Desmodium triflorum*	*Coronopus didymus*	*Cyperus rotundus*	*Digitaria sanguinalis*	*Dichanthium annulatum*	*Dactyloctenium aegyptium*	*Boerhavia diffusa*	*Alysicarpus vaginalis*
Isoproturon	0.937	1.00^{a*} (0)	1.00^{a} (0)	7.13^{b} (50)	9.27^{c} (89)	5.85^{c} (33)	9.77^{cd} (94)	8.89^{cde} (78)	9.49^{d} (89)	7.55^{bc} (56)	3.46^{b} (11)	8.25^{b} (67)
Mesosulfuron + iodosulfuron	0.014	1.00^{a} (0)	4.81^{bc} (22)	9.69^{c} (94)	7.88^{bc} (61)	5.85^{c} (33)	9.18^{bcd} (83)	9.49^{de} (89)	8.25^{bc} (67)	7.55^{bc} (56)	3.46^{b} (11)	9.49^{c} (89)
Clodinafop + metribuzin	0.216	1.00^{a} (0)	4.16^{b} (17)	1.00^{a} (0)	6.31^{b} (39)	1.00^{a} (0)	8.55^{bc} (72)	5.83^{b} (33)	6.32^{b} (39)	5.20^{ab} (26)	4.80^{c} (22)	8.89^{c} (78)
2,4-D amine	0.500	9.17^{b} (83)	5.34^{cd} (28)	9.46^{c} (89)	7.50^{bc} (56)	3.47^{ab} (11)	4.80^{a} (22)	8.89^{cde} (78)	10.34^{d} (106)	8.25^{c} (67)	3.46^{b} (11)	8.89^{c} (78)
Bispyribac-sodium	0.025	1.00^{a} (0)	5.34^{cd} (28)	9.69^{c} (94)	7.88^{bc} (61)	9.48^{e} (89)	9.5^{bcd} (89)	9.49^{de} (89)	1.00^{a} (0)	6.16^{bc} (37)	4.80^{c} (22)	8.25^{b} (67)
Metribuzin	0.120	1.00^{a} (0)	4.16^{b} (17)	1.00^{a} (0)	6.31^{b} (39)	1.00^{a} (0)	8.21^{b} (67)	7.55^{bc} (56)	9.49^{d} (89)	6.71^{bc} (44)	4.80^{c} (22)	8.89^{c} (78)
Metsulfuron	0.005	10.31^{c} 106)	1.00^{a} (0)	4.19^{ab} (17)	6.74^{b} (44)	3.47^{ab} (11)	10.04^{d} (100)	8.89^{cde} (78)	10.05^{d} (100)	8.25^{c} (67)	3.46^{b} (11)	1.00^{a} (0)
Carfentrazone-ethyl	0.020	10.34^{c} (108)	4.16^{b} (17)	4.81^{ab} (22)	7.13^{bc} (50)	4.19^{abc} (17)	8.21^{b} (67)	8.89^{cde} (78)	9.49^{d} (89)	7.55^{bc} (56)	3.46^{b} (11)	1.00^{a} (0)
Metsulfuron + carfentrazone-ethyl	0.025	10.31^{c} (106)	1.00^{a} (0)	1.00^{a} (0)	1.00^{a} (0)	1.00^{a} (0)	10.04^{d} (100)	10.05^{d} (100)	10.05^{d} (100)	6.71^{bc} (44)	1.00^{a} (0)	1.00^{a} (0)
Metsulfuron-methyl + chlorimuron-ethyl	0.004	10.31^{c} (106)	4.16^{b} (17)	4.81^{ab} (22)	6.31^{b} (39)	5.35^{bc} (28)	10.04^{d} (100)	9.49^{de} (89)	10.58^{d} (111)	8.25^{c} (67)	3.46^{b} (11)	1.00^{a} (0)
Ethoxysulfuron	0.018	1.00^{a} (0)	4.81^{bc} (22)	10.57^{c} (111)	7.13^{bc} (50)	7.88^{d} (61)	4.17^{a} (17)	9.49^{de} (89)	10.05^{d} (100)	8.25^{c} (67)	3.46^{b} (11)	8.25^{b} (67)
Halosulfuron	0.050	8.22^{b} (67)	5.85^{d} (33)	9.69^{c} (94)	6.75^{b} (44)	7.51^{d} (56)	1.00^{a} (0)	10.05^{d} (100)	10.05^{d} (100)	7.55^{bc} (56)	4.80^{c} (22)	8.89^{c} (78)
Atrazine	1.000	9.17^{b} (83)	1.00^{a} (0)	7.13^{b} (50)	7.13^{bc} (50)	4.19^{abc} (17)	8.55^{bc} (72)	9.49^{de} (89)	9.49^{d} (89)	8.25^{c} (67)	4.80^{c} (22)	8.89^{c} (78)
Hand weeding twice (15 days interval)	-	1.00^{a} (0)	1.00^{a} (0)	1.00^{a} (0)	1.00^{a} (0)	1.00^{a} (0)	4.17^{a} (17)	1.00^{a} (0)	1.00^{a} (0)	1.00^{a} (0)	1.00^{a} (0)	1.00^{a} (0)
Un-weeded (control)	-	10.31^{c} (105)	5.85^{d} (33)	9.69^{c} (94)	9.44^{c} (89)	9.48^{e} (89)	10.04^{d} (100)	10.05^{d} (100)	10.34^{d} (106)	8.25^{c} (67)	4.80^{c} (22)	9.49^{c} (89)

Values in the parentheses are original means. Data was subjected to square root transformation ($\sqrt{x+1}$). Different alphabets indicate significant differences (p<0.05) according to Duncan's test effect of mesosulfuron + iodosulfuron 0.014 kg/ha, 2,4-D amine 0.50 kg/ha, metsulfuron 0.005 kg/ha, carfentrazone-ethyl 0.020kg/ha, metsulfuron + carfentrazone-ethyl 0.025 kg/ha, metsulfuron-methyl + chlorimuron-ethyl 0.004 kg/ha, ethoxysulfuron 0.018 kg/ha and halosulfuron 0.050 kg/ha on grass weeds was poor and was similar to weed check (**Table 1, 2** and **3**) (Siddappa *et al.* 2015a, LeStrange and Reynolds 2016). Metsulfuron + carfentrazone-ethyl 0.025 kg/ha provided complete control of *Boerhavia diffusa* upto 45 DAS and recorded significantly lower density than all other weed control treatments except hand weeding twice (McAfee and Baumann 2007). Whereas, isoproturon 0.937 kg/ha, mesosulfuron + iodosulfuron 0.014 kg/ha, 2,4-D amine 0.50 kg/ha, metsulfuron 0.005 kg/ha, carfentrazone-ethyl 0.020 kg/ha, metsulfuron-methyl + chlorimuron-ethyl 0.004 kg/ha and ethoxysulfuron 0.018 kg/ha provided significantly lower *B. diffusa* density than weedy check and were at par with each other (**Table 1, 2** and **3**). Metsulfuron 0.005 kg/ha, carfentrazone-ethyl 0.020 kg/ha, metsulfuron + carfentrazone-ethyl 0.025 kg/ha and metsulfuron-methyl + chlorimuron-ethyl 0.004 kg/ha provided complete control of *Alysicarpus vaginalis* and its density was significantly lower than all other PoE treatments and at par with hand weeding twice **(Table 1, 2** and **3)**. McAfee and Baumann (2007) reported that carfentrazone and metsulfuron PoE effectively controlled broad-leaved weeds.

Weed biomass

In summer season, among PoE herbicides, lowest total dry weed biomass was recorded in clodinafop + metribuzin 0.216 kg/ha and was followed by metsulfuron + carfentrazone-ethyl 0.025 kg/ha, isoproturon 0.937 kg/ha, metribuzin 0.120 kg/ha and metsulfuron 0.005 kg/ha (**Table 4**). The grass and broad-leaved weeds density showed similar trends at 30 and 45 DAS (**Table 2** and **3**)

In summer season, clodinafop + metribuzin 0.216 kg/ha found effective in controlling grass and broad-leaved weeds (**Table 1, 2** and **3**) and reported highest WCE (33.6 %) among PoE which was followed by metsulfuron + carfentrazone-ethyl 0.025 kg/ha (31.5 %) at 45 DAS (**Table 4**).

Turfgrass characteristics

Phyto-toxicity

The phyto-toxicity rating on turfgrass was recorded periodically at 3, 7, 10, 15 and 25 DAS of different herbicides. The visual observations revealed that grasses, broad-leaved weeds and sedges were effectively controlled with the application of PoE herbicides without any visually detrimental phyto-toxic effect on the turfgrass (*Cynodon dactylon*), except in plots that were treated with clodinafop + metribuzin 0.216 kg/ha where slightly straw-coloured leaf blades were observed. However, the turf recovered effectively and regained its natural green colour at 35 days after application of clodinafop + metribuzin during winter season. However, due to greater weed density (**Table 1**) before herbicide spray during summer season, there was no observation of phytotoxicity and weeds were controlled very effectively with use of herbicide treatments.

Table 4. Effect of post-emergence herbicides on total dry biomass of weeds and weed control efficiency in bermuda grass

Treatment	Dose (kg/ha)	Total dry biomass of weeds (g/m^2)				Weed control efficiency (%)			
		Winter season		Summer season		Winter season		Summer season	
		30 DAS	45 DAS	30 DAS	45 DAS	30 DAS	45 DAS	30 DAS	45 DAS
Isoproturon	0.937	2.94^{cd*} (7.6)	3.58^{bc} (11.8)	13.49^{bcd} (181.1)	13.97^{bcd} (194.1)	68.3	62.1	29.3	27.8
Mesosulfuron + iodosulfuron	0.014	3.60^{ef} (11.9)	3.76^{cd} (13.1)	14.47^{e} (208.4)	14.91^{f} (221.4)	50.4	58.0	18.6	17.7
Clodinafop + metribuzin	0.216	2.88^{bc} (7.3)	3.64^{bcd} (12.2)	12.91^{b} (165.6)	13.4^{b} (178.6)	69.7	60.8	35.3	33.6
2,4-D amine	0.500	3.76^{gh} (13.1)	3.89^{cde} (14.1)	15.40^{f} (236.3)	15.82^{g} (249.3)	45.5	54.8	7.7	7.3
Bispyribac-sodium	0.025	3.69^{fg} (12.6)	4.14^{ef} (16.2)	14.05^{cde} (196.4)	14.51^{def} (209.4)	47.5	48.2	23.3	22.2
Metribuzin	0.120	2.89^{bc} (7.4)	3.64^{bcd} (12.2)	13.59^{bcd} (183.8)	14.06^{bcde} (196.8)	69.4	60.7	28.2	26.8
Metsulfuron	0.005	3.38^{de} (10.4)	3.89^{cde} (14.1)	13.66^{bcd} (185.6)	14.13^{bcde} (198.6)	56.8	54.8	27.5	26.2
Carfentrazone-ethyl	0.020	3.46^{ef} (11.0)	4.01^{de} (15.1)	14.06^{cde} (196.6)	14.51^{def} (209.6)	54.3	51.6	23.2	22.1
Metsulfuron + carfentrazone-ethyl	0.025	2.74^{b} (6.5)	3.33^{b} (10.1)	13.38^{bc} (177.9)	13.61^{bc} (184.3)	72.9	67.5	30.5	31.5
Metsulfuron-methyl + chlorimuron-ethyl	0.004	3.86^{gh} (13.9)	4.35^{f} (17.9)	13.77^{cde} (188.7)	14.24^{cdef} (201.7)	42.1	42.4	26.3	25.0
Ethoxysulfuron	0.018	2.99^{cd} (7.9)	3.79^{cd} (13.4)	14.30^{de} (203.6)	14.8^{ef} (218.7)	67.1	57.1	20.5	18.9
Halosulfuron	0.050	3.74^{gh} (13.0)	4.25^{f} (17.0)	15.65^{f} (243.8)	15.98^{g} (254.4)	46.0	45.4	4.8	5.4
Atrazine	1.000	3.29^{de} (9.8)	3.69^{bcd} (12.6)	15.97^{f} (254.0)	16.37^{g} (267.0)	59.1	59.7	0.8	0.7
Hand weeding twice (15 days interval)	-	1.00^{a} (0)	1.37^{a} (0.9)	1.00^{a} (0)	2.35^{a} (4.5)	100.0	97.1	100.0	98.3
Un-weeded (control)	-	5.01^{i} (24.07)	5.67^{g} (31.18)	16.03^{f} (256.00)	16.43^{g} (269)	0.0	0.0	0.0	0.0

*Values in the parentheses are original means. Data was subjected to square root transformation ($\sqrt{x+1}$). Different alphabets indicate significant differences ($p<0.05$) according to Duncan's test.

Sward height

The mean sward height of turfgrass was measured highest in hand weeding twice (8.4 cm) followed by plots that were treated with metsulfuron + carfentrazone-ethyl 0.025 kg/ha (8.2 cm), atrazine 1.0 kg/ha (7.7 cm), metsulfuron 0.005 kg/ha (7.6 cm), carfentrazone-ethyl 0.020 kg/ha (7.6 cm). The mean height of sward was recorded lowest (4.9 cm) in weedy check during winter season (**Figure 1**) whereas in summer, values revealed that hand weeding twice were measured significantly taller (24.1cm) sward height compared with weedy check and other herbicide treatments. Hand weeding twice and clodinafop + metribuzin 0.216 kg/ha and metsulfuron + carfentrazone-ethyl 0.025 kg/ha, recorded sward height of 21.5 cm and 21.1 cm, respectively. The greater sward height was associated with the lower weed density and biomass (**Table 1,2,3,4**).

Turfgrass colour and dry weight

The colour of turfgrass was visually assessed and designated with a numerical value on 1-9 scale at 60 DAS. The slight deviation in hue of green was noticed in all the weed control treatments, but the numerical value assessed over 1-9 colour scale was found non-significant for all the weed control treatments (data not presented). In winter season, hand weeding twice resulted in maximum dry weight of turfgrass clippings (41.74 g/m^2) followed by herbicide treated plots with metsulfuron + carfentrazone-ethyl 0.025 kg/ha (40.46 g/m^2) and isoproturon 0.937 kg/ha (40.61 g/m^2). Minimum dry weight of turfgrass clippings was recorded in un-weeded control (23.69 g/m^2) (**Figure 1**). In summer, two hand weedings resulted in maximum dry weight followed by herbicide treated plots with clodinafop + metribuzin 0.216 kg/ha. The total weed dry weight and dry weight of turfgrass clippings in lawn during both seasons was found negatively correlated at 60 DAS after mowing (**Figure 2**).

Economics

The economics of spraying of different post-emergence herbicides and manual weeding in lawn was calculated and profit margin was assessed over the conventional hand weeding practice. Manual weeding in lawn might provide nearly complete control of different types of weeds, however being more labour-intensive and time-consuming, this practice is less profitable as compared to chemical weed control (Glowicka *et al.* 2020). Metsulfuron + carfentrazone-ethyl 0.025 kg/ha provided effective

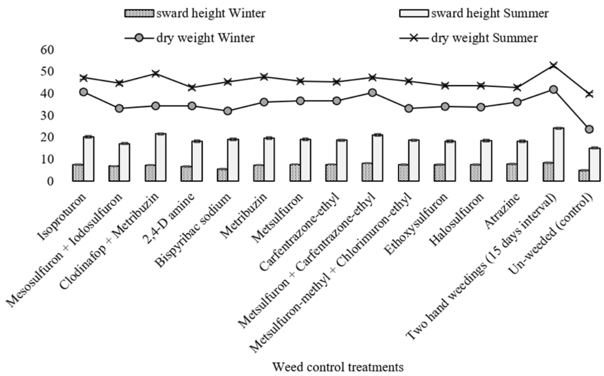

Figure 1. Effect of different weed control treatments on sward height and dry weight of turfgrass at 60 DAS

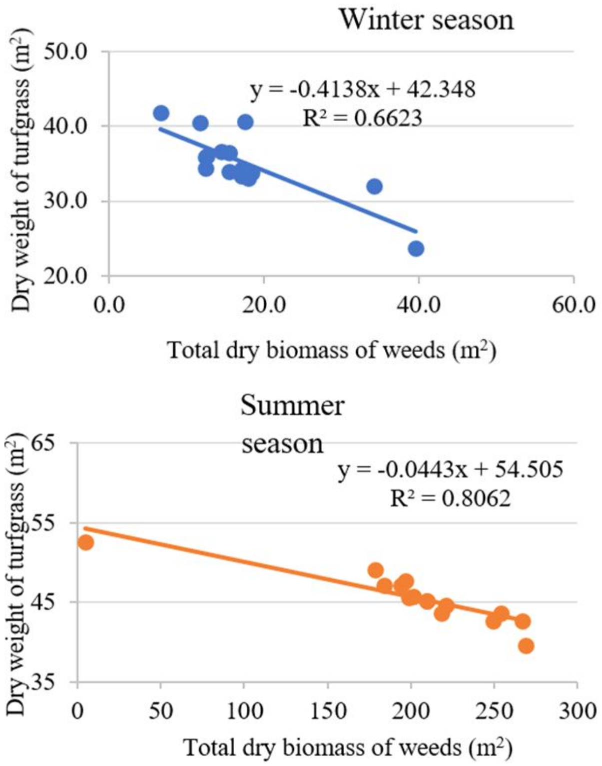

Figure 2. Correlation of weeds dry biomass (g/m^2) and dry weight (g/m^2) of turfgrass

control of broad-leaved weeds and recorded highest WCE. Cost saving in metsulfuron + carfentrazone-ethyl 0.025 kg/ha over hand weeding twice was INR 13427/ha, followed by metribuzin 0.120 kg/ha (INR 13992/ha) and INR 13102/ha in isoproturon 0.937 kg/ha. Application of clodinafop + metribuzin 0.216 kg/ha was found effective on grass and broad-leaved weeds with a saving of INR 12477/ha over hand weeding. Saving over hand weeding with halosulfuron 0.050 kg/ha was INR 12112/ha which performed better than other post-emergence herbicides for the control of sedges (*Cyperus rotundus*). The economics of weed control with the application of herbicides proved more profitable (82.2 to 95.4 %) over manual weeding during our period of experiment in established lawn of Bermuda grass 'Selection No. 1'. The results are in conformity with the findings of Siddappa *et al.* (2015b).

REFERENCES

Busey P. 2003. Cultural management of weeds in Turfgrass. *Crop Science Society of America* **43**(6): 1899–1911.

Danilo CM, Cesarin AE, Martins PFRB, Ferrarezi DP, Alves PL and Pivelta KFL. 2016. Selectivity and efficiency of herbicide in warm season turfgrass varieties. *African Journal of Agricultural Research* **11**(35): 3299–3306.

Doughlas RS, Cardina J and Grewal SP. 2005. Influence of grass species and endophyte infection on weed populations during establishment of low maintenance lawn. *Agriculture, Ecosystems & Environment* **115**: 27–33.

Glowicka R, Woloszyn A, Stanislawska J, Kozera A and Sawiska Z. 2020. Economic efficiency of weed control methods in winter wheat cultivation on large-scale farms. *Annals of the Polish Association of Agricultural and Agribusiness Economists*. **XXII** (4): 62–73

LeStrange M and Reynolds CA. 2016. Pest notes: Weed management in lawns. University of California Agriculture and Natural resources publication. www.ipm.ucdavis.edu/PMG/PESTNOTES.

Mani VS, Gautam KC and Kulshreshtha G. 1976. Progress of aquatic weed control in India and suggestions for further research. pp. 224-232. In: *Aquatic weeds in SE Asia*, (Eds. Varshney CK and Rzoska J). The Hague, Netherlands.

McAfee J and Baumann PA. 2007. Herbicides for weed control in turfgrass. Department of Soil and Crop Sciences, Texas A&M University, College Station, Texas. SCS-2007-13. https://agrilifeextension.tamu.edu.

McCarty LB, Everest JW, Hall DW, Murphy TR and Yelverton F. 2008. Color Atlas of Turfgrass Weeds. 2nd Edn., John Wiley and Sons, New York, USA. pp. 19-31.

McCurdy JD, McElroy JS and Flessner ML. 2013. Differential Response of Four Trifolium Species to Common Broadleaf Herbicides: Implications for Mixed Grass Legume Swards. *Weed Technology* **27**:123–28.

Ramachandra C, Shivakumar N and Ningaraju GK. 2014. Effect of herbicides and their combination on weed dynamics in rice-based cropping system. *Indian Journal of Weed Science* **46**(2): 123–125.

Rao VS. 1986. *Principles of weed science*, Oxford and IBH Publishing Co., Private Limited, New Delhi pp. 450

Siddappa, Jayaprasad KV and Sanjay MT. 2015a. Effect of herbicides on management of weeds in lawn. *The Bioscan* **10**(1): 285–289.

Siddappa, Raj L, Geeta BL, Jaya KV, Prosad MT and Sanjay. 2015b. Economics of weed management in lawn. *Trends in Biosciences* **8**(12): 3074–3076.

Siddappa, Shivappa MK, Asha KM, Vikash HM and Jayaprasad KV. 2016. Uptake and removal of nutrient by different chemical weed management practices in lawn. *Environment and Ecology* **34**: 309–317.

Sondhia S. 2014. Herbicides residues in soil, water, plants and non-targeted organisms and human health implications: an Indian perspective. *Indian Journal of Weed Science* **46**(1): 66–85.

Uddin MK, Juraimi AS and Ismail M. 2012. Weed management in tropical turfgrass areas. *Archives of Biological Sciences* **64**(2): 597–603.

Zhang J, Glenn B, Unruh J B, Kruse J, Kenworthy K, Erickson J, Rowland D and Trenholm L. 2017. Comparative performance and daily light integral requirements of warm-season turfgrasses in different seasons. *Crop Science* **57**(4): 2273–2282.

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RESEARCH NOTE

Weed management in zero-till wheat grown after greengram

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ABSTRACT

An experiment was conducted on zero-till (ZT) wheat grown after greengram at Jhansi during 2019-20. Broad-leaved weeds dominated (90-95%) the field, with limited occurrence of grassy weeds (5-10%). Weed density was higher under conventional tillage (CT) than ZT. Wheat grain yield was the highest under ZT, but there was no effect of greengram residue along with ZT. Pre-emergence application (PE) of pendimethalin followed by (*fb*) post-emergence application (PoE) of sulfosulfuron provided effective control of weeds, and improved weed control efficiency (88.2–90.5%). Herbicidal efficiency index also was maximum with pendimethalin PE *fb* sulfosulfuron PoE. The improved profitability with enhanced productivity of wheat can be achieved with ZT with application of glyphosate before sowing wheat after greengram and usage of sulfosulfuron PoE for controlling weeds. The greengram residues along with ZT may prove beneficial in the long-run.

Keywords: Greengram, Sulfosulfuron, Weed management, Wheat, Zero tillage

Wheat (*Triticum aestivum* L. emend Fiori & Paol.) is predominantly grown in sequence with greengram (*Vigna radiata* (L.) R. Wilczek), blackgram (*Vigna mungo* (L.) Hepper), sesame (*Sesamum indicum* L.) or groundnut (*Arachis hypogaea* L.) in the Bundelkhand region. The acreage under wheat has increased over time at the cost of traditional pulse and oilseed crops due to availability of irrigation in most areas (Yadav 2021). The late sowing of wheat from the end of November up to the beginning of January, broadcast sowing of seed, weed infestation, inadequate fertilization and low varietal replacement rate are responsible for low yields (~3 t/ha) in the Bundelkhand region (Sharma *et al.* 2020). Conventional tillage involving repeated ploughing of the land also leads to delayed sowing. Zero tillage is known to advance sowing of wheat (Sharma 2021), and influences weed infestations significantly (Saharawat *et al.* 2010). Zero tillage along with residue retention led to higher wheat yields over conventional tillage in north-western India (Brar and Walia 2007, Kumar *et al.* 2017). The pre-emergence application (PE) of pendimethalin and post-emergence application (PoE) of 2,4-D, metsulfuron, sulfosulfuron, pinoxaden and clodinafop or their mixtures are recommended for weed control in wheat (Dawson *et al.* 2008, Manhas 2017). However, information is scanty on the efficacy of recommended herbicides to manage weeds in zero tillage wheat grown after greengram in the Bundelkhand region. Hence, this study was conducted to assess the effect of tillage and weed management practices on wheat productivity and profitability.

An experiment was conducted during 2019–20 at the research farm of Rani Lakshmi Bai Central Agricultural University, Jhansi on loamy soil, low in organic C (0.47%) and available N (255 kg/ha), and medium in available P (17 kg/ha) and K (245 kg/ha). A uniform crop of greengram was grown during *Kharif* (rainy) season (mid-July to mid-October), after which the experimental wheat was grown in *Rabi* (winter) season (third week of November 2019 to early April 2020) with a total of twelve treatment combinations involving three tillage practices, *viz.* conventional tillage (CT) (3 ploughings with harrow and cultivator), zero tillage (ZT) (no ploughing), and ZT + greengram residue 3 t/ha retention (ZT+R); and four weed management practices, *viz.* pendimethalin PE 1.0 kg/ha, pendimethalin PE followed by (*fb*) sulfosulfuron PoE 25 g/ha, pendimethalin *fb* hand weeding (HW) at 30 days after sowing (DAS), and unweeded control. A randomized block design with 3 replications was used with plot size of 45 m^2.

Wheat cv. HI 1544 was sown on 19 November, 2019 with Happy Seeder using seed rate of 100 kg/ha at 20 cm row spacing. In all the ZT plots, glyphosate 1.0 kg/ha was sprayed before sowing. Application of 50 kg N/ha along with 25.8 kg P and 32.2 kg K/ha

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was done as basal placement with seed drill, and 50 kg N/ha was applied as top dressing after first irrigation. Besides a pre-sowing irrigation, three irrigations were given at 21, 54 and 86 DAS. Harvesting was done on 3 April 2020 (134 DAS). Observations were recorded on species-wise weed density and tillering of wheat at 30 days interval. Wheat yield was recorded from net plot area of 20 m^2, and various efficiency indices were worked out as per standard procedures.

Effect on weeds

The major dominant weeds in the experimental field included: *Medicago denticulata, Anagallis arvensis, Melilotus alba, Coronopus didymus, Spergula arvensis, Cynodon dactylon* and *Cyperus rotundus* **(Table 1)**. *M. denticulata* and *A. arvensis* emerged at the early stages of crop (30 DAS), while the other species *M. alba*, *C. didymus* and *S. arvensis* appeared at the later stages of crop growth. Perennial grassy weeds like *C. dactylon* and sedges like *C. rotundus* occurred in lesser density. Total weed density was maximum at 30 DAS and decreased at 60 and 90 DAS **(Table 2)**. ZT+R showed significantly lower weed density than ZT alone, both of which were superior to CT. The highest weed density under CT was possibly due to intensive ploughing of the land, bringing weed seeds from lower soil layers to the surface and also improving their germinability due to exposure to light and temperature (Shyam *et al.* 2009). However, the weed seeds lying near the surface under ZT emerged in the first flush and there was no emergence from the seeds lying below the surface layer (Brar and Walia 2009). These initial findings are in contrast to the conventional opinion of increased weed infestations under ZT systems.

At 60 DAS, weed density decreased drastically with sulfosulfuron PoE and HW at 30 DAS **(Table 2)**. A similar trend was observed at 90 DAS, with superior weed control by sulfosulfuron PoE than HW. Weed density with pendimethalin PE remained on par with unweeded control at all the sampling intervals as pendimethalin was a grassy weed killer and did not have effect on the broad-leaved species in the field (Chhokar *et al.* 2012). This suggests that the choice of herbicide for weed control should be based on the predominating weed flora. Sulfosulfuron PoE has been recommended for the control of isoproturon-resistant *Phalaris minor* (Kumar *et al.* 2007, Chhokar *et al.* 2012), and it was also found effective to control the broad-leaved weeds in the present study.

Effect on wheat

Emergence of wheat was equal under ZT and CT, and higher than ZT+R **(Table 2)**. Normally, the emergence of seeds is similar irrespective of tillage if sowing is done in optimum soil moisture at the desired soil depth using a well-calibrated seed drill. Rice residue load of 5.0–7.5 t/ha had no adverse effect on germination of ZT wheat (Chhokar *et al.* 2009, Kumar *et al.* 2013), but greengram residue 3 t/ha was fibrous and also not well dried, which

Table 1. Relative dominance (%) of weed species in unweeded check at different growth intervals of wheat

Days after wheat seeding (DAS)	*Medicago denticulata*	*Melilotus alba*	*Anagallis arvensis*	*Coronopus didymus*	*Spergula arvensis*	*Cynodon dactylon*	*Cyperus rotundus*
30	75.5	3.6	9.8	0.0	0.0	2.1	8.8
60	52.0	16.0	7.8	6.1	13.1	2.2	2.3
90	43.8	7.7	28.9	6.3	7.6	2.5	2.7

Table 2. Effect of tillage and weed management on weed density and crop growth at different stages of wheat

Treatment	Weed density (no./m^2)			Wheat emergence count at 15 DAS (no./m^2)	Tillers/m^2			Plant height at maturity (cm)
	30 DAS	60 DAS	90 DAS		30 DAS	60 DAS	90 DAS	
Tillage								
ZT	261.0	170.1	166.6	147.0	221.6	462.0	365.4	108.3
ZT+R	240.0	96.9	89.8	136.1	208.7	456.6	358.7	107.6
CT	307.1	219.5	208.8	149.7	235.0	450.0	350.8	107.9
LSD (p=0.05)	24.0	14.2	13.4	8.6	18.6	NS	NS	NS
Weed management								
Pendimethalin PE	268.5	265.4	248.2	144.3	216.6	427.7	323.8	108.1
Pendimethalin PE *fb* sulfosulfuron PoE	266.8	32.1	34.6	146.5	222.7	504.3	416.6	107.4
Pendimethalin PE *fb* HW	259.0	75.5	81.4	144.1	226.1	483.3	382.7	108.3
Unweeded control	283.2	275.6	256.1	142.3	221.7	409.4	310.0	107.6
LSD (p=0.05)	NS	10.7	9.1	NS	NS	31.6	23.7	NS

*PE = pre-emergence application, PoE = post-emergence application, HW = hand weeding, ZT = zero tillage, CT = conventional tillage, R = residue retention, *fb* = followed by intermingled with the tines of Happy Seeder and blocked the pores occasionally during sowing. Number of tillers/m^2 at 30 DAS was also significantly lower under ZT+R than ZT and CT but recovered in later stages, resulting in non-significant differences among tillage treatments at 60 and 90 DAS. The wheat crop under ZT+R looked less vigorous for about a month but the growth picked up after first irrigation and top dressing of N fertilizer.

There was no effect on tillers/m^2 at 30 DAS due to weed management treatments **(Table 2)**. However, at 60 and 90 DAS, pendimethalin PE *fb* sulfosulfuron PoE was the best followed by pendimethalin PE *fb* HW, both of which were significantly superior to pendimethalin PE and unweeded check, which remained at par with each other. Tillering improved after 30 DAS when weeds were controlled by sulfosulfuron PoE or HW. Nonetheless, the differences in plant height at maturity remained non-significant with tillage and weed management practices.

Mean grain yield of wheat was the highest under ZT and on par with ZT+R, but was significantly higher than CT **(Table 3)**. Similarly, pendimethalin PE *fb* sulfusulfuron PoE was significantly superior to pendimethalin PE *fb* HW, both of which were vastly superior to pendimethalin PE alone and unweeded control. The mean loss in wheat grain yield due to weeds was 17.7%. Interaction data revealed that the highest grain yield was obtained with pendimethalin PE *fb* sulfosulfuron PoE under ZT. This suggests that ZT should be accompanied with efficient weed control for achieving higher wheat productivity. The greengram residue effect was not observed in the first year of experimentation but it is likely to prove beneficial in the long-run due to improvement in soil fertility besides moisture conservation and weed control (Kumar *et al.* 2017). Straw yield was not influenced significantly with tillage, but pendimethalin PE *fb* sulfosulfuron PoE or HW was superior in increasing wheat straw yield over pendimethalin PE alone and unweeded control.

Effect on efficiency indices

Harvest index was relatively higher under ZT than CT, and with pendimethalin PE *fb* sulfosulfuron PoE or HW compared with pendimethalin PE alone and unweeded control **(Table 3)**. Weed control efficiency (WCE) based on weed density was very low (0.8–4.9%) with pendimethalin PE alone, but improved (to 88.2–90.5%) when sulfosulfuron PoE was sprayed at 30 DAS. However, HW failed to provide complete control of the weeds, especially those along the crop rows and thus resulted in lower WCE (59.2–80.2%). Herbicidal efficiency index (HEI), which is the ratio of percent increase in grain yield and percent weed weight in the treatment, was maximum (1.85–2.10) with pendimethalin PE *fb* sulfosulfuron PoE at 30 DAS. This suggests that pendimethalin PE *fb* sulfosulfuron PoE was the best treatment to control all weeds effectively leading to higher grain yield, which resulted in increased HI, WCE and HEI. ZT with or without residue was superior to CT in improving the efficiency indices.

Economics

The highest net B:C was obtained under ZT, which decreased when greengram residue was also applied along with ZT due to its inclusion in the cost of cultivation and no increase in yield **(Table 3)**. However, both these treatments were superior to CT. The highest returns were under pendimethalin PE *fb* sulfosulfuron PoE, and superior to pendimethalin PE *fb* HW.

Table 3. Effect of tillage and weed management on wheat yield, B:C ratio, weed control efficiency and herbicidal efficiency index

Treatment	Grain yield (t/ha)	Straw yield (t/ha)	Harvest index (%)	Net B:C ratio	Weed control efficiency (%)	Herbicidal efficiency index
Tillage						
ZT	4.64	6.43	41.8	2.18	52.1	0.83
ZT+R	4.46	6.34	41.1	1.81	56.4	0.97
CT	4.22	6.16	40.6	1.61	51.5	0.84
LSD (p=0.05)	0.29	NS	-	-	-	-
Weed management						
Pendimethalin PE	4.12	6.04	40.5	1.72	3.2	0.015
Pendimethalin PE *fb* sulfosulfuron PoE	4.92	6.71	42.2	2.07	89.0	1.95
Pendimethalin PE *fb* HW	4.66	6.50	41.7	1.78	67.9	0.68
Unweeded control	4.05	5.99	40.3	1.88	-	-
LSD (p=0.05)	0.12	0.19	-	-	-	-

PE = pre-emergence application, PoE = post-emergence application, HW = hand weeding, ZT = Zero tillage, CT = conventional tillage, R = residue retention, *fb* = followed by

It was concluded that improved productivity and profitability of wheat can be achieved by growing wheat under zero tillage after greengram with application of glyphosate before sowing and pendimethalin PE *fb* sulfosulfuron as post-emergence for controlling weeds, in the Bundelkhand region.

REFERENCES

Brar AS and Walia US. 2007. Influence of planting techniques and weed control treatments on nutrient uptake by *P. minor* Retz. and broadleaf weeds in wheat (*Triticum aestivum* L.). *Indian Journal of Weed Science* **39**(1&2): 55–61.

Brar AS and Walia US. 2009. Weed dynamics and wheat (*Triticum aestivum* L.) productivity as influenced by planting techniques and weed control practices. *Indian Journal of Weed Science* **41**(3&4): 161–166.

Chhokar RS, Sharma RK and Sharma I. 2012. Weed management strategies in wheat - A review. *Journal of Wheat Research* **4**(2): 1–21.

Chhokar RS, Singh S, Sharma RK and Singh M. 2009. Influence of straw management on *Phalaris minor* Retz. control. *Indian Journal of Weed Science* **41**(3&4): 150–156.

Dawson J, Smeia W, Yadav RK and Govardhan S. 2008. Effect of different herbicides for weed control in late sown wheat. *Agricultural Science Digest* **28**(1): 33–35.

Kumar S, Dwivedi SK, Kumar R, Mishra JS, Singh SK, Prakash V and Bhatt BP. 2017. Productivity and energy use efficiency of wheat (*Triticum aestivum*) genotypes under different tillage options in rainfed ecosystem of middle Indo-Gangetic Plains. *Indian Journal of Agronomy* **62**(1): 31–38.

Kumar S, Malik RS, Yadav A and Malik RK. 2007. Performance of cultivars and sulfosulfuron against weeds in wheat. *Indian Journal of Weed Science* **39**(1&2): 44–47.

Kumar V, Singh S, Chhokar RS, Malik RK, Brainard DC and Ladha JK. 2013. Weed management strategies to reduce herbicide use in zero-till rice–wheat cropping systems of the Indo-Gangetic Plains. *Weed Technology* **27**(1): 241–254.

Manhas SS. 2017. Demonstrations of pendimethalin for control of *Phalaris minor* in wheat crop. *Indian Journal of Extension Education* **53**(3): 132–137

Saharawat YS, Singh B, Malik RK, Ladha JK, Gathala M, Jat ML and Kumar V. 2010. Evaluation of alternative tillage and crop establishment methods in a rice–wheat rotation in North Western IGP. *Field Crops Research* **116**(3): 260–267.

Sharma AK, Mishra CN, Singh BP, Singh SK and Singh GP. 2020. Perspective of enhancing wheat production and productivity in Uttar Pradesh by improving varietal replacement rate. *Journal of Cereal Research* **12**(1): 19–22.

Sharma AR. 2021. Conservation agriculture in India: History, progress and way forward. *Indian Journal of Agronomy* **66**(1): 1–18.

Shyam R, Rohitashav S, Singh VK and Guru SK. 2009. Effect of wheat establishment methods and weed management practices on weed dynamics and productivity of wheat grown in succession to rice. *Indian Journal of Weed Science* **41**(1): 70–72.

Yadav S. 2021. Changing cropping pattern in UP Bundelkhand region. *National Geographical Journal of India* **67**(4): 385–402.

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RESEARCH NOTE

Effect of planting methods, hybrids and weed management on weeds and productivity of rainy season maize

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ABSTRACT

A field experiment was conducted at Chaudhary Charan Singh Haryana Agricultural University, Regional Research Station, Karnal during rainy season (*Kharif*) 2015. Two planting methods, *viz.* zero tillage and raised beds each with and without residues were evaluated with three maize hybrids (HQPM-1, HM-4 and HM-10) and two weed management treatments *viz.* pre-emrgence application (PE) of atrazine 750 g/ha followed by (*fb*) hand weeding (HW) at 30 days after seeding (DAS) and unweeded check, in a split plot design. *Dactyloctenium aegyptium, Brachiaria reptans, Eragrostis tenella, Portulaca oleracea*, *Ammania baccifera* and *Cyperus rotundus* along with some other broad-leaved weeds (BLW) predominated the experimental field. Zero tillage with residues and atrazine 750 g/ha PE *fb* 1 HW at 30 DAS recorded the lowest density and biomass of weeds, at 20 and 40 DAS, greater number of grains/cob, grain yield and net returns. However, the benefit- cost ratio (B:C) was maximum with zero tillage without residue. Lower weed density was observed with maize hybrid HM-10 and HM-4 as compared to HQPM-1. The minimum biomass of BLW, maximum number of grains/cob, grain yield, net returns and B:C were observed with hybrid HM-4, while the minimum biomass of grassy weeds and sedges was with HM-10.

Keywords: Crop residues, Economics, Maize hybrids, Planting methods, Weed management, Zero-tillage

Maize is predominantly a rainy season crop that constitutes 85% of the total maize area in India. Maize contributes almost 9% to India's food basket and 5% to world's dietary energy supply (Yakadri *et al.* 2015). Maize in the rice- wheat system and alternate tillage systems will help sustainability of cropping systems in Indo-Gangetic Plains. In India, maize is cultivated in 9.5 million hectare (ha) area and holds an important position in the Indian economy (DAC&FW 2019). Weeds emerge fast and grow rapidly competing with the crop severely for growth resources, *viz.* nutrients, moisture, sunlight and space during entire vegetative and early reproductive stages of maize causing the maize yield reduction of 27-60%, depending upon several factors (Kumar *et al.* 2015). Hence, managing weeds is most critical for attaining the higher yields. Among pre-emergence (PE) herbicides, atrazine is the most prevalently used herbicide for weed management in *Kharif* maize, which has greater importance in view of its higher effectiveness from the initial stages. It may be supplemented with one hand weeding (HW) at 30-40 DAS if weeds emerge (Dahal and Karki 2014). Crop residue retention is a crucial element of sustainable farming systems that raises the quality of the soil, increases its capacity for nutrients and lessens the negative consequences of burning leftover (Kong 2014). However, information on interactive effect of varying planting and residue management methods; and hybrids on weed dynamics is lacking in maize. Hence, present experiment was conducted to study the effect of varying methods of planting and residue management; and hybrids on weeds in *Kharif* maize hybrids and their productivity.

A field experiment was conducted at Chaudhary Charan Singh Haryana Agricultural University (CCS HAU), Regional Research Station, Karnal, Haryana (India) during *Kharif* 2015. The experiment was laid out in split plot design with three replications. Treatments assigned to four main plot treatments (planting methods) were raised beds (RB) with residue (RB+R), raised bed without residue (RB-R), zero tillage (ZT) with residue (ZT+R) and zero tillage without residue (ZT-R), and six sub-plot treatments which were combination of three maize hybrids *viz.*, HQPM-1, HM-4 and HM-10 and two weed management treatments, *viz.* pre-emergence application (PE) of atrazine 750 g/ha followed by (*fb*)1 HW at 30 DAS and unweeded check. Soil of the experiment field was clay loam (sand 48.4%, silt 24.1 and clay 29.4%) in texture, medium in organic carbon

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(0.41%), low in available N (123.0 kg/ha) and medium in available P (25.2 kg/ha) and K (225.0 kg/ha) with slightly alkaline in reaction (pH 8.4) and EC 0.31 dS/m. After the harvest of *Rabi* crop of wheat in April 2015, land preparation was done as per treatments. The tractor drawn harrow was run twice in RB and remaining field left for ZT as it was. After the pre-sowing irrigation, on RB two harrowing + two ploughings followed by planking was done as preparatory tillage to bring soil to a fine tilth before sowing and preparing beds with help of RB planter in RB treatments. The sowing was done on remaining field with ZT seed-cum-fertilizer drill keeping row to row spacing of 75 cm. Sowing of three maize hybrids was done on June 25, 2015 using a seed rate of 20 kg/ha. After that surface application of wheat residue 4 tonne (t)/ha mulching was done in RB and ZT sowing as per treatments.

Nitrogen, phosphorus and potassium were applied uniformly at the rate of 150, 60 and 60 kg/ha through urea (46% N), diammonium phosphate (DAP) (46% P, 18% N) and muriate of potash (MOP) (60% K), respectively. At time of maize sowing, 50% N and entire recommended dose of P and K were applied as basal dose. Remaining 50% N was applied in two splits at 25 and 45 DAS. Atrazine PE was applied just after sowing by knapsack sprayer fitted with flat fan nozzles using water 500 l/ha. In order to maintain spacing of 75 × 20 cm need based thinning and gap filling was done manually at 20 DAS. Hand weeding in plots treated with atrazine was also done at 30 DAS. Data on weed density and biomass was recorded at 20 and 40 DAS using quadrat of 0.5 × 0.5 m by randomly placing twice in each of the plot. The density is expressed as number of weeds/m^2 and the biomass as g/m^2. Data on weed density was subjected to square root transformation $(\sqrt{X+1})$. Manual harvesting of maize hybrid HM-4 was done on September 22, 2015 and; HQPM-1 and HM-10 were harvested on September 29, 2015. Net returns were computed for each treatment after subtraction of total cost of cultivation from gross returns and B:C was calculated by dividing gross returns with total cost of cultivation.

Effect on weeds

Among the planting methods, the lowest density of grassy weeds at 20 and 40 DAS was recorded under ZT+R followed by RB+R, ZT-R and the highest in RB-R (**Table 1**). Similar trend was found with respect to density of broad-leaved weeds (BLW) except at 40 DAS, where RB+R produced the lowest density of BLW. The lowest density of sedges was recorded in RB+R followed by ZT+R and RB-R however, the highest in ZT-R. In general, density of all type of weeds was lower under residue retention as compared to without residue. Lower density of grassy weeds in ZT might be due to killing of weeds with glyphosate before sowing of crop and non-disturbance of the soil surface thereafter. However, slightly higher sedges under ZT particularly at initial stages might be due to regeneration of some of the weeds even after spray of glyphosate. However, at later stages ZT and raised beds became at par with each other. Kumar *et al.* (2013) also reported lower density of weeds under ZT as compared to conventional tillage (CT) maize.

Among the three maize hybrids, the lowest density of grassy weeds and sedges was recorded under HM-10 followed by HM-4 and HQPM-1 at 20 and 40 DAS (**Table 1**). But in case of BLW, the lowest weed density was recorded under HM-4 followed by HM-10 and the highest in HQPM-1. Faster initial growth of HM-10 than other hybrids could be the reason for lower infestation of weeds under HM-10 as compared to other hybrids as the crop growth is inversely related to weed infestation. All grassy weeds, BLW and sedges were significantly lower density (**Table 1**) and biomass (**Table 2**) under atrazine 750 g/ha PE *fb* 1 HW at 30 DAS supporting findings of Khedwal *et al.* (2017).

The weed biomass followed almost similar trend as the density of weeds at different stages with minor variations (**Table 2**). Among the different planting methods, the lowest biomass of grassy weeds and sedges at 20 and 40 DAS was recorded under ZT+R followed by RB+R and ZT-R, whereas the highest in RB-R. Furthermore, RB-R and ZT+R were at par with each other at 40 DAS for grassy weeds (Table-2). The lowest biomass of BLW at 20 and 40 DAS was recorded under ZT+R followed by RB+R, RB-R and the highest in ZT-R. Lower infestation of weeds under ZT as compared to CT maize has been reported by earlier workers as well (Kumar *et al.* 2013). The lowest biomass of grassy weeds and sedges were recorded under HM-4 at 20 DAS, under HM-10 at 40 DAS, which were significantly superior to HQPM-1, but in case of grassy weeds, HM-4 and HM-10 were at par with each other at 20 and 40 DAS (**Table 2**). The lowest biomass of BLW was recorded under HM-4 at 20 and 40 DAS, which was significantly superior to HM-10 and HQPM-1, while HM-4 and HM-10 were at par with each other at 20 DAS. In general, biomass of weeds was the lowest under HM-10 followed by HM-4 and HQPM-1 (**Table 2**).

Effect on yield attributes and yield

Maize sown in ZT+R recorded higher grains/cob and grain yield were statistically similar to RB+R (**Table 2**). Increase in grain yield of maize under ZT+R could be attributed to less weed competition, better water management techniques and increased water and nutrient availability for maize may have provided the crop a competitive edge over weeds, particularly in the early stages (Yadav *et al.* 2021). Residue retention (4 t/ha) resulted in improved grains/cob and grain yield as compared to without residues under both methods of planting confirming (Khedwal *et al.* 2017). HM-4 provided maximum grain yield which was significantly higher than HM-10 and HQPM-1 in succession (**Table 2**). Increase in grain yield could be attributed to the higher number of grains/cob. In weed management treatments, significantly higher grain yield was obtained under atrazine 750 g/ha PE *fb* 1 HW at 30 DAS (**Table 2**) due to minimum crop-weed competition throughout

Table 1. Effect of varying methods of planting, hybrids and weed management on density of weeds

Treatment	Density of weeds (no./m²)*																	
	Grassy weeds								Broad-leaved weeds								Sedges	
	D. aegyptium		*B. reptans*		*E. tenella*		Total		*P. oleracea*		*A. baccifera*		Other weeds		Total		*C. rotundus*	
	20 DAS	40 DAS	20 DAS	40 DAS	20 DAS	40 DAS	20 DAS	40 DAS	20 DAS	40 DAS	20 DAS	40 DAS	20 DAS	40 DAS	20 DAS	40 DAS	20 DAS	40 DAS
Planting methods																		
Raised bed with residue	2.87	2.24	2.62	2.10	3.39	2.61	4.98	3.81	1.58	1.11	1.80	1.05	9.75	7.84	9.90	7.86	6.50	5.06
	(8.3)	(4.9)	(5.9)	(3.5)	(11.0)	(6.2)	(25.2)	(14.6)	(1.6)	(0.3)	(2.4)	(0.1)	(103.9)	(70.3)	(108.5)	(67.2)	(42.5)	(25.4)
Raised bed without residue	3.97	3.12	3.12	2.39	4.17	3.13	6.49	4.89	1.63	1.24	2.38	1.22	16.95	13.02	17.07	13.06	12.22	9.44
	(15.8)	(9.3)	(10.4)	(5.6)	(18.1)	(9.8)	(44.3)	(24.7)	(1.8)	(0.7)	(5.2)	(0.6)	(301.3)	(177.3)	(305.5)	(178.6)	(158.9)	(94.4)
Zero tillage with residue	2.67	1.96	2.32	1.75	2.76	2.21	4.29	3.15	1.41	1.09	1.41	1.77	9.37	7.80	9.72	7.98	7.23	5.10
	(6.8)	(3.1)	(4.7)	(2.3)	(6.9)	(4.0)	(18.4)	(9.4)	(1.2)	(0.2)	(1.2)	(2.6)	(102.2)	(66.8)	(106.7)	(73.1)	(56.3)	(26.6)
Zero tillage without residue	3.28	2.48	2.94	2.28	3.74	2.64	5.67	4.13	1.85	1.52	2.86	2.19	17.70	13.83	17.98	14.03	13.11	10.65
	(11.6)	(6.9)	(8.7)	(4.9)	(16.1)	(6.8)	(36.1)	(18.6)	(2.5)	(1.5)	(7.8)	(4.1)	(321.1)	(196.0)	(331.2)	(201.6)	(180.7)	(122.7)
LSD (p=0.05)	0.11	0.22	0.10	0.15	0.08	0.11	0.09	0.18	0.11	0.11	0.21	0.20	0.06	0.09	0.05	0.09	0.31	0.24
Maize hybrids																		
HQPM-1	3.34	2.53	2.93	2.31	3.79	2.78	5.74	4.27	1.72	1.48	2.43	1.70	13.82	10.90	14.09	11.42	10.20	8.40
	(11.2)	(6.6)	(8.3)	(4.8)	(16.1)	(7.5)	(35.6)	(19.0)	(2.1)	(1.4)	(5.8)	(2.5)	(216.3)	(132.1)	(224.1)	(136.0)	(121.4)	(80.1)
HM-4	2.24	2.52	2.68	2.03	3.51	2.68	5.32	3.97	1.48	1.07	1.90	1.48	12.24	9.63	12.47	9.72	9.84	7.85
	(11.0)	(6.2)	(6.4)	(3.3)	(12.4)	(6.8)	(29.6)	(16.3)	(1.3)	(0.2)	(3.2)	(1.5)	(201.9)	(122.6)	(205.7)	(124.3)	(106.7)	(77.1)
HM-10	3.01	2.30	2.68	2.05	3.24	2.49	5.01	3.75	1.65	1.17	2.01	1.50	14.27	11.34	14.45	11.05	9.25	6.44
	(9.7)	(5.4)	(7.6)	(4.1)	(10.6)	(5.8)	(27.7)	(15.2)	(1.8)	(0.5)	(3.4)	(1.5)	(203.9)	(128.2)	(209.1)	(130.1)	(100.7)	(44.7)
LSD (p=0.05)	0.10	0.11	0.11	0.13	0.09	0.12	0.12	0.13	0.13	0.07	0.11	0.09	0.08	0.09	0.09	0.09	0.23	0.10
Weed management																		
Atrazine 750 g/ha PE *fb* 1 HW at 30 DAS	2.25	1.65	2.33	1.82	2.67	2.04	4.01	2.93	1.44	1.05	1.71	1.25	11.94	9.44	12.08	9.47	11.94	6.88
	(4.5)	(2.1)	(4.8)	(2.6)	(6.6)	(3.3)	(15.7)	(8.0)	(1.2)	(0.1)	(2.2)	(0.7)	(160.3)	(98.9)	(163.7)	(99.8)	(160.3)	(58.6)
Unweeded check	4.15	3.25	3.19	2.44	4.36	3.26	6.71	5.06	1.80	1.42	2.50	1.87	14.95	11.81	15.26	11.99	14.95	8.24
	(16.7)	(9.9)	(10.1)	(5.6)	(19.5)	(10.0)	(46.2)	(25.6)	(2.3)	(1.2)	(6.1)	(3.0)	(253.9)	(156.3)	(262.3)	(160.4)	(253.9)	(75.9)
LSD (p=0.05)	0.08	0.09	0.09	0.12	0.08	0.10	0.09	0.11	0.10	0.05	0.09	0.07	0.07	0.07	0.07	0.07	0.07	0.08

*Original values in parentheses were subjected to square root transformation ($\sqrt{x+1}$) before statistical analysis; PE = pre-emergence application, HW = hand weeding, DAS = days after seeding; *fb*= followed by

Table 2. Effect of varying methods of planting, hybrids and weed management on weed biomass, no. of grains/cob, grain yield and economics

Treatment	Weed biomass (g/m²)						No. of grains/ cobs	Grain yield (t/ha)	Net returns (x10³ ₹/ha)	Benefit-cost ratio
	Total grassy weeds		Total BLW		Total sedges					
	20 DAS	40 DAS	20 DAS	40 DAS	20 DAS	40 DAS				
Planting methods										
Raised bed with residue	4.69	14.41	1.02	1.55	0.94	1.92	432.1	7.00	50.87	1.88
Raised bed without residue	6.76	22.97	1.64	3.06	2.43	6.66	420.8	6.29	50.79	2.08
Zero tillage with residue	3.97	13.51	0.85	2.07	0.74	1.73	441.9	7.32	59.96	2.13
Zero tillage without residue	5.69	20.25	1.99	3.34	2.07	5.06	426.4	6.42	57.47	2.35
LSD (p=0.05)	0.43	1.42	0.06	0.30	0.07	0.74	7.24	0.43	-	-
Maize hybrids										
HQPM-1	5.46	23.26	1.96	3.83	1.91	5.10	417.0	6.40	49.23	2.01
HM-4	5.17	15.37	1.05	1.62	1.32	3.93	449.7	7.04	58.75	218
HM-10	5.24	14.42	1.12	2.07	1.42	2.50	424.2	6.83	56.39	2.14
LSD (p=0.05)	0.24	0.94	0.07	0.26	0.05	0.31	4.57	0.18	-	-
Weed management										
Atrazine 750 g/ha PE *fb* 1 HW at 30 DAS	0.72	1.98	0.96	1.33	0.91	2.12	463.3	7.70	66.59	2.29
Unweeded check	9.83	33.59	1.80	3.68	2.17	5.56	397.4	5.81	42.95	1.93
LSD (p=0.05)	0.20	0.77	0.06	0.21	0.04	0.25	3.73	0.15	-	-

*BLW = broad-leaved weeds; PE = pre-emergence application; HW = hand weeding, DAS = days after seeding; *fb*= followed by the crop growth period, giving the crop better access to resources and more effective use of water and nutrients, a proper maize establishment strategy may give maize a major competitive advantage over weeds (Kaur *et al*. 2020). The lowest yield was recorded in unweeded check because of greater removal of nutrients and moisture by weeds and severe crop-weed competition resulting in poor source and sink development with poor yield attributes.

Economics

Maize sown in ZT+R recorded the highest net returns followed by (*fb*) ZT-R, RB+R and RB-R. In general, ZT resulted in higher net returns than raised beds. Residue retention resulted in improved net returns as compared to without residues. B:C was more under ZT than raised beds, but less under residues than without residues. This could be obviously due to escalated cost of cultivation with residue retention. The hybrid HM-4 provided maximum net returns and B: C which was superior to HM-10 and HQPM-1 in succession. The higher net returns (55.04%) and B:C were observed with atrazine 750 g/ha PE *fb* 1 HW at 30 DAS as compared to unweeded check.

It may be concluded that ZT+R with maize hybrid HM-4 and atrazine 750 g/ha PE *fb* 1 HW at 30 DAS adoption results in effective weed management and economical maize productivity.

REFERENCES

DAC&FW. 2019. *Annual Report 2018*. Krishi Bhawan, New Delhi. p. 4

Dahal S and Karki TB. 2014. Conservation agriculture based practices affect the weed dynamics in spring maize. *World Journal of Agricultural Research* **2**(6A): 25–33.

Kaur R, Kaur C and Kaur T. 2020. Zero-till sowing and residue mulching in rainy season maize: Effect on weeds, crop productivity and profitability. *Indian Journal of Weed Science* **52**(1): 82–88.

Khedwal RS, Yadav DB, Hooda VS, Dahiya S and Singh M. 2017. Zero-till sowing and residue mulching in rainy season maize: effect on weeds, crop productivity and profitability. *Indian Journal of Weed Science* **49**: 198–200.

Kong L. 2014. Maize residues, soil quality, and wheat growth in China. A review. *Agronomy for Sustainable Development* **34(**2): 405–416.

Kumar A, Kumar J, Puniya R, Mahajan A, Sharma N and Stanzen L. 2015. Weed management in maize-based cropping system. *Indian Journal of Weed Science* **47**(3): 254–266.

Kumar B, Kumar R, Kalyani S and Haque M. 2013. Evaluation and economics of different weed management practices in *rabi* maize (*Zea mays* L.). *Trends in Biosciences* **5**: 558–561.

Yadav GS, Das A, Babu S, Mohapatra KP, Lal R and Rajkhowa D. 2021. Potential of conservation tillage and altered land configuration to improve soil properties, carbon sequestration and productivity of maize based cropping system in eastern Himalayas, India. *International Soil and Water Conservation Research* **9**: 279–290.

Yakadri M, Rani PL, Prakash TR, Madhavi M and Mahesh N. 2015. Weed management in zero till-maize. *Indian Journal of Weed Science* **47**(3): 240–245.

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RESEARCH NOTE

Varying weed management treatments impact on weeds and fodder yield relationship in fodder maize

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ABSTRACT

A field experiment was conducted at Forage Research Farm, Department of Plant Breeding and Genetics, PAU, Ludhiana and Regional Research Station, Gurdaspur during the *Kharif* season of 2020 in fodder maize to evaluate the impact of different weed management treatments on the relationship amongst weed parameters, fodder maize crop characters and green fodder yield. Green fodder yield of maize showed a significant positive correlation with weed control efficiency, maize plant dry weight and plant height. On the contrary, these parameters were negatively correlated with the weed density and biomass at the knee high stage of the crop. The average of the two locations indicated that a unit increase in weed density and biomass reduced maize fodder yield by 0.0655 and 0.083 t/ha, respectively. Similarly, the increase in the maize fodder yield due to a unit increase in weed control efficiency was estimated at 0.166 t/ha.

Keywords: Cultivars, Green fodder yield, Inter cropping, Maize, Row spacing, Tembotrione, Weed management

Maize (*Zea mays* L.) is the second most important crop in world in terms of production. In India, maize is the third major crop after rice and wheat. Amongst the varied uses of this crop, its use as green fodder has attracted substantial attention from farmers as well as scientists. The fodder quality of green maize is considered best among non-legume forage crops. Maize is considered ideal forage because it is fast growing and, produces high yields, palatable, rich in nutrients, and helps to increase body weight and milk quality in cattle (Hanif and Akhtar 2020). As fodder for livestock, maize is excellent, highly nutritive and sustainable. It is commonly grown as a summer and *Kharif* fodder in the north-western regions of India. Its quality is much better than sorghum and pearl millet as both sorghum as well as pearl millet has anti-quality components such as hydrocyanic acid and oxalate, respectively.

Maize productivity is limited by a number of factors and the leading one amongst them is the weed infestation. Being a wide row spaced crop along with regular rains especially in *Kharif* season, weeds inflict yield losses up to 68.9% (Sunitha *et al*. 2010, Singh *et al*. 2016). Maize is infested with a variety of weed flora including annual and perennial grasses, sedges and broad-leaved weeds. The critical period of crop-weed competition starts at 30 days after sowing and ends at 60 days after sowing in Northern part of India (Singh *et al.* 2016). Presently, the commonly adopted weed control option in fodder maize is limited to the use of herbicides particularly the pre-emergence herbicides. The adoption of other non-chemical weed management methods is lacking. The objective of the present study was to evaluate the cultivars, row spacings, herbicides and intercropping to manage weeds in fodder maize and to study the relationship amongst weed density and biomass and weed control efficiency with green fodder yield and yield attributing characters of fodder maize.

Field experiment was conducted at Fodder Research Farm, Punjab Agricultural University, Ludhiana and Regional Research Station Gurdaspur during *Kharif* season of 2020. Ludhiana and Gurdaspur are located at 30^{0}54'N75^{0}48'E and 31^{0}55'N75^{0}15'E, respectively. The prevailing weather during the cropping season at Gurdaspur and Ludhiana is presented in **Figure 1**.

The experiment was laid out in split plot design with two cultivars (J1006 and J1007) and two row spacings (30 and 22.5 cm) in main plots and six weed control treatments in sub plots (weedy check, weed free, pre-emergence application (PE) of atrazine 625 g/ha, post-emergence application (PoE) of tembotrione 120 g/ha, maize +cowpea and maize + *guara*). Pre-emergence application of atrazine was done on next day of sowing while post-emergence application of tembotrione was done at 20 DAS or 3-4 leaf stage of weeds with the help of manually operated knapsack sprayer fitted with flatfan nozzle using 500 liters of water/ha. The crop was sown in

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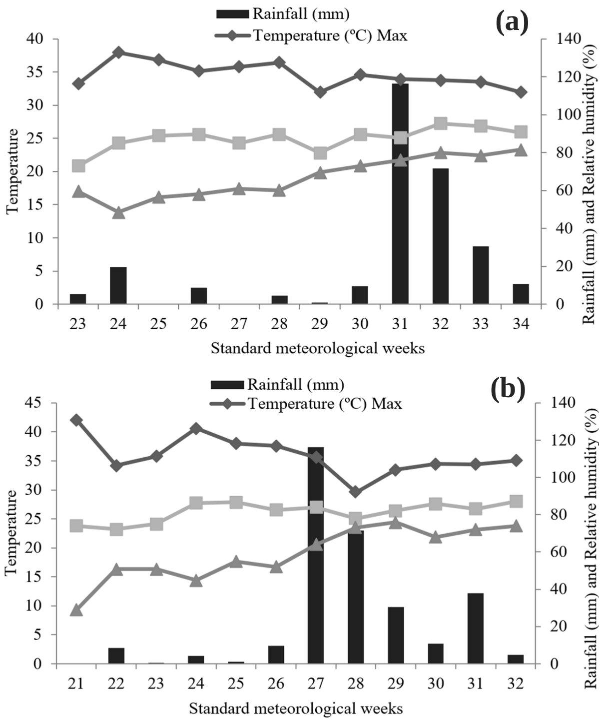

Figure 1. Weekly weather parameter during the crop season at (a) Gurdaspur and (b) Ludhiana

the last week of May at both the locations. A manual hand drill was used for sowing the seed in opened furrows at a depth of 4-6 cm with row spacing as per the treatments. The seed rate for 30 cm row spacing and 22.5 cm row spacing was 75 kg/ha and 90 kg/ha, respectively. For intercrop sowing one row of cowpea and guara as per the treatments were sown in between the maize rows. The crop was fertilized with 87.5:30:20 kg N:P:K/ha through Urea, Single Super Phosphate, Muriate of Potash respectively. One third dose of N and entire dose of phosphorus and potassium was drilled at the time of sowing. The crop was irrigated as when required and depth of each irrigation was 5 cm. The area of each treatment combination was 12 m^2 (4 x 3m) and with three replications. The crop was harvested for taking green fodder yield at dough stage of 78 days after seeding (DAS) at both Ludhiana and Gurdaspur. Maize and intercrops were harvested separately from plots by using sickle. The observations on yield attributes and green fodder yield were recorded at harvest. Maize equivalent green fodder yield was calculated to compare the weed control treatments by converting the green fodder yield of intercropping treatments into maize equivalent green fodder yield based on the prevailing market prices. The density and biomass of weeds were recorded at the knee high stage of the crop corresponding to 35-40 days after sowing (DAS) by placing the quadrat following standard procedure. The mean data of three replications of weed density, weed biomass and weed control efficiency (WCE) were correlated with yield attributes and yields. WCE was computed using weed biomass in treated plots compared to weedy check. Statistical analysis of the data was done using analysis of variance in split plot using OPSTAT software and statistical mean differences were found by Fisher's protected least significant difference test at $p<0.05$. The relationship of weed density, weed dry weight and WCE with green fodder yield was described by using linear regression models.

At the knee high stage of the crop, both the cultivars responded similarly against weed competition at both Gurdaspur and Ludhiana (**Table 1**). Statistically non-significant differences were observed in weed density and biomass at both the locations with the tested two fodder maize cultivars although both weed density and biomass remained comparatively lower in J1007. Nonetheless, a significantly higher maize equivalent green fodder yield (6-7%) was recorded with J1007 due to differential competing ability, inherent genetic yield potential, vigorous crop growth in terms of the plant height and dry weight accumulation which led to more smothering effect on the weeds growing beneath and thus higher yields (Kumar *et al.* 2013).

Row spacings differed significantly in influencing the density and biomass of weeds both at Gurdaspur and Ludhiana (**Table 1**). As compared to wider row spacing, there was significant reduction of 21.3% in weed density and 22.2% in weed biomass in narrow row spacing at Gurdaspur. Similarly, at Ludhiana, weed density decreased significantly by 21.2% and weed biomass by 19.8% in narrow row spacing over the wider rows. This could be possibly due to lesser space available for the weeds to grow in narrow rows of the crop. Narrow row spacing had WCE of 72.5% at Gurdaspur and 70.5% at Ludhiana while the values of WCE for wider rows were 64.8% at Gurdaspur and 63.4% at Ludhiana. Maize equivalent green fodder was observed to be significantly more when the crop was sown in narrow row spacing as compared to the crop sown in wider row spacing. A lesser weed density and biomass in narrow crop rows indicated increased crop competitiveness against weeds (Chauhan and Johnson 2011). This might have led to better utilization of different growth resources by the crop which was ultimately reflected in increased green fodder yield in narrow rows.

Among the different weed control treatments, at the knee high stage of the crop, significantly minimum density and biomass of all types of weeds was recorded in weed free and maximum in un-weeded control at both the locations (**Table 1**). Among the herbicide treatments, significantly higher reduction in weed density and biomass was observed with tembotrione 120 g/ha PoE at Gurdaspur. A significant reduction in density and biomass of grasses and broad-leaved weeds with tembotrione 110 and 120 g/ha was also reported by Kaur *et al.* (2018). Atrazine 625 g/ha PE was found to be at par with maize + cowpea intercropping in the reduction of weed density and biomass. Similar trend was observed at Ludhiana and Gurdaspur. At both the locations, the green fodder yield of maize was significantly highest in weed free treatment followed by the plots treated with tembotrione 120 g/ha. Atrazine 625 g/ha PE and maize sown in intercropping with cowpea recorded statistically similar green fodder yields. While significantly lowest green fodder yield of maize was observed in the weedy plots.

The correlation matrix (**Table 2**) revealed that the density and biomass of weeds were negatively correlated with green fodder yield at both the locations while maize plant dry weight, plant height and WCE had significant positive correlation with green fodder yield (**Table 2**). The highest degree of positive association was observed between weed density and biomass (r = 0.892** at Gurdaspur and r = 0.979** at Ludhiana). This was followed by the correlation of WCE with green fodder yield (r = 0.849**) at Gurdaspur and correlation of plant height with green fodder yield (r = 0.885**) at Ludhiana. In all the cases, the correlations were highly significant *i.e.* at 1% probability level. The correlation coefficients amongst WCE, plant dry weight, plant height and fodder yield were positive (r = 0.562 to 0.849 at Gurdaspur; r = 0.710 to 0.885 at Ludhiana).

The regression analysis of maize equivalent green fodder yield as affected by weed density and biomass also confirmed the negative relationship between these parameters (**Figure 2a** and **2b**). The regression equation predicted a linear reduction in the green fodder yield with a unit increase in the density and dry weight of weeds (Soni *et al*. 2021). The magnitude of reduction could be 0.099 and 0.095 t/ha for weed density and biomass at Gurdaspur and 0.032 and 0.071 t/ha for weed density and biomass at Ludhiana. The reduction in fodder yield could mainly be attributed to reduction in the yield attributing parameters, *viz.* plant dry weight and plant height as indicated by the correlation coefficients. The regression analysis of green fodder yield with WCE

Table 1. Weed density and biomass, weed control efficiency at knee high stage and maize equivalent green fodder yield as affected by different weed management treatments at Gurdaspur and Ludhiana

Treatment	Weed density (no./m²)		Weed biomass (g/m²)		WCE (%)		Green fodder yield (t/ha)	
	Gurdaspur	Ludhiana	Gurdaspur	Ludhiana	Gurdaspur	Ludhiana	Gurdaspur	Ludhian
Cultivar								
J 1006	9.27 (103.3)	13.53 (229.1)	6.59 (56.7)	7.74 (77.1)	68.3	65.6	41.61	37.14
J 1007	9.02 (97.1)	13.09 (216.5)	6.48 (55.3)	7.27 (70.7)	69.1	68.4	44.37	39.37
LSD (p=0.05)	NS	NS	NS	NS			1.57	1.45
Row spacing (cm)								
30	9.69 (112.2)	14.17 (249.2)	7.02 (63.0)	8.02 (82.0)	64.8	63.4	41.09	36.45
22.5	8.61 (88.3)	12.45 (196.4)	6.05 (49.0)	6.99 (65.8)	72.6	70.5	44.90	40.05
LSD (p=0.05)	0.41	0.73	0.25	0.48			1.57	1.45
Weed control								
Weedy check	14.06 (197.9)	23.53 (553.8)	13.40 (179.0)	15.15 (229.1)	0.0	0.0	33.06	28.75
Weed free	1.00 (0.0)	1.00 (0.0)	1.00 (0.0)	1.00 (0.0)	100.0	100	51.88	46.70
Atrazine 625 g/ha	10.23 (103.9)	13.93 (194.9)	6.44 (40.8)	7.18 (51.9)	77.2	77.3	43.25	38.40
Tembotrione 120 g/ha	7.62 (58.9)	11.14 (126.3)	4.42 (19.5)	5.62 (31.3)	89.1	86.3	47.70	41.98
Maize + cowpea	10.71 (114.4)	14.38 (207.6)	6.73 (44.8)	7.70 (60.7)	75.0	73.4	42.46	37.89
Maize + guara	11.26 (126.4)	15.89 (254.2)	7.20 (51.8)	8.39 (70.4)	71.1	69.2	39.59	35.80
LSD (p=0.05)	0.65	0.81	0.64	0.71			1.29	1.18

Table 2. Correlation coefficient (*r*) values of weed density, weed biomass, weed control efficiency with yield and yield attributing characters of fodder maize at Gurdaspur and Ludhiana

Parameter	Weed density		Weed biomass		Weed control efficiency		Plant dry biomass		Plant height		Fodder yield	
	Gurdaspur	Ludhiana	Gurdaspur	Ludhiana	Gurdaspur	Ludhiana	Gurdaspur	Ludhiana	Gurdaspur	Ludhiana	Gurdaspur	Ludhiana
Weed density	1.000	1.000	0.892**	0.979**	-0.881**	-0.974**	-0.888**	-0.779**	-0.732**	-0.812**	-0.955**	-0.944**
Weed biomass	0.892**	0.979**	1.000	1.000	-0.996**	-0.998**	-0.775**	-0.715**	-0.675**	-0.716**	-0.864**	-0.890**
Weed control efficiency	-0.881**	-0.974**	-0.996**	-0.998**	1.000	1.000	0.784**	0.723**	0.668**	0.710**	0.849**	0.878**
Plant dry biomass	-0.888**	-0.779**	-0.775**	-0.715**	0.784**	0.723**	1.000	1.000	0.562**	0.783**	0.835**	0.772**
Plant height	-0.732**	-0.812**	-0.675**	-0.716**	0.668**	0.710**	0.562**	0.783**	1.000	1.000	0.787**	0.885**
Fodder yield	-0.955**	-0.944**	-0.864**	-0.890**	0.849**	0.878**	0.835**	0.772**	0.787**	0.885**	1.000	1.000

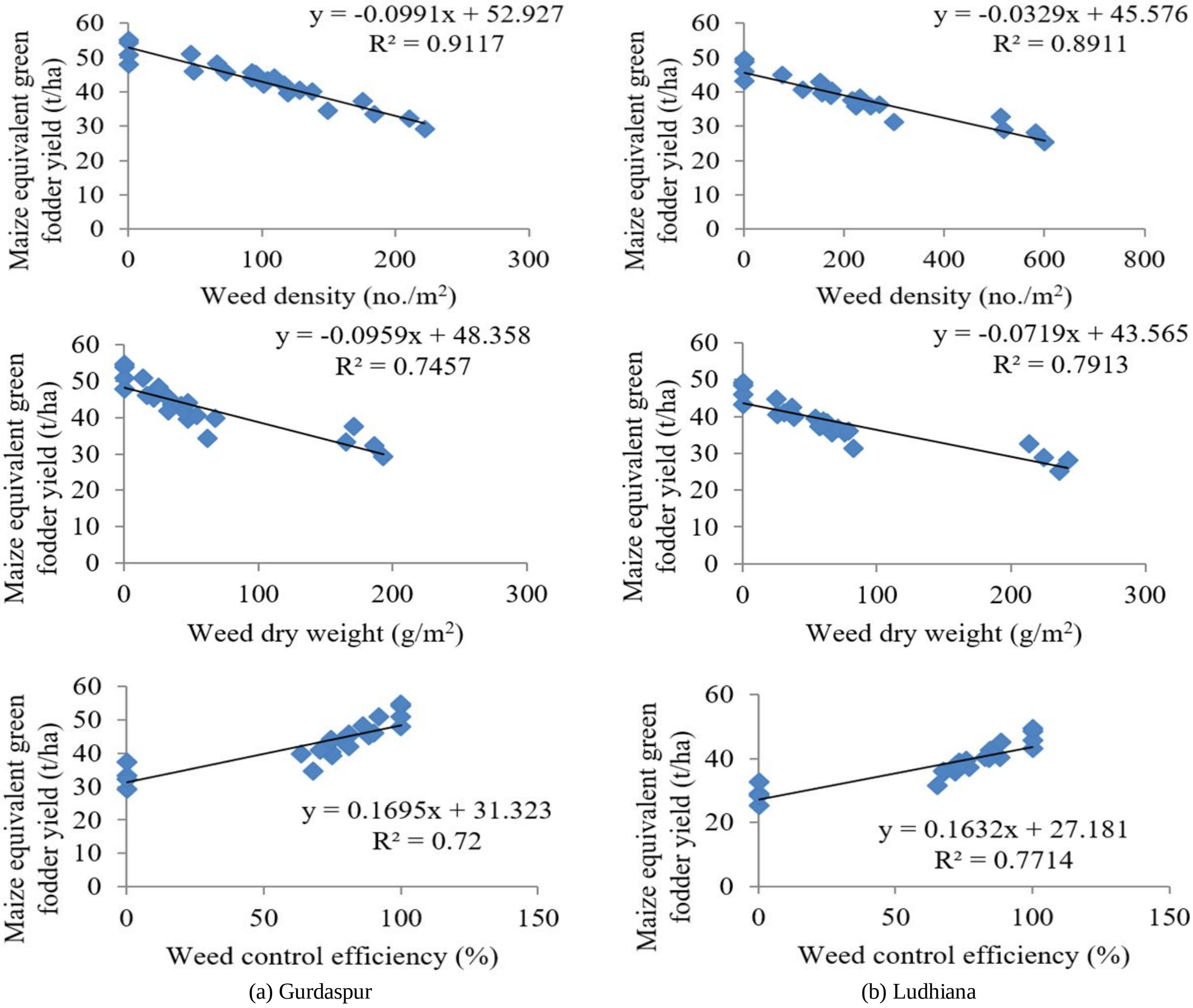

Figure 2. Regression analysis of maize equivalent green fodder yield (t/ha) as affected by weed density, weed dry weight (biomass) and weed control efficiency at (a) Gurdaspur and (b) Ludhiana

revealed that 1% increase in the WCE led to an increase of 0.169 t/ha in the green fodder yield at Gurdaspur and an increase of 0.163 t/ha at Ludhiana. The increase in yield by unit increase in WCE was also reported by Yadav *et al* (2015).

It may be concluded that suppression of weed density and biomass by cultivar J1007 was greater than J1006, although the differences were statistically non-significant. The cultivar J1007 also recorded higher green fodder yield than J1006. Further, the control of weeds at critical stages by the use of narrow row spacing or herbicides or intercropping increased the WCE which in turn enhanced the crop competitiveness and yield attributes resulting in higher green fodder yield of maize.

REFERENCES

Chauhan BS and Johnson DE. 2011. Row spacing and weed control timing affect yield of aerobic rice. *Field Crops Research* **121**: 226–231.

Hanif NQ and Akhtar N. 2020. Nutritional evaluation of maize plant fodder grown in spring and autumn season in Punjab, Pakistan. *Journal of Bioresource Management* **7**(1): 74–93.

Kaur T, Bhullar MS and Kaur S. 2018. Tembotrione - a post-emergence herbicide for control of diverse weed flora in maize in North-West India. *Maydica* **63**(M30): 1–8.

Kumar P, Singh Y and Singh UP. 2013. Evaluation of cultivars and herbicides for control of barnyard grass and nut sedge in boro rice. *Indian Journal of Weed Science* **45**(2): 76–79.

Soni JK, Amarjeet, Punia SS and Choudhary VK. 2021. Herbicide combinations for management of resistance in *Phalaris minor*. *Indian Journal of Weed Science* **53**(1): 41–48.

Singh K, Tarundeep K, Bhullar MS, Brar AS. 2016. The critical period for weed control in spring maize in North-West India. *Maydica* 61(M1): 1–7.

Sunitha N, Reddy MP and Malleswari S. 2010. Effect of cultural manipulation and weed management practices on weed dynamics and performance of sweet corn (*Zea mays* L.). *Indian Journal of Weed Science* **42**(3&4): 184–188.

Yadav KS, Dixit JP, Prajapati BL. 2015. Weed management effects on yield and economics of blackgram. *Indian Journal of Weed Science* **47**(2): 136–138.

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RESEARCH NOTE

Crop establishment methods and weed management on productivity of cowpea

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ABSTRACT

A field study was carried out at College of Agriculture, Vellanikkara during October- December 2020 to study the effect of different crop establishment and weed management methods on the productivity of cowpea. Treatment consisted of two crop establishment methods, *viz.* broadcast seeding and line sowing and six weed management treatments, *viz.* hand weeding twice 20 and 40 days after seeding (DAS), post-emergence application (PoE) of imazethapyr + imazamox (pre-mix) 40 g/ha at 15-20 DAS, imazethapyr + imazamox 40 g/ha (pre-mix) PoE at 15- 20 DAS followed by (*fb*) hand weeding at 40 DAS, imazethapyr 40 g/ha PoE at 15- 20 DAS, imazethapyr, 40 g/ha PoE at 15- 20 DAS *fb* hand weeding 40 DAS and unweeded control. The highest cowpea yield was recorded with hand weeding twice (937.67 kg/ha), followed by imazethapyr + imazamox 40 g/ha PoE at15- 20 DAS *fb* hand weeding (877.30 kg/ha). Line sown crop recorded higher cowpea yield compared with broadcasting. Imazethapyr + imazamox 40 g/ha PoE at 15- 20 DAS *fb* hand weeding at 40 DAS use in broadcasted seeded and line sown cowpea resulted in higher grain yield, net return and B:C and hence can be recommended as a cost effective weed management practice for enhancing productivity of broadcasted seeded and line sown cowpea.

Keywords: Cowpea, Establishment method, Imazamox + imazethapyr, Line sowing, Weed management

Cowpea (*Vigna unguiculata*) is a warm weather leguminous crop, grown in both tropical and subtropical climate. Better performance under harsh and hardy condition, tolerance to heavy rain, smothering character, and soil restoring properties facilitate year round production of cowpea, which grown as sole crop, intercrop, catch crop, cover crop, green manure crop for the purpose of green pods, grains and fodder. Cowpea grain contains 24-32% protein, 50-60% carbohydrate and 1% fat. Protein is 2-3 times of cereal and tubers and rich in lysine and tryptophan, which makes an excellent complimentary food with rice and wheat**.**

Broadcast seeding is the commonly adopted method of planting for cowpea. Line sowing is another method of crop establishment suitable for cowpea. Weed infestation declines the yield, intensifies pest and disease problem, increases the cost of production and reduces the quality of produce. The uncontrolled weeds cause cowpea yield reduction up to 70.8% (Mekonnen *et al.* 2015). Cowpea is considered as a smother crop, due to thick and quick foliage growth but weedy conditions during the initial phase of growth adversely affect the crop. Hence, proper weed management during critical period optimises the overall growth and yield of cowpea.

Manual weeding is time consuming, laborious and uneconomical in large scale cultivation. Use of herbicides appears to be an alternate option, which is easy, economical, rapid in action, effective and safe, if used properly. The research on the economical an effective herbicide for weed management in broadcasted seeded and line sown cowpea is limited. Hence the present study was carried out to identify effective and economical weed management options for enhancing productivity of cowpea established by broadcasting seeding and line sowing.

Field experiment was carried out from October to December 2020 at the Department of Agronomy, College of Agriculture, Vellanikkara. The experiment was laid out with factorial RBD with two factors replicated thrice. Tested treatments include: two methods of crop establishments, *viz.* broadcast seeding and line sowing and six weed management treatments, viz., hand weeding twice at 20 and 40 days after seeding (DAS), post-emergence application (PoE) of imazethapyr + imazamox (pre-mix) 40 g/ha at 15-20 DAS , imazethapyr + imazamox 40 g/ha PoE at 15- 20 DAS followed by (*fb*) hand weeding at 40 DAS, imazethapyr 40 g/ha PoE at 15-20 DAS, imazethapyr 40 g/ha PoE at 15- 20 DAS *fb*

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hand weeding at 40 DAS and unweeded control. Cowpea variety PGCP-6 was used.

The soil of the experimental site was sandy clay loam in texture with a pH of 4.03, low in nitrogen, rich in phosphorous and medium in potassium. Beds of size 3.6 x 3.6 m were prepared for each treatment. Lime was applied at 250 kg/ha and before planting FYM (20 t/ha) was applied. Urea, factomphos and muriate of potash were applied to supply 20:30:30 kg N, P and K per hectare. Broadcast seeding and line sowing were done using seed rate of the rate of 25 kg/ha and 40 kg/ha in respective plots. Line sowing was done at a spacing of 30 cm x 15 cm. Five plants were selected at random for recording observations. The observations on weed density and biomass were taken at 30 and 60 DAS. Weeds samples were collected by using a quadrat of 50 cm x 50 cm. Data was analysed statistically by using GRAPES (General R shiny based Analysis Platform Empowered by Statistics).

Weed flora

Weed flora of experimental site comprised of broad-leaved weeds, grasses and sedges. Among broad-leaved weeds: *Phyllanthus amara, Mimosa pudica, Mitracarpus hirtus, Euphorbia hirta, Scoparia dulcis, Ageratum conyzoides, Cleome burmannii* and *Mollugo* sp. were dominant. *Digitaria ciliaris*, *Echinochloa colona*, *Cynodon dactylon* and *Oryza sativa* were major grassy weeds. *Cyperus iria* was the only sedge observed in field.

Effect on weeds

Line sowing of cowpea resulted in less weed density compared to broadcast seeding. The lowest weed biomass (3.50 and 4.66/gm^2), weed index (22%) and higher weed control efficiency (75% and 70%) was noted from line sown plots compared with broadcast seeded plot having higher weed biomass (5.09 and 4.91/gm^2), lower weed control efficiency (64% and 68%) and higher weed index (24%) as observed by Singh (2011). Higher weed biomass and reduced yield in broadcast seeding method might be a reason for low weed control efficiency and high weed index. In line sowing method, seeds were sown at a particular spacing, the growth of foliage led to faster canopy closer due to narrow spacing that hindered penetration of light causing reduction in germination and growth of weed seedling resulting in reduced weed density and biomass. Ashrafi *et al.* (2009) observed that line sowing is superior to broadcast seeding method of cowpea establishment, for effective weed management.

The broad-leaved weeds and grasses density and biomass; higher weed control efficiency was significantly influenced by weed management practices at both stages of observation. At 30 and 60 DAS, lower weed density and biomass was observed in hand weeded treatment closely followed by imazethapyr PoE *fb* HW at 40 DAS **(Table 1)**. This might be due to the continuous weed control in these treatments due to the hand weeding done at 40 DAS. The efficacy of imazethapyr and imazethapyr + imazamox in lowering weed density and biomass was reported by Rana *et al.* (2019) and Kumar and Singh (201)7.

At 30 DAS, the highest weed control efficiency was noted with hand weeding twice 20 and 40 DAS (90.34 %) followed by imazethapyr + imazamox 40 g/ha PoE 15- 20 DAS *fb* hand weeding 40 DAS (84.7%), which was on par with imazethapyr 40 g/ha PoE 15- 20 DAS (81.73%). Higher weed biomass and reduced yield might be a reason for low weed control efficiency and high weed index in unweeded plot. At 60 DAS also, hand weeding twice recorded higher weed control efficiency (87.38%). Deshkari *et al.* (2019) also reported similar findings. Imazethapyr + imazamox, 40 g/ha PoE 15- 20 DAS + hand weeding at 40 DAS recorded lower weed index.

Imazethapyr + imazamox, 40 g/ha PoE 15-20 DAS *fb* HW 40 DAS recorded lower weed biomass, weed index and higher weed control efficiency compared with imazethapyr + imazamox 40 g/ha PoE 15- 20 DAS. This can be attributed to the higher efficiency of integrated use of herbicides with physical control method such as hand weeding (Lamichhane *et al.* 2017).

Effect on cowpea growth and yield

Significantly higher yield was obtained with line sown cowpea (717 kg/ha) compared with broadcast seeded cowpea. Enough space will be available for line sown crops for the better orientation of leaves, which helps to harvest more light resulted in high photosynthetic rate and accumulation of photosynthates which eventually resulted in high grain yield of cowpea as observed by Mohler *et al.* (2001). Imazethapyr + imazamox 40 g/ha PoE 15- 20 DAS *fb* hand weeding at 40 DAS resulted in taller cowpea plants with higher LAI and dry matter production. Imazethapyr + imazamox 40 g/ha PoE 15-20 DAS *fb* hand weeding registered significantly higher number of pods per plant, pod weight, number of seeds per pod and 100 grain weight. The highest yield was recorded with hand weeding twice (938 kg/ha), followed by imazethapyr + imazamox 40 g/ha

PoE 15- 20 DAS *fb* hand weeding (877 kg/ha) **(Table 2)**. Similar result was also reported by Sasode *et al.* (2020) in blackgram. Adoption of weed management practices resulted in 70% higher yield in cowpea. Efficient weed control by herbicides, hand weeding and herbicides coupled with hand weeding at critical period of crop weed competition reduced competition of weeds with cowpea for resources, resulted in proper absorption of nutrients by crop and higher growth and yield parameters.

Economics

Broadcast seeding recorded higher net returns (₹ 82683/ha) and B:C (2.35) compared with line sowing, which recorded net returns of ₹ 71672/ha and B:C of 1.91. It was due to lower cost of cultivation for broadcast seeded cowpea. Labourers required for dibbling of seeds are more in line sown cowpea which resulted in higher cost of cultivation. Line sown cowpea registered the highest production and gross returns, but owing to high labour cost it recorded lower value of B:C compared to broadcast seeding. Saha *et al.* (2021) also reported that cost of cultivation for manual line sowing was very high compared to drill and broadcast seeding.

The highest net returns (₹ 102861/ha) and B:C (2.45) were noted with imazethapyr + imazamox, 40 g/ha PoE 15- 20 DAS *fb* HW at 40 DAS in broadcast seeded cowpea **(Table 3).** Weed management treatments have reduced weed density and biomass which reduced crop weed competition, helped the crop to grow with maximum potential and increased absorption of nutrients finally resulted in good yield contributing characters and yield. High grain yield resulted in maximum income. Higher net income from treated plot than weedy check might be an evidence for the efficiency of adopted weed control measures as observed by Mansoori *et al.* (2015) and Yadav *et al.* (2015).

Table 1. Effect of crop establishment and weed management treatments on weeds and cowpea growth parameters

Treatment	Total weed density (no./ m^2)		Weed biomass (g/m^2)		Weed control efficiency (WCE) (%)		Weed index (WI)	Leaf area index (LAI)		Dry matter production (DMP) at harvest (kg/ha)
	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS		40 DAS	60 DAS	
Crop establishment method										
Broadcast seeding	3.65(14.2)	2.61(6.7)	2.23(5.1)	2.16(4.9)	64.41	68.61	24.63	6.09	7.74	4501.51
Line sowing	2.74(8.7)	2.65(6.9)	1.86(3.5)	2.12(4.7)	75.49	70.21	22.04	3.55	4.50	4377.81
LSD (p=0.05)	0.09	NS	0.10	0.02				0.18	0.16	NS
Weed management practice										
Hand weeding twice at 20 and 40 DAS	2.48(5.8)	1.95(3.3)	1.34(1.3)	1.58(2.0)	90.34	87.38	1.47	4.76	5.90	4276.71
Imazethapyr + imazamox 40 g/ha PoE 15-20 DAS	2.64(6.7)	2.61(6.3)	1.97(3.5)	2.26(4.6)	75.76	70.55	24.83	4.81	6.21	4488.63
Imazethapyr + imazamox 40g/ha PoE 15-20 DAS *fb* HW 40 DAS	2.63(6.6)	1.95(3.3)	1.63(2.2)	1.88(3.0)	84.70	80.61	7.81	4.86	6.28	4762.75
Imazethapyr 40 g/ha PoE 15- 20 DAS	2.92(8.7)	2.70(6.8)	1.75(2.6)	1.59(2.0)	81.73	87.02	23.97	5.04	6.33	4625.69
Imazethapyr 40 g/ha PoE 15- 20 DAS *fb* HW 40 DAS	2.64(6.6)	2.88(7.5)	1.90(3.2)	1.59(2.0)	77.50	87.07	11.56	5.13	6.20	5084.68
Un weeded control	5.86(34.0)	3.76(13.7)	3.66(13.0)	3.94(15.1)	9.66	38.73	70.38	4.34	5.77	3399.50
LSD (p=0.05)	0.23	0.14	0.17	0.02				0.32	0.28	708.24

PoE: post-emergence application; HW: Hand weeding; DAS: days after seeding

Table 2. Effect of crop establishment and weed management treatments on yield parameters of cowpea

Treatment	Days to 50% flowering	100 grain weight (g)	No. of pods per plant	No. of seeds per pod	Pod weight (g)	Yield (kg/ha)
Crop establishment method						
Broadcast seeding	33.17	10.91	37.61	15.12	1.26	717
Line sowing	31.67	10.93	37.83	14.16	1.31	742
SE (m)	0.12			0.14	0.01	1.8
LSD (p=0.05)	0.37	NS	NS	0.42	0.04	5.2
Weed management practice						
Hand weeding twice at 20 and 40 DAS	32.17	11.08	41.66	15.00	1.49	938
Imazethapyr + imazamox 40 g/ha PoE 15-20 DAS	32.67	10.45	36.00	14.48	1.18	715
Imazethapyr + imazamox 40g/ha PoE 15-20 DAS *fb* HW 40 DAS	32.17	10.65	42.16	14.17	1.53	877
Imazethapyr 40 g/ha PoE 15- 20 DAS	32.67	11.50	35.67	13.80	1.24	723
Imazethapyr 40 g/ha PoE 15- 20 DAS *fb* HW 40 DAS	32.50	11.57	39.33	16.48	1.16	842
Un weeded control	32.33	10.26	31.50	13.90	1.11	282
LSD (p=0.05)	NS	0.54	1.41	0.74	0.06	9.1

PoE: post-emergence application; HW: Hand weeding; DAS: days after seeding

Table 3. Effect of crop establishment methods and weed management treatments on cost of cultivation, gross return, net return and B:C ratio

Treatment	Cost of cultivation (x10^3 `/ha)	Gross returns (x10^3 `/ha)	Net returns (x10^3 `/ha)	B:C
Crop establishment method				
Broadcast seeding	60.76	143.44	82.68	2.35
Line sowing	76.73	148.40	71.67	1.91
Weed management practice				
Hand weeding twice at 20 and 40 DAS	103.36	187.53	84.17	1.83
Imazethapyr + imazamox 40 g/ha PoE 15-20 DAS	65.63	143.07	77.44	2.22
Imazethapyr + imazamox 40g/ha PoE 15-20 DAS *fb* HW 40 DAS	72.60	175.47	102.86	2.45
Imazethapyr 40 g/ha PoE 15- 20 DAS	64.01	144.70	80.69	2.30
Imazethapyr 40 g/ha PoE 15- 20 DAS *fb* HW 40 DAS	71.03	168.33	97.30	2.40
Un weeded control	35.83	56.43	20.60	1.59

PoE: post-emergence application; HW: Hand weeding; DAS: days after seeding

This study indicated that though line sowing resulted in increased productivity, the higher net returns and B:C was obtained with broadcast seeding. Weed management practices increased the productivity of cowpea under both crop establishment methods. Application of imazethapyr + imazamox, 40 g/ha PoE 15-20 DAS *fb* hand weeding at 40 DAS can be recommended as a cost-effective weed management practice for enhancing productivity of broadcast seeded and line sown cowpea.

REFERENCES

Ashrafi ZY, Rahnavard A and Sedigheh S. 2009. Analogy potential effects of planting methods and tank mixed herbicides on wheat yield and weed populations. *Journal of Agricultural Science and Technology* **5**(2): 391–403.

Deshkari SM, Pagar PC, Dangore ST, Khawale VS and Mendhe HS. 2019. Effect of imazethapyr+ imazamox on weed control in soybean. *Journal of Soils and Crops* **29**(2): 280–284.

Kumar P and Singh R. 2017. Integrated weed management in cowpea (*Vigna unguiculata* (L.) Wasp.) under rainfed conditions. *International Journal of Current Microbiology and Applied Sciences* **6**(3): 97–101

Lamichhane JR, Devos Y, Beckie HJ, Owen MD, Tillie P, Messéan A and Kudsk P. 2017. Integrated weed management systems with herbicide-tolerant crops in the European Union: Lessons learnt from home and abroad. *Critical Reviews Biotechnology* **37**(4): 459–475.

Mansoori N, Bhadauria N and Rajput RL. 2015. Effect of weed control practices on weeds and yield of black gram (*Vigna mungo*). *Legume Research* **38**(6): 855–857.

Mekonnen G, Sharma JJ, Negatu L and Tana T. 2015. Effect of integrated weed management practices on weeds infestation, yield components and yield of cowpea [*Vigna unguiculata* (L.) Walp.] in eastern Wollo, northern Ethiopia. *Journal of Experimental Agriculture International* **7**(5): 326–346.

Mohler CL, Liebman M and Staver CP. 2001. *Ecological management of agricultural weeds*. United Kingdom. Cambridge University Press. Pp. 269–321.

Rana SS, Singh G, Rana MC, Sharma N, Kumar S, Singh G and Badiyala. 2019. Impact of imazethapyr and its ready-mix combination with imazamox to control weeds in black gram. *Indian Journal of Weed Science* **51**(2): 151–157.

Sasode DS, Joshi E, Jinger D, Sasode RS, Gupta V and Singh YK. 2020. Conservation tillage and weed management practices effect on weeds, yield and profitability of cowpea (*Vigna unguiculata*). *Indian Journal of Agricultural Science* **90**(1): 86–90.

Singh G.2011. Weed management in summer and kharif season blackgram [Vigna mungo (L.) Hepper]. *Indian Journal of Weed Science* **43**: 77–80.

Yadav KS, Dixit JP and Prajapati BL. 2015. Weed management effects on yield and economics of black gram. *Indian Journal of Weed Science* **47**(2): 136–138.

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RESEARCH NOTE

Effect of weed control methods on weeds, onion growth and yield

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ABSTRACT

Onion (*Allium cepa* L.) is a widely grown vegetable crop in India. Onion production is severely affected by the weed menace which hampers onion growth and yield. A study was conducted at Birsa Agricultural University, Ranchi during 2018 to identify the best feasible method for weed management in onion. Treatments tested include: plastic mulch, available weed mulch at 6t/ha, paddy straw mulch at 7 t/ha, cover crop, pre-emergence application (PE) of oxyfluorfen 0.5 kg/ha, pendimethalin 1 kg/ha PE, mechanical weeding, hand weeding and weedy check. Amongst the treatments, black plastic mulch was found to be most effective in controlling weeds with minimum weed density and biomass, weed index (%) and highest weed control efficiency (%) as compared to other treatments. Onion grown with black plastic mulch showed better onion growth in terms of maximum plant height, number of leaves/plant, neck thickness and maximum onion yield attributes like average bulb weight, average bulb diameter and bulb yield. However, pendimethalin PE recorded highest net returns and B:C as it was cost effective.

Keywords: Mulching, Onion, Oxyfluorfen, Pendimethalin, Weed management

Onion (*Allium cepa* L.) is an important vegetable crop grown all over the world. India grows onion in 1.65 million hectare with production of 26.9 million metric (National Horticulture Board 2020). Onion has sparse foliage and shallow root system which results in greater susceptibility to weeds infestation ultimately leading to low productivity. The growth rate of onion after sprouting is far slow than the weed growth which is often rapid and thus generating competition for space and nutrients. Weed problem in onion is a major constraint in onion which interferes with crop production causing onion yield losses in a range of 49-86% (James and Harlen 2010) and adds to the cost of cultivation (Dhananivetha *et al.* 2017). Close spacing in onion makes manual weeding laborious and expensive. The approach of integration of physical, mechanical and chemical methods involving mulching, hand weeding and use of herbicides, respectively seem better and effective alternative to the traditional hand weeding. The objective of this study was to identify the best method of weed control to realize increased onion growth and yield.

The field experiment was carried out during *Rabi* season of 2018 in the agronomical research farm of Birsa Agricultural University, Ranchi, Jharkhand. The experimental site has sub-humid climate and the soil was of red-yellow light grey type soil representing the major soil group of Chhotanagpur plateau. The experiment was laid out in a randomized block design with nine treatments replicated thrice. The treatments studied were: black plastic mulch, available weed mulch at 6 t/ha, paddy straw mulch at 7 t/ha, cover crop, pre-emergence application (PE) of oxyfluorfen 0.5 kg/ha, pendimethalin 1.0 kg/ha PE, mechanical weeding, hand weeding and weedy check. Coriander was used as a cover crop. Treatments black plastic mulch, available weed mulch, paddy straw mulch and cover crop were applied at the time of transplanting whereas oxyfluorfen and pendimethalin treatments were applied before transplanting. Mechanical weeding with dutch hoe and hand weeding treatments were carried out at three times intervals *i.e.* at 20, 40 and 60 days after transplanting (DAT). Treatment of weedy check was taken as control.

The effect of above treatments on the weed dynamics were evaluated by recording weed density and biomass and estimating weed control efficiency and weed index using standard procedures. Observations on weeds and onion growth parameters were recorded at 30, 60 and 90 days after planting. The density of different weed species in each plot were studied with the help of a square iron frame (quadrat) measuring 25 x 25 cm placed at random spots. Weeds within the quadrat were counted. Thereafter, they were classified into three categories, *viz.* grassy, broad-leaved and sedge weeds. The

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observation thus recorded was computed to give weed density. For estimating dry matter of weeds (biomass), the collected weed samples were sun dried followed by oven drying at 60±5ÚC until attainment of constant weight. Weed control efficiency was calculated on the basis of reduction in weed biomass in treated plot in comparison with the control plot. Weed index was calculated on the basis of reduction in yield of onion in weed free compared to yield in treated plot. Apart from this, their effect on various growth attributes such as plant height, number of leaves/plant, number of tillers/plant and yield attributes like average weight of bulb, bulb diameter, total bulb yield were also recorded.

The analysis of variance method (Gomez and Gomez 2003) was followed for statistical analysis of various data. The significance of different sources of variations was tested by “error mean square method” of Fisher Snedecor’s ‘F’ test at probability level 5 %. Weed density and dry matter of weed were subjected to square root transformation before statistical analysis.

Effect on weed flora

The observed weeds in the onion experimental field were: *Cyperus rotundus, Cynodon dactylon, Parthenium hysterophorus, Digitaria sanguinalis, Convolvulus arvensis, Anagallis arvensis, Chenopodium album, Meliotus indica, Sphaeranthus indicus, Ageratum conyzoides, Ageratum conyzoides, Stellaria media* and *Sorghum halepense*.

Black plastic mulching recorded the lowest weed density at 30, 60 and 90 DAT **(Table 1)**. Black plastic mulch was at par with hand weeding, pendimethalin PE and oxyfluorfen PE at all the studied dates in case of broad-leaved, while in case of narrow-leaved weeds, these treatments were at par at 30 DAT. At 90 DAT black plastic mulch was significantly superior over other treatments. The hand weeding, use of polythene mulch and herbicides reduced the fresh and dry weed biomass. Rajablariani and Aghaalikhani (2012) also reported similar results and attributed it to increase in soil temperature 3.3 to 6.6^0C in mulching compared to no mulch.

The black plastic mulch recorded the lowest biomass of broad- and narrow-leaved weeds at 30, 60, 90 DAT **(Table 1)** and was at par with hand weeding, pendimethalin PE and oxyfluorfen PE at all dates of observation. The highest weed biomass was noted in the weedy check due to the increased weed density, continuous growth and higher amount of nutrient uptake confirming the findings of Ashrafuzzaman *et al.* (2011), Bobby *et al.* (2017), Sathiyamurthy *et al.* (2017) and Barla *et al.* (2018).

Weed control efficiency (58.09, 56.87 and 62.89% at 30, 60, 90 DAT, respectively) was highest with black plastic mulch and it was at par with hand weeding, pendimethalin PE and oxyfluorfen PE at all the time intervals. The weedy check recorded lowest weed control efficiency at all recorded dates.

Table 1. Effect of weed control methods on weed density and biomass in onion

Treatment	Weed density (no./m^2)						Weed biomass (g/m^2)					
	Broad-leaved weeds			Narrow-leaved weeds			Broad-leaved weeds			Narrow-leaved weeds		
	30 DAT	60 DAT	90 DAT	30 DAT	60 DAT	90 DAT	30 DAT	60 DAT	90 DAT	30 DAT	60 DAT	90 DAT
Black plastic mulch	1.99	2.31	2.27	2.44	2.49	2.24	1.00	2.50	2.76	1.21	1.92	1.33
	(1.90)	(2.01)	(1.98)	(2.06)	(2.07)	(1.95)	(1.48)	(2.42)	(2.15)	(1.55)	(1.89)	(1.61)
Available weeds as mulch	3.97	4.03	4.07	5.48	5.76	4.49	1.82	4.47	4.43	1.74	3.15	4.72
	(2.49)	(2.50)	(2.51)	(2.84)	(2.89)	(2.62)	(1.84)	(2.61)	(2.60)	(1.79)	(2.27)	(2.67)
Straw mulch	3.53	3.66	3.76	4.46	4.80	4.63	1.63	4.12	3.99	1.7	3.12	3.63
	(2.38)	(2.41)	(2.43)	(2.61)	(2.69)	(2.63)	(1.77)	(2.51)	(2.47)	(1.78)	(3.12)	(2.41)
Cover crop	3.99	4.05	4.12	5.73	5.92	6.04	1.74	4.49	4.56	1.82	3.49	4.80
	(2.50)	(2.50)	(2.53)	(2.89)	(2.92)	(2.96)	(1.81)	(2.61)	(2.61)	(1.83)	(2.37)	(2.67)
Oxyfluorfen PE	3.25	3.38	3.49	3.83	4.49	4.89	1.38	3.68	3.53	1.48	2.79	2.75
	(2.30)	(2.33)	(2.36)	(2.45)	(2.62)	(2.71)	(1.66)	(2.41)	(2.37)	(1.65)	(2.16)	(2.15)
Pendimethalin PE	3.25	3.32	3.39	3.75	4.19	4.89	1.28	3.49	3.48	1.47	2.16	2.33
	(2.30)	(2.32)	(2.34)	(2.43)	(2.54)	(2.71)	(1.62)	(2.35)	(2.36)	(1.68)	(1.89)	(2.01)
Mechanical weeding	3.48	3.58	3.68	4.72	4.72	6.11	1.47	4.07	3.97	1.51	2.85	3.31
	(2.37)	(2.39)	(2.42)	(2.65)	(2.67)	(2.97)	(1.70)	(2.50)	(2.49)	(1.70)	(2.19)	(2.31)
Hand weeding	2.76	2.93	3.07	2.57	4.16	6.88	1.21	3.07	3.25	1.28	2.12	2.30
	(2.16)	(2.21)	(2.25)	(2.10)	(2.54)	(3.11)	(1.58)	(2.22)	(2.29)	(1.59)	(1.94)	(2.00)
Weedy check	4.56	4.53	4.49	6.32	6.6	7.60	3.01	4.99	5.06	3.01	3.12	5.18
	(2.64)	(2.63)	(2.62)	(3.01)	(3.07)	(3.26)	(2.22)	(2.32)	(2.73)	(2.21)	(2.27)	(2.76)
LSD (p=0.05)	0.41	0.49	0.49	0.45	0.53	0.52	0.29	0.51	0.48	0.32	0.46	0.41

Original values in parentheses are subjected to $\sqrt{x+0.5}$ transformation

The black plastic mulch recorded the lowest weed index (10.58%) followed by pendimethalin (11.51%), oxyfluorfen (17.64 %) whereas highest was noted in weedy check (56.34%).

Effect on onion

Maximum onion plant height, number of leaves, neck thickness was observed with black plastic mulch at all the crop growth stages, due to lesser crop-weed competition at earlier stages of growth for availability of space, light, moisture and nutrients. The crop weed competition for growth resources, water conservation and optimal soil temperature for plants were found to be better under the mulched than unmulched plots. Mulching created a favourable environment in the root zone resulting in absorption of more water and nutrients from soil and provided better control over weed competition throughout different growth stages of the crop. Similar findings were also reported by Rajablariani *et al.* (2012), Hamma (2013) and Rachel *et al.* (2018).

The vitamin C content was highest with black plastic mulch (13.33 mg) which was significant over only treatments of cover crops (11.00 mg) and weedy check (11.00 mg) but was at par with rest of the treatments.

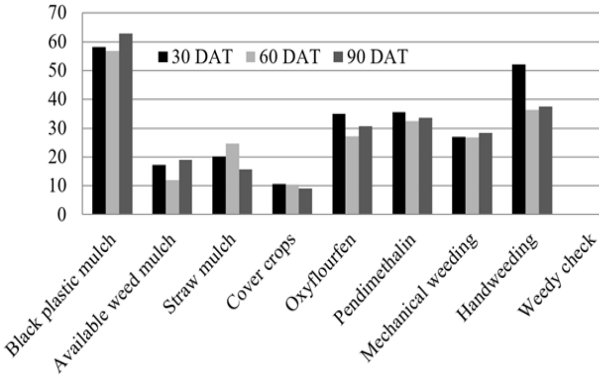

Figure 1. Effect of weed control treatments on weed control efficiency (%) in Onion

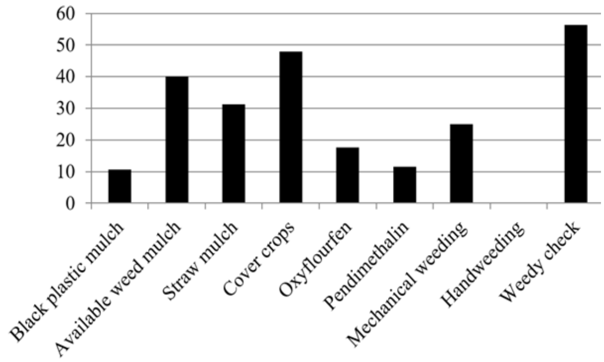

Figure 2. Effect of weed control treatments on weed index (%) in Onion

Table 2. Effect of weed control treatments on vegetative growth and yield parameters in onion

Treatment	Plant height (cm)			No. of leaves			Neck thickness (cm)			Yield	Average bulb circumference (cm)	Average bulb weight (g)	Vit. C content (mg)
	30 DAT	60 DAT	90 DAT	30 DAT	60 DAT	90 DAT	30 DAT	60 DAT	90 DAT	t/ha			
Black plastic mulch	19.39	34.02	42.32	2.66	4.00	7.20	1.96	4.33	4.13	20.99	20.99	89.95	13.33
Available weed mulch	15.42	23.68	32.58	2.32	3.43	4.83	1.37	3.19	2.89	15.00	17.32	67.86	11.33
Straw mulch	16. 23	25.33	35.08	2.27	3.67	4.97	1.76	3.62	2.94	15.99	17.50	68.55	12.00
Cover crops	14.73	23.60	28.75	2.23	3.33	4.60	1.23	2.85	2.53	14.19	16.82	67.04	11.00
Oxyfluorfen PE	16.85	26.89	39.02	2.61	3.73	6.93	1.78	3.88	3.56	17.84	19.27	78.02	12.33
Pendimethalin PE	17.94	27.64	40.13	2.62	3.90	7.03	1.83	4.08	3.82	18.99	20.08	84.94	12.67
Mechanical weeding	16.62	26.46	38.37	2.55	3.73	5.00	1.76	3.62	3.29	16.78	19.15	72.72	12.00
Hand weeding	18.07	32.11	42.32	2.63	3.93	6.50	1.93	4.18	3.99	18.82	20.55	89.84	12.67
Weedy check	14.27	20.28	26.68	2.17	3.23	4.60	1.12	2.73	2.52	13.42	16.45	56.35	11.00
LSD (p=0.05)	3.21	4.78	5.63	0.48	0.84	1.10	0.33	0.77	0.66	30.10	3.42	12.83	2.19

Table 3. Effect of weed control treatments on yield and economics of onion

Treatment	Yield (t/ha)	Cost of cultivation (₹/ha)	Gross returns (₹/ha)	Net returns (₹/ha)	B:C
Black plastic mulch	20.99	253148	524755	271607	2.07
Available weed mulch	15.00	156897	375007	218110	2.39
Straw mulch	15.99	165960	399754	233794	2.41
Cover crops	14.19	156523	354756	198233	2.27
Oxyfluorfen PE	17.84	156139	446004	289865	2.86
Pendimethalin PE	18.99	159690	474757	315067	2.97
Mechanical weeding	16.78	155022	419511	264489	2.71
Hand weeding	18.82	166268	470509	304241	2.83
Weedy check	13.42	153148	335496	182348	2.19
LSD (p=0.05)	3.10				

Price of onion= ₹ 25.00/kg

Onion average bulb circumference, average bulb weight and yield was highest with black plastic mulch treatment followed by pendimethalin PE and hand weeding. Lowest yield observed in the weedy check. Similar results were reported by Rahman *et al.* (2013), Hamma (2013), Masalkar *et al.* (2014) and Rachel *et al.* (2018). Pendimethalin PE recorded highest net return and B:C ratio as it is cost effective (**Table 3**).

It can be concluded that use of black polythene mulch was superior among all studied treatments in reducing weed growth and to attain better growth, development and yield of onion. But in terms of economics, pendimethalin PE was more cost effective and give highest returns and B:C than other control methods.

REFERENCE

Ashrafuzzaman M, Halim MA, Ismail MR, Shahidullah SM and Hossain MA.2011. Effect of black plastic mulch on growth and yield of chilli (*Capsicum annuum* L.). *Brazilian Archives of Biology and Technology* **54**(2): 321–330.

Barla S, Upasani RR, Puran AN and Sinha A. 2018. Effect of Black plastic Mulch and Herbicides on Weed Dynamics and Productivity of Red Gram. *International Journal of Current Microbiology and Applied Sciences* **7**: 363–369.

Bobby A, Prashanth P, Seenivasan N and Mishra P. 2017. Effect of different mulch materials on weed control in cucumber (*Cucumissativus* L.) hybrid "Multistar" under shade net conditions. *International Journal of Pure Applied Bioscience* **5**(5): 1246–1251.

Brewster JL. 1990. Physiology of crop growth and bulbing. In: Rabowitch HD, Brewster JL, Eds., Onions and Allied Crops, CRC Press: Boca Raton, FL. pp. 53–81.

Dhananivetha M, Amnullah MM, Arthanari PM and Mariappan S. 2017. Weed management in onion: A review. *Agricultural Reviews* **38**(1): 76–80.

FAO 2012.World onion production. Food and Agriculture Organization of the United Nations. http://faostat.fao.org.

Griffiths G, Trueman L, Crowther T, Thomas B and Smith B. 2002. Onions: A global benefit to health. *Phytotherapy Research* **16**(7): 603–615.

James RL and Harlen MHV.2010. Multiplication of reduced rate herbicides for weed control in onion. *Weed Technology* **24**: 153–159.

Masalkar SD, Bhalekar MN, Garad BV, Bhangre KK, Shinde US and Kolse RH. 2014. Effect of different mulches on growth and yield of onion cv. Phule Samarth. *BIOINFOLET-A Quarterly Journal of Life Sciences* **11**(2a): 316–318.

National Horticulture Board. 2002. http://nhb.gov.in/Statistics.aspx.

Rachel MG, Mondal MMA, Pramanik MHR and Awal MA. 2018. Mulches enhanced growth and yield of onion. *Bangladesh Journal of Scientific and Industrial Research* **53**(4): 305–310.

Rahman MA, Mahmud JA and Islam MM. 2013. Influence of mulching on the growth and yield of onion. *Technical Journal of Engineering and Applied Sciences* **3**(24): 3497–3501.

Sathiyamurthy VA, Rajashree V, Shanmugasundaram T and Arumugam T. 2017. Effect of different mulching on weed intensity, yield and economics in chilli (*Capsicum annuum* L.). *International Journal of Current Microbiology and Applied Sciences* **6**: 609–617.

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RESEARCH NOTE

Weed control in non-cropped situation using herbicides and their combinations

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ABSTRACT

A field experiment was conducted during rainy season in 2019-20 at Navsari Agricultural University, Navsari to identify efficient herbicides and their combinations to manage weeds in non-crop situation. The experiment was laid out in a randomized block design replicated thrice with seven weed management treatments involving herbicides *i.e.* glyphosate, paraquat, oxyfluorfen, 2,4-D amine salt along with mowing and weedy check. All treatments significantly reduced the weed density and biomass compared to weedy check. Glyphosate 3.0 kg/ha effectively controlled weeds registering negligible weed biomass at 60 days after application (DAA). Glyphosate 2.0 kg/ha alone or in combination with 2,4-D amine salt 2.0 kg/ha (tank-mix) and glyphosate + oxyfluorfen 2.0 kg/ha (ready-mix) were at par in their efficacy to control weeds up to 60 DAA and up to 30 DAA, respectively. Paraquat 4.0 kg/ha and paraquat 2.0 kg/ha + 2,4-D salt 2.0 kg/ha (tank-mix) were found effective up to two weeks only. Thus, glyphosate 2.0 kg/ha alone or in combination with 2,4-D amine salt 2.0 kg/ha (tank-mix) may be used to effectively minimize the weeds biomass and resurgences significantly up to 60 DAA with highest weed control efficiency.

Keywords: 2,4-D amine salt, Glyphosate, Non-cropped areas, Oxyfluorfen, Paraquat, Weed management

Weeds can grow under adverse climatic conditions interfering with the utilization of natural resources and become prolific, persistent, competitive, harmful, and even poisonous in nature (Patel *et al.* 2018). They have wide ecological amplitude, so multiply and flourish well even in aberrant environments. Non-cropland area such as orchards, pastures, grasslands, forests and wasteland ecosystems do not receive frequent cultivation and intensive care of the owners, hence are invaded by obnoxious weeds like *Parthenium hysterophorus, Cynodon dactylon, Cyperus rotundus, Sorghum halepense, Solanum xanthocarpum, Alternanthera sessilis*. The low productivity of these non-cropped ecosystems leads to scarcity of food, fuel wood, fodder, fruits, monkey menace and migration of men to towns and cities in search of jobs after leaving the land fallow (Kandasamy *et al.* 1999, Bajwa *et al*. 2016 and Kaur *et al.* 2020). However, majority of people depend for their subsistence needs on such uncultivated yet degraded lands. Productivity of such lands can be restored by managing these obnoxious perennial weeds with the available technologies. Besides, weeds invasion has led to shrinkage of grazing area for animals, reduction in productivity of grasslands by 90%, threat to plant biodiversity, reduced growth of newly planted trees in manmade forests and interference in succession of natural forests, act as hiding place for wild animals and threat to ecology of the region (Kumar *et al.* 2021). These weeds also cause toxic effects on animals and are threat to human health and environment (Bhowmick *et al.* 2016).

Weed control either manually or mechanically is costlier and less effective (Patel *et al.* 2017) under such situations. Herbicides have been found very effective and economically viable too, for control of weeds in non-cropped lands (Kewat *et al*. 2008; Bhowmick *et al.* 2017 and Kaur *et al.* 2020). Hence, tank mixture of 2,4-D with glyphosate and paraquat and glyphosate + oxyfluorfen (ready-mix) were tested for control of the weeds with regenerate underground parts and check their re-infestation in the same lands within short periods.

This experiment was conducted at College Farm, NMCA, Navsari Agricultural University, Navsari during *Kharif* 2019-20 under non cropped situation in field that was not used for cultivation and undisturbed. The selected site has uniform level and infested with location specific weeds, a true representative of non-cropped area. The soil of experimental site belongs to *Vertisol*, clayey in texture (62.37%), 0.68% organic carbon, 195.3, 51.3 and 480 kg/ha available nitrogen, phosphorus and potassium with pH of 7.6 and EC of 0.70 dS/m. The experiment was laid out in a randomized block design (RDB) with three replications that comprised nine weed management treatments, *viz*. glyphosate 2.0 kg/ha,

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glyphosate 3.0 kg/ha, paraquat 3.0 kg/ha, paraquat 4.0 kg/ha, glyphosate + oxyfluorfen 2.0 kg/ha (ready-mix), glyphosate 2.0 kg/ha + 2,4-D amine salt 2.0 kg/ha (tank-mix), paraquat 2.0 kg/ha + 2,4 D amine salt 2.0 kg/ha (tank-mix), mowing (one weed flush) and weedy check (control).

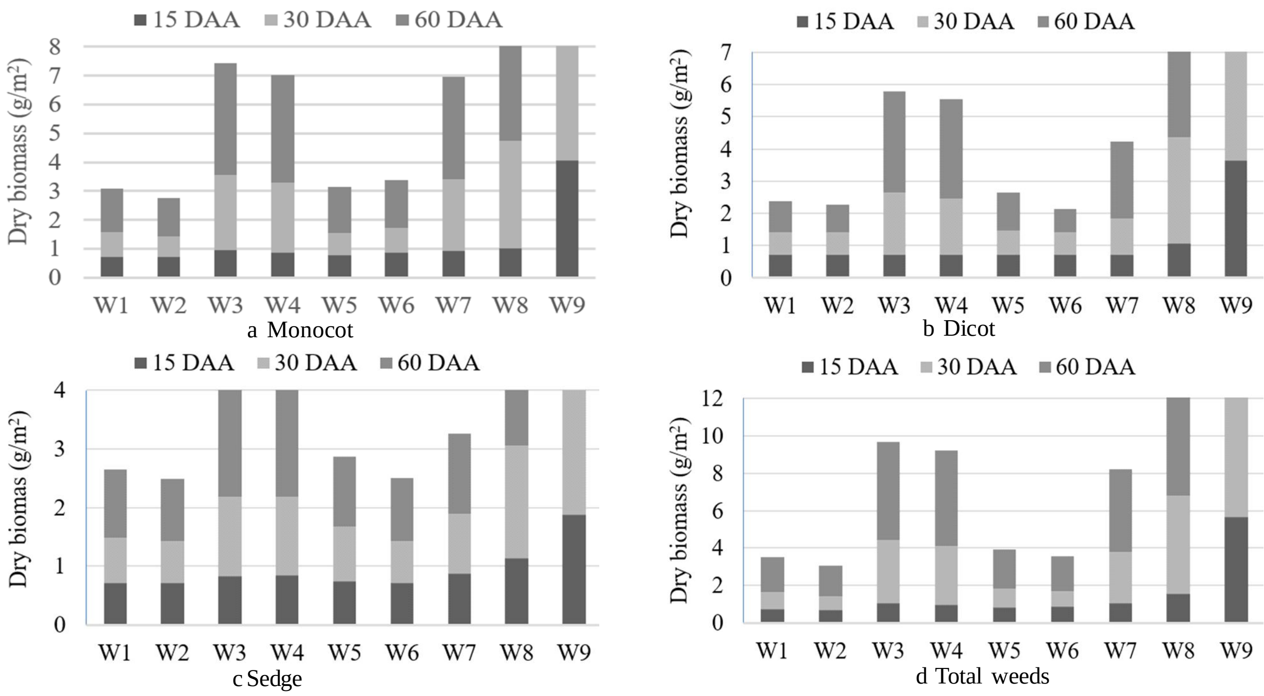
Before the onset of monsoon, selected site was prepared manually, demarcated with the help of wire to each of experimental unit. The net plot size was 5 m x 5 m. The required quantity of herbicides was applied using a knapsack spray fitted with a flat fan nozzle. Fresh solution for individual plot was prepared separately for each plot and spray volume *i.e.* 460 litres/ha was determined after calibration. Mowing was done manually with the help of iron sword. All the weed management treatments were imposed after 25 days of normal session of monsoon. The observation on category wise pre-existing weeds of monocots, dicots and sedges were recorded at 7, 15, 21, 30 and 60 days after herbicidal application by using a quadrat. The quadrat of 1 m^2 (1 x 1 m) was randomly placed in each plot and then the total and species wise weed count (density) was recorded. Weeds were clipped from ground surface, and dried in an oven at 65 ºC ±2 for 48 h for determining dry weed biomass. The data collected were subjected to Fisher's analysis of variance technique using "MSTATC" statistical software at $\sqrt{x+0.5}$ probabilities was applied to compare the differences among treatments means.

Weed flora and relative density

The predominant weeds in the experimental field include: *Sorghum halepense* (9.97%), *Cynodon dactylon* (11.10%), *Digitaria sanguinalis* (10.23%), *Echinochloa crus-galli* (7.77%), *Commelina benghalensis* (6.92%), others monocots (7.08%), *Parthenium hysterophorus* (8.65%), *Solanum xanthocarpum* (4.26%), *Digera arvensis* (9.30%), *Alternanthera sessilis* (8.54%), others dicots (6.44%) and *Cyperus rotundus* (9.82%). Further, non-dominant infestation was observed of *Dactyloctenium aegyptium* and *Eleusine indica* among monocot weeds and *Amaranthus viridis, Trianthema portulacastrum* and *Abelmoschus ficulneus* among dicot weeds.

Weed density and biomass

Monocot weeds: Mowing (one weed flush) was superior in completely reducing monocot weeds initially, and it was closely followed by paraquat (3.0 or 4.0 kg/ha). Further, glyphosate proved its efficacy by significantly reducing the monocot weeds density and biomass. Glyphosate at higher rate (3.0 kg/ha) controlled monocot weeds up to 30 days after herbicide application (DAA) with their minimal occurrence at 60 DAA (**Table 1** and **Figure 1**). Overall, post-emergence application (PoE) of glyphosate 2.0 kg/ha, glyphosate + oxyfluorfen 2.0 kg/ha (ready-mix) and glyphosate 2.0 kg/ha + 2,4-D



W_1: Glyphosate 2.0 kg/ha, W_2: Glyphosate 3.0 kg/ha, W_3: Paraquat 3.0 kg/ha, W_4: Paraquat 4.0 kg/ha, W_5: Glyphosate + Oxyfluorfen 2.0 kg/ha (ready mix), W_6: Glyphosate 2.0 kg/ha + 2,4 D salt 2.0 kg/ha (tank mix), W_7: Paraquat 2.0 kg/ha + 2,4 D salt 2.0 kg/ha (tank mix), W_8: Mowing (one weed flush), W_9: Weedy check (control)

Figure 1. Dry biomass (g/m²) of monocot, dicot, sedge and total weeds

salt 2.0 kg/ha (tank-mix) were found as effective as glyphosate 3.0 kg/ha in reducing the monocot weeds density and their dry biomass up to one 30 DAA with negligible incidence and biomass at 60 DAA. The density of perennial monocot weeds *viz.*, *Sorghum halepense* and *Cynodon dactylon* was reduced to nil at fifteen DAA by the aforesaid herbicides. Whereas the density of *Echinochloa crus-galli* and *Commelina benghalensis* was brought down to nil within a week of application of herbicides.

Dicot weeds: All the herbicidal treatments effectively minimised the weed density resulting in negligible dicot weeds biomass at 15 DAA. Glyphosate minimised the density of weeds *Parthenium hysterophorus* and *Solanum xanthocarpum* by 15 DAA and of *Digera arvensis* and *Alternanthera sessilis* by 7 DAA. Further, limited resurgence was observed under mowing with least weed biomass of 0.64 g/m^2. Further, glyphosate 2.0 or 3.0 kg/ha effectively minimised dicot weed density and biomass to nil up to 30 DAA. Moreover, spraying of glyphosate 2.0 kg/ha most effective when it was applied with 2,4-D salt 2.0 kg/ha (tank-mix) and recorded hundred per cent reduction in dicot weed density and biomass at 60 DAA and was at par with glyphosate 2.0 or 3.0 kg/ha in efficacy. Furthermore, glyphosate + oxyfluorfen 2.0 kg/ha (ready-mix) was at par with glyphosate 2.0 or 3.0 kg/ha and glyphosate 2.0 kg/ha + 2,4-D salt 2.0 kg/ha (tank mix) at 30 DAA.

Sedge: *Cyperus rotundus* was the only sedge observed, which was controlled by mowing (one weed flush) at 7 DAA (**Table 2** and **Figure 1**). Glyphosate 2.0 or 3.0 kg/ha caused complete control with zero density and dry weight at 15 DAA and negligible biomass at 60 DAA. However, effect was more acute with higher dose *i.e*. 3.0 kg/ha and combination of 2.0 kg/ha with 2,4-D amine salt. Moreover, glyphosate + oxyfluorfen 2.0 kg/ha (ready-mix) also significantly minimized the density and biomass of the sedge weed throughout the experiment. Likewise, paraquat 3.0 or 4.0 kg/ha or with 2,4-D salt 2.0 kg/ha significantly reduced the biomass of the sedge at 15 DAA.

Thus, spraying of glyphosate alone/ combinations was found appropriate for minimizing the weeds density and biomass significantly after 15, 30 and 60 days of application of herbicides as glyphosate is non selective translocated herbicide that effectively managed the weeds for longer duration as it affects underground part of weeds. Whereas, paraquat application caused the weeds mortality quickly, but reestablishment of weeds is very common as it is non-selective contact herbicide.

Weed regeneration

Glyphosate 2.0 kg/ha + 2,4-D salt 2.0 kg/ha (tank-mix) has persistent effect and zero resurgence was observed for dicot weeds. Moreover, no resurgence of weeds was observed at 30 DAA with

Table 1. Influence of different weed management treatments on monocot and dicot weed density

Treatment	Monocot weed density (no./m^2)						Dicot weed density (no./m^2)					
	Initial	7 DAA	15 DAA	21 DAA	30 DAA	60 DAA	Initial	7 DAA	15 DAA	21 DAA	30 DAA	60 DAA
Glyphosate 2.0 kg/ha	9.39 (87.3)	3.41 (10.7)	1.14 (0.3)	1.14 (0.3)	1.14 (0.3)	3.35 (10.3)	7.96 (63.0)	2.49 (5.3)	1.00 (0.0)	1.00 (0.0)	1.00 (0.0)	1.87 (2.7)
Glyphosate 3.0 kg/ha	8.97 (80.0)	3.05 (8.3)	1.00 (0.0)	1.00 (0.0)	1.00 (0.0)	2.85 (7.3)	7.45 (55.0)	2.08 (3.3)	1.00 (0.0)	1.00 (0.0)	1.00 (0.0)	1.33 (1.0)
Paraquat 3.0 kg/ha	9.65 (92.3)	1.38 (1.0)	1.91 (2.7)	4.19 (16.7)	6.29 (38.7)	8.36 (69.0)	8.01 (63.3)	1.00 (0.0)	1.00 (0.0)	2.08 (3.3)	3.95 (14.7)	6.80 (45.3)
Paraquat 4.0 kg/ha	9.37 (87.0)	1.38 (1.0)	1.73 (2.0)	3.83 (13.7)	5.91 (34.0)	8.04 (63.7)	7.78 (59.7)	1.00 (0.0)	1.00 (0.0)	1.79 (2.7)	3.59 (12.0)	6.60 (42.7)
Glyphosate + oxyfluorfen 2.0 kg/ha (ready-mix)	8.98 (79.7)	2.87 (7.3)	1.28 (0.7)	1.00 (0.0)	1.14 (0.3)	3.49 (11.3)	7.34 (53.0)	1.91 (2.7)	1.00 (0.0)	1.00 (0.0)	1.14 (0.3)	2.57 (5.7)
Glyphosate 2.0 kg/ha + 2,4-D salt 2.0 kg/ha (tank-mix)	9.60 (91.3)	3.16 (9.0)	1.61 (1.7)	1.14 (0.3)	1.24 (0.7)	3.19 (9.7)	7.76 (59.3)	1.52 (1.3)	1.00 (0.0)	1.00 (0.0)	1.00 (0.0)	1.00 (0.0)
Paraquat 2.0 kg/ha + 2,4-D salt 2.0 kg/ha (tank-mix)	9.36 (86.7)	1.91 (2.7)	1.47 (1.3)	3.87 (14.0)	5.95 (34.7)	8.43 (70.3)	7.83 (61.0)	1.00 (0.0)	1.00 (0.0)	1.00 (0.0)	2.30 (4.3)	5.79 (32.7)
Mowing (one weed flush)	9.71 (93.3)	1.00 (0.0)	3.16 (9.0)	6.16 (37.0)	7.77 (59.3)	9.96 (98.3)	7.85 (61.3)	1.00 (0.0)	2.14 (3.7)	4.79 (22.0)	5.82 (33.0)	7.50 (55.3)
Weedy check (control)	9.15 (83.0)	9.72 (93.7)	10.29 (105.0)	10.74 (114.3)	11.31 (127.0)	11.75 (137.3)	7.79 (59.7)	8.16 (65.7)	8.72 (75.0)	9.03 (80.7)	9.41 (87.7)	9.85 (96.0)
LSD (p=0.05)	NS	0.45	0.44	0.38	0.52	0.98	NS	0.27	0.22	0.53	0.36	0.59

*Data in parentheses indicate actual value and $(\sqrt{x+1})$ transformed value of weeds those outside.; DAA = days after herbicide application

Table 2. Influence of different weed management treatments on monocot and dicot weed density

Treatment	*Cyperus* density (no./m^2)						Total weed density (no./m^2)					
	Initial	7 DAA	15 DAA	21 DAA	30 DAA	60 DAA	Initial	7 DAA	15 DAA	21 DAA	30 DAA	60 DAA
Glyphosate 2.0 kg/ha	4.11 (16.0)	3.15 (9.0)	1.00 (0.0)	1.00 (0.0)	1.28 (0.7)	2.44 (5.0)	12.91 (166.3)	5.10 (25.0)	1.14 (0.3)	1.14 (0.3)	1.38 (1.0)	4.33 (18.0)
Glyphosate 3.0 kg/ha	4.24 (17.0)	2.87 (7.3)	1.00 (0.0)	1.00 (0.0)	1.00 (0.0)	2.23 (4.0)	12.33 (152.0)	4.47 (19.0)	1.00 (0.0)	1.00 (0.0)	1.00 (0.0)	3.64 (12.3)
Paraquat 3.0 kg/ha	4.00 (15.0)	1.72 (2.0)	1.49 (1.3)	1.99 (3.0)	2.76 (6.7)	4.04 (15.3)	13.10 (170.7)	2.00 (3.0)	2.21 (4.0)	4.88 (23.0)	7.80 (60.0)	11.43 (129.7)
Paraquat 4.0 kg/ha	4.08 (15.7)	1.63 (1.7)	1.52 (1.3)	1.73 (2.0)	2.51 (5.3)	3.96 (14.7)	12.77 (162.3)	1.91 (2.7)	2.08 (3.3)	4.39 (18.3)	7.23 (51.3)	11.04 (121.0)
Glyphosate + oxyfluorfen 2.0 kg/ha (ready-mix)	4.16 (16.3)	2.63 (6.0)	1.14 (0.3)	1.14 (0.3)	1.82 (2.3)	2.64 (6.0)	12.25 (149.0)	4.10 (16.0)	1.41 (1.0)	1.14 (0.3)	2.00 (3.0)	4.88 (23.0)
Glyphosate 2.0 kg/ha + 2,4-D salt 2.0 kg/ha (tank-mix)	4.46 (19.0)	1.79 (2.3)	1.00 (0.0)	1.00 (0.0)	1.00 (0.0)	2.15 (3.7)	13.06 (169.7)	3.69 (12.7)	1.61 (1.7)	1.14 (0.3)	1.24 (0.7)	3.75 (13.3)
Paraquat 2.0 kg/ha + 2,4-D salt 2.0 kg/ha (tank-mix)	4.43 (18.7)	1.52 (1.3)	1.52 (1.3)	1.91 (2.7)	2.08 (3.3)	2.93 (7.7)	12.93 (166.3)	2.23 (4.0)	1.90 (2.7)	4.20 (16.7)	6.57 (42.3)	10.55 (110.7)
Mowing (one weed flush)	4.16 (16.3)	1.00 (0.0)	2.44 (5.0)	3.04 (8.3)	3.37 (10.3)	4.12 (16.0)	13.10 (171.0)	1.00 (0.0)	4.31 (17.7)	8.26 (67.3)	10.18 (102.7)	13.06 (169.7)
Weedy check (control)	4.24 (17.0)	4.43 (18.7)	4.47 (19.0)	4.71 (21.3)	4.86 (22.7)	5.10 (25.0)	12.67 (159.7)	13.37 (178.0)	14.14 (199.0)	14.74 (216.3)	15.44 (237.3)	16.10 (258.3)
LSD (p=0.05)	NS	0.51	0.38	0.37	0.26	0.36	NS	0.44	0.46	0.42	0.52	0.85

*Data in parentheses indicate actual value and $(\sqrt{x+1})$ transformed value of weeds those outside.; DAA = days after herbicide application

glyphosate 3.0 kg/ha. However, lower dose of glyphosate *i.e.* 2.0 kg/ha and glyphosate 2.0 kg/ha coupled with either oxyfluorfen 2.0 kg/ha (ready-mix) or 2,4-D amine salt 2.0 kg/ha (tank-mix) showed the re-establishment of weeds after 21 DAA. The paraquat and mowing caused the weeds resurgence within 10-15 DAA. Further, mowing treatment gave complete control of total weeds initially but significant resurgence of weeds was observed after 15 days of treatment. Similarly, paraquat was found effective up to 15 DAA and later weeds resurgence was witnessed. Further, application of higher rate of glyphosate *i.e*. 3.0 kg/ha has completely managed the weeds upto 30 DAA with minimum weed density at 60 DAA and it was closely followed by glyphosate 2.0 kg/ha alone or in combination with 2,4-D amine salt 2.0 kg/ha (tank-mix).

Weed control efficiency

Glyphosate 3.0 kg/ha recorded highest weed control efficiency at 15, 30 and 60 DAA, and it was closely followed by glyphosate 2.0 kg/ha + 2,4-D amine salt 2.0 kg/ha (tank-mix), glyphosate 2.0 kg/ha and glyphosate + oxyfluorfen 2.0 kg/ha (ready-mix).

It is inferred that glyphosate 2.0 kg/ha alone or in combination with 2,4-D amine salt 2.0 kg/ha (tank-mix) may be used to effectively minimize the weeds biomass and resurgences significantly up to 60 DAA with highest weed control efficiency in non-cropped land.

REFERENCES

Bajwa AA, Chauhan BS, Farooq M, Shabbir A and Adkins SW. 2016. What do we really know about alien plant invasion? A review of the invasion mechanism of one of the world'sworst weeds. *Planta* **244**: 39–57.

Bhowmick MK, Duary B, Bhattacharyya P, Dhara MC and Biswas PK. 2017. Herbicidal management of weeds in non-crop areas. *International Journal of Bio-resource, Environment and Agricultural Sciences* **3**(1): 477–481.

Bhowmick MK, Duary B, Dhara MC, Biswas PK, Patra DK and Bhattacharyya P. 2016. Weeds as alternate hosts of plant pathogens and their chemical management. *Journal of Interacademicia* **20**(4): 569–584.

Kandasamy OS, Raja D and Chandrasekhar. 1999. Chemical control of bermuda grass under non crop situation. *Indian Journal of Weed Science* **30** (1&2): 96–98.

Kewat ML, Meena V, Sharma N and Jha AK. 2008. Effect of time of application on the efficacy of Combi and glyphosate against paragrass in non-cropped area. *Indian Journal of Weed Science* **40** (3&4): 159–161.

Kaur N, Sethi R and Bhullar MS. 2020. Weed management in non-cropped areas with pre-mix of indaziflam and glyphosate in Punjab. *Indian Journal of Weed Science* **52**(4): 358–361.

Patel TU, Lodaya DH, Italiya AP, Patel DD and Patel HH. 2018. Bio-efficacy of herbicides in direct-seeded rice. *Indian Journal of Weed Science* **50**(2): 120–123.

Patel TU, Zinzala MJ, Patel DD, Patel HH and Italiya AP. 2017. Weed management influence on weed dynamics and yield of summer lady's finger. *Indian Journal of Weed Science* **49**(3): 263–265.

Kumar S, Bhowmick MK and Ray P. 2021. Weeds as alternate and alternative hosts of crop pests. *Indian Journal of Weed Science* **53**(1): 14–29.

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RESEARCH NOTE

Effect of chocolate weed (*Melochia corchorifolia* L.) leachates on the mortality of storage pests, pulse beetle (*Callosobruchus maculatus* F.) and rice weevil (*Sitophilus oryzae* F.)

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ABSTRACT

Insecticidal potential of whole plant leachate of chocolate weed (*Melochia corchorifolia* L.) on storage pests, *viz.* *Callosobruchus maculatus* (F.) and *Sitophilus oryzae* (L.) was assessed under laboratory conditions. Results revealed that whole plant leachate of *M. corchorifolia* had insecticidal action against *C. maculatus* and *S. oryzae*. Mortality rate of storage pests was found to be concentration dependent and the highest leachate concentration (15 %) resulted in significantly higher mortality rate. LC_{50} and LC_{95} values for the mortality of rice weevils and pulse beetles after 48 h of treatment were 11.69, 15.50 mg/L and 32.89 and 43.45 mg/L, respectively. The result clearly indicated the presence of a toxicant or growth inhibitor principle in the whole plant leachate of *M. corchorifolia*. Identification and isolation of active ingredient in the whole plant leachate of *M. corchorifolia* will help to develop an eco-friendly biopesticide against *C. maculatus* and *S. oryzae.*

Keywords: Chocolate weed, Insects mortality, Leachate, Pulse beetle, Rice weevil, Storage pests, Weeds usage

Stored grain pests accounts for 20 to 25% damage in food grains (Rajashekhar *et al.* 2010). Among the various storage insect pests rice weevil (*Sitophilus oryzae*), pulse beetle (*Callosobruchus maculatus)*, lesser grain borer (*Rhyzopertha dominica* F.), Khapra beetle (*Trogoderma granarium* Everts), red flour beetle (*Tribolium castaneum* Herbst.) *etc*. are most detrimental and causes greater damage to the stored grains.

Rice weevil cause heavy losses of stored food grain quantitatively and qualitatively throughout the world (Arannilewa *et al*. 2002). *Callosobruchus* spp. are the major storage pests which cause damage to almost all the pulse crops and adversely affect the seed quality (Park *et al.* 2003). However un-systemic application of synthetic pesticides calls to implement safe alternative options to tackle stored pests. Identifying the insecticidal properties of indigenous plants may be environmentally and socio-economically feasible option to manage these pests.

Chocolate weed (*Melochia corchorifolia* L.) a member of Malvaceae family has become a devastating weed in the sesame growing tracts of *Onattukara*, Kerala. Weed management by their utilization is one of the component of integrated weed management. It is the economic utilization of invasive/noxious species by harnessing their economic potential for meeting the basic human needs and at the same time prevent its spread and eradicating them (Tessema 2012). Plant secondary metabolites acts as signals and provide benefits like defense against herbivores, fungi and bacteria. Leaf/flower/seed extracts of plants, *viz. Acalypha indica*, *Vitex negundo*, *Nerium oleander* can be effectively utilized for the management of storage pests (Sathyaseelan *et al*. 2008). Beneficial effects of chocolate weed for storage pests management has not been explored thoroughly. This experiment aims to study the insecticidal effect of chocolate weed against storage pests *C. maculatus* and *S. oryzae.*

Chocolate weed samples from infested ûelds (8.93° N and 76.39° E at 3.05 m MSL) of *Onattukara* Regional Agricultural Research Station (ORARS), Kayamkulam, Kerala, India were used for the experiment. Fresh plant samples at active growth stage (30 DAS) were collected carefully from the field without damaging the roots and washed in clean water to remove the dirt and soil adhered to the roots. The study was conducted with leachate of chocolate weed.

Preparation of leachate: Plants were chopped into small pieces of 2 cm length using a fodder cutter. Leachate was prepared by soaking the weighed plant (25, 50, 100 and 150 g) material for 48 h in 1000 mL distilled water to make leachates of 4 different

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concentrations of 2.5, 5, 10 and 15 % , respectively (Ameena and Geethakumari 2016).

Culturing of test insects: The test insects, *viz*. *S. oryzae* (rice weevil) and *C. maculatus* (pulse beetle) adults were obtained from the storage insects' culture from Department of Entomology, College of Agriculture, Vellayani and were mass cultured in 1 kg capacity glass jars of size 20 × 10 cm containing respective food materials (rice and chick pea) as a nutritional source at 60-70 per cent relative humidity and temperature range from 30-35^0C. Then glass jars were covered with a fine muslin cloth and secured with a rubber band. Half of the completely infested food materials were replaced with the same quantity of non-infected materials at an interval of two generations. A continuous insect culture was thus maintained throughout the experiment period. The freshly emerged adult beetles were used for the experiments (Kathirvelu and Raja 2015).

Petri dishes of 9 cm diameters were used for the study. Separate experiment was conducted for each insect in completely randomized design (CRD) with five treatments (four different concentrations of whole plant leachates of *M. corchorifolia* and a control) in four replications. Different concentrations of whole plant leachates of *M. corchorifolia* were 2.5, 5, 10 and 15 %. Twenty-five insects (rice weevil/ pulse beetle) were placed in petri dishes. Petri dishes were moistened daily with a fine spray of 1.5 ml leachate using an atomiser. Control treatments were moistened using distilled water. The number of dead insects at 6, 12, 24, 36 and 48 h after spraying (HAT) were recorded. The experiments were repeated thrice for confirmation. Statistical analysis of the data and probit analysis to determine the LC_{50} and LC_{95} values for the mortality of rice weevils and pulse beetles were done using software grapes Agri 1 (Gopinath *et al.* 2021).

Mortality of rice weevil (*S. oryzae*): Mortality of rice weevil occurred due to the leachates of chocolate weed, *M. corchorifolia* (**Table 1**). The highest mortality was observed in 15 % leachate (33.33 %) (**Plate 1**) which was significantly different from all other concentrations of *M. corchorifolia* after 6 h of treatment. Similar trend was observed after 12, 24, 36 and 48 h of treatment.

Mortality of pulse beetle (*C. maculatus*): After 6 h of treatment, the highest mortality of pulse beetle, *C. maculatus* was recorded in 15% leachate (30.67%) (**Plate 2**) followed by 10% leachate (22.67%). Similar trend was observed at 24, 36, 48 h after treatment except at 12 h. The percent mortality was on par with 10 and 15% leachates after 12 h of treatment (**Table 2**)

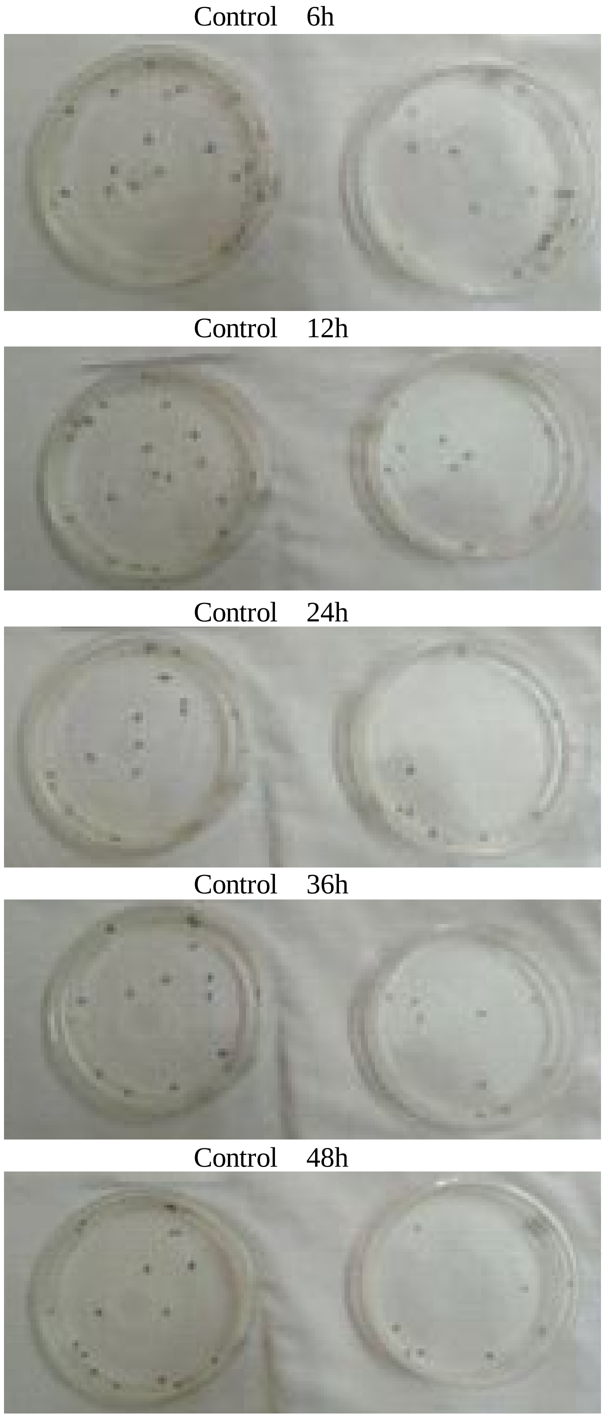

Plate 1. Number of live rice weevils left at different time intervals (15 % leachate concentration)

Toxicity of chocolate weed whole plant extract on the mortality of test insects

Rice weevil (*S. oryzae*): LC_{50} and related parameters of toxicity of whole plant leachate of chocolate weed (*M. corchorifolia*) against rice weevil (**Table 3**) indicated LC_{50} and L95 values for the mortality of *S. oryzae* as 23.32 mg/L and 55.61 mg/L , respectively after 6 h of treatment. After 12 h, LC_{50} and LC_{95} values for the mortality were observed to be 18.07 and 41.84 mg/L, respectively. LC_{50} value of 13.96 mg/L and

Table 1. Mortality of *S. oryzae* L. (rice weevil) after treatment with leachate of chocolate weed (*M. corchorifolia*)

Concentration of leachate (%)	Mortality of rice weevil (%)				
	6 HAT	12 HAT	24 HAT	36 HAT	48 HAT
2.50	10.67	10.67	13.33	14.67	16.00
5.0	17.33	18.67	21.33	29.33	32.00
10.0	25.33	28.00	29.33	38.67	41.33
15.0	33.33	42.68	57.33	60.00	62.67
LSD (p=0.05)	3.799	4.518	5.038	4.234	2.444

HAT: hours after treatment

Table 2. Mortality of *C. maculatus* (pulse beetle) after treatment with leachate of chocolate weed (*M. corchorifolia*)

Concentration of leachate (%)	Mortality of pulse beetle (%)				
	6 HAT	12 HAT	24 HAT	36 HAT	48 HAT
2.50	12.00	13.33	14.67	18.67	20.00
5.0	16.00	21.33	22.67	24.00	26.67
10.0	22.67	26.67	29.33	34.67	37.33
15.0	30.67	40.00	42.67	48.00	49.33
LSD (0.05)	5.09	4.52	3.67	6.03	6.88

HAT: hours after treatment

Table 3. Toxicity of chocolate weed whole plant leachate (*M. corchorifolia*) on the mortality of *Sitophilus oryzae* (rice weevil)

Toxicity of leachate for mortality of pulse beetle (mg/L)			
HAT	LC_{50}	LC_{95}	Chi square
6	25.42	59.17	0.000
12	19.97	49.39	0.002
24	18.61	47.53	0.004
36	15.80	40.85	0.000
48	15.50	43.45	0.000

HAT: hours after treatment

Table 4. Toxicity of leachate of chocolate weed (*Melochia corchorifolia* L.) on the mortality of pulse beetle, *Callosobruchus maculatus* F

Toxicity of leachate for mortality of rice weevil (mg/L)			
HAT	LC_{50}	LC_{95}	Chi square
6	23.32	55.61	0.001
12	18.07	41.84	0.000
24	13.96	30.35	0.022
36	12.42	32.94	0.008
48	11.69	32.89	0.009

HAT: hours after treatment

LC_{95} value of 30.35 mg/L were observed 24 h after treatment and recorded 0.022 as chi square value. After 36 and 48 h, LC_{50} and LC_{95} values recorded were 12.42, 11.69 mg/L and 32.94, 32.89 mg/L, respectively.

Pulse beetle (*C. maculatus*): The leachate showed LC_{50} value of 25.41 mg/L and LC_{95} value of 59.17 mg/L at 6 h after treatment to kill the pulse beetle and at 12 h, LC_{50} and LC_{95} values for the mortality of pulse beetle were 19.97 and 49.39 mg/L, respectively. At 24 h, 18.61 mg/L was the LC_{50} value and 47.53 mg/L was the LC_{95} value. Similarly, after 36 h, the LC_{50} value of pulse beetle was 15.79 mg/L and LC_{95} value was 40.85 mg/L, respectively. After 48 h, the LC_{50} and LC_{95} values of pulse beetle were observed to be 15.50 and 43.45 mg/L, respectively (**Table 4**).

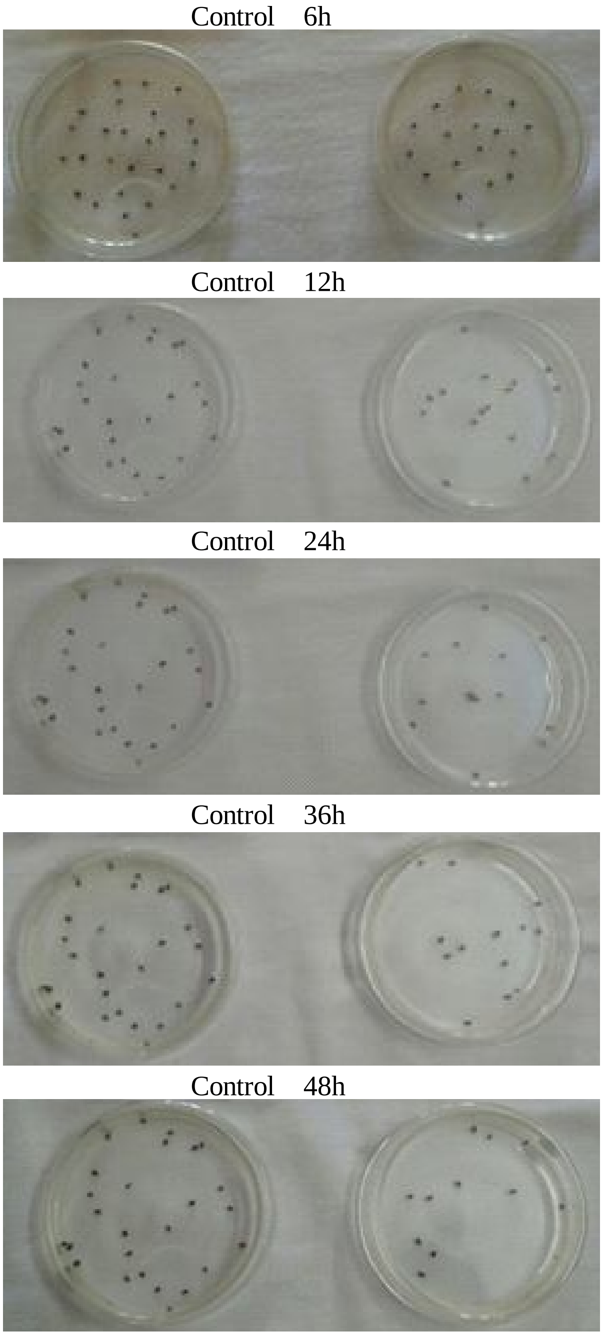

Plate 2. Number of live pulse beetles left at different time intervals (15 % leachate concentration)

Mortality per cent of rice weevil gradually increased with time. The whole plant leachate concentrations (2.5, 5, 10 and 15%) showed the highest mortality percentage at 48 hours after treatment (HAT). Similarly, the mortality percent increased with increase in leachate concentration. Whole plant leachate of 15% concentration resulted in the highest mortality of rice weevil (62.67%).

Jayakumar (2010) opined that plant extracts can effect post embryonic survival of insects, leading to adult emergence with hike in concentration. Kumar *et al*. (2010) observed that higher concentration of ethanolic extracts of *Annona squamosa* leaves had a potent knock down effect on *S. oryzae*. The results are in accordance with the findings of Rani *et al.* (2019) who observed that higher concentrations of *Ocimum sanctum* leaves resulted in higher mortality (66.7%).

Mortality percent of pulse beetle also followed the same pattern and was directly proportional with leachate concentration. The dead pulse beetle per cent also increased as time passed and exhibited the highest values at 48 HAT. The leachate concentration of 15 % recorded the highest mortality (49.33%) at 48 HAT. The mortality per cent values of pulse beetle were lesser than that of rice weevil implying that whole plant leachate of chocolate weed was more effective against rice weevil.

Raja *et al.* (2001) observed that botanicals from *M. corchorifolia* inhibited adult emergence in pulse beetle. They suggested that this may be due to the repellent activity or changes induced by the chemical properties of extracts resulted in reduced egg laying capacity of beetles. Rahman and Talukder (2006) reported that mortality percentage of pulse beetle was directly related to the plant extract concentrations and also with the time after treatment. The plant extract of *Vitex negundo* had the highest toxic effect against pulse beetle. Manju *et al.* (2019) revealed that maximum mortality of pulse beetle was observed at 12, 24 and 48 h when treated with 1 per cent *Piper nigrum* extract.

The present study has revealed the efficacy of *M. corchorifolia* leachate against rice weevil and pulse beetle. Mortality percent values have gradually increased with an increase in whole leachate concentration indicating the presence of a toxicant or growth inhibitor principle in the leachate. Identification and isolation of active ingredient in the leachate is a future thrust area. Advanced studies on the effect of leachate on adult emergence, oviposition and egg viability could pave the way for a new bio pesticide for storage pest control as a component in integrated pest management.

REFERENCES

Ameena M and Geethakumari V. 2016. Application of nutsedge (*Cyperus rotundus* L.) extracts for weed suppression and identification of allelochemicals. *Journal of Crop and Weed* **12**(2): 102–105.

Arannilewa ST, Ekrakene T and Akinney JO. 2002. Laboratory evaluation of four medicinal plants as protectants against the maize weevil, *Sitophilus zeamais* (Mots). *African Journal of Biotechnology* **5**(21): 2032–2036.

Gopinath, PP, Prasad R., Joseph B and Adarsh VS. 2021. Grapes Agri1: Collection of Shiny Apps for Data Analysis in Agriculture. *Journal of Open-Source Software* **6**(63): 34–37.

Jayakumar M. 2010. Oviposition deterrent and adult emergence activities of some plant aqueous extracts against *Callosobruchus maculatus*. *Journal of Biopesticides* **3**(1): 325–329.

Kathirvelu C and Raja RS. 2015. Efficacy of selected plant extracts as insecticidal fumigant against certain stored grain insect pests under laboratory conditions. *Plant Archives* **15** (1): 259–266.

Kumar JA, Rekha T, Devi SS, Kannan M, Jaswanth, A. and Gopal, V. 2010. Insecticidal activity of ethanolic extract of leaves of *Annona squamosa*. *Journal of Chemical and Pharmaceutical Research* **2**(5): 177–180.

Manju K, Jayaraj J and Shanthi M. 2019. Efficacy of botanicals against pulse beetle *Callosobruchus maculatus* (F.) in green gram. *Indian Journal of Entomology* **81**(1): 144–147.

Park C, Kim SI and Ahn YJ. 2003. Insecticidal activity of asarones identified in *Acorus gramineus* rhizome against three coleopteran stored-product insects. *Journal of Stored Products Research* **39** (3): 333–342.

Rahman A and Talukder F. 2006. Bioefficacy of some plant derivatives that protect grain against the pulse beetle, *Callosobruchus maculatus*. *Journal of Insect Science* **6**(1): 154–158.

Raja N, Babu A, Dorn S and Ignacimuthu S. 2001. Potential of plants for protecting stored pulses from *Callosobruchus maculatus* (Coleoptera: Bruchidae) infestation. *Biological Agriculture and Horticulture* **19**(1): 19–27.

Rajashekar Y, Gunasekaran N, Shivanandappa T.2010. Insecticidal activity of the root extract of *Decalepis hamiltonii* against stored-product insect pests and its application in grain protection. *Journal of Food Science and Technology* **43**(3):310–314.

Rani S, Gailce LJ and Sheeba JR. 2019. Evaluation of plant extracts against rice weevil, *Sitophilus oryzae* (Coleoptera: Curculionidae) in stored sorghum seeds. *The Pharma Innovation Journal* **8**(8): 154–159.

Sathyaseelan V, Baskaran V and Mohan S. 2008. Efficacy of some indigenous pesticidal plants against pulse beetle, *Callosobruchus chinensis* (L.) on greengram. *Journal of Entomology* **5**(2): 128–132.

Tessema YA. 2012. Ecological and economic dimensions of the paradoxical invasive Species - *Prosopis juliflora* and policy challenges in Ethiopia. *Journal of Economics and Sustainable Development* **3**: 62–70.