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Perspective

Opinion

Review

Research articles

Research notes

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Precision weed management: A means of boosting agricultural productivity

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ABSTRACT

Weeds constitute a major constraint to agricultural productivity. Chemical weed management has been the focus in agriculture ever since the discovery of 2,4-D over 75 years ago. But repeated application of one type of herbicides will sort out resistant strains within the weed population. This became real beginning 1957 in U.K., Hawaii, USA and Canada in the case of 2,4-D. With continuous use of same group of herbicides since that time, herbicide resistance has become a significant global problem. Currently, 262 weed species (152 dicots and 110 monocots), infesting 93 crops and non-crop areas in 70 countries, have been identified to develop resistance to different herbicides. In this situation, weed scientists need to look for alternative weed management approaches that enhance agricultural productivity. One such alternative is precision weed management (PWM) which is inclusive of those methods that will ensure greater farm productivity. These include a combination of need-specific, site-specific and cost-effective weed sensing systems (ground-based and aerial-based) in addition to integrated weed management that includes chemical, mechanical, manual and cultural methods. Weed scientists need to look ahead to explore and develop a combination of these methods for the benefit of farming community by reorienting their future research programs in this direction.

INTRODUCTION

Chemical weed management

Weeds constitute a major constraint to global agricultural productivity. The era of chemical weed management with organic synthetic herbicides began with the introduction of 2,4-D, a phenoxy herbicide, in 1945. The discovery of 2,4-D was considered to be "greatest scientific discoveries of the 20th century (Fryer 1980). Its discovery and use was followed by substituted urea and triazine herbicides. Later, numerous other herbicide groups and herbicides over 350 were introduced during the next four decades. These were soon followed by numerous other herbicide groups over the next four decades. These herbicides have been considered the panacea for weed problems in agriculture, aquatics, forestry and non-cropping systems. Subsequently, these chemicals caught the attention of the farmers world over. These were considered viable alternatives for manual and mechanical methods.

The discovery of 2,4-D has also immediately impacted Indian agriculture. Since the initial testing in 1946, a number of herbicides have been tested for their efficacy against many weed species and utility in field crops (Mani 1977, Rao *et al.* 2014). Herbicide usage gained momentum in India since 1980s with their use in wheat followed by rice farmers in Punjab, Haryana and Uttar Pradesh.

Weed science turned a corner when glyphosate was made commercially available in1974. Glyphosate introduction created enormous enthusiasm in weed science community as farmers around the world began to use this broad-spectrum post-emergence herbicide to control a wide range of perennial weeds in croplands. It is also used in no-till and minimum-till farming. In India, glyphosate was introduced in 1980 in tea plantations, followed by other plantation crops and non-crop situations.

Five years after 2,4-D discovery, Blackman (1950) forewarned that forewarned that "repeated spraying with one type of herbicide will sort out resistant strains within the weed population." This warning became reality when, in 1954, a report from U.K. revealed that continuous application of 2,4-D has led to resistance of weed species normally susceptible to it. This was followed by two other reports against 2,4-D in 1957, one from Hawaii where biotypes of *Commelina diffusa* in sugarcane fields (Hilton 1957), and another from Ontario, Canada, where biotypes of *Daucus carota* in sections of highway weeds (Switzer 1957) exhibited resistance. The extensive use of same group of herbicides has resulted in the development and evolution of herbicide resistant species of weeds, and herbicide resistance has become a significant global problem (Beckie *et al.* 2019).

Currently, 263 weed species (152 dicots and 111 monocots) infesting 95 crops and non-crop areas in 71 countries have been identified to develop resistance to 164 different herbicides belonging to 21 of the 31 known herbicide sites of action (Heap 2021). As several species showed resistance to herbicides of multiple sites of action, the number of unique resistant cases stood at 504 (species x sites of action). For example, *Lolium rigidum* is resistant to herbicides of 14 different sites of action. The other prominent ones include *Echinochloa crus-galli* var. *crus-galli* (10), *Poa annua* (9), *Eleusine indica* (8), *Lolium perenne* ssp. *multiflorum* (8), *Alopecurus myosuroides* (7), *Amaranthus palmeri* (7), *Amaranthus tuberculatus* (=*A. rudis*) (7), *Avena fatua* (7) and *Echinochloa colona* (7).

In India, only two species (*Phalaris minor* and *Rumex dentatus*) have been reported to be resistant to three groups of herbicides (ALS, ACCase and Photosystem II inhibitors) [Heap 2021]. However, farmers frequently report about the failure of herbicides in securing effective control of weeds. This was particularly true in the case of glyphosate which was being used for over 40 years, beginning with tea in 1978.

Besides, current weed control practices lack the precision needed to control weeds effectively and safely without harmful side effects. Farmers in many regions rank weed control as their number one production cost. In conventional systems, herbicide resistance, and off-target movement of applied herbicides, have left many growers with few alternatives.

Weed resistance to herbicides has led to the development of crops resistant to previously non-selective herbicides. Around 190 million hectare land around the world have been under biotech transgenic crops in 2019 (ISAAA 2019). Around 80% of this area was under herbicide-resistant ones, either alone or stacked with insect resistance. Herbicide-resistant (HR) biotech crops have made a positive contribution to global crop production and the economies of farmers (Beckie *et al.* 2019), while they certainly raised concerns about biosafety to consumers.

Several countries led by USA have widely adopted HR biotech crops, while India has been growing only the insect-resistant (IR) *Bt* cotton since 2002. With adoption of *Bt* varieties, the country has achieved a great stride in cotton production, accounting for a quarter of market share in global cotton production in 2017. Herbicide-resistant biotech crops are not approved in India, although they are reported to be grown illegally by farmers in key cotton-growing states (Yaduraju 2021).

The current weed control practices lack the precision needed to control weeds effectively and safely without harmful side effects. Farmers in many regions rank weed control as their major production cost. In conventional systems, herbicide resistance, and off-target movement of applied herbicides, have left many growers with few alternatives. Even if they are adopted, biotech crops pose a serious concern about their biosafety in the long run. Biosafety issues have become a crucial limitation to their further development (Rao 2018).

PRECISION WEED MANAGEMENT

Generally, weed management inputs are applied uniformly to the whole field, like most other crop, soil, and pest management practices. However, the occurrence and intensity of weeds are not uniform across the field. They are more often patchy (aggregated or clumped) and uneven due to several agro-ecological factors. Therefore, uniform herbicide application across a field, where target weeds are not uniformly distributed, can waste resources. This may lead to adverse economic, environmental and social concerns about herbicide use. Gerhards *et al.* (2002) achieved herbicide savings of 60% and 92% for dicot and monocot weeds, respectively, in spring barley cultivation, and 11% and 81% for the same weed groups in maize. Normally, the need for herbicide application ranges between 7% and 64% of the total area, suggesting the saving of herbicide used. The spatial heterogeneity of weeds and possibility of reduction in herbicide quantity used has inspired several weed scientists to research on to better weed management practices. One such practice is precision weed management.

Precision weed management (PWM) offers a set of powerful tools to increase the efficiency of weed management by offering the following benefits:

1. Lowers herbicide costs and environmental problems, with greater weed control efficiency, leading to greater acceptance of herbicide usage.
2. Helps use of optimal quantity of management inputs on the target weeds at the right time.

3. Reduces wasteful application of inputs for better environment.
4. Delays, and even possibly eliminates, evolution of herbicide-resistant weed species.
5. Reduces accumulation of herbicide residues in soil, water and environment.
6. May possibly reduce or avoid herbicide toxicity on crops.

Several PWM methods are being developed to scout and detect weeds so that control measures can be applied where and when they are needed. Two such measures include (1) site-specific weed management and (2) robotic technology. These include various other alternative methods in addition to chemical method.

Site-specific weed management

Site-specific weed management (SSWM) technique includes utilization of machinery or equipment embedded with technologies that detect weeds growing in association with crops to maximize their successful control (Brown and Noble 2005, Christensen *et al.* 2009). It is based on the concept of adjusting the intensity of management practices to the actual degree of weed infestation, with only those areas having a weed density at a threshold level that requires treatment (Hamouz *et al.* 2013). If applied at the required quantity of herbicides at threshold weed density level at which crop growth will likely suffer due to weed competition the use may be reduced considerably by 40–60%. Different selective herbicides are applied, alone or in a tank-mix, on weed-infested areas to control broad-leaf and grass weeds differently. For this to be effective, SSWM requires the precise setting of threshold levels for effectiveness and reliability.

Success of SSWM technologies depends on three key elements (Christensen *et al.* 2009):

1. A weed sensing system which identifies, localizes and measures crop and weed parameters.
2. A weed management model that helps applying knowledge and information about crop-weed competition, population dynamics, biological efficacies of control methods and decision-making algorithms, and optimize treatments according to the density and composition of weed species.
3. A precision weed control implement which includes a sprayer with individual controllable boom sections or a series of nozzles that enable spatially variable applications of herbicides.

Another essential part of SSWM technology is the heterogeneous agro-ecosystem encompassing individual crop and weed plants. These could be small units of individual plants, clusters or patches of plants within a field, or even a whole field. In terms of weed management, the hierarchy reflected in the spatial resolution within a farm may follow four levels (Christensen *et al.* 2009):

1. Treat individual plants using highly accurate spraying nozzles, controllable mechanical implements or laser beams.
2. Treatment of a grid adapted to the resolution *e.g.* adjust the spray with a nozzle or a hoe unit.
3. Treat weed patches or subfields with clusters of weed plants.
4. Treat the whole field uniformly.

Weed sensing systems

There are two categories of weed-sensing systems: ground-based and aerial-based, (Wang *et al.* 2019) using digital cameras or non-imaging sensors. In large areas, the most cost-effective approach would be remote sensing, using aircraft or satellites to provide a farm with maps of weed occurrence (David and Brown 2001; Fernández-Quintanilla *et al.* 2018).

Ground-based sensing system. In this, multi-spectral imaging sensors such as colour digital optical cameras are used in a mobile platform that has a sprayer. It works better in the case of spatial treatments at field resolution levels 1, 2 and 3 (Christensen *et al.* 2009). Greater proximity reduces the pixel sizes to millimeters or smaller. This helps in analyzing images of species-specific features, such as shape, texture and plant organization. With spatial resolution lower than 1 mm, images collected from ground-based camera systems and subsequent image processing routines will help delineating individual weed plants from the crop plants (Thorp and Tian 2004). As much greater computational load is on the sprayer control system, it detects and identifies weeds and then determines and administers the appropriate action in real time (Brown and Noble 2005). Data must therefore be processed at a very high rate for the sprayer to progress at a reasonable speed. Unlike the aerial mapping approach, there are no additional tasks and infrastructure required.

Aerial-based remote sensing (ARS) system. This airborne remote sensing, done from either an aircraft or a satellite platform, requires two things. First: suitable differences in spectral reflectance or texture must exist between weeds and their background soil and plant canopy. The second requirement is remote sensing instrument must have sufficient spatial and spectral resolution to detect weed plants. ARS methods can be successfully applied to detect distinct weed patches which are dense and uniform, and have unique spectral characteristics (*i.e.* weed patches larger than 1×1 m). Therefore, this method is only applicable for whole-field treatments or to treat weed patches or sub-fields with clusters of weed plants. A major disadvantage of ARS is that it can be difficult to acquire the data when needed, particularly if weather conditions are not ideal when the satellite or the aircraft passes over. In this situation, data acquisition can be delayed for days or weeks (Christensen *et al.* 2009).

The current knowledge on the utility of Unmanned Aircraft Systems (UAS) platforms and remote sensing tools for weed monitoring and precision weed management were reviewed recently (Singh *et al.* 2020). Despite studying a wide range of weed sensing techniques and modest advancement in weed mapping and control software available for precision agricultural practices over the past few years, few farmers have so far adopted site-specific management of weeds. No technique has been developed into a commercial product till now. The economic and technological limitations for SSWM may preclude its widespread adoption. However, as research is developed and technology refined, costs lowered, the opportunities for site-specific management of weeds at the farm level will greatly increase.

Robotic technology

In the recent past, the dawn of robotic technology has become an alternative option to site-specific weed management. This evolutionary step in precision agriculture including weed management is very much like hand hoeing or knap-sack spot spraying but without the need for a human presence (Osten and Crook 2016). An agricultural weeding robot consists of hardware and software and it has an unmanned, self-steered platform that hosts an array of weed detection units. These, in turn, activate an array of weeding tools whether it is spray nozzle, microwave unit or tillage tool (Osten and Crook 2016). Agricultural robotic systems will be multi-purpose (sowing, fertilizing, spraying, scouting, counting, sensing, *etc*.), multi-model (chemical, mechanical, electrical, thermal weed control) and long-enduring to reduce the need for tractor work (Perez and Gonzalez 2014, Swift 2015). They will reduce both soil compaction and labour requirement.

Currently, a wide array of robotic machines and systems has been developed across the world. These include Hortibot, Robocrop, IC-Cultivator, Robovator Hoeing Robot, Thermal Hoeing Robot, EcoRobot, Ladybird, Bonirob, AgBot, Swarmbots, RIPPA, *etc.* (**Figure 1**) (Rao 2018).

Hortibot: It is a semi-autonomous robot with a navigational platform fitted with different weed management tools to either mechanically remove weeds or precision-spray them. It uses a vision-based system of downward-focussed cameras to navigate around the crop. It is equipped with a computer and GPS to find the exact location of weeds and plants. It can manually pick weeds, spray or remove them by using flames or a laser. It will spray herbicides exactly above the weeds. This eco-friendly robot, weighing 200–300 kg, can identify around 25 different kinds of weeds ((https://www.zdnet.com/article/hortibot-a-weed-removing-robot/). Further improvements can allow it to more number of weeds.

Robocrop. It is the first commercially available robotic weeding machine. It was developed by Tillet and Hague Technology Ltd, in U.K. It utilizes a forward-looking camera that detects crop plants and a set of rotating disc blades mounted on an off-centre shaft that cultivate around the crop plants within the row. Its inter-row precision guidance system uses a digital video camera to capture images of the crop within the row. These images are analyzed to find the position of the individual plants. This information is then utilized for lateral steering of the hoe and individual synchronization of the In-Row Weeder disc, which is controlled via the parallel linkage wheel unit. Rotation of the disc is synchronized with forward movement and the plant positional information from the imaging camera. Robocrop programs the computer to constantly adjust the rotational speed of disc to suit the variability of plant spacing. It removes up to 3 plants per second per row. A 6 m-wide system with a plant-spacing of 50 cm travelling at 5.4 km/h may cover 3.2 ha/h. This robot machine can cultivate over 98% of the area. It, however, does not operate effectively in rows with densely and or irregularly spaced crop plants, and where weeds and crop plants are similar in size.

IC cultivator: Developed in the Netherlands in 2012 and released in Europe in 2013, IC cultivator uses hooded cameras with artificial LED (light- emitting diode) lighting on each planted row to identify crop plants. As the machine moves forward, a pneumatic cylinder opens and closes a set of cultivator knives into the seed line around the crop plants to uproot weeds. A camera detects the plant and sees the row pattern. The width of this hydraulically-operated modular how blade ranges from 1.5 to 6.0 m, with a hoeing capacity of 3–4 plants/sec at an operating speed of 3–4 km/h.

Robovator hoeing robot: Developed in Denmark, Robovator Hoeing Robot is similar in concept and operation to the IC-Cultivator but it is non-hooded with artificial lighting for consistent image quality. In this, the robot is equipped with a special plant detection camera above each row. It has a mechanical tool which is operated by hydraulic power. The "intelligent" weeding tools normally stay in the row, but they move out of the row when a crop plant is passing. The specially designed plant detection cameras fitted on each parallelogram continuously monitor the passing plants. If a crop plant passes, the computer will send a signal to the hydraulic controlled tool which at the specified time will be moved out of the row. When the crop plant has passed, the tool will be moved into the row again. If there is a gap in the row, and one or more plants are missing, the tool will just stay in the row. The automatic lateral control will make sure that the machine stays in the exact position even if the tractor goes off track.

Thermal Hoeing Robot: Thermal hoeing robot, also developed in Denmark, utilises the Robovator vision system to identify crop plants. A series of plasma jets are oriented towards the crop row that deliver flame to kill weeds. Multiple jets are used to deliver a sufficient quantity of heat to kill them. It operates at 1–6 km//h.

EcoRobot: Developed in Switzerland by Ecorobotix, EcoRobot is a small revolutionary robot for ecological and economical weeding of row crops. The robot performs weeding by combining an advanced vision system that recognizes weeds and a faster robotic arm to remove them either by spot spray or spinning disk. It is light-weight and easy to transport. It is solar-powered and can run for several days performing weed control with 95% efficacy.

Ladybird: Named after its resemblance to the beetle (Blucher 2014), Ladybird was developed at the University of Sydney's Australian Centre for Field Robotics (ACFR) for use on commercial vegetable farms to undertake autonomous tasks such as mapping, surveillance, classification and detection of a variety of vegetables and weed control. This omni-directional solar-electric powered ground vehicle is fitted with sensors (lasers, stereo and hyper-spectral cameras) to detect vegetable growth, weeds and animal pests. A robotic arm for removing weeds but with autonomous harvesting potential is also fitted to Ladybird (Hollick 2014).

Bonirob: Bonirob was developed by Deepfield Robotics of Bosch, Germany. It is the size of a small compact car. It moves around the field using video and LIDAR (Light Detection and Range)-based

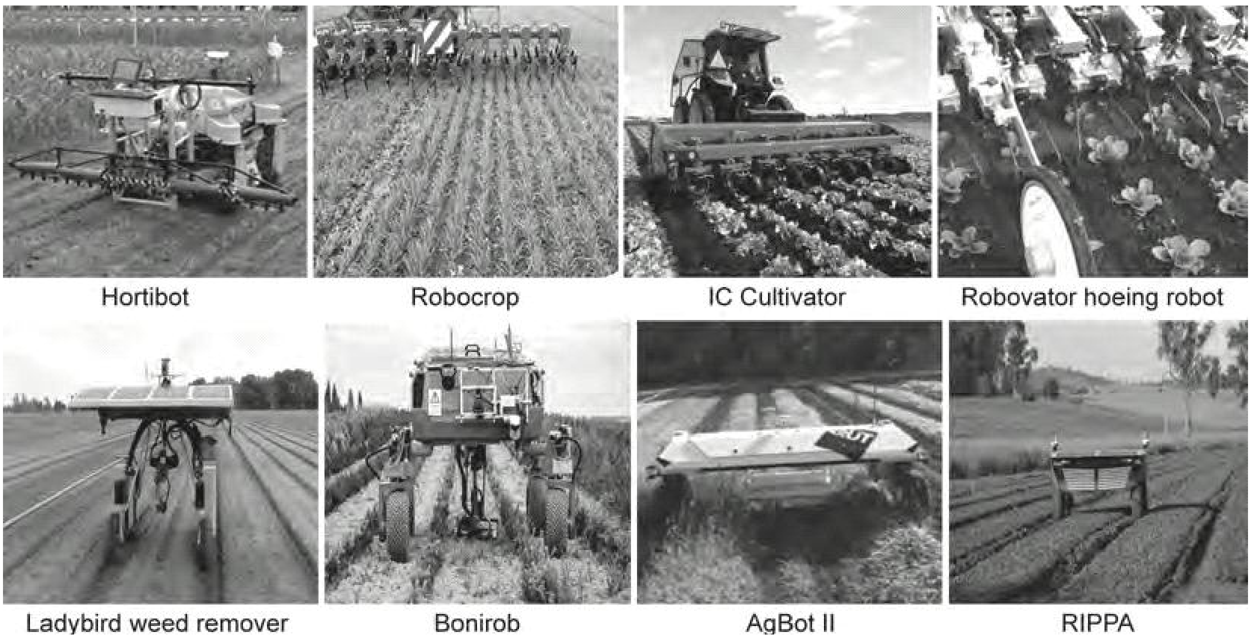

Figure 1. Different robotic machines and systems developed and under development across the world (Rao 2018). a) Hortibot: Piquepaille 2007; b) Robocrop: Tillett. 2008; c) IC Cultivator: Agri-Trade 2019; d). Robovator 2018; e). Ladybird Weed Remover: Underwood. 2016; Bonirob: Anonymous 2015; AgBot 11: Bryant 2014; RIPPA: Australian Centre for Field Robotics—University of Sydney)

positioning as well as satellite navigation, and it knows its location to the nearest centimetre. LIDAR is a remote sensing method that uses light in the form of a pulsed laser to measure ranges (variable distances) to the Earth. Bonrob is capable of distinguishing between weeds and crops by comparing them to images using machine learning. These include several factors for the analysis, such as leaf colour, shape and size. Fitted with a rod, weeds are mechanically controlled by a simple but swift ramming into the ground (Anonymous 2015) like a punch, rather than with herbicides. Bonirob punch is considered a better solution since it involves only one action compared to pulling out a weed which requires grasping and then doing something with it. The punch or ramming is fast (0.01 sec) and easy making it a task well-suited to a robot. The onboard generator allows it to operate for 24 h without needing to refuel.

AgBot: Agribot is a light-weight, golf-buggy sized robot designed as an autonomous vehicle by Queensland University of Technology, Australia. The newer prototype AgBot II helps farmers with seeding, fertilizer application and weed control (Bryant 2014). It uses myriad sensors, software and other electronics to make its way through a field while detecting, accurately classifying and destroying weeds. Weed destruction is carried out by herbicides applied with pinpoint accuracy, reducing waste or through a mechanical hoe. Mechanical removal is used on weed species that have become herbicide resistant. This solar-powered Weed Terminator, Agbot II which can reduce the costs of weeding crops by around 90%.

RIPPA: RIPPA (Robot for Intelligent Perception and Precision Application) is being developed by the Australian Center for Field Robotics at Sydney University. This autonomous solar-powered and battery-operated ground vehicle has an ability to collect data using sensors that also map the crop area and detect weeds. It is fitted with a smart applicator to apply the herbicide at correct dose at a high speed. Currently, this machine can estimate crop yield, spray weeds and fertilizer, and can operate up to 21 h in one trip.

INTEGRATED WEED MANAGEMENT

Success of ground-based and aerial-based remote sensing systems depends on the size of farm holdings and costs. This technology is more apt for larger land holdings. Therefore, despite good promise, PWM is unlikely to be a commercial success in India in near future. Over 85% of farm holdings in India are less than 2 ha. This is likely to go up to 91% by 2030. However, small holdings account for only 45% of the land under cultivation.

Over-reliance on any one method of weed management can overtime reduce its efficacy against weeds. Just as using the same herbicide continuously can lead to resistance as mentioned earlier. Therefore, the need-specific integrated weed management (IWM) is a better option. IWM is based on diversification. IWM requires tactics beyond herbicides. These include pre-planting, post-planting and post-harvest management measures. Two factors to be considered when developing IWM plan include: a) target weed species and b) time, resources and capabilities required to implement it.

NEXT GENERATION WEED SCIENTISTS

Weed scientists of next generation will face challenging issues in developing and implementing best weed management practices. Herbicides will continue to be used, though perhaps in a more limited fashion. Therefore, intensive training in herbicide chemistry, physiology and technology must continue. Weed biology will continue to grow in importance because of growing weed resistance to herbicides. Development of herbicide resistant biotech crops will continue, despite problems in their adoption over long time. Precision weed management, now in initial stages of development, will grow. All of these require weed scientists develop skills in the following:

1. Fundamental mechanisms underlying plant-plant interactions.
2. Plant population modelling.
3. Weed genomics (genome sequencing), metabolomics (metabolome analysis) [Rao 2018] and methods of high-throughput screening of herbicides.
4. Evolution of resistance of weeds to herbicides, particularly non-target resistance; their infestation and spread.
5. Approaches to improve crop competition with weeds. These include altered crop growth response, allelopathy, *etc*.
6. Precision weed management and robotics technologies automated recognition of weeds and invasive plants (machine vision, geographic information systems and remote sensing, *etc*.).
7. Precision weed management technologies in regard to chemical and physical, novel methods.

8. Collaboration with software specialists and engineers to develop new and improved ground-based and aerial-based remote sensing systems.

Training and involvement of weed scientists in these technologies are required to have a paradigm shift in weed management.

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Invasive alien freshwater hydrophytes: Co-facilitating factors with emphasis on Indian scenario

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ABSTRACT

The vulnerability of the freshwater ecosystem due to the global atmospheric changes is an agonizing concern. Exacerbating greenhouse gases, the temperature and ill-considered anthropogenic activities are manifesting the disruption in the ecosystems worldwide including the freshwater ecosystem. The objective of this review work is scrutinization of the invasive, alien, and stress-tolerant aquatic plant species – how their augmentation and endurance are facilitated by myriad factors (both biotic and abiotic) with a special focus on Indian climatic condition. The groundwork is concentrated mainly on the few invasive aquatic weeds like *Eichhornia crassipes* (Mart.) Solms, *Pistia stratiotes* L., *Salvinia molesta* D.S.Mitch., and *Alternanthera philoxeroides* (Mart.) Griseb. as they are more problematic and more pernicious. However, the other less invasive ones should not be underestimated as they can also boom any time in the future due to the impact of climate change and might cause havoc. In this paper, we have tabulated 130 species of alien and invasive freshwater hydrophytes and evaluated discrete forces that might promote their invasiveness. The temperature, precipitation, wind pattern, salinity, nutrient concentration, natural calamities (like flood and drought), elevation, run-offs, habitat fragmentation, and many other elements diminishing the natural biogeochemistry of the freshwater ecosystem. The hydrophytes invasiveness undermines the society, ecologically and economically as well. There are more than one hundred freshwater invasive hydrophytes, found in India. Aquatic macrophytes rather than hydrophytes are the imperative unit of the freshwater ecosystem by providing food, oxygen, and habitat for aquatic organisms including enormous imperiled ones too and thus playing a crucial role in maintaining the food web. But the invasiveness of the alien species restrains all-embracing ecological balance, and also getting promoted due to some environmental issues like increased temperature, nutrient enrichment, humanitarian interferences. Undoubtedly, the management of invasive species is a prodigious challenge. It is candidly essential to be aware of the way and effects of climate change on the freshwater ecosystem for the better understanding and scope to implement potential management measurements - physical, mechanical, chemical, and biological to preserve the indigenous ecological aspects for the freshwater ecosystem. Such studies shall help the investigators attain better perception about these plants and will provide scope to excel in strategic management under changing climatic conditions.

Exponential population growth, and social and economic globalization are enforcing a robust badger on the earth's comprehensive environment. The human society's over exploitation of natural resources and the imprudent anthropogenic activities are a major driver for the ever increasing global pollution. The crucial aspect for the modification in the ecosphere's retaliation is the alteration in global stressors' quality and quantity, considering the atmospheric change along with its mutability and land-use conversion (Thomas *et al.* 2008). Hydrophytes are the foundational background for aquatic ecosystems maintenance of aquatic biodiversity, gaseous exchange through photo-synthesis, and energy transformation (Sushilkumar 2011). The demotion in endemic aquatic floral and faunal heterogeneity of this ecosystem is taking place due to some pivotal menaces like contamination in various ways, incompatible baroscopic switching, eutrophication, nutrient loading, and intrusiveness of non-native species (Chambers *et al.* 2008). A huge amount of nutrients, toxic heavy metals, insecticides, and other contaminants are incorporated into the freshwater ecosystem over the last decades, in the form of domestic sewages, agricultural runoffs and industrial waste materials (Sushilkumar 2011). The excess contaminant ingredients lead to the transposition of water chemistry and encroachment of invasive alien species (IAS). The native biodiversity cannot withstand a certain level of remolding at the habitat and the intrusiveness of non-native species occurs (**Figure 1**). The rapid growth pattern, fertile aquatic habitat, sometimes the warmer temperature, stress-tolerant physiological metabolisms, and weaker restrictions of spreading advocate the invasive nature of the alien plant species by substituting the vernacular community structure and reducing the biodiversity. The native community either prefers migrating to any other suitable habitat or extinct. Sometimes invasive species flourishment is very much profuse forming dense mats all over the water surface so that any tiny animals cannot even be immersed and will stay there (Anderson 2003). This type of invasiveness is demonstrated by their diversified asexual propagative ways and dispersal techniques supporting to adapt in severe climatic conditions (Fawad *et al.* 2013). The connectivity between the trophic status of freshwater ecosystems and their hydrophytes has been investigated since decades (Wolverton and McDonald 1978) yet it still remains an ambiguous area (Thomas *et al.* 2008).

The existence of various hydrophytes describes the eutrophic aquatic systems (Brönmark and Hanson 2001). The IAS slump the native ecological condition of the freshwater ecosystem by facilitating the deterioration of the water quality, a downturn in the biodiversity quantity, slow water regime, disrupting the food web, and food production, impairing navigation, hydro-electric power generation, increased evapotranspiration rate, flood, drought frequency, and intensity, habitat destruction, the desolation of agricultural lands and a lot more. The carriage and repository networks in different aquatic bodies and waterways are becoming congested due to the population outburst of aquatic weeds resulting in adulteration in that process (Datta 2009).

The impacts of metrological shifting and non-native, intimidating species possibly manifest adverse consequences by hindering the habitual ecological services which are economical as well and detrimental to individual well-being. Different species-specific characters, weather conditions also differ in places showing variation in their influences. Sometimes, those situations either buttress other IAS or not and the effects can fluctuate accordingly like escalation, diminution, or no effect (Thomas *et al.* 2008). The high-water loss through evapotranspiration occurs due to aquatic invasive weeds (Mahmoud Ali and Khedr 2018). Since 1951, the mean annual freshwater convenience is alleviating for each person in India, from 5177 cubic meters to 1869 cubic meters in 2001 and it can further go down to 1341 cubic meters in 2025 and 1140 cubic meters in 2050 (Kumar 2003).

Earth is the secured place for human's subsistence and the biodiversity furnishes its environment flamboyantly awarding us with its immeasurable products like food, air, water, natural resources, trades – forestry, agriculture, fishery, materials for survival like organisms with medicinal properties, wood, diversified gene pool *etc*. The invasive ubiquitous habit of few species is challenging the presence of bio-diversities and our social security incidentally. The perseverance of biodiversity of all the ecosystems including the freshwater and well - grounded solutions are much needed. In this review, the invasive freshwater hydrophytes from India are listed along with details of their interaction and responses with the co-facilitating factor which will provide a progressing premise for prospective researchers for better freshwater eco-system management.

Freshwater ecosystem and its hydrophytes

The freshwater ecosystem occupies only approximately 0.8% of the Earth's surface (Dudgeon *et al.* 2007) despite 70% of our planet is covered with water. Freshwater ecosystems are the fecund and variegated ecosphere including all the aquatic bodies except the marine water. India contains only 4% of the world's freshwater. This planet is the low salt concentration environment of which the temperature, depth, shape depends on the location, area of flowing, seasons *etc*., and is one of the biodiversity hotspots. The aqueous environment may be fresh, somewhat saline of brackish water in nature establishing a prime wedge of inland waters (Chandra *et al.* 2018). The different forms of freshwater regions are 1: Ponds with smaller and lesser deep regions and stagnant water; 2: Lakes with larger and deeper regions with stagnant or slow-moving water; 3: Streams and rivers – the incessantly flowing water system with or without large flowing area and specific direction respectively, and 4: Wetlands – the transitional area for both the terrestrial and aquatic ecosystems saturated or covered with a temporary or permanent

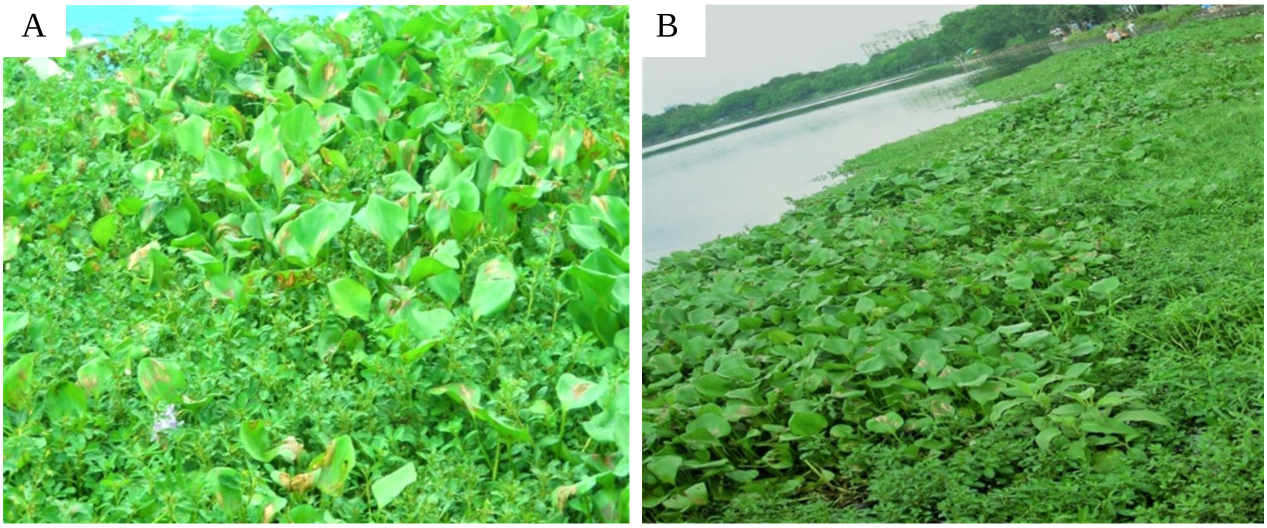

Figure 1. The fresh water invasive weeds succession - the water hyacinth getting substituted by another IAS *Ludwigia adscendens*, B – Invasion by common water hyacinth (Location: Subhas Sarober, Kolkata, West Bengal)

water level at or near the surface advocating diversified biodiversity. Besides the living existence of the water supplier for all purposes - domestic, industrial, agricultural, tourism, communication, *etc.* the freshwater ecosystem mitigates the risk of different natural issues such as flood, soil erosion and safeguards the other ecosystem by hindering the marine water infringement. It is also a great reservoir for global carbon sinking and filtration zone of excess nutrients and various pernicious elements like cadmium, lead *etc*. Sometimes, the genes from many wild bio-diversities of freshwater ecosystems are using manipulating genes to invent more germane products for society's benefit (Buchar *et al*. 1997).

'Hydro' means something related to water and 'phytes' is the group of plants. So, the vascularized plants which can be acclimatized entirely or partially to spend their life cycle and submerged in water or moist places, are called hydrophytes. These are refined with unique adaptive characteristics like having larger and broad-leaves with more stomata and narrow cuticle, lesser root quantity and mechanical tissue, higher amount of air vacuoles in the plant body, and others. Those freshwater hydrophytes can be categorized into few groups – 1. Free-floating: the floating plants on the water surface having the entire body above the water except for its roots. It is in immediate contact with both the air and water, but not the soil; 2. Suspended hydrophytes: which are completely submerged underwater in stagnant or slow-moving water and roots are also not attached with the soil at its matured condition; 3. Submerged anchored: It is the underwater, well-rooted, astomatic, aquatic vegetation growing below the motionless or flowing water; 4. Anchored with floating shoots: The root of few hydrophytes is at the floor of the aquatic body in a well-anchored condition, but the shoots are of creeping habit along the water surface; 5. Anchored but with floating leaves only; 6. Emergent hydrophytes – Aquatic plants with well-projected aerial shoots above water, supple stem, and anchored rhizome to substratum below water. They are implied for having their amphibious nature as found in both shallow water and wetlands. The aquatic habitat includes 7.5% and 11% of dicotyledonous and monocotyledonous flora, respectively (Les and Schneider 1995).

The IAS are the non-native, dominating, sometimes stress-tolerant any kind of living organisms affecting all types of ecosystems globally both ecologically and economically. Few IAS can also be spotted among hydrophytes of the freshwater ecosystem. Among all, *Eichhornia crassipes, Pistia stratiotes, Hydrilla verticillata, Nelumbo nucifera, Ipomoea aquatic, Ipomoea cornea, Vallisneria spiralis, Typha angustifolia, Salvinia molesta* few *Nympheae* sp., *Alternanthera philoxeroides* are the primary concerning IAS for India now (Sushilkumar 2011).

Total 130 aquatic macrophytes and 40 families are explored associated with the invasiveness of the freshwater ecosystems in India. It is observed that the family - Pontederiaceae, Lemnaceae, Salviniaceae, Onagraceae, Hydrocharitaceae, and Alismatacae –are dominating in waters, while the wetland is ruled by, Cyperaceae and Poaceae mainly (**Table 1**). There, 13 free-floating, 16 rooted floating, 1 suspended, 3 anchored hydrophytes with floating leaves, 13 rooted submerged, and 84 emergent aquatic plant species are found (**Table 2**). So, the

Table 1. The percentage distribution of taxonomic families of freshwater ecosystems hydrophytes occurring in India

Family name	No. of available hydrophytes	Family name	No. of available hydrophytes
Alistamaceae	6	Lythraceae	1
Amaranthaceae	3	Araliaceae	1
Araceae	5	Marsileaceae	2
Asteraceae	7	Menyanthaceae	1
Butomaceae	1	Najadaceae	2
Boraginaceae	2	Nelumbonaceae	1
Brassicaceae	3	Nymphaeaceae	3
Ceratophyllaceae	1	Onagraceae	5
Martyniaceae	1	Plantaginaceae	1
Commelinaceae	1	Poaceae	9
Convolvulaceae	3	Cannaceae	1
Cabombaceae	1	Polygonaceae	5
Cyperaceae	14	Pontederiaceae	6
Fabaceae	4	Potamogetonaceae	8
Haloragaceae	2	Salviniaceae	5
Hydrocharitaceae	4	Solanaceae	3
Lamiaceae	5	Trapaceae	1
Lemnaceae	3	Typhaceae	3
Sparginaceae	1	Orchidaceae	1
Lentibulariaceae	1	Oxalidaceae	1

Source: https://www.invasivespeciesinfo.gov/resources
https://www.ncbi.nlm.nih.gov/taxonomy
http://www.bsienvis.nic.in/database/invasive_alien_species_15896.aspx
https://weedsdb.live-website.com/
http://www.theplantlist.org/
https://www.ncbi.nlm.nih.gov/Taxonomy/Browser/wwwtax.cgi?mode=info&id=33090

invasive suspended hydrophyte is the least and the emergent anchored is highest in terms of species richness in this ecosystem. Excluding Cyperaceae and Poaceae, Typhaceae, Polygonaceae, Asteraceae, Lamiaceae, Fabaceae, and Amaranthaceae are pre-eminent families among emergent anchored sections. It can also be noticed that the invasive and alien rooted hydrophytes with floating shoots are more than the ones rooted with floating leaves. Most of the emergent anchored hydrophytes are from the marshy swampland. The average surveillance for all those species is they all are stress-tolerant and are utilizing the supplementary nutrients and other atmospheric conditions for the flourishment within that ecosystem.

Hydrophytes status in Kolkata and surrounding area

A meticulous scrutinization is carried out regarding the chosen problem by exploring both the field studies and the published research articles and databases.

We have gathered the data of the freshwater hydrophytes' diversity and its abundance from the extensive fieldwork – a meticulous survey of the ponds, lakes, canals, wetlands, and the accessible part of the river the Ganges for five months (January 2021 to May 2021) in Kolkata and nearby few sunburn areas of North and South-24 Parganas districts. The freshwater floral diversity and the identification of the invasive aquatic weeds were the principal goal of this survey so that we can relate the literature results with the field survey data to synthesize an accurate result. The samples of the unknown species are collected and identified later in the laboratory with the expert help of and by reviewing relevant literature - Bengal Plants. It was not possible to conclude about the freshwater floral species of India through this short survey. Hence, we have surveyed the literature to ascertaine about all the freshwater invasive plants of entire India. We followed The Plant List – a synergistic perspective by the Royal Botanic Gardens, Kew, and Missouri Botanical Garden http://www.plantlist.org/ providing a potent directory where researchers can find the floral information comfortably, about different flora. We have also consulted https://sites.google.com/site/efloraofindia/home. The invasive nature of the weed in India is assured through these databases - https://weedsdb.live-website.com/ and http://www.bsienvis.nic.in/Database/Invasive_Alien_species_15896.aspx,.

For building a relationship over time, we reviewed this less investigated freshwater floral weed by concentrating on the research works of the last decade mainly. We have searched for peer-reviewed journals - http://www.aquaticinvasions.net/, https://www.science.org/, https://www.journals.elsevier. com/aquatic-botany, https://www.frontiersin.org/journals/plant-science and other websites, books, conference papers through Google (https://www.google.co.in/), Researchgate (https://www.researchgate.net/), Academia (https://www.academia.edu/), and Google Scholar (https://scholar.google.com/) platforms.

Heterogenous ecological responses

The significance of the illustrations between the hydrophytes and different environmental gradients in the aquatic ecosystem has been well explained by Hutchinson (1975). The principal determinant for ecological replacement is the man-made activities right away (Vitousek *et al.* 1997). Though, the amplification of terrestrial biodiversity is developing presently (Parmesan 2006; Root *et al.* 2003, Walther *et al.* 2002), the upgraded illustrations from the watery world are also anticipating (Parmesan 2006). A significant percentage of plants of total vascular flora are gradually establishing their population in the non-native environments of any ecosystems (Pysek *et al.* 2017, 2020). Different components like temperature, water flow, *etc*. along with the escalating concentration of carbon dioxide, and

Table 2. Habitat based categorization of hydrophytes of fresh water ecosystems in India

Category	Scientific name	Common name	Family	Native range	References
Free-floating	*Eichhornia crassipes* (Mart.) Solms	Water hyacinth	Pontederiaceae	South America	Obianuju *et al.* 2020
	Salvinia molesta D.S.Mitch.	Kariba weed	Salviniaceae	South-eastern Brazil	Julien *et al.* 2009
	Salvinia natans L.	Floating water moss	Salviniaiaceae	Central and south eastern Europe and the major part of Asia	Polechońska *et al.* 2019
	Salvinia auriculata (Mitch) Syn.	Eared water moss	Salviniaceae	South and Central America	Banerjee and Matai 1990
	Azolla pinnata R. Br.	Mosquito fern	Salviniaceae	Africa, Asia, and parts of Australia	Mostafa *et al.* 2021
	Azolla cristata Kaulf.	Water velvet	Salviniaceae	North and South America	Ahad *et al.* 2012
	Lemna minor L.	Common duck weed	Lemnaceae	Africa, Asia, Europe, and North America	Paolacci *et al.* 2018
	Lemna gibba L.	Duckweed	Lemnaceae	Ireland	Paolacci *et al.* 2018
	Wolffia columbiana Karsten	Columbian water meal	Araceae	North America	Shah and Reshi 2012
	Lemna perpusilla Torr.	Duckweeds	Lemnaceae	New England	https://gobotany.nativeplanttrust.org/species/lemna/perpusilla/
	Pistia stratiotes L.	Water lettuce	Araceae	Uncertain, probably pantropical, first found from Africa or South America	Coelho *et al.* 2005
	Spirodela polyrhiza (L.) Schleid.	Common duck-meat	Araceae	Florida	https://plants.ifas.ufl.edu/plant-directory/spirodela-polyrhiza/
	Wolffia globosa (Roxb.) Hartog & Plas	Asian water meal	Araceae	Asia	http://www.plantsoftheworldonline.org/taxon/urn:lsid:ipni.org:names:1135607-2
	Potamogeton pectinatus L.	Sago pond weed	Potamogetonaceae	North America	Vierssen *et al.* 1982
Rooted-floating	*Potamogeton filiformis* Pers.	Fine leaf pond weed	Potamogetonaceae	Temperate Northern Hemisphere, Hispaniola, Ecuador to South America	http://www.efloras.org/florataxon.aspx?flora_id=110&taxon_id=242340932
	Potamogeton fluitans Roth	Long leaf pond weed	Potamogetonaceae	Eurasia and the Americas	Shah and Reshi 2012
	Nymphaea tuberosa Paine.	Tuberous water-lily	Nymphaeceae	North America	Pandit *et al.* 2005
Rooted-floating	*Nymphaea lotus* L.	Egyptian white-water lily	Nymphaeceae	Africa and Asia	Tungmunnithum *et al.* 2021
	Nymphaea mexicana Zucc.	Mexican water lily	Nymphaeceae	North America/South Oklahoma to Southeast U.S.A. and Mexico	Nachtrieb *et al.* 2011
	Marsilea minuta L.	Dwarf water clover	Marsiliaceae	Asia, Europe	Shah and Reshi 2012
	Marsilea quadrifolia L.	Water clover	Marsileaceae	Caucasia, western Siberia, Afghanistan southwest India, China, Japan, and North America	Soni and Singh 2012
	Utricularia flexuosa Vahl	Bladder wort	Lentibulariaceae	Northern Hemisphere	
	Trapa natans bispinosa (Roxb.) Makino	Water chestnut	Trapaceae	Taiwan, China, Korea, and Japan	Kak (1990)
	Ipomoea aquatica Forssk.	Water Morning Glory	Convolvulaceae	Southeast Asia	Austin, 2005
	Ipomea hederacea	Ivy-leaved morning glory	Convolvulaceae	tropical parts of the Americas	Smith and Rausher 2006
	Ludwigia parviflora Roxb.	Perennial water primrose	Onagraceae	South America	Gobalakrishnan *et al.* 2020
	Ludwigia peploides (Kunth) P.H.Raven	Floating primrose-willow	Onagraceae	Central and South America	Mitchel and White 2013
	Ludwigia palustris (L.) Elliot	Marsh seed box	Onagraceae	North America and Eurasia	Dite *et al.* 2017
	Ludwigia adscendens (L.) H.Hara	Water primrose	Onagraceae	uncertain - Asia/ Australia/South America/Africa	http://www.plantsoftheworldonline.org/taxon/urn:lsid:ipni.org:names:144324-2
	Ceratophyllum demersum L.	Common hornwort	Ceratophyllace-ae	All continents except Antarctica	Gupta 2001
Suspended rooted-submerged	*Elodea canadensis*	American waterweed	Hydrocharitaceae	North America	USFW, 2019
	Vallisneria spiralis L.	Eel grass	Hydrocharitaceae	Southern Europe	Soni and Singh 2012
	Hydrilla verticillata (L. f.) Royle	Indian star-vine.	Hydrocharitaceae	Probably Africa or Europe	Alix *et al.* 2009
	Ottelia alismoides (L.) Pers.	Duck lettuce	Hydrocharitaceae	Asia and northern Australia.	Wagutu *et al.* 2021
	Myriophyllum verticillatum L.	Parrot feather	Haloragidaceae	Temperate Northern hemisphere	http://www.plantsoftheworldonline.org/taxon/urn:lsid:ipni.org:names:430479-1
	Najas minor All.	Brittle naiad	Najadaceae	Europe, western Asia, and northern Africa	USFW, 2018
	Najas marina L.	Spiny Naiad	Najadaceae	Caribbean Territories, California, Hawaii, continental US, and Eurasia	USFW, 2012
	Potamogeton crispus L.	Curly leaf pond weed	Potamogetonac-eae	Eurasia	Shah and Reshi 2012
	Potamogeton natans L.	Broad-leaved Pond weed	Potamogetonaceae	Europe	Shah and Reshi 2012
	Potamogeton lucens L.	Shining pondweed	Potamogetonaceae	Eurasia and North Africa	
	Potamogeton pusillus L.	Small pond weed	Potamogetonaceae	North America	Lupoae *et al.* 2015
	Cabomba aquatica Aubl.	Gul Kabomba	Cabombaceae	South America	
	Heteranthera dubia (Jacq.) MacMill	Water star grass	Pontederiaceae	North and Central America	Driesche *et al.* 2002
	Nelumbo nucifera Gaertn.	Indian lotus	Nelumbonacea-e	Central and northern India	Shah and Reshi, 2012
Anchored hydrophytes with floating leaves	*Potamogeton nodosus* Poir.	Long-leaf pond weed	Potamogetonaceae	Florida	https://plants.ifas.ufl.edu/plant-directory/potamogeton-nodosus/
	Sagittaria guayanensis Kunth	Guyanese arrow head	Alistamaceae	Mexico, Central America, the West Indies, and much of South America, West Africa , south and southeast Asia, Sudan and Madagascar	https://indiabiodiversity.org/species/show/259147
	Myriophyllum indicum Willd.	Water milfoil	Haloragaceae	India	http://www.plantsoftheworldonline.org/taxon/urn:lsid:ipni.org:names:430420-1
Emergent anchored	*Persicaria amphibia* (L.) Delarbre	water knot weed	Polygonaceae	Europe, Asia, North America, and parts of Africa	http://www.plantsoftheworldonline.org/taxon/urn:lsid:ipni.org:names:30193627-2
	Hydrocotyle umbellata L.	Many flower marsh penny wort	Araliaceae	Brazil	Hamdey *et al.* 2018
	Fimbristylis miliacea (L.) Vahl	Grasslike fimbry	Cyperaceae	Tropical America	Schaedler *et al.* 2013

Category	Scientific name	Common name	Family	Native range	References
Emergent anchored	*Meteranthera limosa* (SW) Wild	Mud plantain	Pontederiaceae	Tropical and subtropical America	Mitchell 1985
	Monochoria vaginalis Presl.	Heartshape false pickerel weed	Pontederiaceae	Asia and across many of the Pacific Islands	Shah and Reshi 2012
	Pontederia cordata L.	Pickrel weed	Pontederiaceae	American continents	https://www.itis.gov/servlet/SingleRpt/SingleRpt?search_topic=TSN&search_value=42620#null
	Monochoria hastata (L.) Solms	Arrow leaf pond weed,	Pontederiaceae	South-East Asia and Oceania	Mitchell 1985
	Panicum perpurascens Raddi.	Para grass	Poaceae	South America and West Africa	
	Paspalum fluitans Kunth	Water paspalum	Poaceae	South America, Central America, and North America	
	Phragmites karka (Retz.) Trin. ex Steud.	Tall Reed	Poaceae	West tropical Africa to Kenya, Tropical& Subtropical Asia to Pacific.	http://powo.science.kew.org/taxon/urn:lsid:ipni.org:names:415942-1
	Phragmites australis (Cav.) Trin. Ex Steud.	Common reed	Poaceae	North America	Hazelton *et al.* 2014
	Echinochloa colona (L.) Link	Jungle rice	Poaceae	Tropical and subtropical Asia,	Ray and Chatterjee, 2017
	Chloris barbata Sw.	Swollen finger Grass.	Poaceae	Tropical America	https://www.itis.gov/servlet/SingleRpt/SingleRpt?search_topic=TSN&search_value=565064#null
	Echinochloa cruss-galli Beauv.	Barnyard grass	Poaceae	Tropical Asia	VKM Report, 2016
	Paspalum distichum L.	Knot grass	Poaceae	North and South America	https://www.cabi.org/isc/datasheet/38952
	Phalaris arundianacea L.	Canary grass	Poaceae	Eurasia and North America	Lavergne and Molofsky, 2004
	Alternanthera philoxeroides (Mart.) Griseb.	Alligator weed	Amaranthaceae	Temperate regions of South America	Pan 2017
	Alternanthera sessilis (L.) R.Br. ex DC	Dwarf copper leaf	Amaranthaceae	Tropical Asia.	Rao 2018
	Alternanthera caracasana Kunth.	Khaki weed	Amaranthaceae	South America	Iamonico and Pino 2016
	Alisma gramineum Lej.	Narrow water plantain	Alismataceae	Temperate Northern Hemisphere.	http://www.plantsoftheworldonline.org/taxon/urn:lsid:ipni.org:names:77097302-1
	Alisma lanceolatum With.	Lance leaf water plantain	Alismataceae	Asia-Temperate, Europe, Northern Africa	Shah and Reshi, 2012
	Alisma plantago aquatica L.	American water plantain	Alismataceae	parts of Australia	Ash *et al.* 2004
	Saggitaria latifolia Willd.	Duck potato	Alismataceae	Southern Canada and most of the contiguous United States, as well as Mexico, Central America, Colombia, Venezuela, Ecuador, and Cuba	Shah an Reshi 2012
	Saggitaria sagittifolia L.	Hawaii Arrowhead	Alismataceae	Europe from Ireland and Portugal to Finland and Bulgaria, and in Russia, Ukraine, Siberia, Japan, Turkey, China, India, Australia, Vietnam and the Caucasus	USFW, 2012
	Commelina benghalensis L.	Benghal day flower	Commelinacea-e	Tropical and subtropical Asia and Africa	Ghosh *et al.* 2019
	Cyperus glomeratus L.	Clustered Sedge.	Cyperaceae	Europe/Asia	Shah and Reshi, 2012
	Cladium jamaicense C rantz.	Saw-grass	Cyperaceae	Caribbean Territories, America, Hawaii	https://www.itis.gov/servlet/SingleRpt/SingleRpt?search_topic=TSN&search_value=39878#null
	Cyperus alternifolius L.	Umbrella sedge	Cyperaceae	Panama, Madagascar	http://www.plantsoftheworldonline.org/taxon/urn:lsid:ipni.org:names:303729-1
	Carex diandra Schrank	tussock-sedge	Cyperaceae	Europe and North Africa.	
	Cladium mariscus (L.) Pohl.	swamp sawgrass	Cyperaceae	Temperate Europe and Asia	
	Eleocharis equisetoides (Ell.) Torr.	Jointed spikerush	Cyperaceae	South America	
	Eleocharis acicularis (L.) Roem et Schlt.	Needle spike sedge	Cyperaceae	Temperate Northern Hemisphere to South America	Shah and Reshi 2012
	Eleocharis parishii Britton.	Parish's spike rush.	Cyperaceae	Northern Mexico, the Southwestern United States	Shah and Reshi 2012
	Eleocharis pauciflora Link	Few-flowered spike-rush	Cyperaceae	North America	Shah and Reshi 2012
	Cyperus compressus L.	Poorland flat Sedge	Cyperaceae	Tropics & Subtropics.	Shah and Reshi 2012
	Cyperus rotundus L.	Nut sedge	Cyperaceae	Africa, southern and central Europe (north to France and Austria), and southern Asia	Barai *et al.* 2017
	Cyperus iria L.	Rice Flat Sedge.	Cyperaceae	Tropical Asia	Shah and Reshi 2012
	Cyperus difformis L.	Small flower umbrella-sedge	Cyperaceae	southern Europe, most of Africa and Asia, and Australia	Derakhshan and Gherekhloo, 2013
	Lycopus europeus L	European bugleweed	Lamiaceae	Azores, Europe to China	https://nas.er.usgs.gov/queries/GreatLakes/FactSheet.aspx?Species_ID=2694
	Mentha aquatica L.	Water mint	Lamiaceae	Europe, northwest Africa and southwest Asia	Anca-Raluca *et al.* 2013
	Mentha arvensis L.	Corn mint	Lamiaceae	Temperate regions of Europe and western and central Asia, east to the Himalaya and eastern Siberia, and North America	Thawkar *et al.* 2016
	Mentha piperita L.	Pepper mint	Lamiaceae	Europe	Shah and Reshi 2012
	Mentha spicata L.	Spearmint	Lamiaceae	Europe and southern temperate Asia	https://www.gbif.org/es/species/113618163
	Cassia occidentalis L.	Kalkashunda	Caesalpinaceae	Tropical and subtropical regions of the America	Yadav *et al.* 2009

Category	Scientific name	Common name	Family	Native range	References
Emergent anchored	*Cassia uniflora* Mill.	Oneleaf senna	Caesalpinaceae	Tropical South America.	Joshi 1991
	Cassia tora L.	Sickle senna	Caesalpiniacea-e	Central America	Pradhan *et al.* (2005)
	Nicotiana plumbaginifolia Viv.	Tex-mex tobacco	Solanaceae	Mexico, South America, and parts of the Caribbean	Knapp and Clarkson, 2004
	Datura inoxia Mill.	Pricklyburr	Solanaceae	Southwestern United States, Central, and South America	Cinelli and Jones 2021
	Datura metel L.	Stinkweed	Solanaceae	Southern China	Vadlapudi and Kaladhar 2012
	Sparganium erectum Huds.	Branched burreed	Sparginaceae	North America	
	Menyanthes trifoliata L.	Bog bean	Menyanthaceae	Labrador to Alaska south to Wyoming, Nebraska, Missouri, Ohio, and Virginia.	http://www.plantsoftheworldonline.org/taxon/urn:lsid:ipni.org:names:50970102-1
	Rumex aquaticus L.	Willow dock	Polygonaceae	Temperate Eurasia	Shah and Reshi 2012
	Rumex conglomeratus Murry	Sharp dock	Polygonaceae	Europe, Asia and North Africa	Shah and Reshi 2013
	Polygonum nepalensis (Meisn) Gross	Nepalese smart weed	Polygonaceae	Eastern Africa, including Madagascar, and parts of Asia.	https://www.inaturalist.org/guide_taxa/1229222
	Polygonum lapathifolium L.	Pale smart weed	Polygonaceae	North America and Eurasia	https://www2.ic.edu/prairie/pond_smartweed.htm
	Polygonum barbatum L.	Knot grass	Polygonaceae	Asia	CABI, 2019
	Canna indica L.	Indian shot	Cannaceae	Tropical America	Kumbhar *et al.* 2018
	Utricularia vulgaris L.	Greater bladder wort	Lentibulariaceaee	Northern Europe, Asia	
	Herminium lanceum (Thunb. ex Sw.) Vuijk	Chinese Lady's-Tresses	Orchidaceae	Mongolia to Tropical Asia	Raskoti *et al.* 2017
	Oxalis corniculata L.	Creeping woodsorrel	Oxalidaceae	probably southeast Asia	Groom *et al.* 2019
	Typha angustifolia L.	Narrowleaf cattail	Typhaceae	North America, Europe, and Asia.	Ciotre *et al.* 2012
	Typha latifolia L.	Broad-leaf cattail	Typhaceae	North and South America, Europe, Eurasia and Africa	Bansal *et al.* 2019
	Typha orientalis C.Presl	Cumbungi	Typhaceae	Australia, New Zealand, Malaysia,Indonesia, Japan, Korea, Mongolia,Myanmar, Philippines, China, and Russia Parts of Africa, and much of Asia, Europe	https://tropical.theferns.info/viewtropical.php?id=Typha+orientalis
	Rorripa islandica Borbas	Northern marshyellowcress	Brassicaceae	Eurasia, North America, and the Caribbean.	https://inaturalist.ca/taxa/64162-Rorippa-palustris
	Cardamine flexuosa With.	wavy bittercress	Brassicaceae	Europe and Eastern Asia	Marhold *et al.* 2016
	Cardamine hirsuta L.	Hairy bittercress	Brassicaceae	Western Asia	Marble *et al.* 2021
	Aeschynomene aspera L.	Sola pith plant	Fabaceae	Bangladesh, Bhutan, Cambodia, India,Indonesia, Laos, Malaysia, Myanmar,Nepal, Pakistan, Sri Lanka, Thailand, and Vietnam	http://www.plantsoftheworldonline.org/taxon/urn:lsid:ipni.org:names:472655-1
	Parthenium hysterophorus L.	Whitetop weed	Asteraceae	American tropics.	Kaur *et al.* 2014
	Gnaphalium polycaulon Pers.	Stem cud weed	Asteraceae	Asia/Zimbabwe	http://www.plantsoftheworldonline.org/taxon/urn:lsid:ipni.org:names:209889-1
	Grangea maderaspatana (L.) Poir.	Madras carpet	Asteraceae	Asia, Africa	https://sites.google.com/site/efloraofindia/species/a---l/ar/asteraceae/asteroideae/astereae/grangea/grangea-maderaspatana
	Ageratum conyzoides L.	Billygoat-weed	Asteraceae	Tropical America, especially Brazil	Bosi *et al.* 2013
	Blumea laciniata (Roxb.) DC.	Cutleaf Blumea	Asteraceae	India to New Guinea and the Solomon Islands	http://powo.science.kew.org/taxon/urn:lsid:ipni.org:names:185697-1
	Bidens bitternata (Lour.) Merr. & Sheriff	Spanish needles	Asteraceae	Asia	Shah and Reshi 2012
	Eclipta alba (L) Hassk.	False daisy	Asteraceae	Tropical America	Shah and Reshi 2012
	Myosotis caespitosa Schultz	Tufted forget-me-not	Boraginaceae	Europe	https://keyserver.lucidcentral.org/weeds/data/media/Html/myosotis_laxa_subsp._caespitosa.htm
	Myosotis laxa Lehm.	Mall-flowered forget- me-not	Boraginaceae	Africa	Swenson *et al.* 1997
	Martynia annua L.	Cat's claw	Martyniaceae	Mexico, Central America, and the Caribbean	CABI, 2019
	Lytharum salicaria L.	Purple loosestrife	Lytharaceae	Europe and Asia	Shah and Reshi, 2012
	Hippuris vulgaris L.	Common mare's-tail	Plantaginaceae	Subarctic & Temperate regions	http://www.plantsoftheworldonline.org/taxon/urn:lsid:ipni.org:names:430352-1
	Epilobium hirsutum (L.) Gray	Cherry-pie	Onagraceae	North Africa, Europe up to southern Sweden, and Asia	Shah and Reshi, 2012
	Butomus umbellatus L.	Flowering-rush	Butomaceae	Africa, Asia, and Eurasia	Shah and Reshi, 2012
	Colocasia esculenta (L.) Schott	Wild taro	Araceae	Tropical Asia probably South-East or southern Central Asia	Shah and Reshi, 2013
	Ipomoea carnea Jacq.	Morning glory-bush	Convolvulaceae	South America	Chaudhuri *et al.* 1994

greenhouse gases like methane gas, nitrous oxide in the atmosphere, the changing rainfall amount are also predominating issues for having some footprints on the endowment and distribution of aquatic invasive species (Thomas *et al.* 2008, Lamsal *et al.* 2017). An elaborate evaluation of morphological, physiological, and molecular aspects of the plant community structure and its adaptations should be explored considering all the biotic and abiotic environmental factors (Wittyngham *et al.* 2019, Dalla Vecchia *et al.* 2020). The mass production of sexual and asexual reproductive propagules and its remote dissemination helps the invasive hydrophytes across freshwater bodies and wetlands, causing both native biodiversity and provident deprivation (Richardson *et al.* 2000, Kercher and Zedler 2004). It has been estimated statistically that a great portion of our planet's ecosystem is already invaded by invasive plant species and they are mostly seen in the economically developed countries (Rai and Singh 2020), although the impacts of the ecological and economic will be encountered globally due to this invasion.

Nutrient encroachment: Aquatic vegetation is the primary producer of freshwater ecosystems. They require many elements - light, water, and carbon dioxide to complete the photosynthesis, respiration, metabolic activities, etc. (Moss 1988). Enormous recyclable and non-recyclable products are pouring into the freshwaters every day and from different sources leading to the nutrient-enriched and violated the condition that shapes the freshwater ecosystem rather than biodiversity and its hydrology primarily or in different auxiliary ways (O'Hare *et al.* 2018). The aquatic floral world – its structure, composition, and interactions can be substituted by the prevailing inflation in carbon dioxide content (Feely *et al.* 2004) and the physiological metabolisms like reproduction, absorption, and water content are exhilarated among aquatic under-growths (Weltzin *et al.* 2003). The obnoxious species, *Hydrilla verticillata* was observed growing rapidly with a higher proportion of carbon dioxide and temperature (Chen *et al.* 1994). The amount of nutrients like nitrogen, phosphorus, becomes higher in freshwaters from varieties of sources anthropogenically (Hou *et al.* 2013). Hydrophytes, epiphytes, and planktons struggle for daylight after the nutrient loading (Hilton *et al.* 2006). Phosphorus is the moderately available and much-needed nutrient for autotrophs representing greater scope to stop the extension (Schindler *et al.* 1977). Solar radiation can't invade the condensed intrusion by IAS on the entire water surface and without light other plants can't grow. The invasive hydrophytes which are not anchored to the soil and can sail with water current exacerbate their growth with a more nutrient-loading state (Poikane *et al.* 2018, van Zuidam and Peeters 2013, Verhofstad *et al.* 2017), while higher salinity negatively provokes the standard hydrophytes growth. The inconsistency can also be seen for the fauna as nutrients, food, and higher biological and chemical oxygen demand is scarce. Those components are utilized entirely by the IAS. Aquatic organisms can't sustain in such a suffocating environment due to the prosperity in the microorganisms' community. When both the nitrogen and phosphorus are accumulated at an outrageous rate, the mushrooming can also be curbed for local hydrophytes (Anderson *et al.* 2002, Fisher *et al.* 1992).

Eutrophication is a common outcome found in the freshwater ecosystem of those ravaging. It is a serious problem for this ecosystem as a greater amount of nutrients facilitates the speedy multiplication rate for some alien, stress-tolerant, invasive hydrophytes and toxic algal species and thus lowers the abundance of biodiversity and hampers the entire food web rather than environmental stability. Such affected aquatic bodies remind us about sustainable development for the long run on this planet (Dubey and Datta 2020). The leaves of the submerged hydrophytes become fully covered with the extravagant phytoplankton and periphyton growth giving an inappropriate amount to the light exposure and thus the community structure is controlled (O'Hare *et al.* 2018). The gradual depletion of hydrophytes occurs due to the strong pressure of invasive ones as the fight is at a greater percentage for survival (Hilton *et al.* 2006). The secretion of toxic cyanotoxins from the algal bloom may be lethal to other aquatic organisms also. A few such abundant but harmful algal species found in India include *Microcystis* sp., *Anabaena* sp., and *Gloeotrichia* sp. The water color may get altered as per the algal pigment like brownish, different greenish and other shades. Eutrophication is a universal hassle and can be observed more in highly populated areas and near the farmlands (Smith 2003). This phenomenon also depends on variation in abiotic factors like salinity, humidity, precipitation, latitude, altitude, season *etc*. (Liu *et al.* 2010). Furthermore, nutrients promote faster-growing free-floating or canopy-forming macrophyte species outcompeting slower-growing or shorter species (Poikane *et al.* 2018, van Zuidam and Peeters 2013, Verhofstad *et al.* 2017).

Temperature: The unscrupulous attitude of human society towards the environment leads to the increased level of greenhouse gases in the earth's atmosphere and causing global warming. Presently, the glaciers and icebergs are melting at a great percentage and the water temperature is higher than the normal condition affecting the aquatic ecosystem (Mooij *et al.* 2005, Woolway *et al.* 2017). It is manifested that the surface water temperature is identical to the atmospheric temperature and the warm discharges from industrial belts are also responsible for the warmer condition in the freshwater ecosystem. The warmer temperature and changes in precipitation dynamics are better catalysts than higher carbon dioxide concentration to aid for invasive hydrophytes proliferation (Ojala *et al.* 2002). For example, *Phragmites australis* advances more expeditiously at higher temperatures (Wilcox *et al.* 2003). It happens because the temperature induces the anatomical metabolisms of the hydrophytes including its reproductive nature. It was studied that the submerged hydrophytes can photosynthesize well within the range of 25 and 32°C (Barko *et al.* 1982, Santamaría and Van Vierssen 1997, Pedersen *et al.*

2013) and in India, this range is common. The average temperature remains around 25-26°C representing suitable weather for the IAS – freshwater hydrophytes. The gross photosynthetic rate is two times within the range of 10 and 30 ° C (Drew *et al.* 1979). Maximum photosynthesis, respiration, light compensation points can work 50% more during the elevation of 5 to 10°C (Hootsmans and Vermaat 1991). Warmer temperature also reduces the nutrient and stoichiometric equilibrium - the temperature-plant physiological hypothesis (Reich and Oleksyn 2004), as aquatic vegetation needs a smaller amount of alimentative for its perpetuation (Reich and Oleksyn 2004, Zhang *et al.* 2016). In the shallow freshwater area, the temperature also controls the decay and assimilation rate of organic matters (Carpenter and Adams 1979, Federle *et al.* 1982, Brock *et al.* 1983, Brock 1984). Increasing temperature and the invasiveness both instigate pronounced evapotrans-piration rate and water extraction from the ecosystem resulting in habitat loss and drought conditions also. This drying effect only can be remunerated by an ample amount of rainfall (Hanseen *et al.* 2003). Otherwise, provisional bogs will be obliterated along with their paramount biodiversity reservoir (Gibbs 1993, Semlitsch *et al.* 1996, Semlitsch and Brodie 1998).

Human endeavors: It is an irrevocable issue and a broadly accepted fact that the main reason for global atmospheric changes is for inconsiderate anthropogenic activities, like exorbitant exploitation of the natural resources, burning fossil fuel, destructing greenery, restyling of natural organisms and their products *etc*. causing disruption of natural cycles in all types of ecosystems (IPCC 2021). Excessive human force from different aspects like scarcity of space for urbanization, global e-commerce *etc*. alters the environmental components like temperature and many others which ultimately ameliorates the invasive nature of the biological organisms (Bolpagni 2021). Extended warmer seasons reinforce the exorbitant biomass of freshwater ecosystems and explain the instability rate among freshwater hydrophytes including IAS according to the metrological influences (Rooney and Kalff 2000). The massive utilization of freshwater ecosystem by copious means such as for food, as a drainage basin, power generation, transportation, urbanization *etc*. is polluting this environment and shows disturbance in its common behavior (Vitousek 1994, Nelson 2005). Kolar and Lodge (2000) pointed out heterogeneous humanitarian interference and its consequences for this ecosystem along with the explanation of how the invasiveness is inspired from varied aspects: entertainment purposes, surplus food production, formation of concrete structures on waterways, and filling up the local freshwaters. The intensified rate of population growth demands more basic commodities and advanced culture. Human society is sharing those components to improve civilization as the natural depository is fixed in its amount. The dams were constructed for hydroelectric power generation by fragmenting the aquatic body and the natural habitat as well. We extract water, its flora, and fauna from this ecosystem for miscellaneous purposes such as food, fodder, industrial usage etc., and evacuating virulent detritus into it. The native freshwater communities can't hold out against contamination and increased levels of flooding, drought, altered fluvial characters surge the extinction rate as they are not getting the desirable habitat. It is denoted that any disturbed habitat rather than the undisturbed ones is more susceptible to transgression (Mack *et al.* 2000) while the simplification of such occurrence – the relationship, was described (Hobbs 2000). A greater level of chemical usage and genetic engineering for better production and quality of products is slowly degenerating rather than destroying the ecosystem. The urbanization, excess agricultural operations easing the conditions for the IAS (hydrophytes) into the freshwater ecosystem (Glassner-Shwayder 2000) leading to interruptions and unevenness to that certain ecosystem ecology (Hansen and Clevenger 2005, Mack *et al.* 2000).

Potential measures

The IAS including hydrophytes are conferring serious threat to the ecosystem rather than to the freshwaters (Enserink 1999, Kolar and Lodge 2000, Pimentel *et al*. 2000, Palumbi 2001). So, the realization, researches, and conservation is depending on the better clarity of the interrelation between the ecosystem and its various modules sharply (Hansen *et al.* 2003). Except for the mass awareness and meticulous laws, we should distribute our analysis to divergent fields. The principal focus should be the restoration and maintenance of native freshwater biodiversity in cost-effective methods before it's become too late as we already have lost enough resources. Preventive management refers to the manual removal, monitoring, and barricading technique (Sushilkumar 2011). As an instance, Jamshedpur municipality, Jharkhand has applied this technique to pull out the water hyacinth from the river (Sushilkumar 2011). Mechanical procedures are also easier and more money-saving ones. The use of the net, proper drainage, harvesters, and other weed cutters can be introduced frequently. Chemical management is another approach to control the invasive freshwater hydrophytes. Different non-ecofriendly herbicides like 2,4-D, glyphosate were registered in India for managing invasive weeds and minimize their harmful effects on aquatic biodiversity.

Biological control methods are the most environment-friendly, the cheapest process, though it is time-consuming. The host-specific bio agents are incorporated into the inland water systems and the IAS can be eradicated (Sushilkumar 2011). The clogging by *Salvinia molesta* is checked by the integration of weevil into the city canals in Kerala (Jayanth 1987). The integrated measures (integration of biological and chemical approaches) can also be followed as per the requirement as used in Jabalpur, Madhya Pradesh for water hyacinth control (Sushilkumar 2011a).

Conclusion

The freshwater IAS are truly hazardous for this ecosystem and Indian climatic conditions provide congenial environment for them to flourish. Moreover, the narcissistic attitude of the human is a resentful concern of our society for this dismantlement. The growth, disadvantageous aspects and factors of the ambience by which freshwater IAS are thriving need to be re-evaluated. The excessive proliferation of hydrophytes needs to be managed (Datta 2009) by paving the path in such a way that the management of invasive hydrophytes coincides with efforts to restore the native biodiversity.

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Weed competitive cultivars as a component of integrated weed management in direct-seeded rice: A Review

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ABSTRACT

Lower input (water, labour and energy) demand of direct-seeded rice (DSR), compared to conventional puddled transplanted rice (PTR), is the key driver for expanding the DSR area in many countries of Asia. The success of DSR, however, lies in effective management of weeds. For sustainable weed management, DSR systems need management interventions other than herbicides. Identification and introduction of weed competitive rice cultivars offers one of the potential and safe approaches to manage weeds in DSR. This article reviews the research on role of weed-competitive rice cultivars in managing weed infestation in DSR. It is reported that higher early vigour on account of rapid early growth, leaf area and biomass accumulation; plant height, root and shoot competition; crop duration and allelopathy *etc*. are the key traits associated with weed competitiveness. We aim to provide a logical perspective of exploring and exploiting the competitiveness of rice cultivars to strongly compete for resources with the associated weed flora to overcome stress, which is essential to realize potential yields in DSR system.

INTRODUCTION

Rice (*Oryza sativa* L.) is one of the major cereal crops structuring the staple diet for more than half of the world's population (Kumar 2018, Khir *et al.* 2019). More than 90% of rice is produced and consumed in Asia (Singh *et al.* 2019a). Globally, India is the second largest producer and consumer of rice in the world after China, which accounts for 21% of the world's total rice production (APEDA 2021). Hence, rice is the lifeline for millions of people. The global population is predicted to reach 9 billion and food demands are projected to rise by 70-100% by 2050 (FAO 2017, Huang *et al.* 2017). Hence, there is a need to increase rice productivity with limited natural resources (as shrinking natural resources pose a challenge to attain peak productivity) to attain food security.

Rice is mainly established by two methods (1) transplanting and (2) direct seeding. Puddled transplanted rice (PTR) is water, energy and labor intensive (Jat *et al.* 2019, Shekhawat *et al.* 2020). The direct-seeding of rice (DSR) skips practices like nursery raising, puddling and transplanting, and thus reduces both labour and irrigation requirement (Bhullar *et al.* 2018). Therefore, DSR is gaining popularity over PTR due to increased economic and ecological benefits such as saving of labour (8 to 60%), irrigation water (12 to 60%), less drudgery, early maturity (7-10 days), reduced cost of cultivation, improved fertilizer use efficiency, offers better soil environment and improves the productivity of succeeding crops, and less emission of greenhouse gases (Gathala *et al.* 2011, Jat *et al.* 2014, Chakraborty *et al.* 2017, Kaur and Singh 2017, Dhillon and Mangat 2018, Kumar *et al.* 2018, Ranbir *et al.* 2019, Basavalingaiah *et al.* 2020). In parts of India, Covid-19 pandemic situation severely affected the labor movement, which delayed the crop establishment and made farmers to explore the alternative rice establishment methods such as direct-seeding and transplanting of rice using machinery (Shirsath *et al.* 2020). As the cost of irrigation water and labour are likely to rise in future which will not only make DSR economically more attractive option but will also tend to increase area under DSR (Hossain *et al.* 2016, Dhillon *et al.* 2021a).

The higher weed infestation in DSR due to absence of the size (age) differential between the crop and the weeds and the lack of standing water for suppressing weed growth at crop establishment (Shekhawat *et al.* 2020, Panneerselvam *et al.* 2020, Chauhan 2012, Kumar *et al.* 2013) are among major constraints in the adoption of DSR as high weed infestation significantly reduces the grain yield (Matloob *et al.* 2015, Chauhan *et al.* 2015, Priya *et al.* 2017, Sandhu *et al.* 2019). Direct sown fields are reported to have more diverse weed flora than transplanted rice fields (Dhillon and Mangat 2018). Weed flora in DSR broadly includes grasses, sedges and broad leaf weeds (BLW) (Kumar 2018, Singh *et al.* 2019b, Sharma *et al.* 2020). Major grasses causing yield losses includes *Echinochloa colona* (L.), *Echinochloa crus-galli (*L.), *Leptochloa chinensis* (L.), *Dactyloctenium aegyptium* (L); sedges includes *Cyperus iria (*L.), *Cyperus difformis (*L.), *Fimbristylis miliacea (*L.); BLW includes *Eclipta prostrata* (L.), *Sphenoclea zeylanica (*G.) and *Ludwigia hyssopifolia* (G. Don.). Among 1800 weed species reported in rice, grasses and sedges are found predominant (Banik *et al.* 2020). Weeds cause 50-60% of yield losses in PTR and 70-80% in DSR (Pooja and Saravanane 2021, Das *et al.* 2021, Banik *et al.* 2020). In India, yield reduction of 20-85% due to presence of weeds have been reported in DSR fields (Banik *et al.* 2020) which indicates that proper weed management is a key to the success of DSR. Kumar and Ladha (2011) reported 15-100% yield reduction due to presence of weeds in DSR. Yield reductions up to 40-100% are reported under heavy weed infestations (Pooja and Saravanane 2021, Shekhawat *et al.* 2020). Competition offered by weeds for sunlight, water, space and nutrition not only reduces the crop yield but significantly deteriorates the quality of produce (Verma *et al.* 2015). Mixing of rice seeds with weedy rice during harvesting impairs the milling quality of rice (Ottis *et al.* 2005). Hence, the effective control of more intensified and diversified weed flora are major concerns for sustained productivity of rice using direct-seeding method of establishment.

Significance of competitive cultivar in managing weeds in DSR

Chinnusamy *et al.* (2000) reported critical period of crop weed competition in medium duration genotypes under DSR to be between 15-45 days after sowing (DAS). Similar data on critical period of weed control in DSR has been revealed by Chauhan and Johnson (2011), which is between 14-41 DAS. Likewise, Raj and Syriac (2017) reported that the weed competition beyond 15 DAS in DSR can significantly reduce crop yields. Control of weeds or suppression of their competitive ability against crop before the critical period, significantly increases the quality and yield of a crop (Fahad *et al.* 2015, Hussain *et al.* 2015).

Weed management during the critical period of crop weed competition in DSR can be accomplished by various physical, chemical or cultural practices (Banik *et al.* 2020). Physical methods like hand weeding was found to be the most effective and eco-friendly method of weed control, but due to slow, cumbersome and labour intensive nature, it proved uneconomical (Dnyaneshwar *et al.* 2018). Similarly, adoption of agronomic manipulations in crop production is effective as a cultural weed control method but have limited scope under dense and diverse weed conditions. Although herbicides may provide a satisfactory control of weeds, but intensive herbicide use can cause environmental contamination and may increase the risk of evolution of herbicide resistance in weeds (Dass *et al.* 2017, Mahajan and Chauhan 2013). Therefore, eco-friendly approaches like; selection of weed competitive genotypes (Zhao *et al.* 2006a, Ramesh *et al.* 2017), alteration of seed rates (Anwar *et al.* 2011, Dass *et al.* 2017) and stale seed-bed (Chauhan 2012, Singh *et al.* 2016) could be exploited to reduce selection pressure and manage the herbicide resistance in weeds (Lutman *et al.* 2013, Chauhan 2020).

Amongst these approaches, use of competitive cultivars for weed control is the most important non-monetary strategy which can reduce herbicide use, will minimize environment degradation and delay evolution of herbicide resistance in weeds (Mahajan and Chauhan 2013). Many good weed competitive rice cultivars have been reported in different regions, such as, '*Apo*' and '*UPLRi-7*' with rapid seedling and early biomass in Philippines (Zhao 2006b), *Oryzica sabana* 6 with high leaf area index and tiller density in Latin America (Fischer *et al.* 2001), M-202 with high leaf area and root biomass in North America (Gibson *et al.* 2003).

Weed competitive cultivars

Weed-competitive ability is a complex trait as it is the result of the interaction among several desirable traits. Commonly, it's a challenge for a plant breeder to develop weed-competitive crop cultivar without dropping any other significant trait. Consequently, it is imperative to determine the complexity of the mechanisms and agro-morphological traits that confer weed competitiveness to develop superior weed-competitive rice cultivars (Dimaano *et al.* 2017, Chauhan *et al.* 2015). Weed competitive cultivars are able to grow better even in the presence of weeds by providing them competition for survival without much loss of yield and quality of crop. It may be because of the advantage due to some added morphological traits like bigger leaves which can shade growing weeds deep roots for better water uptake (Schreiber *et al.* 2018) and other identified traits/characteristics (**Table 1**).

Competition between crop and weed is natural, abundant and undesirable in agriculture (Dass *et al.* 2017). Therefore, using a competitive plant that can efficiently suppress the growth of weeds around it, without sacrificing its yield, can be used as a viable option. The crop cultivars vary widely in their ability to compete with weeds within a single species and these may perform differently in different regions and growing conditions. Hence, selection for competitive cultivars is a very difficult task (Dass *et al.* 2017).

The genotypic differences were found to exist in relative competitiveness of cultivars in different crops and the use of intervention of weed competitive ability of cultivars as a part of integrated weed management systems has been experimented. Rice cultivars with early vigour, rapid growth, high leaf area index *etc*. were found to be responsible for crop competitivenes (Dass *et al.* 2017). Hence, breeding of crop cultivars for their ability to suppress weeds and its exploitation for weed management would be effective (Korres 2018). Development and use of such competitive cultivars in crops will reduce the need for mechanical weed control (Sardana *et al.* 2017), besides reduction in herbicide load and ultimately cost of production.

Table 1. The traits/characteristics reported to be associated with rice competitiveness against weeds

Traits/characteristics	References
Rapid growth in early stages	Zhao *et al.* 2006a
Early stages leaf area	Namuco *et al.* 2009
Early seedling vigour	Mahajan and Chauhan 2013, Shekhawat *et al.* 2020
Biomass in early stages	Namuco *et al.* 2009
Plant height: Tall	Prasad 2011, Mahajan *et al.* 2014,
Plant height: Short	Fukai 2002
Shoot competition	Chauhan and Johnson 2010
Root competition	Perera *et al.* 1992
Root characteristics	Schreiber *et al.* 2018,
Crop duration	Dingkuhn *et al.*1999
Tillers per plant	Zhao *et al.* 2006b, Shekhawat *et al.* 2020
Allelo-chemicals/ Allelopathy	Shrestha *et al.* 2020

Use of weed competitive cultivars: Morphological, physiological and biochemical traits collectively control plants competitiveness. Use of strong weed competitive cultivars is a low cost and environmentally safe strategy for weed management (Shekhawat *et al.* 2020, Dass *et al.* 2017, Singh *et al.* 2016). Such cultivars reduce the weed infestation through strong competition for limited resources, production of allelo-chemicals (chemical exudates to reduce growth) (Shrestha *et al.* 2020). In general, there are two aspects of cultivar competitiveness, weed suppression and weed tolerance ability (Hansen *et al.* 2008). Weed tolerance is the ability to maintain high yields despite weed pressure while weed suppression is the ability of cultivar to reduce seed production in weeds or to suppress the weed growth *via* competition (Raj and Syriac 2017). Weed suppression is more desirable than weed tolerance as it avoids the seed buildup in soil for future infestations. The inclusion of medium-duration rice hybrid resulted in higher rice and system yields (Singh *et al.* 2020). Wang *et al.* (2002) found that "competitive" rice cultivars excelled the "non-competitive" cultivars in grain yield by 7-9 per cent. Hence, these can serve as a potential tool for long-term weed control in DSR systems through weed suppression.

Characteristics of weed competitive cultivars: The traits in rice that are likely to be most helpful for weed management and related to weed competitiveness includes; seed size, quicker emergence, plant height, high and early seedling vigour with rapid leaf area development during the early vegetative stage for weed suppression, rapid growth, high tillering ability, orientation of leaves (droopy), high early biomass accumulation rates, high leaf area index , rapid ground cover by canopy, deep and prolific roots, ability to withstand biotic and abiotic stresses, cultivars having an allelopathic effect, early maturity, herbicide-resistance and many more (Mahajan and Chauhan 2013, Shekhawat *et al.* 2020, Singh *et al.* 2016, Dass *et al.* 2017, Shrestha *et al.* 2020). Chauhan *et al.* (2015) suggested that genotypes with a larger leaf area could be integrated with other weed management strategies to achieve sustainable weed control in DSR production systems. This shows that there is a need to integrate cultivars with different traits for better outcomes. Hence, whole plant needs to be studied to understand the competitiveness of a genotype. Some information complied on potential traits for weed competitiveness in rice reported by different researchers has been specified in **Table 1**. Several weed competitive cultivars were identified by researchers (**Table 2**).

Table 2. Weed competitive rice cultivars

Competitive genotypes	References
Oryzica sabana 6	Fischer *et al.* 2001
M-202	Gibson *et al.* 2003
Apo and UPLRi-7	Zhao *et al.* 2006a
CG20	Moukoumbi *et al.* 2011
R-1033-968-2-1 and Kakro	Chaudhari *et al.* 2014
PR 120	Mahajan *et al.* 2014
IR 84899-B-183-CRA-19-1 and CR Dhan 40	Kumar *et al.* 2016
PI312777, PI338046, and RONDO	Shrestha *et al.* 2020
B2 and B81 (weedy rice accessions)	Shrestha *et al.* 2020
IR5 orIR442-2-58; Prabhat and Krishna Hamsa	Shekhawat *et al.* 2020

Plant growth habits

The traits associated to greater light interception by rice are plant height, tillering ability, leaf morphology while other characteristics like root density and biomass are important in terms of nutrients capture by rice. The early and rapid ground cover during early stages by rice cultivar results in weed biomass reduction (Schreiber *et al.* 2018, Zhao *et al.* 2006a). The strong weed suppression by Apo as compared to other aerobic genotypes like IR60080 and IRAT 216 was due to faster canopy cover by each plant (Zhao *et al.* 2006a). At early growth stages, leaf area and dry matter of rice seedling were found to be correlated with plant competitiveness (Namuco *et al.* 2009). The rice inbreds and hybrids differ in their growth and weed competitive abilities. The rice hybrids yielded 15-25 per cent more over inbred and demonstrated comparatively higher weed suppression (Chauhan *et al.* 2012, Dass *et al.* 2017). The plant vigour was found to indirectly affect the grain yield by offering strong competition to weeds (Shekhawat *et al.* 2020, Mahajan and Chauhan 2013).

Plant stature: Tall statured genotypes with drooped leaves were found to be more competitive although they were poor yielder than short and erect leaved genotypes (Kumar 2018). The tallest cultivar CR Dhan 40 was found successful in suppressing weeds (Kumar *et al.* 2016). The tall traditional cultivars were reported to have smothering effect against weeds (Prasad 2011) as they can intercept greater proportion of photosynthetically active radiations (PAR) for effective weed suppression while short statured cultivars were found to be overpowered by aggressive weeds and thus yields low. However, tallness is not considered a desirable trait for future rice breeding due to its susceptibility to lodge under nitrogen rich conditions and more straw biomass, the disposal of which is a serious issue in many countries including north western India. This disadvantage can be managed by considering the use of semi dwarf genotypes with medium height and stiff stem as a better option (Fukai 2002, Shekhawat *et al.* 2020).

The better competitiveness of rice cultivar '*Mahsuri*' than '*IR 8*' was reported to be due to its height and more relative leaf area growth rate (Bastiaans *et al.* 1997). A negative correlation was found between plant height and relative yield losses under partial weedy conditions (Mahajan *et al.* 2014). The plant height plays a positive part in weed suppression with a negative correlation with weed biomass (Ekeleme *et al.* 2007). However, some short stature cultivars of rice were found to be better competitors and can compete like tall cultivars (Fischer *et al.* 2001, Fukai 2002). Hence, for DSR, the stature of cultivar between traditional tall and intermediate heights is more suitable (Take-tsaba 2018).

Tillering ability: Tillering is among foremost traits in rice which significantly affects biological and economic yields. It is evident that tillering in rice is governed by multiple factors like genetic character, cultivar duration, seedling age at transplanting, time of transplanting/seeding, seed rate and spacing, crop establishment method, in-season crop management factors (water-, nutrient-, weeds-, pest- management etc.), climate, etc (Dhillon *et al.* 2020 and Dhillon *et al.* 2021b). Occurrence of weeds substantially affects the tillering which subsequently leads to loss in yield and quality. Panicle density is the true representation of plant population which finally contributed to the yield.

Saito *et al.* (2010) found that cultivars with more biomass, produced more tillers during vegetative growth stage showed strong weed suppressive ability. The tillering, plant height and grain yield were highly positively correlated with weed-competitiveness (Moukoumbi *et al.* 2011, Zhao *et al.* 2006 b). However, Fischer *et al.* (2001), found no relationship between plant height and tiller ability regarding weed-competitiveness. Sunyob *et al.* (2015) also observed that tillering ability is not significantly important for weed competition.

Above and below ground competition: Both shoot and root competition of rice were found to be important for competing with against weeds. The better shoot competition helps in greater interception of light and, on the other hand, better root competition will help the rice to absorb water and nutrients more vigorously than weeds. Chauhan and Johnson (2010) reported that magnitude of reduction in growth and yield of rice plant growing along weeds (*Echinocloa colona* or *Ludwigia* spp.) was more due to shoot competition than root competition indicating shoot competition as a primary mechanism in determining the competitive ability.

Very few investigations have been made on below ground part studies in cereal crops. It may be partly due to difficulty associated in studying below ground parts and measuring root traits (Andrew *et al.* 2015). However, studies have revealed the importance of root competition to be stronger than competition for light, specifically for nitrogen in many cereal crops (Lamb *et al.* 2007). Rice traits associated with the development of root systems are found important in respect to absorb more nutrients (Schreiber *et al.* 2018, Shekhawat *et al.* 2020). Role of below ground parts is important for competitive success as nutrient uptake during initial stages reduces the nutrition availability for nearby plants, hence offering competitive advantage.

Duration to maturity: The time of flowering and duration of crop have proved to be useful in selection of weed competitive rice cultivars as they help to handle initial competition. The early maturing short duration hybrids were reported as more competitive than long duration genotypes due to their ability of early growth and ground cover which was responsible for better smothering effect of cultivars on weeds (Namuco *et al.* 2009, Mahajan *et al.* 2011). Similalry, Sunyob *et al.* (2015) concluded that early maturing varieties had an advantage over weed competition *i.e.* shorter duration varieties minimize the effect of weed competition. On contrary, Rodenburg *et al.* (2009) reported that genotypes with late maturity have greater weed suppression abilities. Chaudhari *et al.* (2014) reported genotypes R-1033-968-2-1 and Kakro as high yielder under both weedy and weed free conditions due to their early seed vigour, tall height, high yield potential and good competitive ability.

The limited information of suitable weed-competitive cultivars is the major constraint to utilize rice cultivars as a component of integrated weed management in DSR. Hence, more research is needed to develop and identify high yielding weed-competitive cultivars suited to DSR conditions.

CONCLUSIONS

The area under DSR is more likely to increase in future due to both water and labour crisis. Risk free crop establishment coupled with efficient weed management are the key to success of DSR. Weeds need to be managed for wider-scale adoption and better yield realization in DSR. Competitive rice cultivars could provide a potentially attractive, non-monetary, socially acceptable, technically feasible and environmentally safe weed management option which can minimize environment contamination and delay weed resistance by curtailing the herbicide usage. Competitive rice cultivars suppress the growth of weeds on account of variation in growth habits, morphological advantages offered by cultivar or by strong competition etc. Hence, there seems tremendous scope to incorporate these competitive rice cultivars in DSR systems to manage weeds. As part of integrated weed management strategies, weed competitive inbreds or hybrids should be included all together with other chemical, mechanical and cultural measures as a sustainable approach. In near future, it is proposed to consider the weed competitive score as a key trait along with other criteria for DSR breeding and varietal release programs operational in different geographies across the country.

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Effect of organic sources of nutrients and weed management on weed flora, basmati rice growth and yield in Jammu region

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ABSTRACT

A field experiment was conducted during *Kharif* (rainy) seasons of 2015 and 2016 to study the response of varying organic and inorganic sources of nutrients and weed management on weed flora, basmati rice growth and yield. Application of 100% organics + vesicular-arbuscular mycorrhiza (VAM) recorded significantly higher values of growth parameters, yield attributes, grain yield, net returns and B:C ratio of rice which was statistically at par with 100% organics + marigold for potato on border as trap crop and bottle guard as trap crop for french bean and 100% organics (100% recommended nitrogen using different organic sources each equivalent to 1/3 of recommended nitrogen *i.e.* farm yard manure (FYM)+ vermicompost + non edible oil cake). Amongst the weed management treatments, application of mustard seed meal 5 t/ha resulted in significantly lowest weed density and biomass (species wise and total); highest weed control efficiency; lowest weed index; highest growth, yield attributes and grain yield of basmati rice which was statistically at par with application of rice bran 4 t/ha and weed free treatment. However, the highest net returns and B:C ratio were obtained in weed free plots.

INTRODUCTION

Rice (*Oryza sative* L.) is one of the main staple food crops of India, covering an area of about 43.8 million hectares with total production of 118.4 million tons and productivity of 2.7 t/ha (Anonymous 2019). Out of the total 736-thousand-hectare net cultivated area in the Jammu and Kashmir state, rice is cultivated on 274-thousand-hectare area with productivity of 3.64 t/ha. In Jammu province, rice is cultivated on 116 thousand hectares area with production of 3284 thousand quintals and productivity of 28.31 quintals per hectare (Anonymous 2016). Among the rice cultivars, basmati rice requires low nutrients for its growth as compared to course rice cultivars, therefore can best fit in the system based organic agriculture. Adoptions of organic agriculture practices address the growing global awareness on quality food, good health and safe environment and thus there has been a paradigm shift and interest to adopt organic crop production systems which are ecologically and economically viable and socially justified (Aher *et al.* 2012). Organic sources of nutrients are the best alternative for improving physical and biological properties of soil and improving crop productivity of rice based high value crops (Yadav *et al.* 2013). It has been also realized that weed infestation is the major yield limiting factor in rice production causing heavy rice yield losses (Rao *et al.* 2007), particularly in organic culture. Hence, studies were conducted on assessing the organic nutrition options and identify economical organic weed management treatment in Jammu region.

MATERIALS AND METHODS

The study was conducted at Research Farm of AICRP-IFS, Chatha, SKUAST-Jammu during *Kharif* (rainy) season of 2015 and 2016 in split-plot design with 3 replications. The soil of experimental field was clay loam having initial pH 8.04, organic carbon (0.55%) and available nitrogen (N), phosphorous (P) and potassium (K) of 220.40, 18.25 and 118 kg/ha, respectively. The treatments consisted of six sources of nutrients in main plot, *viz*. 50% recommended (Rec.) NPK using inorganic fertilizers + 50% N using farm yard manure (FYM) + inorganic source of micronutrients as per soil test, 100% Rec. N using different organic sources each equivalent to 1/3 of Rec. N *i.e.* FYM + vermicompost + non edible oil cake, 100% organics (100% Rec. N using different organic sources each equivalent to 1/3 of Rec. N *i.e.* FYM+ vermicompost + non edible oil cake)+ marigold planted on border for potato crop as trap crop and bottle guard was planted on border as trap crop for french bean in the following seasons, 50% Rec. N using vermicompost + biofertilizers for N + rock phosphate to substitute the P requirement + phosphate solubilizing bacteria (PSB 10 kg/ha), 100% organics (100% Rec. N using different organic sources each equivalent to 1/3 of Rec. N *i.e.* FYM + vermicompost + non edible oil cake) + VAM, 100% Rec. NPK + secondary and micronutrients based on soil test using inorganic fertilizer and sub plots comprised of four weed management treatments, *viz.* weed free, mustard seed meal 5 t/ha, Rice bran 4 t/ha and weedy check. Rice was transplanted at a spacing of 20 x 10 cm. Irrigation was applied at regular intervals in rice as per need. Mustard seed meal and rice bran were applied as pre-plant incorporation (PPI) ten days before transplanting of rice. Hand weeding (30 man days/ha) was done till the crop reaches physiological maturity in weed free plots with the help of *khurpi* hand operated small spade.

A quadrat of $1m^2$ was used to take observation on species wise weed density and biomass through random sampling in each plot at 60 days after transplanting (DAT). The species wise and total number of weeds (weed density) were counted in each plot separately and analyzed after subjecting the original data to square-root transformation. For weeds dry biomass, species wise weeds were collected from $1m^2$ area were dried under the sun and then in oven at 70^oC for 48 h and weighed at 60 DAT. Weed control efficiency (at 60 DAT) and weed index were calculated based on the data recorded in rice as per standard formula. Plant height (cm), number of tillers/m^2 and dry matter accumulation (g/m^2) were measured at flowering stage of the crop. Number of effective tillers/m^2, number of grains/panicles, 1000 grain weight (g) and grain yield was recorded just before harvesting. The grain yield was recorded from 13.2 m^2 area and rice grain yield was expressed at 14% moisture content. The net returns were computed by deducting the total cost of cultivation from the gross returns as per treatments. While the benefit: cost ratio was calculated by dividing the net returns with the cost of cultivation for different treatments. However, for better understanding, original values of weed density and biomass are given in parenthesis. While the ANOVA indicated significant treatment effects, means were separated at $p<0.05$ and adjusted with Fisher’s protected least significant difference (LSD) test.

RESULTS AND DISCUSSION

Weed flora

Weed flora of the experimental plots comprised of grasses: *Cynodon dactylon*, *Echinocloa* spp. broad-leaved weeds: *Commelina benghalensis, Ammania baccifera, Alternanthera philoxeroides, Phyllanthus niruri* and *Sphenoclea zeylanica,* and sedge: *Cyperus* spp.

Weed density and biomass, weed control efficiency and weed index

The species wise and total weed density, species wise and total weed biomass among different sources of nutrients at 60 DAT during both the crop seasons were not different statistically (**Table 1** and **2**). The application of 100% organics + VAM recorded the lowest species wise and total weed density, biomass, highest weed control efficiency at 60 DAT. Among the organic weed management treatments, application of mustard seed meal 5 t/ha significantly reduced the species wise and total weed density and biomass and recorded highest weed control efficiency with lowest weed index which was at par with application of rice bran 4 t/ha. However, a slight decrease in species wise and total weed density and biomass was observed in the second year experimentation rice crop (2016).

This could be attributed to better efficacy and due to presence of glucosinolates in mustard seed meal and enzymatic hydrolysis to isothiocyanates, thiocyanate, nitriles and other compounds which may be partly responsible for phytotoxic effect and did not allow the weeds to germinate and even resulted, reduction in leaf area and diminution of photosynthesis process (Stevens *et al.* 2009). Thiocyanate ion is reportedly released from mustard seed meal (MSM) in the presence of myrosinase enzyme and water and may be partially responsible for the observed phytotoxicity to weeds (Borek and Morra 2005). Application of rice bran 4 t/ha also reduced the species wise and total weed density and biomass, which might be due to because of high concentration of phytotoxic substances, that reduce weeds, including organic acids, ammonia, ethylene oxide, phenolic compounds and growth inhibitors present in the rice bran (Kuk *et al.* 2001,Khan *et al.* 2007 and Bhuiyan *et al.* 2014).

Among the different sources of nutrients, lowest weed index was observed with the application of 100% organics + marigold for potato on border as trap crop and bottle guard as trap crop for french bean whereas, the highest weed index was recorded in 50 % Rec. N using vermicompost + biofertilizers for N + rock phosphate to substitute the P requirement + PSB during both the years of experimentation (**Table 3**). The performance of crops is directly related to the weed control efficiency and therefore inversely associated with the weed index.

Rice growth, yield attributes and grain yield

Plant growth parameters such as plant height (cm), dry matter accumulation (g/m^2) and number of tillers/m^2 were significantly influenced by organic sources of nutrients and weed management treatments during both the years of experimentation (**Table 4**). The overall growth of rice crop measured in terms of plant height, dry matter accumulation and number of tillers/m^2 was comparatively less during the first year of experimentation due to less distribution of rainfall as compared to second year. Between the various sources of nutrients, application of 100% organics + VAM recorded significantly highest plant height (cm), dry matter accumulation (g/m^2), number of tillers/m^2, no. of effective tillers/m^2, no. of grains/panicle, 1000 grain weight, and grain yield, which was statistically at par with 100% organics + marigold for potato on border as trap crop and bottle guard as trap crop for french bean and 100% Rec. N using different organic sources each equivalent to 1/3 of Rec. N *i.e.* FYM+ vermicompost + non edible oil cake (T**abble 4** and **5**). Significant increase in growth parameters of rice *i.e.* plant height, dry matter accumulation and number of tillers/m^2 might be due to release of sufficient amounts of N by mineralization at constant level, which in turn resulted in better crop growth of rice crop (Yadav *et al.* 2009, 2013, Davari and Sharma 2010 and Pandey *et al.* 2015), and Singh *et al.* (2011). Increased radiation interception as well as better nutrition of crop plant due to organic manures application might have increased the photosynthesis rate which was reflected in significant increase in the growth characters and yield of rice (Singh and Mandal, 1997).

Among different weed management treatments, application of mustard seed meal 5 t/ha recorded significantly highest plant height, dry matter accumulation, number of tillers/m^2, highest no. of effective tillers/m^2, no. of grains/panicle, 1000 grain

Table 1. Effect of varying sources of nutrients and weed management treatments on species wise and total weed density in rice at 60 DAT

Treatment	*Cynodon dactylon*		*Echinocloa* spp.		*Commelina benghalensis*		*Ammania baccifera*		*Cyperus* spp.		Other weeds		Total weed density (no./m^2)	
	2015	2016	2015	2016	2015	2016	2015	2016	2015	2016	2015	2016	2015	2016
Sources of nutrients														
50% Rec. NPK using fertilizer + 50% N through FYM + inorganic source of micronutrients as per soil test	3.46 (12.76)	3.56 (11.49)	2.41 (5.48)	2.33 (5.04)	2.67 (7.15)	2.57 (6.60)	2.68 (7.31)	2.59 (6.75)	4.26 (20.86)	4.09 (19.13)	2.18 (4.10)	2.10 (3.73)	6.80 (57.64)	6.54 (52.76)
100% organics (100% Rec. N using different organic sources each equivalent to 1/3 of Rec. N *i.e.* FYM+ vermicompost + non edible oil cake)	3.41 (12.58)	3.50 (11.33)	2.36 (5.35)	2.27 (4.92)	2.60 (6.95)	2.50 (6.42)	2.62 (7.08)	2.51 (6.56)	4.21 (20.60)	4.03 (18.90)	2.15 (4.05)	2.06 (3.69)	6.76 (56.61)	6.51 (51.83)
100% organics + marigold for potato on border as trap crop and bottle guard as trap crop for french bean	3.36 (12.39)	3.47 (11.16)	2.33 (5.33)	2.26 (4.90)	2.57 (6.92)	2.49 (6.39)	2.59 (7.05)	2.50 (6.52)	4.14 (20.32)	3.98 (18.65)	2.11 (4.00)	2.05 (3.65)	6.73 (56.00)	6.46 (51.27)
50% Rec. N using vermicompost + biofertilizers for N + rock phosphate to substitute the P requirement + PSB	3.55 (13.25)	3.67 (11.93)	2.49 (5.70)	2.42 (5.24)	2.75 (7.49)	2.67 (6.90)	2.77 (7.68)	2.70 (7.08)	4.36 (21.56)	4.20 (19.76)	2.21 (4.22)	2.15 (3.84)	6.97 (59.90)	6.61 (54.77)
100% organics + VAM	3.35 (12.30)	3.49 (11.07)	2.31 (5.23)	2.27 (4.82)	2.55 (6.77)	2.49 (6.26)	2.56 (6.89)	2.51 (6.38)	4.14 (20.19)	4.00 (18.53)	2.11 (3.98)	2.07 (3.63)	6.68 (55.36)	6.41 (50.69)
100% Rec. NPK + secondary and micronutrients based on soil test using inorganic fertilizer	3.52 (12.97)	3.60 (11.68)	2.46 (5.54)	2.37 (5.10)	2.71 (7.24)	2.61 (6.68)	2.74 (7.41)	2.63 (6.84)	4.32 (21.15)	4.13 (19.40)	2.20 (4.15)	2.12 (3.78)	6.95 (58.47)	6.58 (53.49)
LSD (p=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Weed management														
Weed free	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)
Mustard Seed Meal 5 t/ha	4.01 (15.17)	3.76 (13.23)	2.44 (4.99)	2.31 (4.35)	2.63 (6.03)	2.49 (5.25)	2.62 (5.94)	2.48 (5.18)	4.62 (20.48)	4.33 (17.86)	2.35 (4.54)	2.22 (3.96)	7.61 (57.15)	7.12 (49.83)
Rice bran 4 t/ha	4.12 (16.04)	3.86 (13.96)	2.51 (5.33)	2.37 (4.64)	2.74 (6.53)	2.58 (5.69)	2.74 (6.54)	2.58 (5.69)	4.76 (21.73)	4.46 (18.92)	2.40 (4.76)	2.27 (4.14)	7.86 (60.92)	7.34 (53.04)
Weedy check	4.53 (19.63)	4.42 (18.59)	3.52 (11.43)	3.47 (11.03)	4.09 (15.78)	4.03 (15.2)	4.18 (16.5)	4.11 (15.89)	6.47 (40.91)	6.36 (39.47)	2.83 (7.03)	2.79 (6.78)	10.59 (111.2)	10.38 (107.0)
LSD (p=0.05)	0.14	0.13	0.08	0.07	0.12	0.10	0.13	0.12	0.17	0.16	0.06	0.06	0.26	0.23

LSD = Least significant difference at the 5% level of significance; DAT - Days after transplanting; the figures in the parentheses are original values

Table 2. Effect of varying sources of nutrients and weed management treatments on species wise and total weed biomass in rice at 60 DAT

Treatment	*Cynodon dactylon*		*Echinochloa* spp.		*Commelina benghalensis*		*Ammania baccifera*		*Cyperus* spp.		Other weeds		Total weed biomass (g/m^2)	
	2015	2016	2015	2016	2015	2016	2015	2016	2015	2016	2015	2016	2015	2016
Sources of nutrients														
50% Rec. NPK using fertilizer + 50% N using FYM + inorganic source of micronutrients as per soil test	3.09 (9.81)	2.96 (9.23)	2.90 (9.21)	2.79 (8.87)	2.86 (8.71)	2.74 (8.29)	2.94 (9.13)	2.83 (8.69)	3.80 (16.30)	3.66 (15.49)	2.62 (6.89)	2.60 (6.55)	6.90 (60.05)	6.65 (57.13)
100% organics (100% Rec. N using different organic sources each equivalent to 1/3 of Rec. N *i.e.* FYM+ vermicompost + non edible oil cake)	3.03 (9.64)	2.89 (8.75)	2.83 (8.94)	2.74 (8.43)	2.79 (8.42)	2.68 (7.83)	2.86 (8.78)	2.74 (8.14)	3.76 (16.16)	3.60 (14.88)	2.61 (6.78)	2.51 (6.21)	6.78 (58.72)	6.48 (54.24)
100% organics + marigold for potato on border as trap crop and bottle guard as trap crop for french bean	2.98 (9.45)	2.87 (8.58)	2.79 (8.90)	2.73 (8.39)	2.75 (8.38)	2.67 (7.78)	2.74 (8.72)	2.72 (8.09)	3.72 (16.01)	3.59 (14.74)	2.58 (6.65)	2.48 (6.10)	6.72 (58.12)	6.46 (53.69)
50% Rec. N using vermicompost + biofertilizers for N + rock phosphate to substitute the P requirement + PSB	3.16 (10.27)	2.98 (9.31)	2.98 (9.67)	2.83 (9.08)	2.94 (9.19)	2.79 (8.51)	3.03 (9.71)	2.87 (8.98)	3.86 (16.67)	3.66 (15.34)	2.68 (7.21)	2.65 (6.61)	7.01 (62.73)	6.72 (57.83)
100% organics + VAM	2.96 (9.37)	2.86 (8.50)	2.76 (8.71)	2.70 (8.22)	2.74 (8.17)	2.64 (7.60)	2.78 (8.48)	2.70 (7.87)	3.71 (15.94)	3.58 (14.68)	2.58 (6.59)	2.50 (6.04)	6.67 (57.26)	6.40 (52.90)
100% Rec. NPK + secondary and micronutrients based on soil test using inorganic fertilizer	3.13 (10.01)	2.94 (9.07)	2.95 (9.34)	2.77 (8.79)	2.91 (8.84)	2.75 (8.20)	2.99 (9.29)	2.82 (8.60)	3.84 (16.46)	3.63 (15.14)	2.64 (7.03)	2.62 (6.44)	6.98 (60.96)	6.62 (56.25)
LSD (p=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Weed management														
Weed free	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)
Mustard seed meal 5 t/ha	3.38 (10.51)	3.18 (9.15)	2.65 (6.14)	2.49 (5.33)	2.71 (6.50)	2.56 (5.65)	2.87 (7.37)	2.70 (6.40)	4.04 (15.34)	3.79 (13.37)	2.86 (7.26)	2.70 (6.32)	7.34 (53.12)	6.85 (46.23)
Rice bran 4 t/ha	3.51 (11.36)	3.31 (10.00)	2.79 (6.83)	2.64 (6.02)	2.86 (7.23)	2.70 (6.35)	3.04 (8.34)	2.87 (7.34)	4.12 (16.03)	3.88 (14.13)	2.96 (7.77)	2.80 (6.88)	7.63 (57.55)	7.17 (50.71)
Weedy check	4.25 (17.17)	4.17 (16.48)	4.95 (23.56)	4.91 (23.17)	4.66 (20.73)	4.59 (20.14)	4.62 (20.36)	4.56 (19.84)	5.88 (33.65)	5.80 (32.69)	3.66 (12.40)	3.61 (12.11)	11.35 (127.88)	11.19 (124.42)
LSD (p=0.05)	0.13	0.13	0.14	0.15	0.14	0.14	0.19	0.18	0.12	0.12	0.14	0.12	0.30	0.32

LSD = Least significant difference at the 5% level of significance; ; DAT - Days after transplanting; the figures in the parentheses are original values

Table 3. Effect of varying sources of nutrients and weed management treatments on weed control efficiency and weed index in rice

Treatment	Weed control efficiency (%) at 60 DAT		Weed index (%)	
	2015	2016	2015	2016
Sources of nutrients				
50% Rec. NPK using fertilizer + 50% N using FYM + inorganic source of micronutrients as per soil test	52.07	54.47	5.10	5.10
100% organics (100% Rec. N using different organic sources each equivalent to 1/3 of Rec. N *i.e.* FYM + vermicompost + non edible oil cake)	52.63	54.80	3.98	4.07
100% organics + marigold for potato on border as trap crop and bottle guard as trap crop for french bean	52.71	54.88	3.44	3.47
50% Rec. N using vermicompost + biofertilizers for N + rock phosphate to substitute the P requirement + PSB	50.84	53.18	5.35	5.34
100% organics + VAM	52.80	54.95	3.60	3.64
100% Rec. NPK + secondary and micronutrients based on soil test using inorganic fertilizer	51.68	53.95	5.15	5.14
LSD (p=0.05)	-	-	-	-
Weed management				
Weed free	100.00	100.00	0.00	0.00
Mustard seed meal 5 t/ha	56.08	60.65	-2.53	-2.87
Rice bran 4 t/ha	52.41	56.84	-0.91	-1.10
Weedy check	0.00	0.00	21.19	21.80
LSD (p=0.05)	-	-	-	-

LSD = Least significant difference at the 5% level of significance; DAT = Days after transplanting

Table 4. Effect of varying sources of nutrients and weed management on growth parameters of rice

Treatment	Plant height (cm)		Dry matter accumulation (g/m^2)		No. of tillers/m^2	
	2015	2016	2015	2016	2015	2016
Sources of nutrients						
50% Rec. NPK using fertilizer + 50% N through FYM + inorganic source of micronutrients as per soil test	101.50	102.84	333.85	336.24	258.50	265.76
100% organics (100% Rec. N using different organic sources each equivalent to 1/3 of Rec. N *i.e.* FYM+ vermicompost + non edible oil cake)	108.07	109.60	378.42	382.05	294.05	302.30
100% organics + marigold for potato on border as trap crop and bottle guard as trap crop for french bean	108.87	110.25	380.47	384.17	297.27	305.62
50% Rec. N using vermicompost + biofertilizers for N + rock phosphate to substitute the P requirement + PSB	92.27	93.35	302.82	304.30	236.27	242.87
100% organics + VAM	112.14	113.78	386.84	390.71	302.85	311.35
100 % Rec. NPK + secondary and micronutrients based on soil test using inorganic fertilizer	95.22	96.38	311.80	313.53	241.77	248.53
LSD (p=0.05)	4.33	4.52	13.36	13.72	10.45	10.74
Weed management						
Weed free	105.42	106.82	355.25	358.36	276.48	284.86
Mustard seed meal 5 t/ha	108.30	109.92	366.15	370.00	285.56	294.52
Rice bran 4 t/ha	105.85	107.34	359.45	362.91	280.07	288.72
Weedy check	92.48	93.39	315.28	316.06	245.04	249.52
LSD (p=0.05)	3.63	3.72	12.26	12.58	9.68	9.93

LSD = Least significant difference at the 5% level of significance

Table 5. Effect of varying sources of nutrients and weed management treatments on yield attributes, grain yield and economics of rice

Treatment	No. of effective tillers/m^2		No. of grains/panicle		1000 grain weight (g)		Grain yield (t/ha)		Net returns (x10^3 Rs/ha)		B:C ratio	
	2015	2016	2015	2016	2015	2016	2015	2016	2015	2016	2015	2016
Sources of nutrients												
50% Rec. NPK using fertilizer + 50% N using FYM + inorganic source of micronutrients as per soil test	253.67	258.32	62.00	63.42	24.82	25.20	3.61	3.76	18.17	43.90	0.27	0.66
100% organics (100% Rec. N using different organic sources each equivalent to 1/3 of Rec. N *i.e.* FYM+ vermicompost + non edible oil cake)	266.55	268.55	65.33	66.59	25.81	26.23	3.81	3.96	35.33	68.58	0.49	0.95
100% organics + marigold for potato on border as trap crop and bottle guard as trap crop for french bean	268.88	270.95	65.75	67.02	26.13	26.56	3.88	4.04	37.52	71.40	0.52	0.99
50% Rec. N using vermicompost + biofertilizers for N + rock phosphate to substitute the P requirement + PSB	249.80	256.31	57.67	58.96	24.00	24.04	3.34	3.48	25.50	54.90	0.37	0.81
100% organics+ VAM	269.66	271.75	66.00	67.27	26.31	26.74	3.95	4.10	38.38	72.75	0.52	1.00
100% Rec. NPK + secondary and micronutrients based on soil test using inorganic fertilizer	251.02	257.57	58.17	59.47	24.05	24.10	3.37	3.51	14.50	38.68	0.22	0.60
LSD (p=0.05)	10.92	11.21	3.10	3.18	1.24	1.28	1.51	1.76	-	-	-	-
Weed management												
Weed free	261.65	266.14	64.47	66.04	25.31	25.65	3.83	3.98	65.42	96.91	1.78	2.66
Mustard seed meal 5 t/ha	267.05	271.97	66.47	68.16	26.08	26.47	3.93	4.09	-26.32	6.41	-0.20	0.05
Rice bran 4 t/ha	265.02	269.75	65.36	66.99	25.54	25.91	3.86	4.02	23.93	55.95	0.30	0.71
Weedy check	246.01	247.76	53.64	53.97	23.82	23.89	3.03	3.13	49.90	74.21	1.60	2.41
LSD (p=0.05)	9.75	10.00	2.33	2.40	1.20	1.24	1.16	1.35	-	-	-	-

LSD, least significant difference at the 5% level of significance

weight and grain yield of rice which was statistically at par with application of rice bran 4 t/ha and weed free treatment (T**abble 4** and **5**). Higher nutrient content of mustard seed meal and minimal crop-weed competition due to significant reduction in weed density and biomass leading to increase in the availability of moisture, nutrients, space and light in favour of crop rather than those of weeds as reported by Ullah *et al.* (2008), Ibrahim and Mumtaz (2014) and Boydston *et al.* (2008).

Economics

The economic feasibility and usefulness of a treatment can be effectively adjudged in terms of B:C ratio and net returns. Among the sources of nutrients, application of 100% organics + VAM fetched higher net returns (₹ 38385/ha) and B:C ratio (0.52) closely followed by the application of 100% organics + marigold for potato on border as trap crop and bottle guard as trap crop for french bean and 100% Rec. N using different organic sources each equivalent to 1/3 of Rec. N *i.e.* FYM+ vermicompost + non edible oil cake (**Table 5**). Almost a similar trend with respect to relative economics of rice was recorded during the second year (2016) of cropping except for that an improvement in net returns and B:C ratio was observed in the second-year rice crop as also reported by Meena *et al.* (2010). Amongst weed management treatments, highest net returns of Rs. 65419/ha and B:C ratio (1.78) were obtained in weed free plots (**Table 5**). Higher grain yield of rice in weed free treatment might have been responsible for the highest net returns and B:C ratio. However, the application of mustard seed meal 5 t/ha and rice bran 4 t/ha recorded the lowest net returns (Rs. -26318/ ha) and B:C ratio (-0.20) which was due to higher cost of inputs.

It is concluded that wide spectrum weed control and higher yield of basmati rice may be obtained with 100% organics (100% Rec. N using different organic sources each equivalent to 1/3 of Rec. N *i.e.* FYM+ vermicompost + non edible oil cake) + VAM and weed free conditions, depending on labor availability.

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Conservation agriculture effects on weed dynamics and maize productivity in maize- wheat- greengram system in north-western Indo-Gangetic Plains of India

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ABSTRACT

Conservation agriculture (CA) can promote sustainable crop intensification. However, weeds are the major constraints under CA, in the initial years. Nitrogen (N) management under CA is also crucial. A field experiment was undertaken to study the effect of conventional tillage (CT) and CA with and without residue using 75 and 100% recommended N dose on weed dynamics and crop productivity during 2018-19 and 2019-20 in maize (*Zea mays* L.) under maize - wheat (*Triticum aestivum* L.) - greengram (*Vigna radiata* (L.) Wilczek) cropping system at ICAR-Indian Agricultural Research Institute, New Delhi. Nine CA-based treatments and one conventional tillage were laid out in a randomized complete block design with three replications. CA-based zero till (ZT) bed planting systems with residue retention resulted in significant reductions in total weed density and biomass compared to CT. Permanent broad bed with residue using 75% N resulted in 34% lesser weed density than CT. Among the CA-based treatments, the permanent broad bed with residue using 100% N resulted in ∼22% higher maize grain yield than CT (5.72 t/ha) with 36% higher net returns than CT. However, the permanent broad bed with residue using 75% N was found comparable in this regard and may be recommended for sustainable maize production under the maize-wheat-greengram system in north-western Indo Gangetic Plains of India.

INTRODUCTION

Conservation agriculture (CA) is a "concept for resource-saving agricultural crop production that strives to achieve acceptable profits together with high and sustained production levels while concurrently conserving the environment" (FAO, 2001). CA is characterized by three inter-linked principles, namely continuous no or minimal mechanical soil disturbance, maintenance of a permanent biomass mulch cover on soil surface and diversified crop rotations including a legume (Ladha *et al.* 2016, Kassam *et al.* 2019). CA is being promoted and adopted for sustainable crop intensification (Kassam *et al.* 2009, FAO 2011 Chakraborty *et al.* 2017). Maize has wider adaptability and compatibility under diverse soil and climatic situations and can be a potential substitute of rice in areas with scarcity of labour and water (Gathala *et al.* 2013, Susha *et al.* 2014, Das *et al.* 2018). Several researchers have identified CA-based sustainable intensification of maize-wheat-greengram system, which can enhance crop productivity, profitability, water use efficiency, energy use efficiency, weed control efficiency and lead to accumulation of more organic carbon in soil with high sequestration potential (Saad *et al.* 2015, Nath *et al.* 2017, Das *et al.* 2018, Ghosh *et al.* 2019, Jat *et al.* 2020). However, weeds are major constraint for the success of CA. The absence of tillage in CA makes weed management a greater challenge than conventional agriculture (Chauhan *et al.* 2012). In addition, with frequent rainfall in rainy (*Kharif*) season, weeds continue to emerge in repeated flushes and pose severe competitive interference with maize. Weeds are ubiquitous, having a wide range of ecological amplitude that determines their adaptability

(Das 2008). Certain weed species germinate and grow more profusely than others under continuous zero till (ZT) system. As a result, weed shift occurs (Erenstein and Laxmi 2008, Nichols *et al*. 2015) with the change from conventional till (CT) to ZT system which can affect weed dynamics including weed seed distribution and abundance in soil seed bank (Mulugeta and Stoltenberg 1997, Nath *et al*. 2015). Weeds pose tremendous challenge for successful crop production and their management usually costs higher than that of other agro-practices (Das *et al*. 2020). However, weed problems are likely to reduce in course of time, if the three principles of CA are combinedly used (Nichols *et al*. 2015). Thus, the objective of this study was to quantify the weed dynamics and productivity and profitability of maize cultivation under CA-based maize-wheat-greengram system.

MATERIALS AND METHODS

A field experiment was carried out during the rainy (*Kharif*) seasons of 2018-19 and 2019-20 (*i.e.* in the 9^{th} and 10^{th} year of a long-term CA experiment) at Division of Agronomy, ICAR-Indian Agricultural Research Institute, New Delhi. Ten treatments with three replications were laid out in a randomized complete block design. The experiment was a part of a long-term CA system, initiated in 2010. In this system, different CA-based practices such as zero till (ZT) permanent narrow, broad and flat beds with and without retention of maize, wheat and greengram crops residues) and 75% and 100% of the recommended dose of N were compared with CT practice. The treatments comprised of conventional tillage [*i.e*. conventional tillage without residue but with 100% N (CT)], and nine CA practices: ZT with permanent narrow bed (PNB), broad bed (PBB) and flat bed (FB) without residue but with 100% N (3 treatments: PNB+100N, PBB+100N and FB+ 100N); PNB, PBB and FB with residue (R) and 75% N (three treatments; PNB+R+75N, PBB+R+75N, FB+R+75N); and PNB, PBB and FB with R and 100% N (three treatments: PNB+R+100N, PBB+R+100N and FB+R+100N). CT plots were prepared using tractor-drawn disc plough followed by planking.

In CA-based treatments (PNB, PBB and FB with or without residue), no ploughing was done. The PNB plots had the dimension of 40 cm bed and 30 cm furrow. The PBB plots had 110 cm bed and 30 cm furrow. In CA-based residue retention plots, residues of wheat grown in previous season were applied and plots with no residues were left undisturbed. Soil of the experimental site was clayey loam, pH (8.2), organic C (0.60%), medium in available N (285 kg/ha) and P (18 kg/ha) and high in K (329 kg/ha). A pre-sowing irrigation was given to entire field to ensure smooth germination of maize. Maize variety 'PMH 1' was sown during rainy (*Kharif*) season with a seed rate of 20 kg/ha at 70 cm row spacing. In CT, maize was sown using a tractor-drawn seed cum fertilizer drill. In CA-based PNB plots, it was sown using a bed planter. In PBB and FB plots, the sowing was done using turbo seeder. The recommended dose 150 kg N, 26 kg P and 33 kg K was applied to maize crop under the 100% N treatments irrespective of CA and CT plots. In CA-based plots with 75% N, 112.5 kg N was applied. The 50% amount of the 75% and 100% N (as applicable to the treatment) and full dose of P and K were applied as basal. Remaining N was applied in 2 equal splits at 30 and 60 days after sowing (DAS) of maize. Nitrogen was applied using urea and diammonium phosphate (DAP), P was applied using DAP, and K using muriate of potash (MOP).

Species-wise, category-wise and total weed population (density) and dry weight (biomass) were recorded at 30 DAS. An area of 0.25 m^2 surrounding a maize crop row was selected randomly at 3 spots by a quadrat (0.5 × 0.5 m) and weed species were counted from that area. Species-wise collected weed samples were sun-dried for three days and kept in an oven at 70^0C till constant weight obtained. Data on weed density and biomass were transformed through square-root [$\sqrt{x+0.5}$] method before analysis of variance (Das 1999). The total weed density and biomass were computed as the summation of original values of grasses, broad-leaved weeds and sedges and then these values were transformed through square root method. Maize cobs of the net plot area were separated from plants, sun-dried for 5 days and cob yield was recorded. Maize grains were separated from the cobs and dried to about 12% moisture in an oven for recording cob grain yield. The cost of cultivation under various treatments was estimated on the basis of prevailing market prices of various inputs used in the treatments. For gross returns, minimum support price of maize grains declared by the Government of India during 2018 and 2019, and the market price of maize stover were considered. The net benefit: cost of various treatments was estimated as the ratio of net returns to cost of cultivation. The two-year pooled data on weed density, weed biomass, crop productivity, net returns, net benefit: cost and nutrient uptake were subjected to analysis of variance (ANOVA) in a randomized completed block design using R (version 4.0.5) statistical software to determine the statistical significance of treatment effects (R Core Team, 2013). The treatment differences were tested with the help of Tukey Multiple Comparison Test at 5% level of significance.

RESULTS AND DISCUSSION

Weed density and biomass

Weed flora in maize comprised of *Setaria viridis* (L.) P.Beauv., *Leptochloa chinensis* (L.) Nees, *Cynodon dactylon* (L.) Pers., *Dinebra retroflexa (Vahl) Panz.*, *Dactyloctenium aegyptium* (L.) Willd. among grasses; *Commelina benghalensis* L., *Digera arvensis* Forssk., *Euphorbia hirta* L., *Euphorbia microphylla* Lam., *Trianthema portulacastrum* L., *Amaranthus viridis* L. among broad-leaved weeds and *Cyperus rotundus* L. and *Cyperus esculentus* L. among sedges. Among them, the most dominant were *S. viridis*, *C. benghalensis* and *C. esculentus*. Differences in weed density and biomass of grassy, broad-leaved and sedge weeds at 30 DAS were significant due to differential crop establishment, residue and N management practices (**Table 1**). Among different weed flora, sedges density was higher in CT. The CT treatment reduced grassy weeds, but was not effective in reducing total weed density and biomass. Among CA-based treatments, the residue retention has caused significant reduction in weed density compared to no residue treatments. Permanent narrow bed with residue retention with 75% N caused significant reduction in both *S. viridis* and *C. benghalensis*, whereas *C. esculentus* density and biomass was significantly reduced under permanent broad bed with residue retention with 100% N (**Figure 1** and **2**). The prevalence of grassy weeds was significantly lower under PNB+R+75N. Both the PBB+R+75N and PNB+R+100N treatments were found to be superior in controlling broad-leaved weed density. Similarly, sedges were significantly reduced under FB+R+75N and PBB+R+100N. Grassy weeds and sedges were higher in second year than first year, whereas broad-leaved weed population was significantly lower in second year. The CA-based practices also resulted in significant reduction in total weed density and biomass. The treatments PBB+R+75N and PNB+R+75N were superior in causing significant reduction in total weed density and biomass. PNB+R+75N and PBB+R+75N recorded 28% and 34% lesser weed density, respectively than the CT practice due to emergence of greater number of grasses and sedges than broad-leaved weeds. Higher infestation of these weeds in CT might be due to soil inversion caused by tillage, greater aeration and periodical irrigation application (Baghel *et al*. 2020). CA-based treatments with residue retention led to reduce weed interference due to the smothering effect on weeds. In CA, weed interference and N immobilization can be reduced by adaptive N fertilizer application and weed management (Oyeogbe *et al*. 2018). CA practices helped prevent proliferation of weeds and minimized negative impact of weeds on crop productivity. Soil inversion with CT led to increased weed pressure. Crop residue retention with ZT could delay as well as suppress weed germination and emergence. It could be a multi-tactic approach for sustainable weed management in crop rotations, reducing the need for herbicides application (Christoffoleti *et al*. 2007, Susha *et al*. 2014, Nath *et al*. 2016).

Maize yield and economics

Maize yield differed significantly amongst the tested treatments in both years (**Table 2**). The CA-based permanent broad bed with residue retention with 100% N (PBB+R+100N) recorded significantly higher grain as well as stover yield of maize under maize-wheat-greengram system. It registered 24% and 20% higher grain yield than CT practice, in 2018 and 2019, respectively. The combination of broad bed with residues using 75% or 100% N (PBB+R+75N or

Table 1. Category-wise weed density and weed biomass as influenced by treatments at 30 DAS in maize (pooled of two years)

Treatment	Weed density (no./m^2)				Weed biomass (g/m^2)			
	Grassy weeds	Broad-leaved weeds	Sedges	Total weeds	Grassy weeds	Broad-leaved weeds	Sedges	Total weeds
CT	6.2^g	4.7^b	17.4^a	19.3^a	5.82^h	3.33^b	11.61^a	13.59^a
PNB	5.9^{gh}	5.4^a	12.9^b	15.7^c	5.59^h	3.64^a	7.84^b	10.61^c
PNB+R+75N	5.8^h	4.7^b	11.6^c	14.0^d	6.35^g	2.38^e	5.67^e	8.87^f
PNB+R+100N	8.4^e	3.1^d	9.5^d	13.0^e	7.30^e	1.87^g	5.75^e	9.44^e
PBB	10.5^b	5.0^a	12.1^c	17.2^b	9.31^a	2.88^c	6.32^d	11.60^b
PBB+R+75N	9.1^d	2.8^e	8.3^e	12.7^e	7.87^d	1.80^g	5.00^f	9.47^e
PBB+R+100N	11.5^a	4.0^c	6.4^f	13.9^d	9.00^b	2.60^d	3.43^h	10.00^d
FB	8.1^f	3.7^c	8.3^e	12.7^e	6.81^f	2.11^f	4.55^g	8.65^f
FB+R+75N	9.7^c	3.8^c	8.1^e	13.2^e	8.34^c	2.34^e	4.91^f	9.97^d
FB+R+100N	9.0^d	3.9^c	11.6^c	15.6^c	7.91^d	2.33^e	6.61^c	10.72^c

Refer materials and methods for treatment details

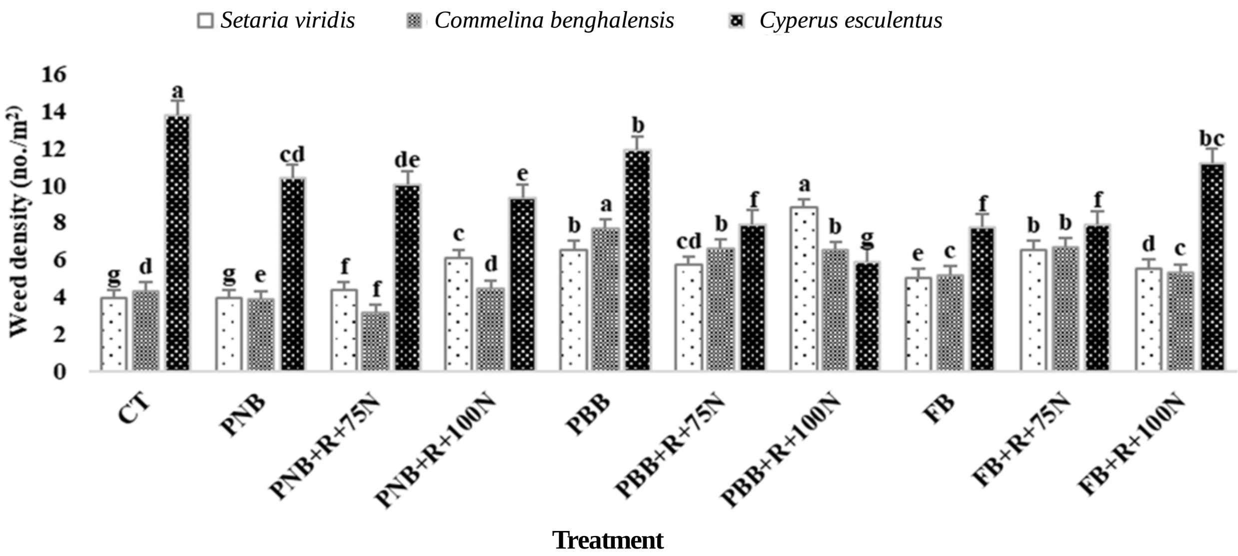

Figure 1. The density (no./m^2) of *Setaria viridis, Commelina benghalensis* and *Cyperus esculentus* (dominant weeds) as influenced by treatments at 30 DAS in maize (pooled of two years)

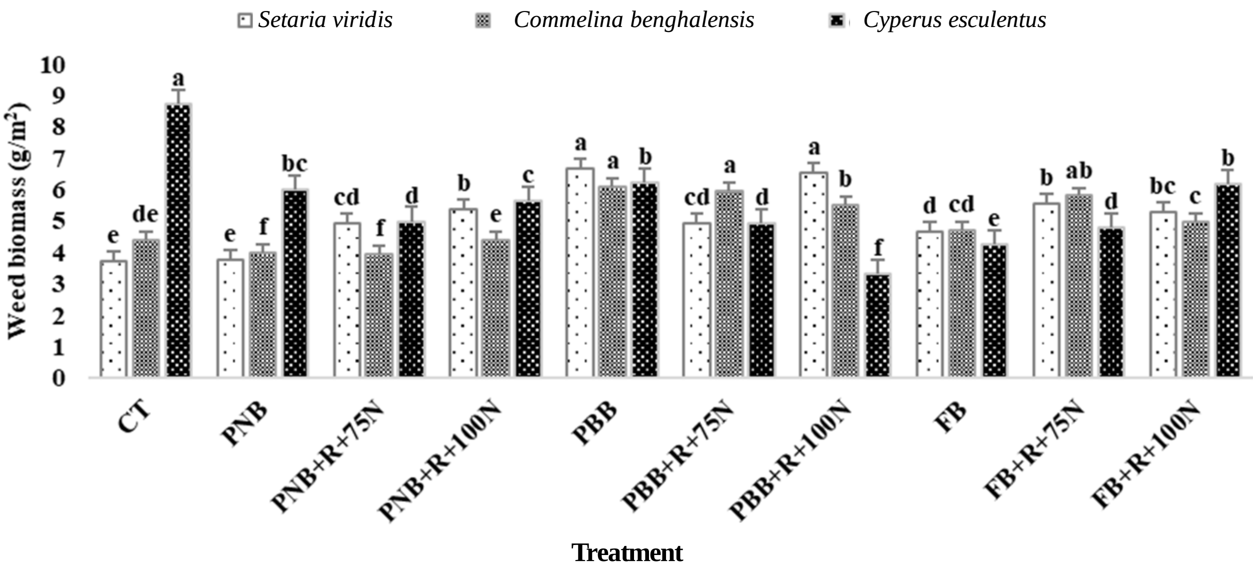

Figure 2. The biomass (g/m^2) of *Setaria viridis, Commelina benghalensis* and *Cyperus esculentus* (dominant weeds) as influenced by treatments at 30 DAS in maize (pooled of two years)

PBB+R+100N) gave comparable yield of maize. Weed interference and crop yield are negatively correlated (Das and Yaduraju 2011). A considerable reduction in weed density and biomass due to greater suppressive effect of CA-based permanent broad bed with residue retention (PBB+R) led to higher grain yield of maize compared to CT and other ZT bed planting practices without residue. Besides, better weed management, the triple zero tillage systems involving retention of residues of maize, wheat and greengram might have led to better soil aggregation (Bhattacharyya *et al.* 2013), higher soil moisture retention capacity (Nath *et al.* 2015) and more C and N sequestration (Das *et al.* 2018) leading to higher yield of maize over the years in this CA-based practice. The ZT broad bed planting with residue retention helped increase in yield attributing characters of maize such as grains/cob and seed index, which resulted in higher grain as well as biological yield of maize (Saad *et al.* 2015). Retention of greengram residue along with wheat residue might have increased soil N, which favored better growth and development in maize in CA-based practices. The CA-based practices with residue retention registered 16-22% higher grain yield and 12-17% higher stover yield of maize than CT practice, indicating the superiority of CA practices in favorably influencing the better photosynthates accumulation, growth and development of maize crop than CT. Grain yield of maize was also influenced by the growing season. The grain and stover yields were found higher in first year than second year. The CA-based practices without residue retention gave lower grain and stover yields than residue retained plots indicating the need for residue retention for better weed management and higher maize yield. The PBB+R+100N treatment through better weed management and higher maize yield could compensate the cost of residue addition and resulted in higher net returns and net benefit: cost than CT and other CA practices in both years. This treatment resulted in 35.8% higher net returns than CT. The next best treatment was FB+R+100 N in terms of net returns as well as net benefit: cost. The PBB+R+75N was statistically at par with PBB+R+100N in terms of net returns due to savings in N application and higher grain and stover yield. CT practice had lower net benefit: cost due to higher cost involved in land preparation, manual weeding and lower grain and stover yield (Chander *et al*. 2013). The cost incurred by CT was observed to be 5.0%, 6.4% and 10.6% higher than permanent broad-bed planting+R+100N, permanent broad-bed planting+R +75N, and permanent broad- bed planting without residue, respectively. The ZT bed planting practices with or without residues were comparable in terms of net benefit: cost because of savings in cost incurred due to residue addition (**Table 2**).

Contrast analysis for weed biomass and maize grain yield

The impacts of individual treatments tested in this study were also assessed through contrast analysis (**Table 3**). The contrast analysis showed that CA was not found effective in reducing biomass of *S. viridis*. It resulted in significant reduction in biomass of *C. benghalensis* in second year than first year and significantly reduced *C. esculentus* biomass during both the years. In case of reduction in total weed

Table 2. Grain, stover and total biomass yields of maize, net returns and net benefit: cost as affected by different treatments

Treatment	Grain yield (t/ha)			Stover yield (t/ha)			Total biomass yield (t/ha)			Net returns (× 10³ ₹/ha)			Net B:C
	2018-19	2019-20	Pooled	2018-19	2019-20	Pooled	2018-19	2019-20	Pooled	2018-19	2019-20	Pooled	
CT	5.80^{d}	5.63^{d}	5.72^{e}	8.62^{d}	9.08^{c}	8.85^{c}	14.42^{e}	14.71^{d}	14.57^{f}	75.96^{d}	73.87^{c}	74.92^{f}	1.80^{c}
PNB	6.46^{c}	6.09^{cd}	6.28^{d}	9.27^{cd}	9.64^{abc}	9.46^{b}	15.73^{d}	15.74^{c}	15.74^{e}	92.54^{c}	87.15^{b}	89.85^{e}	2.40^{b}
PNB+R+75N	6.65^{abc}	6.31^{abc}	6.48^{bcd}	9.78^{abc}	9.90^{ab}	9.84^{ab}	16.43^{cd}	16.21^{abc}	16.32^{cd}	95.30^{bc}	89.94^{ab}	92.62^{cde}	2.38^{b}
PNB+R+100N	6.83^{abc}	6.48^{abc}	6.66^{abc}	9.70^{abc}	10.12^{ab}	9.91^{ab}	16.53^{cd}	16.60^{ab}	16.57^{c}	97.69^{abc}	92.91^{ab}	95.30^{bcde}	2.41^{b}
PBB	6.61^{bc}	6.18^{bc}	6.40^{bcd}	9.36^{cd}	9.79^{ab}	9.57^{b}	15.97^{cd}	15.97^{bc}	15.97^{de}	95.21^{bc}	88.97^{ab}	92.10^{cde}	2.46^{ab}
PBB+R+75N	6.95^{abc}	6.49^{abc}	6.72^{ab}	9.61^{abcd}	10.11^{ab}	9.86^{ab}	16.57^{cd}	16.61^{ab}	16.59^{c}	100.07^{abc}	93.65^{ab}	96.86^{abc}	2.49^{ab}
PBB+R+100N	7.21^{a}	6.75^{a}	6.98^{a}	10.58^{a}	10.17^{a}	10.37^{a}	17.79^{a}	16.91^{a}	17.35^{a}	105.80^{a}	97.70^{a}	101.75^{a}	2.58^{a}
FB	6.55^{bc}	6.10^{cd}	6.32^{cd}	9.47^{bcd}	9.54^{bc}	9.50^{b}	16.02^{cd}	15.63^{c}	15.82^{de}	94.36^{c}	87.00^{b}	90.68^{de}	2.42^{b}
FB+R+75N	6.97^{abc}	6.41^{abc}	6.69^{abc}	9.83^{abc}	10.07^{ab}	9.95^{ab}	16.80^{bc}	16.48^{ab}	16.64^{bc}	100.74^{abc}	92.10^{ab}	96.42^{abcd}	2.48^{ab}
FB+R+100N	7.11^{ab}	6.62^{ab}	6.86^{a}	10.42^{ab}	10.14^{ab}	10.28^{a}	17.53^{ab}	16.75^{a}	17.14^{ab}	103.78^{ab}	95.36^{ab}	99.57^{ab}	2.52^{ab}

Refer the materials and methods for details of the treatments

Table 3. Contrast analysis on weed biomass and maize grain yield over the years

Parameter		Contrast treatment	2018		2019	
			Estimate	p-value	Estimate	p-value
Weed biomass	*Setaria viridis*	CA *vs* CT	1.33	<0.01	1.86	<0.01
		Residue *vs* no residue	-0.14	<0.01	0.96	<0.01
		75% N *vs* 100% N	-0.33	<0.01	-0.84	<0.01
	Commelina benghalensis	CA *vs* CT	1.78	<0.01	-0.49	<0.01
		Residue *vs* no residue	0.46	<0.01	-0.15	0.88
		75% N *vs* 100% N	-0.56	<0.01	1.12	<0.01
	Cyperus esculentus	CA *vs* CT	-3.69	<0.01	-3.44	<0.01
		Residue *vs* no residue	0.58	<0.01	-1.61	<0.01
		75% N *vs* 100% N	0.03	0.86	-0.34	0.09
	Total weed	CA *vs* CT	-2.67	<0.01	-4.65	<0.01
		Residue *vs* no residue	-0.63	<0.01	-0.46	<0.01
		75% N *vs* 100% N	-0.90	<0.01	-0.33	<0.01
Maize grain yield		CA *vs* CT	1.02	<0.01	0.75	<0.01
		Residue *vs* no residue	0.41	<0.01	0.39	<0.01
		75% N *vs* 100% N	-0.19	0.25	-0.21	0.15

biomass, CA showed superiority over CT practice. CA recorded higher grain yield of maize compared to CT during both the years of the study. Contrast analysis revealed that residue retention was superior to no residue towards reducing weed biomass. Residue-retained treatments significantly reduced biomass of *S. viridis* during first year and that of *C. benghalensis* and *C. esculentus* in second year. Residue retention caused significant reduction in total weed biomass compared to no-residue treatments during both the years. These treatments recorded significantly higher maize grain yield than no-residue treatments. The 100% N application resulted in more weed proliferation compared to treatments with 75% N. The treatments with 75% N significantly reduced *S. viridis* during the both years and *C. benghalensis*. The contrast between 75% N and 100% N were found to be non-significant in reducing infestation of *C. esculentus* during both the years. Treatments with 75% N significantly reduced total weed growth compared to treatments with 100% N. The residue retention was proved superior to no-residue treatments in enhancing maize grain yield. The differences between 75% N and 100% N were found to be non-significant during both the years, indicating that these were similar with each other in recording maize grain yield. Thus, CA with residue retention and with 75% N could be used to reduce weed growth and enhance grain yield of maize.

Nutrient uptake by maize

The tillage/bed planting, residue, and N management significantly influenced N, P and K uptake by crop. The highest nutrient (N, P and K) uptake in maize was observed under PBB+R+100 N and the least was in CT during both the years (**Figures 3, 4, 5, 6, 7, 8, 9, 10** and **11**). Residue retention, better weed management, better root growth and proliferation and improved soil physical, chemical and biological properties under zero tillage enhanced nutrient uptake by both grain and stover. The significantly higher N uptake was recorded with

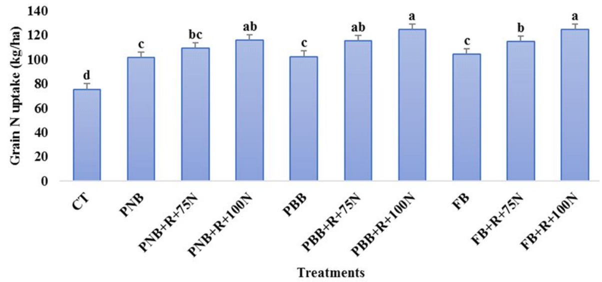

Figure 3. N uptake by maize grain as affected by treatments (pooled of two years)

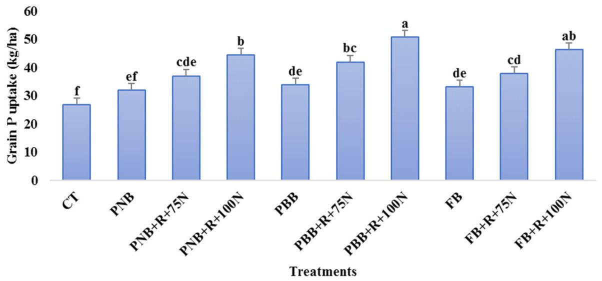

Figure 4. P uptake by maize grain as affected by treatments (pooled of two years)

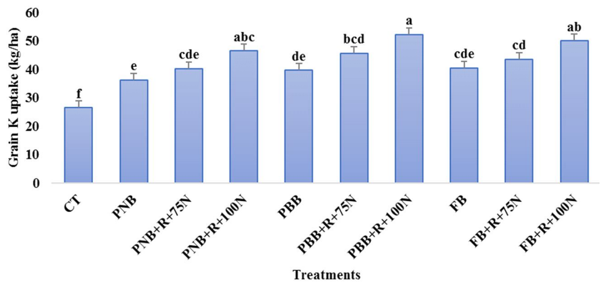

Figure 5. K uptake by maize grain as affected by treatments (pooled of two years)

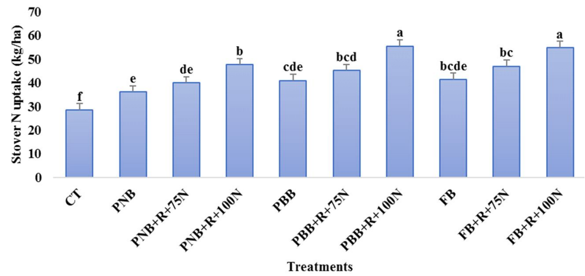

Figure 6. N uptake by maize stover as affected by treatments (pooled of two years)

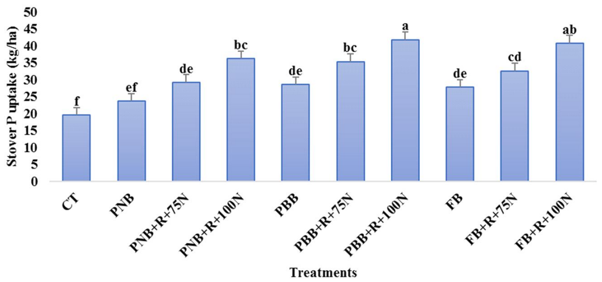

Figure 7. P uptake by maize stover as affected by treatments (pooled of two years)

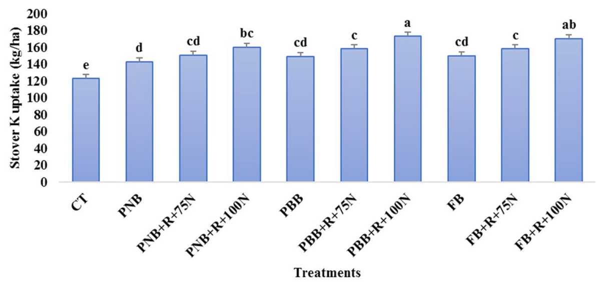

Figure 8. K uptake by maize stover as affected by treatments (pooled of two years)

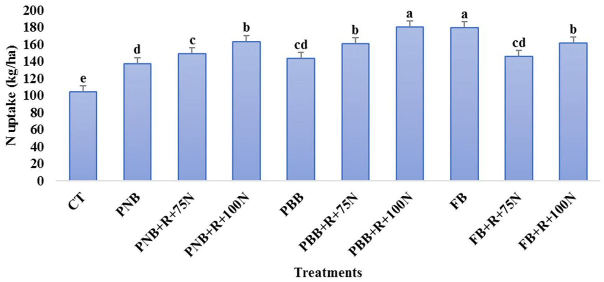

Figure 9. Total N uptake by maize as affected by treatments (pooled of two years)

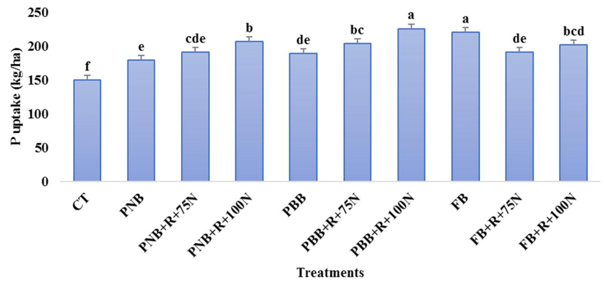

Figure 10. Total P uptake by maize as affected by treatments (pooled of two years)

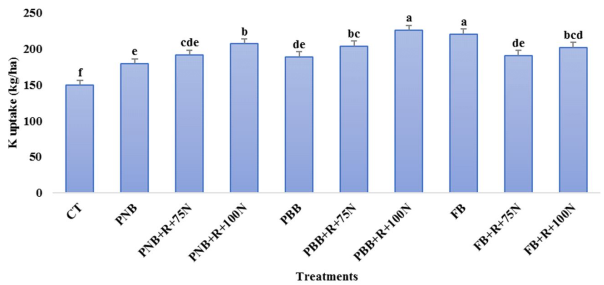

Figure 11. Total K uptake by maize as affected by treatments (pooled of two years)

FB+R+100N in the first year and PBB+R+100N in the second year. The later recorded higher P and K uptake during both the years. The treatment PBB+R+100 N caused mean of grain N uptake of 124.62 kg/ha, grain P uptake of 50.7 kg/ha and grain K uptake of 52.32 kg/ha. Similarly, this treatment registered mean stover N uptake of 55.52 kg/ha, stover P uptake of 41.82 kg/ha and stover K uptake of 173.34 kg/ha. The PBB+R+100N recorded total N uptake of 180.14 kg/ha, P uptake of 92.52 kg/ha and K uptake of 225.66 kg/ha. The CA-based treatments with residue retention caused considerably higher nutrient uptake than those without residue retention. The reduction in nutrient uptake by maize in CT practice was due to emergence of more grassy weeds and sedges, intensive tillage operations, nutrient losses, less soil water retention and impaired soil physical, chemical and biological properties (Nath *et al.* 2015, Singh *et al.* 2016, Das *et al.* 2018).

The study indicates that the CA-based permanent broad bed with residue retention and 100% N (PBB+R+100N) results in considerable reduction in total weed density and biomass with a significant increase in productivity, nutrients (N, P and K) uptake and net returns in maize under the maize–wheat–greengram triple cropping system. However, PBB+R+75N (*i.e.*, with 75% N) treatment gave comparable maize yield, net returns and net benefit: cost with the PBB+R+100N (i.e. with 100% N) and led to a saving of 37.5 kg N/ha, which may likely reduce greenhouse gas (~N_2O) emission from maize field. Hence, PBB+R+75N may be adopted for maize under the maize – wheat – greengram system in north-western Indo-Gangetic Plains of India.

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Phalaris minor management in wheat by post-emergence application of metribuzin based tank-mixed herbicides in north-western Indo-Gangetic Plains

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Metribuzin
Phalaris minor
Weed management
Wheat

ABSTRACT

Phalaris minor is the major problematic weed in wheat in the north-western Indo-Gangetic Plains including Punjab and Haryana regions. The accelerated development of herbicide resistance in weed species has narrowed down the chemical options with the wheat farmers for the effective control of weeds. In this regard, a study was conducted with different post-emergence (PoE) herbicides (clodinafop 60 g/ha, fenoxaprop 100 g/ha, sulfosulfuron 25 g/ha, pinoxaden 50 g/ha, mesosulfuron + iodosulfuron 14.4 g/ha, sulfosulfuron + metsulfuron 32 g/ha, clodinafop + metsulfuron 64 g/ha) alone and in combination with metribuzin (105 g/ha) at CCS Haryana Agricultural University, Regional Research Station Uchani, Karnal during 2018-19 and 2019-20. The metribuzin based tank mixed PoE herbicides application resulted in 70-89% weed control efficiency as compared to 17-54% with their application alone, during both the years. The tank mixed metribuzin based PoE herbicides application resulted in effective control of *P. minor* as well as broad-leaved weeds and also resulted in higher wheat grain yields (5.59 to 5.98 t/ha) when compared to sole application of PoE herbicides (4.18 to 5.19 t/ha). However, soil type, soil moisture and cultivars should be taken in to consideration while using the effective tank-mixed metribuzin based combinations.

INTRODUCTION

Wheat is an important crop in India cultivated over 30 million hectares with an annual production of 100 million tons (t) and average productivity of 3.22 t/ha (Anonymous 2019). After the green revolution, wheat productivity has increased many folds but currently the wheat productivity is declining or stagnated (Pathak *et al.* 2003). The competition for the resources by the weeds plays a significant role in reducing the wheat productivity. The wheat is invaded with composite weed flora consisting of grasses along with broad-leaved weeds. Amongst grasses: *Phalaris minor, Avena ludoviciana, Poa annua* and *Polypogon monspeliensis* are dominant. Amongst broad-leaved weeds, *Chenopodium album, C. murale, Rumex dentatus, R. spinosus, Coronopus didymus, Anagallis arvensis, Medicago denticulata, Melilotus indica, Malva parviflora* and *Convolvulus arvensis* are dominant (Singh *et al.* 1995, Chhokar *et al.* 2012). The cultural practices such as continuous adoption of rice-wheat system, delayed wheat sowing, excessive use of nitrogenous fertilizers, burning of rice residue *etc*. are mainly responsible for the heavy infestation of *P. minor* and other weeds in north-western Indo-Gangetic Plains (Singh *et al.* 2021). The *P. minor* mimics wheat and is very difficult to distinguish it during early stages. Further, due to labor scarcity and higher wages, farmers generally prefer chemical weed control in wheat and herbicides' role is indispensable. Herbicides play a major role in controlling the weeds in wheat.

The populations of *P. minor,* initially exposed to greater continuous application of single herbicide isoproturon for several years has enhanced the probability of development of herbicide resistance by imposing the strong selection pressure (Singh *et al.* 2021). Further, over reliance on herbicides with same mode of action has resulted in evolution of cross and multiple herbicide resistance in *Phalaris minor*

(Chhokar and Sharma 2008, Chhokar *et al.* 2018). The first case of resistance in *P. minor* to isoproturon was reported during 1995 in India and the task of managing *P. minor* in wheat is becoming more difficult with the evolution of multiple resistance over the years (Dhawan *et al.* 2009) due to inappropriate herbicide usage methods adoption by the farmers and not following the herbicide rotation (Malik and Singh 1995, Chhokar *et al.* 2018). *Phalaris minor* has developed multiple resistance to PS-II (photosynthesis at the photosystem-II site-A), Acetyl Coenzyme-A Carboxylase (ACCase) and Acetolactate Synthase (ALS) inhibitor herbicides (Chhokar *et al.* 2018). Further the problem of resistance has aggravated with the addition of *Rumex dentatus* in the list of herbicide resistant weeds in India. The resistance in *Rumex dentatus* to metsulfuron-methyl has been confirmed in Haryana and Punjab states of India (Chhokar *et al.* 2013, Chaudhary and Kaur 2018, Dhanda *et al.* 2020). For the management of herbicide resistant *Phalaris minor*, combination of herbicides with different modes of action may be an ideal strategy. Thus, there is need to identify effective herbicides with alternate modes of action and or tank-based mixtures for effective control of herbicide resistant weeds in wheat to ensure higher productivity. The earlier studies reported that tank-mix application of post-emergence herbicides like clodinafop, sulfosulfuron, fenoxaprop with metribuzin provided effective control of *P. minor* along with broad-leaved weeds (Yadav *et al.* 2016, Walia *et al*. 2011, Punia *et al*. 2017). The present study was conducted to find out the effect of different post-emergence (PoE) herbicides sprayed alone and as tank mixed with metribuzin on *P. minor* and other weeds, phyto-toxicity (if any) to wheat and wheat productivity, and to identify effective PoE herbicide combinations to recommend for better weed management in wheat.

MATERIALS AND METHODS

The study was conducted, during 2018-19 and 2019-20, at CCS Haryana Agricultural University, Regional Research Station, Uchani, Karnal, in the location with a history of poor control of *Phalaris minor* with clodinafop and sulfosulfuron. The wheat *cv* '*HD-2967*' and '*WH-1105*' were sown on 6 November 2018 and 7 November 2019, and harvested on 17 April and 20 April during 2018-19 and 2019-20, respectively. The soil of experimental site was clay loam in texture, low in organic carbon, nitrogen, medium in phosphorus and potassium. The weather data pertaining to the location during both the years of study presented in **Figure 1** (*Rabi* 2018-19) and **Figure 2** (*Rabi* 2019-20). Field was prepared by conventional method *i.e.*, harrowing followed by (*fb*) tiller and planking. Wheat was sown using seed rate of 100 kg/ha with row spacing 20 cm. The herbicidal treatments included clodinafop 60 g/ha, fenoxaprop 100 g/ha, sulfosulfuron 25 g/ha, pinoxaden 50 g/ha, mesosulfuron + iodosulfuron (ready mix [RM]) 14.4 g/ha, sulfosulfuron + metsulfuron (RM) 32 g/ha, clodinafop+metsulfuron (RM) 64 g/ha, clodinafop+ metribuzin 60 + 105 g/ha, fenoxaprop + metribuzin 100+105 g/ha, sulfosulfuron + metribuzin 25 + 105 g/ ha, pinoxaden + metribuzin 50 + 105 g/ha, mesosulfuron + iodosulfuron (RM) + metribuzin 14.4 + 105 g/ha, sulfosulfuron + metsulfuron (RM) + metribuzin 32 + 05 g/ha, clodinafop + metsulfuron (RM) + metribuzin 64 + 105 g/ha were evaluated along with weed free and weedy checks. The surfactant (S) was also added with herbicides sulfosulfuron, mesosulfuron+ iodosulfuron, sulfosulfuron+ metsulfuron, clodinafop+ metsulfuron at 1250 ml/ha, and 500 ml/ha with fenoxaprop. The experiment was laid out in randomized block design with three replications. The herbicides were sprayed at 35 days after sowing (DAS) with knapsack sprayer fitted with flat-fan nozzle using water volume of 500 l/ha. In weed free treatment, hand weeding was done whenever required and no weed management practice was

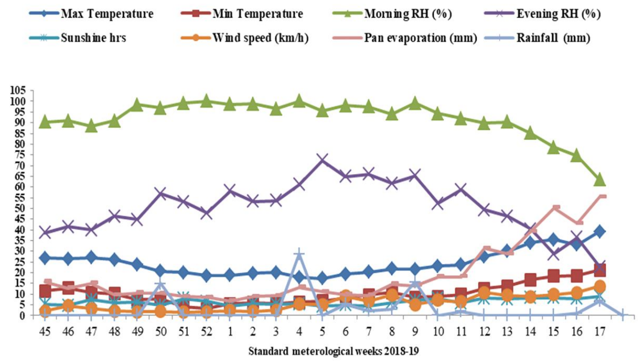

Figure 1. Weekly weather data of experimental site during *Rabi* 2018-19

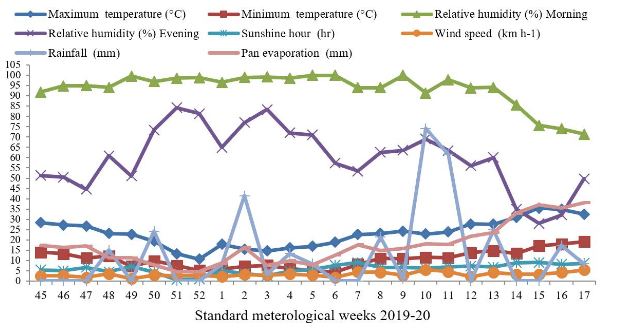

Figure 2. Weekly weather data of experimental site during *Rabi* 2019-20

taken in weedy check. All other agronomical practices were followed to raise the crop as per recommendation of the state university. The weed samples were collected at 75 DAS with the help of a quadrat (0.5 x 0.5 m) from two places in random manner from each plot. Each weed sample was separated as *P. minor*, broad-leaved weeds, counted and expressed as weed density (no./m^2). Weed samples from each plot were first sun dried and thereafter kept in oven at 65±5ºC until a constant weight was achieved to record the dry weight of weeds which was expressed as weed biomass (g/m^2). The data related to growth, yield attributes and yield were recorded at maturity. Benefit-cost ratio was calculated by dividing gross returns with total cost of cultivation. The statistical analysis was made with the help of OPSTAT software of CCSHAU (Sheoran *et al*. 1998), with least significant difference tested at 5% level of significance.

RESULTS AND DISCUSSION

Effect on weeds

The experimental site was primarily dominated by *P. minor, Rumex dentatus*, and *Melilotus indica* during both the years. The application of pinoxaden + metribuzin resulted in minimum density of *P. minor* during both the years (**Table 1**). The metribuzin based tank mix application of post-emergence herbicides provided effective control of *P. minor* and reduced the biomass of *P. minor* during 2018-19 (4.4 to 28.8 g/m^2) and 2019-2020 (4.6 to 12.7 g/m^2) as compared to their alone application (40.3 to 78.7 g/m^2 and 30.5 to 58.5 g/m^2 during 2018-19 and 2019-2020, respectively) and weedy check (94.9 g/m^2 and 73.6 g/m^2 during 2018-19 and 2019-2020, respectively). Not only *P. minor*, broad-leaved weeds were also effectively controlled with the metribuzin based tank mix application of post-emergence herbicides in comparison to their sole application. Yadav *et al.* (2016) also reported that the tank-mix application of metribuzin with clodinafop and sulfosulfuron caused effective control (99%) of all types of weed species in wheat. The application of fenoxaprop+metribuzin (88.5%) and sulfosulfuron + metribuzin (88.2%) resulted in maximum weed control efficiency (WCE) during 2018-19 and 2019-20, respectively (**Table 1**). Punia *et al.* (2017) also reported that application of fenoxaprop+metribuzin and clodinafop+metribuzin resulting in effective control of herbicide resistant biotypes of *P. minor.* The effective weed control in mixtures is due to combined action of herbicides with different modes of action. Pandey *et al.* (2006) reported the higher WCE with the application of metribuzin (86-94%) in wheat as compared to sulfosulfuron (55-87%). Pendimethalin and metribuzin based tank mixture as pre-emergence application was found to improve control of *P. minor*, *Medicago denticulata*, *Rumex dentatus* and *Chenopodium album* (Kaur *et al.* 2017)

Effect on crop

There was no phyto-toxicity of any of the herbicide combinations with metribuzin on wheat

Table 1. Effect of post-emergence herbicides alone and as tank mixed with metribuzin on density and biomass of *Phalaris minor* and other weeds and weed control efficiency (%) at 75 days after seeding (DAS) in wheat

Treatment	Dose (g/ha)	*P. minor* density (no./m^2) 75 DAS*		Weeds biomass (g/m^2) 75 DAS: *P. minor*		Weeds biomass (g/m^2) 75 DAS: Broad-leaved		Weed control efficiency (%)	
		2018-19	2019-20	2018-19	2019-20	2018-19	2019-20	2018-19	2019-20
Clodinafop	60	5.02(25)	5.76(33)	63.2	56.0	5.2	7.7	29.7	22.9
Fenoxaprop	100	6.28(41)	6.41(41)	48.5	44.4	4.8	9.7	45.2	34.5
Sulfosulfuron	25	5.89(35)	6.95(49)	61.9	58.5	3.8	9.0	32.5	18.3
Pinoxaden	50	4.49(19)	4.99(24)	40.3	35.8	4.2	9.7	54.2	45.0
Mesosulfuron + iodosulfuron	14.4	6.74(45)	5.28(27)	66.3	30.5	5.0	9.0	26.7	52.2
Sulfosulfuron + metsulfuron	32	6.06(38)	7.32(53)	59.7	46.0	4.5	2.7	34.0	41.1
Clodinafop + metsulfuron	64	7.48(55)	6.16(37)	78.7	49.1	2.3	5.0	16.8	34.5
Clodinafop + metribuzin	60+ 105	4.59(21)	3.68(13)	23.4	10.7	5.1	7.0	70.7	78.6
Fenoxaprop + metribuzin	120+ 105	4.16(19)	4.10(16)	11.2	10.4	0.0	6.3	88.5	79.8
Sulfosulfuron + metribuzin	25+ 105	4.42(22)	3.39(11)	28.8	9.7	0.0	0.0	70.4	88.2
Pinoxaden + metribuzin	50+ 105	2.34(5)	3.18(9)	4.4	4.6	7.3	10.3	88.0	81.9
Mesosulfuron + iodosulfuron + metribuzin	14.4+105	4.08(17)	3.18(9)	14.9	6.7	2.0	5.7	82.6	85.0
Sulfosulfuron + metsulfuron + metribuzin	32+ 105	4.49(22)	4.43(19)	24.7	12.7	2.3	3.7	72.2	80.2
Clodinafop + metsulfuron + metribuzin	64+ 105	3.48(12)	3.23(10)	18.1	9.3	0.0	1.0	81.4	87.5
Weedy free		1.00(0)	1.00(0.0)	0.0	0.0	0.0	0.0	100.0	100.0
Weed check		7.13(53)	7.44(55)	94.9	73.6	2.4	9.0	0.0	0.0
LSD (p=0.05)		2.4	1.2	12.8	19.2	4.4	6.1	-	-

*Original values in parentheses subjected to square root transformation before data analysis

Table 2. Effect of post-emergence herbicides alone and as tank mixed with metribuzin on yield attributes and grain yield (t/ha) of wheat

Treatment	Dose (g/ha)	Plant height (cm)		Effective tillers/mrl		Spike length (cm)		Grain yield (t/ha)		Benefit cost ratio	
		2018-19	2019-20	2018-19	2019-20	2018-19	2019-20	2018-19	2019-20	2018-19	2019-20
Clodinafop	60	106	98	68	60	10	11	4.89	4.18	0.89	0.80
Fenoxaprop	100	107	98	72	63	10	11	5.16	4.46	0.94	0.84
Sulfosulfuron	25	106	98	70	61	9	11	4.98	4.40	0.92	0.86
Pinoxaden	50	106	99	74	67	10	11	5.19	4.74	0.94	0.91
Mesosulfuron + iodosulfuron	14.4	106	97	72	68	10	11	4.88	4.97	0.89	0.97
Sulfosulfuron + metsulfuron	32	107	99	73	62	10	10	5.08	4.68	0.93	0.91
Clodinafop + metsulfuron	64	106	99	72	63	10	11	4.87	4.67	0.87	0.89
Clodinafop + metribuzin	60+105	106	99	82	75	10	10	5.70	5.60	1.06	1.11
Fenoxaprop + metribuzin	120+105	108	98	80	74	10	10	5.98	5.59	1.12	1.09
Sulfosulfuron + metribuzin	25+105	107	98	79	75	10	11	5.76	5.68	1.10	1.14
Pinoxaden + metribuzin	50+105	106	97	80	77	10	11	5.95	5.85	1.10	1.11
Mesosulfuron + iodosulfuron + metribuzin	14.4+105	108	98	79	76	10	10	5.89	5.89	1.11	1.14
Sulfosulfuron + metsulfuron + metribuzin	32+105	106	97	79	75	10	11	5.70	5.71	1.06	1.13
Clodinafop + metsulfuron + metribuzin	64+105	107	97	80	76	10	11	5.80	5.92	1.07	1.17
Weedy free		106	99	84	80	10	11	6.01	6.07	0.88	0.96
Weed check		106	100	59	56	10	11	4.36	3.40	0.75	0.58
LSD (p=0.05)		NS	NS	6	8	NS	NS	0.50	0.30	-	-

Mrl: Meter row length

crop. Different herbicidal treatments did not have the influence on plant height and spike length of wheat during both the years. However, metribuzin based post-emergence herbicides treatments were found at par with each other with respect to number of effective tillers per meter row length (mrl) (74-82/mrl) along with weed free plots (80-84/mrl) but significantly higher to alone application of post-emergence herbicides (60-74/mrl) during both the years of study (**Table 2**).

The higher wheat grain yield was recorded with metribuzin based tank mix application of post-emergence herbicides (5.70–5.98 t/ha and 5.59 to 5.92 t/ha during 2018-19 and 2019-20, respectively) as compared to their application alone (4.87 to 5.19 t/ha and (4.18 to 4.97 t/ha during 2018-19 and 2019-20, respectively) without any toxicity on wheat crop (**Table 2**). The metribuzin based tank-mix applications resulted in 31-37% and 64-74% increase in grain yield of wheat as compared to weedy check during 2018-19 and 2019-20, respectively. The highest grain yield was obtained under tank mix of metribuzin with fenoxaprop in 2018-19 and clodinafop+ metsulfuron (RM) in 2019-20. However, all the metribuzin based tank-mix treatments were at par with each other. The higher wheat grain yield in metribuzin based tank-mix applications might be due to broad spectrum of weed control along with better control of *P. minor* as compared to application of herbicides alone. Walia *et al.* (2011) also reported that application of fenoxaprop-p-ethyl+metribuzin in wheat resulted in effective control of *P. minor* and broad-leaved weeds and increased the wheat grain yield by 59% in comparison to untreated control. The significantly higher wheat grain yield was also observed by Yadav *et al.* (2016) with the application of tank mix of metribuzin with clodinafop and sulfosulfuron. Higher benefit cost ratio (1.06-1.17) was observed with tank mix application of metribuzin with post-emergence herbicide as compared to alone application (0.80-0.97).

Based on this study, it may be concluded that application of metribuzin (105 g/ha) based tank-mixed post-emergence herbicides at recommended doses (clodinafop 60 g/ha, fenoxaprop 100 g/ha, sulfosulfuron 25 g/ha, pinoxaden 50 g/ha, mesosulfuron+ iodosulfuron 14.4 g/ha, sulfosulfuron + metsulfuron 32 g/ha, clodinafop+ metsulfuron 64 g/ha) provided effective control of *P. minor* and other broad-leaved weeds in wheat as their application resulted in 70-89% weed control efficiency, without any phyto-toxicity of metribuzin on wheat, as compared to 17-54% control with their sole application. The farmers' adoption of tank mix of herbicides with different modes of action or herbicide rotation along with other cultural practices may also delay the evolution of herbicide resistance in weeds, and help to achieve sustained wheat yield for national food security. However, soil type, soil moisture and cultivars should be taken in to consideration while recommending these combinations.

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Weed management effect on weed dynamics, nutrient depletion and productivity of barley under north-western plain zone

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ABSTRACT

A field experiment was conducted on loamy sand soil at Agricultural Research Station, Sriganganagar, Rajasthan, India during two consecutive *Rabi* (winter) seasons of 2012-13 and 2013-14 to identify effective weed management treatments for attaining higher productivity of barley (*Hordeum vulgare* L.), while understanding the associated weeds dynamics. *Chenopodium album* and *Chenopodium murale* were the major dicot weeds that occurred along with the emergence of crop. *Cyperus rotundus*, *Phalaris minor* and *Asphodelus tenuifolius* were the dominant monocot weed species. The hand weeding twice at 25 and 45 days after seeding (DAS) and isoproturon at 500 g/ha + 2,4-D at 250 g/ha 30 DAS resulted in significant reduction in weed density and weed biomass. Maximum weed control efficiency (WCE) with minimum N, P and K depletion by weeds at harvest was observed with hand weeding twice (95.06%) followed by isoproturon 500 g/ha + 2,4-D at 250 g/ha 30 DAS (80.24%). Significantly higher seed, straw, biological yields of barley were observed with hand weeding twice. Next best treatments were isoproturon 500 g + 2,4-D at 250 g/ha 30 DAS and isoproturon at 500 g + metsulfuron methyl 4 g/ha 30 DAS.

INTRODUCTION

Barley (*Hordeum vulgare* L.) is a major source of food for large number of people living in the cooler semi-arid areas of the world. Barley is an important cereal in India. The chief barley growing regions in the country are higher Himalayas (Himachal Pradesh, Jammu Kashmir and West Bengal), central parts of eastern Uttar Pradesh, eastern parts of Rajasthan and north-western parts of North Bihar. The barley is mostly used in India as grain feed to livestock and poultry, as malt for manufacture of beer and other liquors like whisky, brandy *etc* (Kumar *et al*. 2019). In Rajasthan, during 2017-18 the barley was cultivated on 3.01 mha with 10.78 mt of production and 3.58 t/ha productivity. The average productivity of barley in the state is far lower (Government of Rajasthan, 2020) than the attainable yield of 4.0-5.0 t/ha (Choudhary *et al*. 2014).

The losses caused by weeds were estimated to be much higher than those caused by insects, pests and diseases together (Gharde *et al.* 2018). Weed competition throughout the crop season reduces yield by 10-38% depending upon time and intensity of weed infestation (Balyan and Malik 1994, Kumar *et al.* 2010). Conventional cultural practices of weed management are time consuming and labour intensive, even though, the additional benefits of providing greater aeration, improving root growth enabling greater absorption of moisture and nutrients from deeper soil layers and moisture conservation cannot be ignored. The farmers sometimes fail to carry out the timely agricultural operations including manual weeding because of the increasing demand of labour due to rapid urbanization / industrialization and adoption of intensive and multiple cropping systems. In barley, very limited herbicides have been tested and recommended. Thus, exploring the possibility of a suitable broad spectrum and cost-effective herbicide deserves the attention. Among the herbicides, 2,4-D is widely used in barley to control broad-leaf weeds.

The tank mix application of isoproturon and 2,4-D was recommended to control mixed weed flora in barley (Ram *et al.* 2003). The major concern with the over-dependence on single herbicide is build-up of herbicide resistant weeds and shift in weed flora. Therefore, new herbicides having a different mode of actions in various combinations are mainly needed to use as one of the management strategies for integrated weed management in barely (Yadav *et al.* 2018 and Ram *et al.* 2020). The herbicides such as metsulfuron-methyl, sulfosulfuron, carfentrazone and isoproturon have shown excellent efficiency in the control of broad and narrow leaf weeds in wheat and barley crop. The study was conducted to identify efficient weed management options to minimize the weed infestation with minimal nutrient removal by weeds and attain higher barley productivity in Sriganganagar region of Rajasthan.

MATERIALS AND METHODS

Studies were conducted at Research Farm, Agricultural Research Station, Sriganganagar, Rajasthan (India) in two *Rabi* (winter) seasons of 2012-13 and 2013-14. This station is located between 28.4^0 to 30.3^0 North latitude and 72.3^0 to 75.3^0 East longitudes and the study area receives average annual rainfall of 322 mm, with temperature ranged fluctuates as low as – 10 ^{0}C to as high as 48.9 ^{0}C from December to June. The soil of experimental field was loamy sand with low organic carbon (0.33%), low in available nitrogen (138.60 kg/ha) medium in available phosphorus (21.60 kg/ha) and potassium (231.8 kg/ha), and slightly alkaline (pH 8.2) in reaction. The experiment was laid out in randomized block design with three replications and eight treatments, *viz.* 2,4-D at 250 g/ha, isoproturon at 500 g/ha, isoproturon at 500 g + metsulfuron-methyl at 4 g/ha, isoproturon at 500 g/ha + carfentrazone at 15 g/ha, isoproturon at 500 g/ha + 2-4-D at 250 g/ha (tank-mixtures), fenoxaprop -ethyl at 75 g/ha, hand weeding twice at 25 and 45 DAS, weedy check. Barley variety '*RD 2035*' was used as test crop. All post-emergence herbicides, *viz.* 2,4-D, metsulfuron-methyl, sulfosulfuron, carfentrazone and isoproturon herbicides were applied at 30 days after seeding (DAS), excepting fenoxaprop -ethyl was only applied at 25 DAS. Herbicides were applied using knapsack hydraulic sprayer using spray volume of water 500 lit/ha. The urea and DAP were uniformly applied at the time of last ploughing. Bullock drawn desi plough was used for sowing in row spaced at 22.5 cm with average depth of 5.0 cm with seed rate of 100 kg/ha. The crop was sown at 7th and 9th November, 2012-13 and 2013-14 and harvested on 8th and 12th April, respectively during 2013 and 2014. All the plant protection measures were adopted to ensure good and healthy crop. For weed density estimation, an area of 0.25 m^2 was selected randomly by a metallic quadrat of size 0.25 × 0.25 m at two places before treatment application, and after treatment application and expressed as density (number/m^2). Total number of weeds were counted species wise taken from each plot and analyzed. Weed samples for dry matter production (biomass) were taken to assess the effect of various treatments on weed growth. The collected weed samples were first sun-dried and then in oven at 70^{0}C till constant weight to estimate weed biomass. Crop biomass yield of a net plot was weighted after harvesting at physiological maturity and expressed in tons/ha. Grain yield was calculated by threshing of total plot biomass and presented in tons/ha. Economics of different treatments was worked out by taking the prevailing market prices of inputs and produce under consideration. The nutrient content (NPK) estimation in weeds at 90 DAS, calculation of weed control efficiency (WCE) and weed index (WI) were done as per standard methods. The original data on weed density at all stages were subjected to square root transformation before statistical analysis to analyze the significant effect of different weed management treatments on weed growth.

RESULTS AND DISCUSSION

Effect on weed flora

Both monocot and dicot weeds were observed but dominance of dicot weeds was more in entire field as observed earlier by Poornima *et al.* (2018). Major weed flora observed in the experimental field of barley during *Rabi* (winter) seasons of 2012-13 and 2013-14 were: *Chenopodium murale* L., *Asphodelus tenuifolius* cav., *Rumex dentatus* L., *Melilotus alba* Medik., *Spergula arvensis* L., *Cynodon dactylon* (L.) Pers., *Anagallis arvensis* L., *Convolvulus arvensis* L., *Heliotropium ellipticum* Ledeb., *Launaea aspleniifolia* (Willd.) Hook.f., *Cyperus rotundus* L., *Phalaris minor* Retz. and *Verbesina encelioides* (Cav.) A.Gray.

Effect on weed density before and after herbicides spray

The differences in weed species wise and total weeds density were non-significant before application of treatments (**Table 1, 2** and **3**). However, after application of treatments, significantly lowest density of monocots (*Avena fatua*, *Phalaris* *minor*, *Cyprus rotundus* and others) and dicots (*Chenopodium album*, *C. murale*, *C. arvensis*, *Anagallis arvensis, Coronopus didymus, Rumex* and others) were recorded with hand weeding twice. Among the herbicide treatments, significantly lowest density of monocot and dicot as well as total weeds was observed with the application of isoproturon at 500 g/ha + 2, 4-D at 250 g/ha and isoproturon at 500 g + metsulfuron-methyl at 4 g/ha. The maximum weed density was recorded in weedy check during both the seasons. These results were in concurrence with the findings of Puniya *et al.* (2016).

Weed biomass

All the weed control treatments led to significant reduction in weed biomass of monocots and dicots than weedy check (**Table 4**). The lowest biomass of monocots (*Avena fatua*, *Phalaris minor*, *Cyprus rotundus*, others), dicots (*Chenopodium album*, *C. murale*, *C. arvensis*, *Anagallis arvensis*, *Coronopus didymus*, *Rumex* and others), total monocot, total dicot (4.35 g/m^2) and total weeds was observed in hand weeding twice. Among the herbicidal treatments, lowest weed biomass of monocot, dicot, total monocot and dicot as well as total weeds was recorded with isoproturon 500 g/ha + 2,4-D 250 g/ha followed by isoproturon 500 g + metsulfuron-methyl

Table 1. Effect of weed control treatments on weed density (no./m^2) before spray in barley (pooled data of two years)

Treatment	Monocot weed				Dicot weed						
	Avena fatua	*Phalaris minor*	*C. rotundus*	Others	*C. album*	*C. murale*	*C. arvensis*	*Anagallis arvensis*	*Coronopus didymus*	*Rumex*	Others
2,4-D 250 g/ha at 30 DAS	2.83 (7.54)	2.61 (6.33)	2.70 (6.78)	2.52 (5.87)	2.94 (8.16)	2.81 (7.40)	2.67 (6.65)	2.62 (6.39)	2.23 (4.47)	1.86 (2.96)	1.35 (1.31)
Isoproturon 500 g/ha at 30 DAS	2.87 (7.74)	2.64 (6.49)	2.73 (6.96)	2.55 (6.03)	2.98 (8.38)	2.85 (7.60)	2.71 (6.83)	2.66 (6.56)	2.25 (4.58)	1.88 (3.03)	1.36 (1.35)
Isoproturon 500 g + metsulfuron-methyl 4 g/ha at 30 DAS	2.84 (7.58)	2.62 (6.36)	2.71 (6.82)	2.53 (5.90)	2.95 (8.21)	2.82 (7.44)	2.68 (6.69)	2.63 (6.42)	2.23 (4.49)	1.86 (2.97)	1.35 (1.32)
Isoproturon 500 g/ha + carfentrazone 15 g/ha at 30 DAS	2.86 (7.70)	2.64 (6.46)	2.73 (6.93)	2.55 (6.00)	2.97 (8.34)	2.84 (7.56)	2.70 (6.79)	2.65 (6.52)	2.25 (4.56)	1.88 (3.02)	1.36 (1.34)
Isoproturon 500 g/ha + 2-4-D 250 g/ha at 30 DAS	2.85 (7.62)	2.63 (6.39)	2.71 (6.85)	2.54 (5.93)	2.96 (8.25)	2.82 (7.48)	2.69 (6.72)	2.64 (6.46)	2.24 (4.51)	1.87 (2.99)	1.35 (1.32)
Fenoxeprop-ethyl 75 g/ha at 25 DAS	2.89 (7.86)	2.66 (6.59)	2.75 (7.07)	2.57 (6.12)	3.00 (8.51)	2.87 (7.72)	2.73 (6.93)	2.68 (6.66)	2.27 (4.66)	1.89 (3.08)	1.37 (1.37)
Hand weeding twice at 25 and 45 DAS	2.89 (7.86)	2.66 (6.59)	2.75 (7.07)	2.57 (6.12)	3.00 (8.51)	2.87 (7.72)	2.73 (6.93)	2.68 (6.66)	2.27 (4.66)	1.89 (3.08)	1.37 (1.37)
Weedy check	2.86 (7.66)	2.63 (6.43)	2.72 (6.89)	2.54 (5.97)	2.97 (8.29)	2.83 (7.52)	2.69 (6.76)	2.64 (6.49)	2.24 (4.54)	1.87 (3.00)	1.35 (1.33)
LSD (p=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Values are $\sqrt{x+0.5}$ transformed and actual values are in parentheses

Table 2. Effect of weed control treatments on weed density after spray (50 DAS) in barley (pooled data of two years)

Treatment	Monocot weed (no./m^2)				Dicot weed (no./m^2)						
	Avena fatua	*Phalaris minor*	*C. rotundus*	Others	*C. album*	*C. murale*	*C. arvensis*	*Anagallis arvensis*	*Coronopus didymus*	*Rumex*	Others
2,4-D 250 g/ha at 30 DAS	1.81 (2.76)	1.68 (2.32)	1.73 (2.49)	1.63 (2.15)	1.85 (2.93)	1.78 (2.65)	1.70 (2.39)	1.67 (2.29)	1.45 (1.60)	1.25 (1.06)	0.98 (0.47)
Isoproturon 500 g/ha at 30 DAS	1.92 (3.17)	1.78 (2.66)	1.83 (2.85)	1.72 (2.47)	1.96 (3.36)	1.88 (3.04)	1.80 (2.74)	1.77 (2.63)	1.53 (1.84)	1.31 (1.22)	1.02 (0.54)
Isoproturon 500 g + metsulfuron-methyl 4 g/ha at 30 DAS	1.69 (2.36)	1.57 (1.98)	1.62 (2.12)	1.53 (1.84)	1.73 (2.50)	1.66 (2.26)	1.59 (2.03)	1.57 (1.95)	1.37 (1.37)	1.18 (0.90)	0.95 (0.40)
Isoproturon 500 g/ha + carfentrazone 15 g/ha at 30 DAS	1.77 (2.64)	1.65 (2.22)	1.70 (2.38)	1.60 (2.06)	1.82 (2.80)	1.74 (2.54)	1.67 (2.28)	1.64 (2.19)	1.42 (1.53)	1.23 (1.01)	0.97 (0.45)
Isoproturon 500 g/ha + 2,4-D 250 g/ha at 30 DAS	1.63 (2.15)	1.52 (1.81)	1.56 (1.94)	1.48 (1.68)	1.67 (2.28)	1.60 (2.07)	1.54 (1.86)	1.51 (1.79)	1.32 (1.25)	1.15 (0.83)	0.93 (0.37)
Fenoxeprop-ethyl 75 g/ha at 25-DAS	1.86 (2.97)	1.73 (2.49)	1.78 (2.67)	1.68 (2.31)	1.91 (3.14)	1.83 (2.85)	1.75 (2.56)	1.72 (2.46)	1.49 (1.72)	1.28 (1.14)	1.00 (0.50)
Hand weeding twice at 25 and 45 DAS	1.18 (0.89)	1.12 (0.75)	1.14 (0.80)	1.09 (0.70)	1.20 (0.95)	1.17 (0.86)	1.13 (0.77)	1.11 (0.74)	1.01 (0.52)	0.92 (0.34)	0.81 (0.15)
Weedy check	2.78 (7.23)	2.56 (6.07)	2.65 (6.51)	2.48 (5.63)	2.86 (7.66)	2.73 (6.95)	2.60 (6.24)	2.55 (6.00)	2.17 (4.19)	1.81 (2.77)	1.32 (1.23)
LSD (p=0.05)	0.13	0.12	0.14	0.09	0.15	0.11	0.11	0.12	0.09	0.06	0.03

Values are $\sqrt{x+0.5}$ transformed and actual values are in parentheses at 4 g/ha. This might be due to their effectiveness in reducing weed density and biomass due to better weed control. Bhullar *et al.* (2013) reported that the application of carfentrazone-ethyl or metsulfuron-methyl was effective in reducing density and biomass of broad-leaf weeds.

Weed control efficiency

All the weed control treatments had significant effect on monocot and dicot weeds control efficiency (**Table 5**). Among the herbicide treatments, the maximum WCE of monocot, *viz. Avena fatua* (80.24%), *Phalaris minor* (80.22%), *C. rotundus* (80.23%), other monocot (80.22%) and dicot, *viz. C. album* (80.22%), *C. murale* (80.22%), *Anagallis arvensis* (80.23%), *Coronopus didymus* (80.22%), *Rumex* (80.24%) and other dicot (80.20%) was recorded with isoproturon at 500 g/ha + 2,4-D at 250 g/ha followed by isoproturon at 500 g + metsulfuron-methyl at 4 g/ha. Similarly, highest WCE of total monocot (80.24%), total dicot (80.23%) and total weeds (80.24%) was found with isoproturon at 500 g/ha + 2,4-D at 250 g/ha followed by isoproturon at 500 g + metsulfuron-methyl at 4 g/ha. This may be attributed to better weed management achieved with these treatments resulting in reduced weed density and biomass and improved WCE, which provided more space and resources to the crop as reported by Bhullar *et al.* (2013) and Ram *et al.* (2020).

Table 3. Effect of weed management treatments on total monocot and dicot weeds density (no. m^2) before and after spray of herbicides (pooled data of two years)

Treatment	Before spray			After spray (50 DAS)		
	Total monocot weed	Total dicot weed	Total weeds (monocot+dicot)	Total monocot weed	Total dicot weeds	Total weeds (monocot+dicot)
2,4-D 250 g/ha at 30 DAS	5.20(26.52)	6.15(37.14)	8.02(63.86)	3.20 (9.72)	3.73 (13.39)	4.86 (23.11)
Isoproturon 500 g/ha at 30 DAS	5.26(27.22)	6.23(38.33)	8.13(65.55)	3.41 (11.15)	3.98 (15.36)	5.20 (26.51)
Isoproturon 500 g + metsulfuron-methyl 4 g/ha at 30 DAS	5.21(26.66)	6.17(37.53)	8.04(64.19)	2.96 (8.29)	3.45 (11.42)	4.50 (19.71)
Isoproturon 500 g/ha + carfentrazone 15 g/ha at 30 DAS	5.28(27.08)	6.21(38.13)	8.11(65.21)	3.13 (9.29)	3.65 (12.80)	4.75 (22.09)
Isoproturon 500 g/ha + 2-4-D 250 g/ha at 30 DAS	5.22(26.80)	6.18(37.73)	8.06(64.53)	2.84 (7.58)	3.31 (10.44)	4.30 (18.02)
Fenoxeprop-ethyl 75 g/ha at 25 DAS	5.30(27.64)	6.28(38.92)	8.19(66.57)	3.31 (10.44)	3.86 (14.37)	5.03 (24.81)
Hand weeding twice at 25 and 45 DAS	5.30(27.64)	6.28(38.92)	8.19(66.57)	1.91 (3.14)	2.20 (4.23)	2.82 (7.47)
Weedy check	5.24(26.94)	6.20(37.93)	8.08(64.88)	5.09 (25.45)	5.96 (35.04)	7.81 (7.49)
LSD (p=0.05)	NS	NS	NS	0.27	0.23	0.22

Values are $\sqrt{x+0.5}$ transformed and actual values are in parentheses

Table 4. Effect of weed control treatments on weed biomass (g/m^2) after spray (60 DAS) (pooled data of two years)

Treatment	*Avena fatua*	*P. minor*	*C. rotundus*	Other monocot	*C. album*	*C. murale*	*C. arvensis*	*Anagallis arvensis*	*Coronopus didymus*	*Rumex*	Other dicot	Total monocot	Total dicot	Total weed (monocot +dicot)
2,4-D 250 g/ha at 30 DAS	1.87 (7.23)	1.74 (6.06)	1.79 (6.50)	1.69 (5.63)	1.94 (7.83)	1.86 (7.09)	1.78 (6.38)	1.75 (6.12)	1.51 (4.28)	1.30 (2.83)	1.01 (1.26)	3.33 (25.42)	3.93 (35.79)	5.10 (61.21)
Isoproturon 500 g/ha at 30 DAS	1.90 (7.36)	1.76 (6.17)	1.82 (6.62)	1.71 (5.73)	1.97 (7.97)	1.89 (7.21)	1.80 (6.49)	1.77 (6.24)	1.53 (4.36)	1.31 (2.88)	1.02 (1.28)	3.38 (25.88)	3.99 (36.44)	5.18 (62.33)
Isoproturon 500 g + metsulfuron-methyl 4 g/ha at 30 DAS	1.86 (4.12)	1.73 (3.46)	1.78 (3.71)	1.68 (3.21)	1.93 (4.46)	1.85 (4.05)	1.76 (3.64)	1.74 (3.49)	1.50 (2.44)	1.29 (1.62)	1.01 (0.72)	3.31 (14.50)	3.90 (20.41)	5.06 (34.91)
Isoproturon 500 g/ha + carfentrazone 15 g/ha at 30 DAS	1.87 (5.40)	1.73 (4.53)	1.78 (4.86)	1.68 (4.21)	1.93 (5.85)	1.85 (5.30)	1.77 (4.77)	1.74 (4.58)	1.50 (3.20)	1.29 (2.12)	1.01 (0.94)	3.31 (19.00)	3.91 (26.75)	5.07 (45.75)
Isoproturon 500 g/ha + 2-4-D 250 g/ha at 30 DAS	1.79 (3.51)	1.66 (2.95)	1.71 (3.16)	1.61 (2.74)	1.85 (3.80)	1.77 (3.45)	1.70 (3.10)	1.67 (2.98)	1.45 (2.08)	1.25 (1.38)	0.98 (0.61)	3.16 (12.32)	3.72 (17.40)	4.83 (29.75)
Fenoxeprop-ethyl 75 g/ha at 25 DAS	1.90 (7.59)	1.76 (6.37)	1.81 (6.83)	1.71 (5.91)	1.97 (8.22)	1.88 (7.46)	1.80 (6.70)	1.77 (6.44)	1.53 (4.50)	1.31 (2.98)	1.02 (1.32)	3.38 (26.71)	3.99 (37.61)	5.18 (64.32)
Hand weeding twice at 25 and 45 DAS	1.75 (0.88)	1.63 (0.74)	1.68 (0.79)	1.58 (0.68)	1.81 (0.95)	1.74 (0.86)	1.66 (0.77)	1.64 (0.74)	1.42 (0.52)	1.23 (0.34)	0.97 (0.15)	3.09 (3.09)	3.63 (4.35)	4.71 (7.44)
Weedy check	1.97 (17.8)	1.83 (14.9)	1.88 (16.0)	1.77 (13.8)	2.04 (19.2)	1.96 (17.4)	1.87 (15.7)	1.84 (15.1)	1.58 (10.5)	1.35 (6.97)	1.04 (3.09)	3.52 (62.5)	4.16 (88.0)	5.40 (150.6)
LSD (p=0.05)	0.27	0.26	0.30	0.28	0.32	0.39	0.34	0.26	0.21	0.10	0.09	0.47	0.72	0.75

Values are $\sqrt{x+0.5}$ transformed and actual values are in parentheses

Table 5. Effect of weed control measures on weed control efficiency (WCE %) after spray (60 DAS) (pooled data of two years)

Treatment	*Avena fatua*	*Phalaris minor*	*C. rotundus*	Other monocot	*C. album*	*C. murale*	*C. arvensis*	*Anagallis arvensis*	*Coronopus didymus*	*Rumex*	Other Dicot	Total monocot	Total dicot	Total weeds (Monocot +Dicot)
2,4-D 250 g/ha at 30 DAS	59.32	59.32	59.32	59.29	59.32	59.30	59.28	59.30	59.30	59.32	59.30	59.35	59.34	59.35
Isoproturon 500 g/ha at 30 DAS	58.58	58.59	58.58	58.54	58.60	58.54	58.53	58.57	58.57	58.58	58.55	58.60	58.60	58.60
Isoproturon 500 g + metsulfuron-methyl 4 g/ha at 30 DAS	76.81	76.78	76.80	76.78	76.81	76.79	76.77	76.79	76.80	76.81	76.78	76.81	76.81	76.81
Isoproturon 500 g/ha + carfentrazone 15 g/ha at 30 DAS	69.62	69.58	69.58	69.56	69.59	69.59	69.57	69.59	69.60	69.62	69.55	69.61	69.61	69.61
Isoproturon 500 g/ha + 2-4-D 250 g/ha at 30 DAS	80.24	80.22	80.23	80.20	80.22	80.22	80.22	80.23	80.22	80.24	80.20	80.24	80.23	80.24
Fenoxeprop-ethyl 75 g/ha at 25 DAS	57.28	57.26	57.27	57.22	57.29	57.22	57.27	57.28	57.22	57.28	57.23	57.27	57.27	57.28
Hand weeding twice at 25 and 45 DAS	95.06	95.06	95.06	95.06	95.06	95.05	95.06	95.06	95.06	95.06	95.06	95.06	95.06	95.06
Weedy check	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
LSD (p=0.05)	1.33	1.34	1.28	1.35	1.20	1.50	1.56	1.34	1.51	1.33	2.56	0.54	0.49	0.32

Table 6. Effect of weed control treatments on nutrient content of weeds (pooled data of two years)

Treatment	N (%)		P (%)		K (%)		N removal (kg/ha)		Total N removal (kg/ha)	P removal (kg/ha)		Total P removal (kg/ha)	K removal (kg/ha)		Total K removal (kg/ha)
	Mono cot	Dicot	Monocot	Dicot	Monocot	Dicot	Monocot	Dicot		Monocot	Dicot		Mono cot	Dicot	
2,4-D 250 g/ha at 30 DAS	1.027	1.042	0.208	0.223	1.235	1.250	26.10	37.29	63.39	5.30	8.00	13.30	31.41	44.75	76.16
Isoproturon 500 g/ha at 30 DAS	1.031	1.046	0.209	0.224	1.240	1.255	26.67	38.10	64.77	5.41	8.17	13.58	32.08	45.74	77.82
Isoproturon 500 g + metsulfuron-methyl 4 g/ha at 30 DAS	1.040	1.055	0.211	0.226	1.251	1.266	15.07	21.52	36.59	3.06	4.61	7.67	18.13	25.83	43.96
Isoproturon 500 g/ha + carfentrazone 15 g/ha at 30 DAS	1.049	1.064	0.213	0.228	1.261	1.276	19.92	28.44	48.36	4.04	6.09	10.13	23.97	34.15	58.12
Isoproturon 500 g/ha + 2-4-D 250 g/ha at 30 DAS	1.067	1.082	0.216	0.231	1.283	1.299	13.18	18.82	31.99	2.67	4.03	6.70	15.85	22.59	38.45
Fenoxeprop-ethyl 75 g/ha at 25 DAS	1.089	1.104	0.221	0.236	1.310	1.325	29.09	41.53	70.61	5.91	8.88	14.78	35.00	49.83	84.83
Hand weeding twice at 25 and 45 DAS	1.088	1.104	0.222	0.235	1.310	1.324	3.36	4.80	8.16	0.68	1.02	1.71	4.05	5.76	9.81
Weedy check	0.985	1.001	0.200	0.215	1.185	1.200	61.58	88.10	149.67	12.50	18.95	31.45	74.07	105.66	179.73
LSD(p=0.05)	0.036	0.038	0.009	0.008	0.048	0.047	0.89	1.56	2.10	0.25	0.33	0.32	1.25	2.40	2.42

Nutrient depletion by weeds

The nutrient contents (NPK) and their removal by monocot and dicot weeds was significantly influenced by different management practices (**Table 6**). The lowest removal of N, P and K and total nutrients by weeds was observed with hand weeding twice and it was on par with isoproturon at 500 g/ha + 2,4-D at 250 g/ha. The highest nutrients removal by monocots, dicots and total weeds was recorded in weedy check. The reduction in NPK depletion by weeds under the effective treatments might be due to the corresponding reduction in dry matter accumulation of weeds due to their effective weed control and smothering effect of crop exerted on weed growth. Greater biomass of weeds accumulated under weedy check might be due to higher nutrients depletion by fast growing weeds (Puniya *et al.* 2016).

Yields and weed index

The hand weeding twice at 25 and 50 DAS resulted in highest grain (6.73 and 7.05 t/ha), straw (7.54 and 7.91 t/ha) and biological yield (14.27 and 14.96 t/ha) in both the years (**Table 7**). Weedy check registered the lowest mean grain, straw and biological yield. Among the herbicide treatments, isoproturon at 500 g/ha + 2,4-D at 250 g/ha has recorded maximum grain yield (6.28 and 6.58 t/ha), straw yield (7.03 and 7.38 t/ha) and biological yield (13.31 and 13.96 t/ha) with significantly minimum weed index (6.82) amongst the treatments tested. The higher yield in these treatments might be due to more availability of

Table 7. Effect of weed control treatments on grain and straw yield of barley and weed index

Treatment	Grain yield (t/ha)		Straw yield (t/ha)		Biological yield (t/ha)		Weed index (%)
	2012-13	2013-14	2012-13	2013-14	2012-13	2013-14	
2,4-D 250 g/ha at 30 DAS	5.64	5.91	6.30	6.62	11.95	12.53	16.14
Isoproturon 500 g/ha at 30 DAS	5.36	5.61	5.98	6.28	11.33	11.89	20.47
Isoproturon 500 g + metsulfuron-methyl 4 g/ha at 30 DAS	6.10	6.39	6.83	7.17	12.93	13.56	9.56
Isoproturon 500 g/ha + carfentrazone 15 g/ha at 30 DAS	5.93	6.21	6.61	6.94	12.55	13.16	12.00
Isoproturon 500 g/ha + 2-4-D 250 g/ha at 30 DAS	6.28	6.58	7.03	7.38	13.31	13.96	6.82
Fenoxeprop-ethyl 75 g/ha at 25 DAS	5.39	5.65	6.20	6.51	11.59	12.16	19.80
Hand weeding twice at 25 and 45 DAS	6.73	7.05	7.54	7.91	14.27	14.96	0.00
Weedy check	4.39	4.68	5.77	6.13	10.16	10.81	34.17
LSD (p=0.05)	0.48	0.40	0.45	0.50	0.62	0.47	5.83

nutrients and moisture as there was less competition between weeds and crop. Bhullar *et al.* (2013) reported that the application of carfentrazone-ethyl or metsulfuron-methyl effectively controlled the broad-leaf weeds and enhanced the grain yield of barley. Ram *et al.* (2020) reported highest grain yield in weed-free treatment which was at par with isoproturon 750 g/ha + 2,4-D 500 g/ha and pinoxaden 40 g/ha + carfentrazone 20 g/ha. Uncontrolled weeds competition in weedy check, caused an average 8-54% barley yield reduction compared to weed-free treatment. These findings were in concurrence with those of Ram and Singh (2009), Puniya *et al.* (2016) and Kumar *et al.* (2019).

It may be concluded that the combination of isoproturon 500 g/ha + 2,4-D 250 g/ha at 30 DAS and alternately, isoproturon at 500 g/ha. + metsulfuron-methyl 4 g/ha at 30 DAS can be used for effective weed control and higher productivity of barley.

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Growth, yield and economics in summer groundnut sequenced with rice under different weed management options

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ABSTRACT

A field experiment was conducted during three consecutive summer seasons of 2016-17, 2017–2018 and 2018-2019 in sandy clay loam soil at the Research Farm, Bidhan Chandra Krishi Viswavidyalaya, West Bengal to study the effect of different weed control methods in summer groundnut. The experiment comprising six treatments was replicated four times in a randomized block design. The pre-emergence application (PE) of pendimethalin 1.5 kg/ha followed by post-emergence application (PoE) of imazethapyr 75 g/ha was found to be the most effective in controlling weeds, and resulted in higher groundnut growth and yield attributes, higher pod yield (2.76 t/ha) and maximum BCR (2.65) than other treatments in summer groundnut crop grown in sequence with rice.

INTRODUCTION

Groundnut (*Arachis hypogea* L.) is one of the most important oilseed crops cultivated for edible oil, protein and confectionery purpose (Vora *et al.* 2019). India has a diverse climate and groundnut is grown throughout the year in one part or the other in the country. The productivity of groundnut under irrigated condition is not stable due to various constrains. Among them weed infestation is considered to be the most important limiting factor in achieving potential productivity of groundnut (Patel *et al.* 2020). Yield losses due to heavy weed infestation in groundnut ranged from 13-80% in India (Ghosh *et al.* 2000). Unlike other crops, weeds interfere with pegging, pod development and harvesting of groundnut besides competing for resources. The crop-weed competition remains maximum during the early stages, especially in bunch-type varieties because of its slow-seedling emergence and initial growth, small foliage cover, prostrate growth habit and consequently poor competitive ability (Sheoran *et al.* 2015). Hand weeding is becoming costlier day by day due to higher wages and non-availability of labour in time particularly at critical period of crop weed competition. Therefore, alternate weed management options and safer herbicides are one of the better substitutes of costly hand weeding (Poddar *et al.* 2017a). Use of different pre- and post-emergence herbicides offers an alternative viable option for effective and timely control of weeds in groundnut. But each herbicide has its own spectrum of weed control (Kundu *et al.* 2020). The pre-emergence application (PE) of herbicides like pendimethalin was found to be effective in controlling the weeds during early stages of crop growth but late flushes and escaped/regenerated weeds in later stages also hamper the crop yield to certain extent possible (Dayal 2004). It necessitates the use of an alternative cost-effective integrated weed-management strategy involving application of both the PE and post-emergence application (PoE) of herbicides in combination with manual or mechanical weeding which will be economical and have least impact on environment and non-target organisms. Thus, the present study was carried out to find out the best weed management practices in groundnut for managing weeds and attain higher productivity of groundnut in rice-groundnut cropping system.

MATERIALS AND METHODS

The experiment was carried out at the Research Farm, Bidhan Chandra Krishi Vishwavidyalaya, West Bengal, India (22°97´ N latitude and 88°43' E longitude with the 9.75 m above the msl). Topographically the land was medium in slope having deep tube well facility and natural weed infestations in summer groundnut during three consecutive year 2016-17, 2017–2018 and 2018-2019. The soil of the experimental site was sandy clay loam (sand 64.8%, silt 10.4%, and clay 24.8%) with a pH of 7.2 and an electrical conductivity of 0.294 ds/m. It contained 0.61% organic C, 177.6 kg available N/ha, 24.3 kg available P/ha and 147.5 kg available K/ha. The climate of the study site was sub-tropical humid. A combination of six treatments, *viz.* weedy check, weed free check, hand weeding (HW) twice at 20 and 40 days after sowing (DAS), pendimethalin 1.5 kg/ha PE followed by (*fb*) one HW at 20 DAS, pendimethalin 1.5 kg/ha PE *fb* quizalofop-p-ethyl 50 g/ha PoE at 20 DAS and pendimethalin 1.5 kg/ha PE *fb* imazethapyr 75 g/ha PoE at 20 DAS, were evaluated in a randomized block design with four replications. Groundnut '*TG51*' was sown at 30 x 10 cm spacing on 3 x 5 m (15 m^2) area in the mid of February in each of the experimental year. Herbicides were applied using spray volume of 400 litres/ha. The recommended dose of fertilizers, *i.e.,* 20 kg N, 60 kg P and 40 kg K/ha were applied before sowing in the seed row zone using Urea, SSP and MOP, respectively. Different categories of individual weeds (grass, sedge and broad-leaved) were counted individually from each plot. Weed population (density) and weed dry matter (biomass) g/m^2 was measured using a quadrat of 0.5 x 0.5 m. The quadrat was thrown randomly at three places in each plot at 20 DAS and 40 DAS and the weeds were counted category-wise and total weed density was calculated. After counting, the weed samples were uprooted washed in tap water and sundried for two days and then kept in an oven at 70 ± 5°C for 48 h for recording weed dry biomass. Weed control efficiency (WCE) (Mani *et al.* 1973), weed persistence index (WPI) (Mishra and Mishra 1997), herbicide efficiency index (HEI) (Mishra and Mishra 1997), weed index (WI) (Mishra and Mishra 1997), crop resistance index (CRI) (Mishra and Mishra 1997) and weed management index (WMI) (Mishra and Mishra 1997) were calculated using the following equations:

$$\mathrm{WCE} = \frac{\mathrm{WDMc-WDMt}}{\mathrm{WDMc}}$$

Where, WDMc is the weed biomass (g/m^2) in control plot; WDMt is the weed biomass (g/m^2) in treated plot.

$$\mathrm{WPI} = \frac{\mathrm{WDMt}}{\mathrm{WDMc}} \times \frac{\mathrm{WDc}}{\mathrm{WDt}}$$

Where, WDc is Weed density in control plot; WCt = Weed density in treated plot.

$$\mathrm{HEI} = \frac{\mathrm{Yt-Yc}}{\mathrm{Yt}} \times \frac{\mathrm{WDMc}}{\mathrm{WDMt}}$$

Where, Yt is crop yield from the treated plot; Yc is crop yield from the control plot; WDMc is the weed biomass (g/m^2) in control plot; WDMt is the weed biomass (g/m^2) in treated plot.

$$\mathrm{WI} = \frac{\mathrm{Yf-Yt}}{\mathrm{Yf}} \times 100$$

Where, Yf is yield from weed-free plot; Yt is yield from treated plot.

$$\mathrm{CRI} = \frac{\mathrm{CDMt}}{\mathrm{CDMc}} \times \frac{\mathrm{WDMc}}{\mathrm{WDMt}}$$

Where, CDMt is groundnut crop dry matter (g/m^2) in treated plot; CRMc is groundnut crop dry matter (g/m^2) in control plot.

$$\mathrm{WMI} = \frac{\text{Per cent yield over control}}{\text{Per cent control of weeds}}$$

Plant height, dry matter, LAI, nodulation number and other growth and yield parameter were recorded as per standard protocol. The crop harvested from the net plot was taken to threshing floor, dried, threshed and pods were weighed to obtained the pod yield plot wise. These observations were then used to get the pod yield in kg/ha at 14% moisture content.

The harvest index (HI) was calculated by using the formula given by Donald (1963).

$$\mathrm{HI}\ (\%) = \frac{\text{Groundnut pod yield}}{\text{Total biological yield}} \times 100$$

Mean values of three years' data on crops and weeds were jointly analyzed using the analysis of variance (ANOVA) technique as suggested by Gomez and Gomez (1984). All the collected data were analyzed statistically by the analysis of variance (ANOVA) technique using the SAS Windows Version 9.3. The values wherever necessary were transformed into square root values as applicable for respective statistical analyses (Panse and Sukhatme 1978).

RESULTS AND DISCUSSION

Effect on groundnut crop growth and yield

The growth parameter like plant height, dry matter accumulation, nodulation number were significantly higher in weed free at all growth stage where as the lowest values were recorded in weedy check (**Table 1**). There was no significant variation in plant height at maturity in different treatments except for weed check (42.2 cm), in which the plant height was slightly lower than the rest of the treatments. The groundnut dry matter accumulation in weed free was significantly higher (328.12 g/m^2) which was 38.98% more than that of weedy check. Pendimethalin PE *fb* imazethapyr PoE was equally effective as weed free and there was no significant variation with hand weeding twice. There was 25.42% to 38.98% higher dry matter accumulation in groundnut due to different weed management approaches. Weed management created a favourable environment for the crop plant and helped to uptake more available resources and ultimately it reflected in its growth parameter (Poddar *et al.* 2017b). Number of nodules/plant and leaf area index (LAI) also followed the similar trends where higher number of nodules and LAI were observed in different weed management treatments as compared with weedy check. Variation in nodules number and LAI due to different weed management was also reported previously by Adhikary *et al.* (2016) and Choudhary *et al.* (2017). Crop growth rate (CGR) was comparatively higher in all the herbicidal treatments and among them pendimethalin PE *fb* imazethapyr PoE and pendimethalin PE *fb* quizalofop-p-ethyl PoE attained the maximum value (4.10 g/m^2/day). Lowest CGR was in weedy check (2.47 g/m^2/day). Similar results were also reported earlier by Olayinka and Etejere (2015).

Yield attributing characters like number of pods / plant, shelling %, 100 kernel weight (KW) varied significantly due to different weed management treatments (**Table 2**). Weed free recorded the highest number of pods/plant (25.3) whereas weedy check was the lowest number (13.7) and both of these were significantly different with each other. Among different treatments, HW twice at 20 and 40 DAS followed by pendimethalin 1.5 kg/ha as PE *fb* 1 HW at 20 DAS have recorded higher pods number/plant. There was no significant difference among the various treatments for shelling % and 100 KW but the highest value was found in weed free followed by HW twice. There was an increase of 24.98% to 37.07% groundnut pod yield with different weed management treatments when compared with weedy check. Pod yield and haulm yield varied significantly due to different weed management treatments (**Table 2**). The weed free check was significantly superior in recording highest pod yield (2.96 t/ha) which was followed by pendimethalin 1.5 kg/ha *fb* imazethapyr 75 g/ha at 20 DAS > two HW at 20 and 40 DAS > pendimethalin 1.5 kg/ha *fb* quizalofop-p-ethyl 50 g/ha at 20 DAS in the order of decreasing groundnut pod yield. However, all the herbicidal treatments were statistically at par in terms of pod yield. Weedy check recorded statistically lowest pod yield (2.16 t/ha). Harvest index did not differ significantly amongst the various treatments. Weed free environment helped the crop plants to grow more vigorously and thus crop produces more yield attributing parameter which ultimately turns into higher yield (Poddar *et al.* 2014). The regression equation predicted linear reduction in

Table 1. Effect of different weed control treatments on growth attributes of summer groundnut (pooled analysis)

Treatment	Plant height at harvest (cm)	Dry matter production (g/m^2)		Nodulation (no./plant)		LAI (%) at harvest	CGR (g/m^2 day)
		45 DAS	75 DAS	45 DAS	75 DAS		
Pendimethalin 1.5 kg/ha PE *fb* 1 HW at 20 DAS	44.3	181.7	296.4	72.0	101.3	2.90	3.83
Pendimethalin 1.5 kg/ha PE *fb* quizalofop-p-ethyl 50 g/ha PoE at 20 DAS	43.6	185.5	308.3	68.3	112.7	2.94	4.10
Pendimethalin 1.5 kg/ha PE *fb* imazethapyr 75 g/ha PoE at 20 DAS	44.5	191.3	314.3	70.7	118.0	3.06	4.10
Hand weeding twice (at 20 and 40 DAS)	43.8	195.2	312.3	80.1	111.3	2.96	3.90
Weed free check	45.2	221.2	328.1	82.7	139.1	3.12	3.57
Weedy check	42.2	162.3	236.1	51.3	80.7	2.74	2.47
LSD (p=0.05)	1.4	6.8	13.6	7.1	8.5	0.28	1.36

Table 2. Effect of different weed control treatments on yield attributes and yields of summer groundnut (pooled analysis)

Treatment	Yield attributes of groundnut			Pod yield (t/ha)				Haulm yield (t/ha)	Harvest index (%)
	No. of pods / plant	Shelling (%)	100 KW (g)	2016-17	2017-18	2018-19	Pooled		
Pendimethalin 1.5 kg/ha PE *fb* 1 HW at 20 DAS	21.1	68.6	44.0	2.66	2.70	2.73	2.70	3.41	44.1
Pendimethalin 1.5 kg/ha PE *fb* quizalofop-p-ethyl 50 g/ha PoE at 20 DAS	18.9	68.1	44.1	2.71	2.69	2.81	2.74	3.46	44.2
Pendimethalin 1.5 kg/ha PE *fb* imazethapyr 75 g/ha PoE at 20 DAS	20.3	69.1	44.1	2.81	2.69	2.79	2.76	3.49	44.2
Hand weeding twice (at 20 and 40 DAS)	22.1	69.0	44.6	2.79	2.73	2.70	2.74	3.44	44.3
Weed free check	25.3	69.9	45.6	3.01	2.96	2.90	2.96	3.66	44.6
Weedy check	13.7	66.1	43.7	2.36	1.99	2.12	2.16	2.81	43.4
LSD (p=0.05)	2.53	NS	NS	0.26	0.41	0.38	0.42	0.53	NS

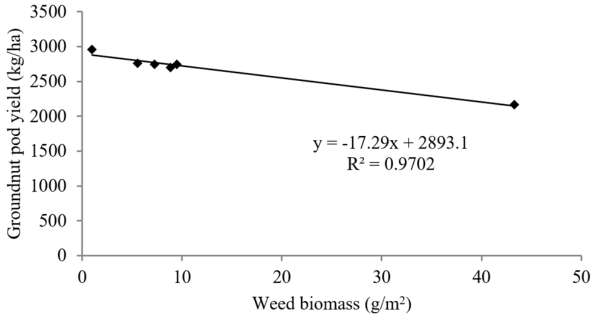

Figure 1. Relationship between groundnut pod yield and weed biomass

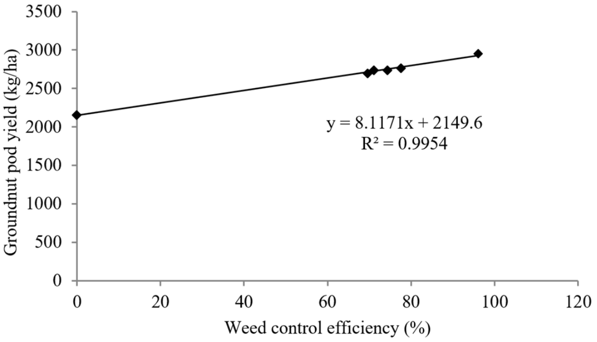

Figure 2. Relationship between groundnut pod yield and weed control efficiency (WCE)

the groundnut pod yield with a unit increase in the dry weight of weeds (**Figure 1**). The extent of reduction of pod yield could be 17.3 kg/ha for weed biomass (kg) per unit m^2 area. The evaluation of weed control efficiency of the different treatments and the regression of yield on it revealed that 1% increase in the weed control efficiency increased the pod yield by 8.12 kg/ha (**Figure 2**). This is in the conformity of the results reported by Singh *et al.* (2014).

Effect on weeds

All the weed management treatments significantly influenced the weed density and biomass in summer groundnut (**Table 2** and **3**). The dominant weed flora in the experimental site was in the order of broad-leaf weeds (47%) > sedges (32%) > grass (21%) at 20 DAS. The lowest density of different categories of weed (grass, sedges and BLW) was recorded in weed free check whereas maximum in case of weedy check all dates of observation. Among different weed management treatments, there was no significant variation in the weed density of grasses, sedges and BLW, however it was lower in plots treated with pendimethalin PE *fb* imazethapyr PoE at the early growth stage (20 DAS) and HW twice at later stage (40 DAS). Pendimethalin PE *fb* 1 HW at 20 DAS proved statistically at par with pendimethalin 1.5 kg/ha PE *fb* imazethapyr 75 g/ha PoE at 20 DAS in terms of weeds density irrespective of categories and growth stage. Weed biomass accumulation was the reflection of weed density in different treatments (**Table 2**) and the results showed that significantly higher and lower weed biomass was recorded in weedy check and weed free treatment, respectively at all growth stages. There was 69.70% to 77.48% and 79.64% to 84.15% reduction in the total weed biomass accumulation across different weed control treatments at 20 and 40 DAS, respectively. Among different treatments, pendimethalin PE *fb* imazethapyr PoE was found very effective in reducing the total weed biomass and it was statistically at par with HW twice treatment at 20 DAS. Pre-emergence application of pendimethalin helped in controlling early emerged weeds whereas

Table 3. Effect of different weed control treatments on weed density (no./m^2) in summer groundnut (pooled analysis)

Treatment	Weed density* (no./m^2) Grasses 20 DAS	Grasses 40 DAS	Sedges 20 DAS	Sedges 40 DAS	Broad leaved weeds 20 DAS	Broad leaved weeds 40 DAS	Total weed density (no./m^2) 20 DAS	Total weed density (no./m^2) 40 DAS
Pendimethalin 1.5 kg/ha PE *fb* 1 HW at 20 DAS	6.4 (2.63)	7.4 (2.81)	11.7 (3.49)	14.2 (3.83)	23.2 (4.87)	22.3 (4.77)	41.3 (6.47)	43.9 (6.66)
Pendimethalin 1.5 kg/ha PE *fb* quizalofop-p-ethyl 50 g/ha PoE at 20 DAS	7.0 (2.74)	7.8 (2.88)	12.0 (3.54)	12.7 (3.63)	27.8 (5.32)	27.9 (5.33)	46.8 (6.88)	48.5 (7.00)
Pendimethalin 1.5 kg/ha PE *fb* imazethapyr 75 g/ha PoE at 20 DAS	7.6 (2.85)	7.7 (2.86)	11.0 (3.39)	12.3 (3.58)	24.1 (4.96)	22.0 (4.74)	42.7 (6.57)	42.0 (6.52)
Hand weeding twice (at 20 and 40 DAS)	8.6 (3.02)	6.1 (2.57)	11.0 (3.39)	11.0 (3.39)	29.2 (5.45)	24.9 (5.04)	48.8 (7.02)	42.0 (6.52)
Weed free check	1.4 (1.38)	1.5 (1.41)	1.9 (1.55)	2.3 (1.67)	5.1 (2.37)	4.1 (2.14)	8.4 (2.98)	7.9 (2.90)
Weedy check	18.1 (4.31)	28.4 (5.38)	27.9 (5.33)	41.1 (6.45)	40.7 (6.42)	85.2 (9.26)	86.7 (9.34)	154.7 (12.46)
LSD (p=0.05)	3.26	3.21	2.41	2.24	1.36	4.80	3.97	5.34

*Data are subjected to square root transformation [$\sqrt{(x+0.5)}$]; values in the parentheses are transformed late flushes were effectively controlled by post-emergence application of imazethapyr which was clearly reflected in terms of weed density and biomass. Hand weeding was also found effective in controlling all categories of weeds. This is in conformity with the earlier findings of (Patel *et al.* 2020).

Weed indices

Different weed indices varied among the different treatments (**Table 5**) due to difference in their weed management efficacy. WCE was highest in weed free treatment. Pendimethalin PE *fb* imazethapyr PoE and HW twice (at 20 and 40 DAS) were next best in terms of WCE at all the dates of observation. WCE varied between 69.70 to 77.48 % at 20 DAS and 78.04 to 87.15% at 40 DAS among the different herbicidal treatments. WPI also followed the similar trend as like WCE and the descending order was pendimethalin 1.5 kg/ha PE *fb* imazethapyr 75 g/ha at 20 DAS>two hand weeding (at 20 and 40 DAS)>pendimethalin 1.5 kg/ha *fb* 1 HW at 20 DAS>pendimethalin 1.5 kg/ha *fb* quizalofop-p-ethyl 50 g/ha at 20 DAS. HEI and CRI were higher in weed free treatment which was followed by pendimethalin 1.5 kg/ha PE *fb* imazethapyr 75 g/ha at 20 DAS (0.97 and 5.91, respectively) and then hand weeding twice (0.82 and 5.13, respectively). Weed index was maximum in weedy check and nil in case of weed free treatment. Among the different herbicidal treatments, pendimethalin 1.5 kg/ha PE *fb* imazethapyr 75 g/ha at 20 DAS closely followed by HW twice and then pendimethalin as PE *fb* quizalofop-p-ethyl as PoE were superior in terms of lower value of WI. There was not much variation in WMI among the different treatments although weed free was the best (0.39) followed by pendimethalin PE *fb* quizalofop-p-ethyl PoE (0.38). Variation in weed indices due to different methods of weed management was also reported earlier by Poddar *et al.* (2017a) and Adhikary *et al.* (2016).

Economics

Weedy check treatment resulted in lowest net returns and benefit: cost ratio (BCR) (**Table 5**). Pendimethalin PE *fb* imazethapyr PoE gave the highest net returns and BCR (2.65) and it was on-par with pendimethalin PE *fb* quizalofop-p-ethyl PoE (2.63). Integration of hand-weeding at 20 DAS with pendimethalin significantly improved the groundnut

Table 4. Effect of different weed control treatments on weed biomass (g/m^2) in summer groundnut (pooled analysis)

Treatment	Weed biomass (g/m^2): Grasses		Sedges		BLW		Total weed biomass (g/m^2)	
	20 DAS	40 DAS	20 DAS	40 DAS	20 DAS	40 DAS	20 DAS	40 DAS
Pendimethalin 1.5 kg/ha PE *fb* 1 HW at 20 DAS	1.23	1.46	1.95	2.83	4.18	4.53	7.36	8.82
Pendimethalin 1.5 kg/ha PE *fb* quizalofop-p-ethyl 50 g/ha PoE at 20 DAS	1.01	2.28	1.62	2.13	4.37	5.10	7.0	9.51
Pendimethalin 1.5 kg/ha PE *fb* imazethapyr 75 g/ha PoE at 20 DAS	0.95	0.96	1.20	1.42	3.32	3.19	5.47	5.57
Hand weeding twice (at 20 and 40 DAS)	1.18	0.87	1.16	1.73	3.92	4.66	6.26	7.26
Weed free check	0.14	0.16	0.20	0.36	0.60	0.49	0.94	1.01
Weedy check	5.28	7.78	6.96	12.21	12.05	23.34	24.29	43.33
LSD (p=0.05)	1.05	1.79	0.43	0.88	0.31	1.02	1.79	1.76

Table 5. Effect of different weed control treatments on different weed indices and economics of summer groundnut (pooled analysis)

Treatment	WCE (%)		WPI		HEI	CRI	Weed index (%)	WMI	Total cost (x10^3 `/ha)	Gross return (x10^3 `/ha)	Net return (x10^3 `/ha)
	20 DAS	40 DAS	20 DAS	40 DAS							
Pendimethalin 1.5 kg/ha PE *fb* 1 HW at 20 DAS	69.7	79.6	0.14	0.06	0.66	4.14	8.82	0.36	34.02	84.52	50.51
Pendimethalin 1.5 kg/ha PE *fb* quizalofop-p-ethyl 50 g/ha PoE at 20 DAS	71.2	78.0	0.16	0.07	0.73	4.53	7.47	0.38	32.67	85.77	53.10
Pendimethalin 1.5 kg/ha PE *fb* imazethapyr 75 g/ha PoE at 20 DAS	77.5	87.1	0.11	0.04	0.97	5.91	6.56	0.36	32.67	86.56	53.90
Hand weeding twice (at 20 and 40 DAS)	74.2	83.2	0.15	0.05	0.82	5.13	7.40	0.36	35.67	85.79	50.12
Weed free check	96.1	97.7	0.00	0.00	6.99	35.91	0.00	0.39	36.77	92.64	52.87
Weedy check	0.0	0.0	1.00	1.00	0.00	1.00	27.05	-	31.20	67.48	36.28

pod yield but the profit margin was reduced due to higher wages spent on human labour. Similarly weed free and hand weeding twice also reduced the net return and BCR because of higher wages of human labour. Similar results were reported by Sheoran *et al.* (2015).

Conclusion

Pendimethalin PE *fb* imazethapyr PoE was very effective in managing different categories of weeds and also recording higher groundnut pod yield, net return and BCR. The next best treatment was pendimethalin PE *fb* quizalofop-p-ethyl PoE. Thus, it can be concluded that pendimethalin PE *fb* imazethapyr PoE is most effective for timely control of weeds and produce the higher pod yield and maximum profit in summer groundnut while reducing the labour requirement and cost for weeding.

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Effective and profitable weed management in rainy season groundnut grown under arid zone of Rajasthan

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ABSTRACT

A field study was conducted under arid climatic conditions at Agricultural Research Station, Mandor, Jodhpur, Rajasthan, India, during rainy season (*Kharif*) of 2018, 2019 and 2020. The aim of this study was to identify effective and profitable weed management practices in groundnut for managing weeds and improve groundnut productivity. The weed density and biomass were reduced significantly with hand weeding twice at 20 and 40 days after sowing (DAS). Next best treatment was pendimethalin 30 EC + imazethapyr 2 EC (ready mix) 1.0 kg/ha pre-emergence application (PE) followed by (*fb*) manual weeding at 30 DAS. The highest weed control efficiency (87.48%) and herbicide efficiency index (4.66%) were also recorded with manual weeding twice at 20 and 40 DAS. Next best treatment was pendimethalin + imazethapyr (ready mix) 1.0 kg/ha PE *fb* manual weeding at 30 DAS in terms of lower weed density and biomass, higher weed control efficiency and herbicide efficiency index. The groundnut pod (2.12 t/ha) and haulm yield (3.89 t/ha) were highest with manual weeding twice at 20-40 DAS. All the weed management treatments did not influence the oil content. The highest net returns (₹ 36033 /ha) and B: C ratio (1.57) were obtained with pendimethalin 1.0 kg/ha PE *fb* imazethapyr 75 g/ha post-emergence application (PoE) at 20 DAS.

INTRODUCTION

Groundnut (*Arachis hypogaea* L.) is an important oilseed crop of India. It is second most important source of vegetable oil in the world (Guchi 2015). In India, groundnut was cultivated in about 4.9-million-hectare area during 2019-20 with a total production of 10.1 million tonnes and average productivity of 2.06 tonnes per hectare (Government of India 2021). Yield loss in groundnut due to weed infestation ranged from 74 to 92% (Jat *et al.* 2011). Critical period for crop-weed competition in groundnut was reported up to 40-60 DAS and weed free environment during this period registered higher pod yield (Geetha *et al.* 2017). The initial growth (generally 6 weeks) of groundnut and its inter row area covering by its canopy is relatively slow which facilitates maximum weed growth and making weeds strongly compete with the crop causing significant reduction in groundnut yield (Shanwad *et al.* 2011). Besides, weeds compete for growth resources (underground space, water, nutrient and light) with the crop, hinder pegging, pod development and make harvesting of groundnut cumbersome (Regar 2017). Hand weeding is an effective method but it is more laborious and expensive (Kalhapure *et al.* 2013, Rao and Chauhan 2015). Chemical control method is quick, more efficient, time and labour-saving method (Kumar 2009). However, there are some harmful effects including the environmental pollutions, animal and human risks as well as impacts on non-target organisms. Selective herbicides control limited weed species but may not be useful on complex of weed flora. The pre-emergence herbicides application (PE) may control weeds for a limited period and late emerging weeds escape from PE, which may need application of post-emergence herbicides application (PoE). There is ample scope for managing weeds by herbicides integration with other weed management methods (Rao and Nagamani 2010, Yaduraju *et al.* 2015). Recently many pre-mix herbicides are available in the market which may be used for effective control of complex of weed flora associated with groundnut. Thus, the present study was conducted to identify effective and economically viable combinations of chemical and cultural methods of weed management for enhancing the groundnut productivity in the arid zone of Rajasthan.

MATERIALS AND METHODS

A field experiment was carried out during three consecutive rainy seasons (*Kharif*) of 2018, 2019 and 2020 at Agricultural Research Station, Mandor (Agriculture University, Jodhpur, Rajasthan, India) located at 26°15 to 26°45 N latitude, 73°E to 73°29 E longitude and 242.6 m above mean sea level. The climate of the area is sub-tropical which received an average annual rainfall of 350 mm. The maximum and minimum temperature was 39.7°C, 18.1°C; 40.8°C, 14.9°C and 39.7°C, 20.3°C during the crop growth in three consecutive years (**Figure 1**). The soil of experimental site was sandy loam in texture with pH 8.2, organic carbon 0.13, available nitrogen (174 kg/ha), phosphorus (22 kg/ha) and potassium (325 kg/ha). Groundnut variety *HNG-69* was sown on 30 June in 2018, 28 June in 2019 and 24 June in 2020. The seeds were sown manually by using 80 kg/ha seed rate with a row spacing of 30 cm and plant spacing of 10 cm. The crop duration was 143, 140 and 141 days during the three respective years of study.

There were nine treatments namely pendimethalin 1.0 kg/ha PE; pendimethalin 30 EC + imazethapyr 2 EC 1.0 kg/ha (ready-mix) PE; pendimethalin 1.0 kg/ha PE followed by (*fb*) quizalofop –p-ethyl 50 g/ha at 20 days after seeding (DAS); pendimethalin 30 EC + imazethapyr 2 EC 1.0 kg/ha (ready-mix) PE *fb* quizalofop –p-ethyl 50 g/ha at 20 DAS; pendimethalin 1.0 kg/ha PE *fb* imazethapyr 75 g/ha at 20 DAS; pendimethalin 1.0 kg/ha PE *fb* manual weeding at 30 DAS; pendimethalin 30 EC + imazethapyr 2 EC 1.0 kg/ha (ready-mix) PE *fb* manual weeding at 30 DAS; manual weeding twice at 20 and 40 DAS and weedy check. The plot size of each treatment was 18 m^2 (5 x 3.6 m^2). The randomized block design with three replications was used. Herbicides were applied by using knapsack sprayer fitted with flat fan nozzle at spray volume of 500 L/ha. The recommended dose of fertilizers for groundnut was 15 kg N, 60 kg P and 250 kg gypsum/ha. The whole quantity of N and P was applied using urea and single superphosphate at the time of sowing of groundnut. Gypsum was applied in two equal splits, one at basal and another at the time of earthing up on 40 DAS. Plant protection measures, harvesting and other management practices were adopted according to standard recommendations. The observations on branches/plant and pods/plant were recorded manually for five randomly selected representative plants from each plot of each replication separately. The oil in groundnut was estimated by using Clevenger's apparatus (AOAC, 1990). Shelling percentage, weed control efficiency (WCE), weed index (WI), herbicide efficiency index and (HEI) was calculated by using the standard formula. Total weed density (number/m^2) and weed dry biomass (g/m^2) were recorded at harvest for each treatment by using a quadrat of 0.5 x 0.5 m (0.25 m^2) size and expressed as number or g/m^2. Data on weed density and biomass were transformed using ($\sqrt{(x+0.5)}$ for comparison among treatments. The experimental data recorded in various observations were statistically analyzed in accordance with the 'Analysis of Variance' technique as described by Panse and Sukhatme (1985). The least significant difference (LSD) was calculated for the comparison among treatments where ever the variance ratio (F test) was found significant at 5% level of probability. To elucidate the nature and magnitude of treatments effects, summary tables with LSD ($p<0.05$) were prepared.

RESULTS AND DISCUSSION

Effect of weed management treatments on weeds

Weed flora in the experimental field consisted of grassy weeds: *Cynodon dactylon*, *Dactyloctenium aegyptium* and *Eragrostis minor;* broad-leaved weeds: *Amaranthus viridis*, *Celosia argentea*, *Chorchorus trilocularis*, *Digera arvensis*, *Phyllanthus niruri*, *Portulaca oleracea* and *Tribulu sterristris*. *Cyperus rotundus and Cyprus esculentus* were dominant sedge weeds during all the three years of experimentation. However, broad-leaved weeds were dominant over grassy and sedge weeds.

The weedy check treatment had the highest weed density and biomass, weed index and lowest WCE and HEI (**Table 1**). The hand-weeding twice at 20 and 40 DAS recorded significantly lowest weed density and was at par with pendimethalin + imazethapyr (ready-mix) 1.0 kg/ha PE *fb* manual weeding at 30 DAS. On pooled data basis, hand-weeding twice at 20 and 40 DAS has reduced weed density at harvest by 87.9 % as compare to the weedy check. Among herbicide treatments, integration of manual weeding at 30 DAS integrated with pendimethalin + imazethapyr (ready-mix) 1.0 kg/ha PE reduced weed density at harvest stage by 85.42 % in comparison with weedy check plot (**Table 1**). Similar pattern was also observed with weed biomass. Lower weed biomass (29.3 g/m^2) was recorded with pendimethalin + imazethapyr (ready-mix) 1.0 kg/ha PE manual weeding at 30 DAS. The biomass in this effective treatment was 85.24, 56.52 and 38.18 % lower than that recorded with weedy check, pendimethalin 1.0 kg/ha PE, pendimethalin +

imazethapyr 1.0 kg/ha (ready-mix) PE and was at par to pendimethalin 1.0 kg/ha PE *fb* manual weeding at 30 DAS (**Table 1**). Venkateshwara *et al.* (2020) also observed significantly lower weed density and biomass with pendimethalin + imazethapyr (ready-mix) 1.0 kg/ha PE *fb* manual weeding at 30 DAS.

The highest WCE and HEI were achieved in manual weeding twice at 20-40 DAS (87.48% and 4.66). The next best was pendimethalin + imazethapyr (ready-mix) 1.0 kg/ha PE *fb* manual weeding at 30 DAS (85.24 and 3.85%), pendimethalin 1.0 kg/ha PE *fb* manual weeding at 30 DAS (83.60% and 3.40) and pendimethalin 1.0 kg/ha PE *fb* imazethapyr 75 g/ha at 20 DAS (82.34% and 3.12) (**Table 1**). These results were in agreement with Parthipan (2020). The pendimethalin + imazethapyr (ready-mix) 1.0 kg/ha PRE resulted in better control of grasses, sedges and broad-leaved weeds by inhibiting weeds root and shoot growth resulting in less crop-weed competition during early stages of the crop growth and later the weed growth was checked by manual weeding at 25-30 DAS. Pawar *et al.* (2018) reported that pendimethalin 1.5 kg/ha (PE) + imazethapyr 0.075 kg/ha at 20-30 DAS was found effective in controlling weeds that shows higher weed control efficiency and lowest weed index.

Weed index is indirectly correlated to the decrease in yield due to higher weed density and biomass. Minimum reduction in pod yield of groundnut due to least weed competition was found in two hand-weeding at 20 and 40 DAS (0.00%). Next lowest weed index (3.99%) was with pendimethalin + imazethapyr 1.0 kg/ha (ready-mix) PE *fb* manual weeding at 30 DAS (3.78%), pendimethalin 1.0 kg/ha PE + manual weeding at 30 DAS (5.91%) and pendimethalin 1.0 kg/ha PE + imazethapyr 75 g/ha at 20 DAS (7.33%). These results were in agreement with findings of Regar *et al.* (2021) and Thorat *et al.* (2020). The treatment two hand-weeding at 20 and 40 DAS recorded minimum weed index which reflected that the lowest weed index results in highest yield of groundnut due lower weed crop competition. All the herbicides showed minimum value as compared to hand weeding twice at 20 and 40 DAS in context to herbicide efficiency index (HEI).

Effect on groundnut growth and yield parameters

All weed management treatments significantly increased the growth and yield parameters *viz.* branches/plant, number of pods/plant and seed index (g) (**Table 2**). The groundnut plant population was not affected by any of weed management treatments while it was significantly affected due to weeds in weedy check treatment. Maximum number of branches/plants was obtained with manual weeding twice at 20-40 DAS, which was at par with pendimethalin + imazethapyr (ready-mix) 1.0 kg/ha PE *fb* manual weeding at 30 DAS and pendimethalin 1.0 kg/ha PE *fb* manual weeding at 30 DAS. Application of pendimethalin + imazethapyr (ready-mix) 1.0 kg/ha PE *fb* manual weeding at 30 DAS caused significantly increased in number of branches/ plant by 12.30% over pendimethalin + imazethapyr 1.0 kg/ha (ready-mix) PE; 5.79% over pendimethalin 1.0 kg/ha PE *fb* imazethapyr 75 g/ha at 20 DAS and 46% over weedy check.

Significantly highest pods/plant was recorded with manual weeding twice at 20-40 DAS and it was at par with pendimethalin + imazethapyr (ready-mix)

Table 1. Effect of weed management treatments on weed density, weed biomass, weed control efficiency, weed index and herbicides efficiency index at harvest in *Kharif* groundnut (pooled data of three years).

Treatment	Weed density (no./m^2)	Weed biomass (g/m^2)	Weed control efficiency (%)	Weed index (%)	Herbicide efficiency index (%)
Pendimethalin 1.0 kg/ha pre-emergence (PE)	4.6 (21.3)	8.0 (67.4)	66.05	33.70	1.10
Pendimethalin 30 EC + imazethapyr (ready-mix) 1.0 kg/ha PE	3.8 (15.1)	6.7 (47.4)	76.15	18.15	2.06
Pendimethalin 1.0 kg/ha PE *fb* quizalofop-p-ethyl 50 g/ha at 20 DAS	4.3 (18.7)	7.6 (59.5)	70.03	29.02	1.38
Pendimethalin + imazethapyr (ready-mix) 1.0 kg/ha PE *fb* quizalofop-p-ethyl 50 g/ha at 20 DAS	3.6 (13.3)	6.4 (42.5)	78.62	14.18	2.41
Pendimethalin 1.0 kg/ha PE *fb* imazethapyr 75 g/ha at 20 DAS	3.1 (9.6)	5.8 (35.1)	82.34	7.33	3.12
Pendimethalin 1.0 kg/ha PE *fb* MW at 30 DAS	2.9 (8.6)	5.6 (32.6)	83.60	5.91	3.40
Pendimethalin + imazethapyr 1.0 kg/ha PE *fb* MW at 30 DAS	2.6 (7.2)	5.3 (29.3)	85.24	3.78	3.85
Manual weeding (MW) twice at 20-40 DAS	2.4 (6.0)	4.9 (24.9)	87.48	0.00	4.66
Weedy check	6.9 (49.4)	13.8 (198.6)	-	58.46	0.00
LSD (p=0.05)	0.26	0.40			

LSD, least significant difference at the 5% level of significance; DAS-days after sowing; the figures in parentheses are original values of weed density and weed dry weight transformed to square root transformation.

1.0 kg/ha PE *fb* manual weeding at 30 DAS, pendimethalin 1.0 kg/ha PE *fb* manual weeding at 30 DAS and pendimethalin 1.0 kg/ha PE *fb* imazethapyr 75 g/ha at 20 DAS (**Table 2**). Weed-free environment created by these treatments facilitated better plant growth and development, flowering, peg initiation and entry into the soil, pod formation and development which lead to increase number of mature pods/plant (Manickam *et al.* 2000, Mishra *et al.* 2020).

Highest seed index was recorded with manual weeding twice at 20-40 DAS (44.1 g) and pendimethalin + imazethapyr 1.0 kg/ha (ready-mix) PE *fb* manual weeding at 25-30 DAS **(**43.6 g**)**. This is might be due to better control of weeds from the initial stage by pendimethalin + imazethapyr (ready-mix) 1.0 kg/ha PE *fb* hand-weeding at 30 DAS as evident by less weed density and biomass. The timely and effective control of weeds is expected to have better availability of moisture, nutrients and solar radiation to the crop plants, thereby increasing total chlorophyll content, photosynthetic rate and nitrate reductase activity (Suseendran *et al.* 2019), resulting to higher rate of supply of carbohydrates which leading to higher increase in growth parameters. Lower weed density also provides ample space for growth of root and nodulation in groundnut (Devi Dayal 2004).

Effect on groundnut pod yield, haulm yield, shelling% and oil content

The yield and shelling% of groundnut significantly influenced by different weed management treatments (**Table 2 and 3**). The application of pendimethalin 1.0 kg/ha PE + imazethapyr 75 g/ha at 20 DAS increased the pod yield by 123.1% over weedy check. However, it was at par with pendimethalin 1.0 kg/ha PE *fb* manual weeding at 30 DAS and pendimethalin + imazethapyr (ready-mix) 1.0 kg/ha PE *fb* manual weeding at 30 DAS. These results were in conformity with findings of Sharma *et al.* (2015), Parthipan (2020) and Mathukia *et al.* (2017).

Highest shelling percentage and haulm yield were recorded with two manual weeding at 20-40 DAS (followed by pendimethalin + imazethapyr

Table 2. Effect of weed management practices on plant growth, yield attributes, shelling and oil content of *Kharif* groundnut (pooled data of three years).

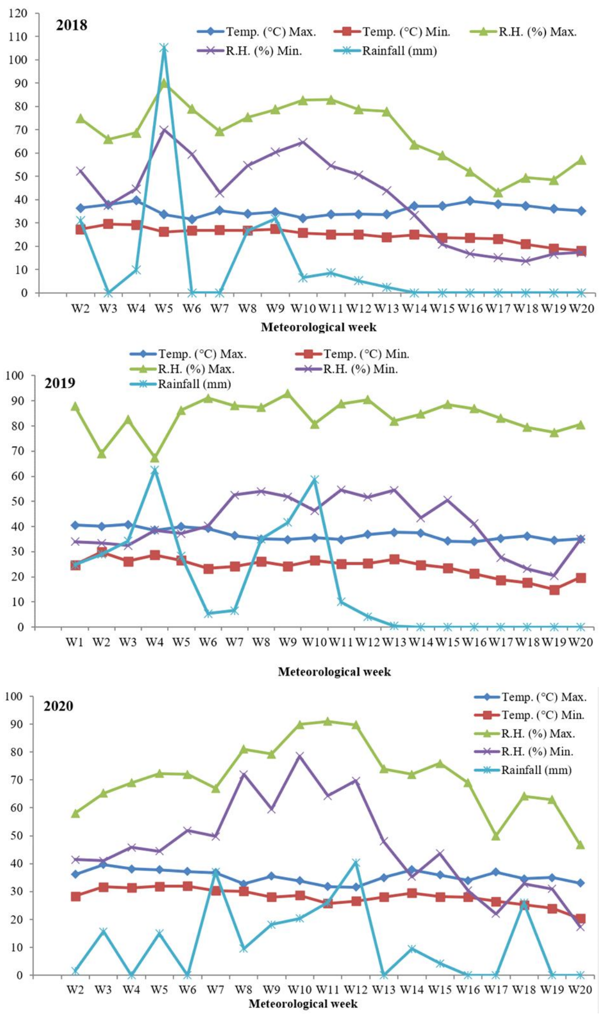
Treatment	Final plant population (000/ha)	Branches /plant	Pods/ plant	Seed index (g)	Shelling (%)	Oil content (%)
Pendimethalin 1.0 kg/ha pre-emergence (PE)	295.1	6.3	14.2	41.5	69.2	48.3
Pendimethalin 30 EC + imazethapyr (ready-mix) 1.0 kg/ha PE	298.8	6.5	16.4	42.1	70.3	48.3
Pendimethalin 1.0 kg/ha PE *fb* quizalofop-p-ethyl 50 g/ha at 20 DAS	306.9	6.4	14.8	42.0	69.4	48.1
Pendimethalin + imazethapyr 1.0 kg/ha PE *fb* quizalofop-p-ethyl 50 g/ha at 20 DAS	305.5	6.8	17.0	42.4	70.2	47.2
Pendimethalin 1.0 kg/ha PE *fb* imazethapyr 75 g/ha at 20 DAS	296.9	6.9	17.8	42.6	71.0	47.3
Pendimethalin 1.0 kg/ha PE *fb* MW at 30 DAS	296.6	7.2	18.7	43.2	70.5	48.5
Pendimethalin + imazethapyr 1.0 kg/ha PE *fb* MW at 30 DAS	308.4	7.3	19.3	43.6	71.6	47.2
Manual weeding (MW) twice at 20-40 DAS	292.9	7.4	20.0	44.1	72.7	47.3
Weedy check	246.1	5.0	11.2	40.7	67.6	47.7
LSD (p=0.05)	15.9	0.3	0.95	1.4	-	-

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

Table 3. Effect of weed management practices on pod yield and haulm yield of *Kharif* groundnut

Treatment	Pod yield (t/ha)				Haulm yield (t/ha)			
	2018	2019	2020	Pooled	2018	2019	2020	Pooled
Pendimethalin 1.0 kg/ha pre-emergence (PE)	1.44	1.52	1.25	1.40	2.92	3.36	2.59	2.95
Pendimethalin 30 EC + imazethapyr (ready-mix) 1.0 kg/ha PE	1.60	2.05	1.54	1.73	3.19	3.60	3.04	3.27
Pendimethalin 1.0 kg/ha PE *fb* quizalofop-p-ethyl 50 g/ha at 20 DAS	1.58	1.62	1.31	1.50	3.13	3.30	2.64	3.02
Pendimethalin + imazethapyr 1.0 kg/ha PE *fb* quizalofop-p-ethyl 50 g/ha at 20 DAS	1.70	2.09	1.67	1.82	3.32	4.11	3.00	3.48
Pendimethalin 1.0 kg/ha PE *fb* imazethapyr 75 g/ha at 20 DAS	1.73	2.44	1.71	1.96	3.45	4.54	3.05	3.68
Pendimethalin 1.0 kg/ha PE *fb* MW at 30 DAS	1.77	2.46	1.74	1.99	3.40	4.55	3.13	3.70
Pendimethalin + imazethapyr 1.0 kg/ha PE *fb* MW at 30 DAS	1.81	2.50	1.80	2.04	3.30	4.64	3.24	3.73
Manual weeding (MW) twice at 20-40 DAS	1.85	2.64	1.86	2.12	3.34	4.91	3.40	3.89
Weedy check	0.84	1.04	0.76	0.88	1.79	2.25	1.84	1.97
LSD (p=0.05)	0.21	0.24	0.26	0.094	0.44	0.63	0.39	0.19

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



W_1: June 18 - June 24; W_2: June 25 - July 1; W_3: July 2-8; W_4: July 9-15; W_5: July 16-22; W_6: July 23-29; W_7: July 30 - August 5; W_8: August 6-12; W_9: August 13-19; W_{10}: August 20-26; W_{11}: August 27- September 2; W_{12}: September 3-9; W_{13}: September 10-16; W_{14}: September 17-23; W_{15}: September 24-30; W_{16}: October 1-7; W_{17}: October 8-14; W_{18}: October 15-21; W_{19}: October 22-28; W_{20}: October 29-November 4

Figure 1. Weather parameters of *Kharif* season during three consecutive years (2018, 2019 and 2020)

(ready-mix) 1.0 kg/ha PE *fb* manual weeding at 30 DAS in pooled data (**Table 2 and Table 3**). Similar observations were made by Kumar *et al.* (2013). Oil content in kernel was not influenced by different weed-management practices (**Table 2**) as reported by Adhikary *et al.* (2016). However, the per cent increase in oil content was found higher in case of pendimethalin 1.0 kg/ha PE *fb* manual weeding at 30 DAS as compared to other treatments.

Economics

All the weed management treatments recorded higher net returns and B:C ratio than weedy check (**Table 4**). Among herbicide-based treatments, higher net returns (₹ 36,033 /ha) and B:C (1.57) ratio was recorded with pendimethalin 1.0 kg/ha PE *fb* imazethapyr 75 g/ha at 20 DAS. Next best was pendimethalin + imazethapyr (ready-mix) 1.0 kg/ha PE *fb* manual weeding at 30 DAS (₹ 34,435 /ha and 1.50) on pooled basis. This was due to higher pod yield and minimum cost of cultivation of groundnut crop than two manual weeding at 20-40 DAS whose cost of cultivation was more due to the higher human labour involved and their higher wages cost. The cost was reduced in herbicidal treatments which gave effective control of weeds while minimizing human labours use. Parthipan (2020) also reported the effective weed management and improved returns in groundnut with pendimethalin + imazethapyr (ready-mix) 1.0 kg/ha as PE *fb* hand weeding at 30 DAS.

It was concluded that pre-emergence application of pendimethalin 1.0 kg/ha followed by imazethapyr 75 g/ha at 20 DAS could be adopted for effective and economic management of weeds with higher productivity of groundnut in arid climatic conditions of Rajasthan.

Table 4. Effect of weed management practices on economics of *Kharif* groundnut (pooled data of three years)

Treatment	Gross returns ($x10^3$ ₹/ha)	Net returns ($x10^3$ ₹/ha)	B:C Ratio
Pendimethalin 1.0 kg/ha pre-emergence (PE)	71.26	10.53	1.17
Pendimethalin 30 EC + imazethapyr (ready-mix) 1.0 kg/ha PE	88.04	26.77	1.44
Pendimethalin 1.0 kg/ha PE *fb* quizalofop-p-ethyl 50 g/ha at 20 DAS	76.23	14.40	1.23
Pendimethalin + imazethapyr 1.0 kg/ha PE *fb* quizalofop-p-ethyl 50 g/ha at 20 DAS	92.38	30.01	1.48
Pendimethalin 1.0 kg/ha PE *fb* imazethapyr 75 g/ha at 20 DAS	99.74	36.03	1.57
Pendimethalin 1.0 kg/ha PE *fb* MW at 30 DAS	101.25	32.67	1.48
Pendimethalin + imazethapyr 1.0 kg/ha PE *fb* MW at 30 DAS	103.56	34.44	1.50
Manual weeding (MW) twice at 20-40 DAS	107.65	34.78	1.48
Weedy check	44.66	-14.11	0.76
LSD (p=0.05)	4.81	-	-

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

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Rice straw mulch mats – biodegradable alternative to herbicides in papaya

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ABSTRACT

Rice occupies a pivotal place in Indian agriculture. Its production leads to generation of excessive rice straw. Since straw is not utilized much, it is subjected to burning in fields causing serious environmental pollution, loss of nutrients and adverse effects on beneficial soil micro-organisms. This study conducted in Punjab Agricultural University, Ludhiana reports the effectiveness of rice straw mulching material on weed control, yield enhancement and quality improvement in Papaya (Var. *Red lady 786*). Woven mulch mats of rice straw resulted in significant reduction in weed density of broad-leaved weeds as well as grasses as compared to control besides improving fruit height (26.3%), fruit yield (31.7%), fruit colour, TSS and carotenoids in papaya. Furthermore, the biodegradable woven mulch has the capability to control weeds for 315 days *i.e.* the entire vegetative as well as fruiting period in papaya.

INTRODUCTION

In India, 50% population is engaged in farming and cultivation of agricultural products. The production of millions of tons of agricultural crop every year has subsequently increased the agricultural waste that we as a country are dealing with right now. The waste, commonly known as 'the residue' is made up of organic compounds from various organic sources like rice straw, coconut shell, sugarcane bagasse to name a few. Since the residue accumulates in large amount, it becomes extremely difficult for farmers to have an alternative access. In the process of harvesting, a humongous quantity of straw/husk is also generated which needs to be recycled in a sustainable way. The easiest way used by the farmers to dispose the remains of rice is incinerating it in the fields, which eventually pollutes the environment and cause huge loss of nutrients. Various studies have shown that incinerating stubble in the fields has been found to be a major hazard. It causes air pollution and adversely affects the organic carbon levels of soil. In northern states of the country, increase in intensity of air pollutants is found to be 20% higher than the threshold for safe air (Anonymous 2019).

Removal of stubble by burning has negative implication on soil health. The nutrients present in the stubble are exhausted while burning and farmers have to shell out extra monetarily on chemical and fertilizers to maintain soil quality. A study (Jitendra *et al* 2017) has quantified that crop residue burning in India releases approximately 149.24 million tonnes of carbon dioxide, 9 million tonnes of carbon monoxide, 0.25 million tonnes of oxides of sulphur, 1.28 million tonnes of particulate matter and 0.07 million tonnes of black carbon. These directly contribute to environmental pollution, and are also responsible for the smog in plain areas. The heat from burning of rice straw penetrates one cm into the soil, elevating the temperature to 33.8 to 42.2 degree Celsius. This kills the bacterial and fungal populations critical for a fertile soil. Burning of crop residue causes damage to other micro-organisms present in the upper layer of the soil as well as its organic quality.

We also need to understand that the burning of rice or stubble leads to the loss of key nutrients as nearly 50% sulphur, 75% potassium and 25% of the nitrogen and phosphorus is lost (Anonymous 2019). As such, stubble burning is a serious issue and it must be managed with immediate effect by opting other potential alternatives.

Solutions to the burning problem

The issue of stubble burning can be forfeited by providing stubble collecting machines (bailers) to the farmers or offering reasonable labour to reap rice. Converting stubble into mulch sheets is another innovative and environment friendly way to address the issue besides exploring its use for weed management in papaya and other fruit tress/ vegetables.

Papaya (*Carica papaya* L.) belongs to family Caricaceae and native of Mexico. Papaya is mainly grown as kitchen garden plant, but due to its nutritional importance, availability of fruits all around the year and the highest returns, it is being commercialized. Papayas are good source of vitamin A and calcium. The papaya fruits also provide folate, potassium, magnesium, copper, pantothenic acid, alpha and beta-carotene, zeaxanthin, lutein, vitamin K, and lycopenes. So, there is vast scope to increase area and production under papaya crop. The major papaya producing states in India are Andhra Pradesh (27.1%), Gujarat (23.2%), Maharashtra (7.6%), Karnataka (10.5%), Madhya Pradesh (5.4%), West Bengal (7.7%) and Assam (3.2%) due to ideal climatic conditions for its growth and production (Anonymous 2010, Suresh and Saha 2004).

Weed control is a big challenge for most of the crops, and papaya is also not an exception. Regular and frequent cultivation of the orchards destroys the physical condition of the soil, increases runoff and soil erosion besides escalating cost of cultivation. It also leads to development of *Phytophthora* disease (Thind 2017). Manual and chemical weed control is expensive, laborious and time consuming (Thakur *et al.* 2012). There is huge pressure to reduce the use of herbicides in horticultural as well as other field crops. So, there is an urgent need to shift towards organic options for weed suppression in fruit crops. Among all the non-chemical methods of weed control, use of mulches helps to reduce weed infestation, maintains soil temperature, improves soil aeration and conservation of soil moisture and increase the soil fertility by addition of organic matter in orchards (Yao *et al.* 2005). Therefore, it was hypothesized that woven mulch mats of rice straw could be effective to manage weeds, enhances fruit yield and quality of papaya.

MATERIALS AND METHODS

Mulch mats of rice straw were developed in the Department of Apparel and Textile Science, Punjab Agricultural University, Ludhiana, (Kaur *et al.* 2020) with three variants of mulching and positioned in papaya orchard for weed management. Traditional *Adda* weaving technique was used to develop the woven mulch mats by using cotton yarn as warp and rice straw as weft. Paper making technique was used for developing non-woven mulch mats with 100% rice straw. Approximately 3- 3.5 kg of rice straw was used to prepare mulch mats of size of 70"x 40" which costed around ` 175/-. To study the effectiveness of these bio-degradable mulch mats, the experiment was conducted in collaboration with Department of Fruit Science at Fruit Research Farm, Punjab Agricultural University, Ludhiana, India during 2018-19 and 2019-20. The experimental area was situated in trans-gangetic agro-climatic zone, representing the Indo-Gangetic alluvial plains at 30^o 56' N latitude, 75^o 52' E longitude and at an altitude of 247 m above mean sea level. The region is characterized as sub-tropical semi- arid with hot summer and very cold winters. As papaya cv. *Red lady 786* is highly susceptible to the attack of pathogens, the experiment was conducted under well ventilated protected net house structure having 625 m^2 area of 25 m length, 25 m width and 4.5 m height. All sides of this net house were covered with 40 mesh insect net to protect crop against *'papaya ring spot virus'* disease. This net house was constructed with galvanized iron (GI) pipes entrenched in concrete pedestal structure.

The soil condition of papaya block at PAU, Ludhiana by the start and termination of experiment was sandy loam in texture, pH 8.1 and 8.0, organic carbon 0.24 and 0.26%, $CaCO_3$ 1%, electrical conductivity 0.20 mmho/cm, available phosphorous 20.1 and 20.4 kg/ha and potash 162.4 and 163.2 kg/ha, respectively. The seeds of papaya *cv. Red lady 786* were sown in 150 gauge thick transparent polythene bags (25 x 10 cm) containing solarized soil, sand and farmyard manure in equal proportions. Before sowing, the seeds of papaya *cv. Red lady 786* were treated with Captan 3 g/kg seed to avoid damping off of seedlings. The seedlings were transplanted after attaining a height of 15 cm above the ground level according to square system of planting at a density of 1.8 x 1.8 m under protected net house in the month of March 2018 and 2019. Three treatments of mulch materials included, woven mulch mats, non-woven mulch mats (both approximately 1cm thick) and loose rice straw 10.5 t/ha (6 cm thick) were placed after one week of transplanting papaya seedlings and compared with non- mulching area (control). Ten trees planted at 1.8 x 1.8 m covering an area of 32.4 m^2 (plot size 3.6 x 9.0 m) represented one replication. The experiment was laid out in randomized block design (RBD) with four treatments and five replications. Uniform cultural practices were followed in the whole experimental area. Soil application of fertilizers with 172.5 g nitrogen, 125 g phosphorous and 75g potassium each per plant were supplemented twice through urea, single super phosphate and muriate of potash, respectively, in February and August during both the years. Irrigation in the whole experimental block was done by the use of online drippers with a discharge frequency of 4 liters per hour. Water capacity was assessed according to pan evaporative value on daily basis.

The data on the efficacy of mulching material against weeds were recorded at an interval of 45 days starting from transplanting to harvesting of Papaya. The data on weed density was recorded from five quadrats in each plot of size 15 x 15 cm, at an interval of 45 days from transplanting of Papaya seedlings up to the fruit maturity (approximately 315 days) and expressed as number of weed plants/m^2. The data on broad-leaved weeds, grasses and sedges was taken according to *Rabi* and *Kharif* season weeds. Weed biomass was recorded by weighing above ground dry weight of weeds (oven-dried at 60±2°C for 72 hours) at the time of fruit maturity and expressed as g/m^2. The weed control efficiency (WCE) was also calculated based on dry weight of weeds.

The physico-chemical attributes of papaya fruits were recorded at the end of harvest. For this, 20 papaya fruits were analyzed per treatment with three replications. Plant height was measured with a measuring pole from the ground level to the top of the tree and expressed in meters. Weight of 20 papaya fruits was recorded with the help of digital weighing balance. Individual fruit weight was calculated and expressed in kilograms per fruit. Total number of fruits per tree was counted as fruit number. Fruit number multiplied with mean fruit weight was accounted as fruit yield and given as kg/tree. Titratable acidity was described in percentage of citric acid by using N/10 NaOH and phenol phthalein as indicator. The content of total carotenoids in the extract was determined by measuring the optical density of diluted sample. DPPH Radical Scavenging Activity was used to estimate Antioxidant Activity. The percentage of inhibition was calculated against blank: where, A blank is the absorbance of the control reaction (containing all reagents except the test compound) and A sample is the absorbance of the test compound.

$$I\% = \frac{\text{A blank - A sample}}{\text{A blank}}$$

The CIE lab values were examined, in which L measures lightness and it varies from 100 for perfect whiteness and zero for perfect black. The chromacity dimensions (a and b) give understandable designations of the colour as a- measures of redness when positive, grey when zero and greenness when negative; b- measures yellowness when positive, grey when zero and blueness when negative. The data were analyzed with SPSS version 22.0 (SPSS Inc., Chicago, Illinois) and significant differences (P = 0.05) between individual means were analyzed for analysis of variance (ANOVA) and subjected to mean comparison by using Duncan multiple range test.

RESULTS AND DISCUSSION

Weed flora

During this investigation, *Chenopodium album, Oxalis corniculata, Gnaphalium purpureum, Rumex dentatus, Coronopus didymus, Launea asplenifolia, Phyllanthus niruri, Cyperus rotundus, Digitaria sanguinalis, Panicum colonum, Cynodon dactylon, Acrachne racemosa* and *Eragrostis tenella* were the different weeds documented at the experimental location. In India, presence of weeds in the field crops resulted in 45% produce loss (Rao 1983). In horticultural crops, the yield losses due to the weeds were reported from 34.0 to 71.7% (Leela 1993). This loss varies according to the nature of diverse weed flora and fruit crops (Abouziena *et al.* 2016). Weeds have competition along with the orchard crops for nutrients, water and they also act as alternate host for incidence of insects and diseases (Futch and Singh 2011). Weed roots also secrete toxins, adversely affecting the vegetative growth and causes loss in yield and quality of fruits (Singh 2000). Weed competition causes a negative impact on the trunk diameter, leaf weight and metabolism in apples (Merwin and Stiles 2016). Therefore, the weed management is a major challenge for the fruit growers especially for papaya growers as it being shallow rooted crop could encounter herbicidal phytotoxicity.

Weed control

In papaya orchard, woven mulch mats resulted in significant reduction in weed density as compared to non- woven mulch mats, loose rice straw and control (**Table 1**). The life span of woven mulch mats has been recorded as one year in the experimental area and the decomposition of the woven mulch mats started thereafter. As papaya has a short span of 11 months, these woven mulch mats were found effective to control the weeds starting from the transplanting of crop up to the fruit harvest period under the protected structure. These woven mulch mats acted as surface barrier to control broad-leaved weeds and sedges (**Table 2**) and also grasses (**Table 3**) for the entire vegetative growth period and fruiting season. Non-woven mulch mats and loose rice straw also proved to be significantly effective to control the diverse weed flora as compared to control (bare soil). However, both of these have to be replaced after a period of 140 days from transplanting of the papaya crop due to their decomposition. No significant difference was recorded between non- woven mulch mat and loose rice straw against weeds as well as for their time of decomposition in papaya orchard field.

Table 1. Effect of woven mulch mats on total weed density at different stages in papaya (pooled data of 2018-19 and 2019-20)

Treatment	Weed density (no./m^2)						
	45 Day	90 Day	135 Day	180 Day	225 Day	270 Day	315 Day
Woven mulch mats	1.39 (1)	1.99 (3)	2.23 (4)	2.23 (4)	2.23 (4)	2.45 (5)	2.31 (4)
Non -woven mulch mats	3.60 (12)	3.99 (15)	4.12 (16)	4.24 (17)	4.24 (17)	4.36 (18)	4.40 (18)
Loose rice straw	3.74 (13)	3.87 (14)	4.12 (16)	4.35(18)	4.47 (19)	4.69 (21)	4.38 (18)
Control	9.38 (87)	11.04 (121)	11.53 (132)	12.08 (145)	12.37 (152)	12.41 (153)	10.00 (99)
LSD (p=0.05)	0.24	0.24	0.18	0.21	0.21	0.2	0.41

Original data given in parenthesis was subjected to square root ($\sqrt{x+1}$) transformation before subjecting to statistical analysis

Table 2. Effect of woven mulch mats on weed density of broad leaf weeds and sedges, and total dry matter after 315 days of planting in papaya ((pooled data of 2018-19 and 2019-20)

Treatment	Weed density (no./m^2)								Total weed biomass (g/m^2)
	Broad-leaved weeds							Sedge	
	Chenopodium album	*Oxalis corniculata*	*Gnaphalium purpureum*	*Rumex dentatus*	*Coronopus didymus*	*Launaea asplenifolia*	*Phyllanthus niruri*	*Cyperus rotundus*	
Woven mulch mats	1.0 (0)	1.0 (0)	1.0 (0)	1.0 (0)	1.0 (0)	1.0 (0)	1.72 (2)	1.72 (2)	1.32 (2.74)
Non-woven mulch mats	1.39 (1)	1.0 (0)	1.0 (0)	1.72 (2)	1.39 (1)	1.99 (3)	1.99 (3)	2.99 (8)	2.60 (5.78)
Loose rice Straw	1.39 (1)	1.39 (1)	1.41 (1)	2.23(4)	1.39 (1)	1.41 (1)	1.72 (2)	2.82 (7)	2.81 (6.91)
Control	3.0 (8)	2.64 (6)	2.23 (4)	3.31 (10)	3.31 (10)	3.99 (15)	4.12 (16)	5.57 (30)	7.70 (58.3)
LSD (p=0.05)	0.28	0.22	0.11	0.26	0.29	0.24	0.29	0.27	0.07

Original data given in parenthesis was subjected to square root ($\sqrt{x+1}$) transformation before subjecting to statistical analysis

Table 3. Effect of woven mulch mats on weed density of grasses in papaya (pooled data of 2018-19 and 2019-20)

Treatment	Weed density (grasses) (no./m^2)				
	Digitaria sanguinalis	*Panicum colonum*	*Cynodon dactylon*	*Acrachne racemosa*	*Eragrostis tenella*
Woven mulch mats	1.0 (0)	1.41 (1)	1.0 (0)	1.0 (0)	1.0 (0)
Non- woven mulch mats	1.41 (1)	1.39 (1)	1.39 (1)	1.0 (0)	1.41 (1)
Loose rice straw	1.72 (2)	1.39 (1)	1.39 (1)	1.39 (1)	1.39 (1)
Control	2.99 (8)	3.6 (12)	1.72 (2)	4.79 (22)	4.35 (18)
LSD (p=0.05)	0.16	0.33	0.30	0.23	0.23

Original data given in parenthesis was subjected to square root ($\sqrt{x+1}$) transformation before subjecting to statistical analysis

All the treatments reduced the total weed biomass as compared to control in papaya crop. Application of woven mulch mats resulted in minimum total weed biomass followed by non-woven mulch mats and loose rice straw mulch treatment up to 315 days of Papaya seedling transplanting (**Table 2**).

The results of a study by Huystteen and Weber (1980) revealed that the yield and quality of grapes was highest with the use of straw mulch in comparison to clean cultivation which led to significant competition for water and nutrients. Another study by Grieshop *et al.* (2012) suggested that wheat straw and spoiled hay were beneficial in reducing weeding time as compared to using wood mulches or using burlap sacks.

Biodegradable mulches can be used as an alternative to synthetic plastic mulches, which are used to improve soil moisture status along with providing weed control (Girgenti *et al.* 2012). If the ingredients of the mulch are permitted, use of such mulch could be desirable as it would not require its removal/ disposal. A study by Benoit *et al.* (2006) elicited that use of biodegradable cellulose mulch provided good weed control in the first year, but lasted only for one year and needed to be replaced for supplying ongoing weed control. Biodegradable manufactured mulches degrade through weathering, ultraviolet radiation exposure and microbial degradation. This material leads dead organic mulch, which enhances control of weeds by suppression and also by curtailing re-generation and subsequent germination in flushes. The maximum weed control efficiency (95.3%) was recorded with woven mulch mats followed by non-woven mulch mats in Papaya orchards (**Figure 1**).

Physico-chemical attributes

All the physico-chemical characters of the papaya plants improved significantly with woven mulch mats as compared to all other treatments (**Table 4**). Plant height increased significantly with woven mulch mats as compared to all other treatments. Fruit number/tree was recorded to be non- significant among different treatments. The weight of papaya fruits (26.3%) was significantly higher with woven mulch mats as compared to

Table 4. Effect of woven mulch mats on physical and biochemical attributes in papaya (pooled data of 2018-19 and 2019-20)

Treatment	Plant height (cm)	Fruit weight (kg/fruit)			Fruit number	Fruit yield (kg/tree)			TSS (^{0} brix)	Acidity (%)	Carote-noids (µg/g)	Antioxi-dants (%)
		2018-19	2019-20	Pooled		2018-19	2019-20	Pooled				
Woven mulch mats	289	1.23	1.27	1.25	48	57.81	62.23	60.0	11.0	0.67	10.79	89.92
Non- woven mulch mats	274	1.17	1.00	1.09	46	55.28	45.00	50.14	11.0	0.74	9.19	86.74
Rice straw mulch	266	1.10	1.06	1.08	45	48.40	48.76	48.60	9.5	0.79	7.36	86.11
Control	250	1.02	0.97	0.99	46	47.43	43.65	45.54	10.0	0.84	6.57	76.52
LSD (p=0.05)	14	0.09	0.13	0.09	NS	5.1 0	8.5 0	5.42	0.65	0.06	1.64	5.01

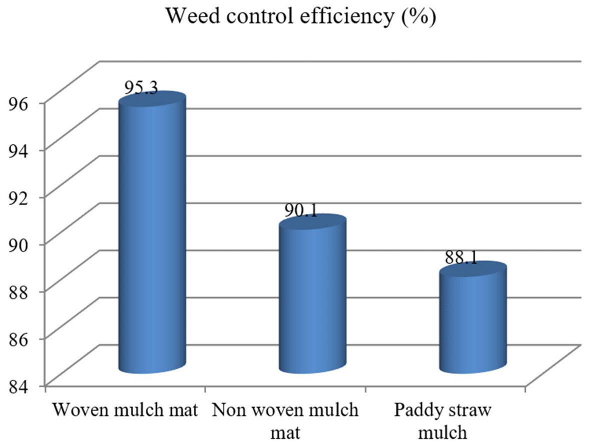

Figure 1. Weed control efficiency of different rice straw mulch treatments

control. Fruit yield (31.7%) also increased significantly with woven mulch mats as compared to control. The results are in agreement with Duppong *et al.* (2004) who also reported increase in yield of catnip by the use of flax straw mat (1.2 cm thickness) for weed management. TSS, carotenoids and antioxidants of papaya fruits were also improved significantly with woven mulch mats as compared to control. Whereas, acidity was recorded to be significantly lower with woven mulch mats as compared to control. It was found that the colour of the fruit was more appealing in case of woven and non-woven mulch mats as compared other two treatments (**Table 5**).

Rice straw mulch effectively controlled weeds in citrus groves (Abouziena *et al.* 2008) and weed free environment with negligible weed competition improved fruit yield and quality of *Kinnow* fruits. Tree productivity (weight of mandarin fruits per tree) was also improved as a result of effective weed control (Abouziena *et al.* 2008). The results indicated that the use of woven mulch mats at the time of transplanting of seedlings provided better and effective control of diverse weed flora in papaya orchard during the entire life span as compared to other treatments. Moreover, this treatment resulted in enhanced tree productivity in terms of fruit quality and quantity of papaya crop.

Table 5. CIE lab values of the papaya fruits

Treatment	L*	a*	b*
Woven mulch mats	50.22	35.35	47.09
Non-woven mulch mats	47.03	27.52	45.48
Rice Straw mulch	54.59	24.38	53.75
Control	57.56	24.31	56.87

L*measures lightness, a* is chromaticity dimension (red) and b* is chromaticity dimension (yellow)

Conclusion

It may be concluded that woven mulch mats might be popularized for effective weed control in papaya. Since rice burning has become a menace, utilizing rice straw for various purposes will not only help to curb this problem but will also help entrepreneurs to raise income for better livelihoods of rural population. This may also give impetus for developing R&D programmes suitable for small scale industries. Rice straw woven mulch effectively controlled weeds in papaya throughout its growing cycle and improved fruit yield and quality. Therefore, such an alternative should be encouraged in Papaya and other orchards as well.

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Weed management in garden cress (*Lepidium sativum* L.) in Rajasthan, India

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ABSTRACT

The field experiment was conducted during winter seasons *(Rabi)* of 2018-19 and 2019-20 at Agricultural Research Station, Navgaon (Alwar), S.K.N Agriculture University, Jobner, Jaipur (Rajasthan) India, to identify effective and economic weed management practices in standing Chandrashoor (*Lepidium sativum* Linn.) crop. The soil of experimental field was sandy loam in texture, low in organic carbon, low in available nitrogen, medium in phosphorus and potassium with alkali in pH. The experiment was laid out in a randomized block design with seven treatments and replicated thrice. The crop was sown as per the package of practices recommended for zone IIIB of Rajasthan. The treatments tested incudes: post-emergence application (PoE) of quizalofop-p-ethyl 50 g/ha, fenoxaprop-p-butyl 100 g/ha, imazethapyr 75 g/ha, imazethapyr (35%) + imazamox (35%) (ready-mix) 100 g/ha, imazethapyr (2%) + pendimethalin (30%) (ready-mix) 2.5 kg/ha; weedy check and weed free. The fenoxaprop-p-butyl 100g/ha PoE recorded significantly higher seed yield of 678 kg/ha in 2018-19 and 693 kg/ha in 2019-20 due to greater weed suppression and lowest weed index. It was at par with quizalofop-p-ethyl 50 g/ha PoE at 30 DAS. However, weed free, by hand weeding twice, recorded higher seed yield and was significantly superior economically over the rest of the weed management treatments.

INTRODUCTION

Chandrashoor (*Lepidium sativum* L.) is also known as asalio and garden cress and it belongs to family Brassicaceae. In India, the common names of garden cress seed include common cress (English), halim (Bengali), aseliyo (Gujrati), chansur (Hindi), allibija, kapila, (Kannada), alian (Kashmiri) asali (Malayalam), ahaliva, haliv (Marathi), allivirai (Tamil) and adityalu, aadalu (Telugu). There are diploid (2n=16) and tetraploid (2n=32) forms of chandrashoor. The species is a native of Ethiopia and is said to have been introduced to Europe and Asia. Chandrashoor seed has been used in curing many health-related complications by our ancients. Chandrashoor plant is erect, glabrous, annual, herbaceous growing up to the height of about 15–60 cm. It is propagated by seeds. It is a fast-growing crop that can be ready to eat within 7 days of sowing the seed. It is most commonly eaten in the seedling form.

The plant is the source of edible oil that can be used for lighting. It is grown in Ethiopia for the edible oil obtained from its seed. Chandrashoor is presently cultivated all over the world. It is considered as an important medicinal crop in India (Raval and Pandya 2011) and is mainly cultivated in U.P., Rajasthan, Gujarat, Maharashtra, and Madhya Pradesh (The Wealth of India, 1962) as winter crop for seeds. Chandrashoor seed has been used in curing many health-related complications by our ancients. It has been used in the treatment of many health problems such as hypertension, kidney diseases, prevention of cancer and mild glycemia. Chandrashoor seed are widely used to heal fractures. Its seed also possesses wide range of antioxidant. Fatty acids of chandrashoor seed oil helps in preventing coronary heart diseases. The chandrashoor seeds are galactagogue, laxative and diuretic. Seeds contain phyto-chemicals that resemble estrogen action. Hence it is used in treating amenorrhoea and irregular menstrual cycles. It is fed to lactating mothers for improving breast milk production. Seed paste is used as poultice to relieve pain, worm infestation in wounds and useful in skin disorders associated with itching. The mucilage obtained from the seeds is used against intestinal irritations. The leaves are used as diuretic and to treat liver diseases. It is also used as salad for treating anaemia (Ghante *et al.* 2011).

The recent studies on incidence of insect pests on medicinal plants are available (Sanjta and Chauhan 2018). But the research on weeds and weed management in medicinal plants is meagre even though it is well known that weeds compete with the medicinal crops for all the inputs which are given for the crop growth and play a significant role in reducing their productivity. The site with very heavy weed infestation in the fields was considered as a challenging site by National Medicinal Plant Board (NMPB 2015). NMPB (2009) suggested, for all the medicinal plants, ensuring a weed free environment to young plants by effectively controlling initial flush of weeds by under taking weeding and hoeing cycles. The weed free environment creation using manual weeding will be costly due to non-availability and increased cost of labour. Thus, herbicide usage for control of weeds was tested and proved successful in many crops. and is now gaining importance in Indian agriculture (Rao and Chauhan 2015). Chemical weed control is a better supplement to conventional methods and forms an integral part of the modern crop production (Rao and Nagamani 2010). Thus, use of herbicides is one of the options available with the farmers to eliminate crop weed competition at early growth stage of chandrashoor. Hence, the present study was carried out to identify effective and economic weed management practices in standing crop of chandrashoor.

MATERIALS AND METHODS

A field experiment was conducted during winter seasons *(Rabi)* of 2018-19 and 2019-20 at Agricultural Research Station, Navgaon (Alwar), S.K.N Agriculture University, Jobner, Jaipur (Rajasthan) India**.** The soil of experimental field was sandy loam in texture, low in organic carbon, low in available nitrogen, and medium in phosphorus and potassium with alkali in pH. The experiment was laid out in a randomized block design replicated thrice with eight treatments: quizalofop-p-ethyl 50 g/ha, fenoxaprop-p-butyl 100 g/ha, imazethapyr 75 g/ha, imazethapyr (35%) + imazamox (35%) (ready-mix) 100g/ha, imazethapyr (2%) + pendimethalin (30%) (ready-mix) 1.0 kg/ha as post-emergence application (PoE) at 30 DAS; weedy check and weed free by hand weeding twice. The crop was grown as per the package of practices recommended for zone IIIB of Rajasthan. The seeds were sown 8 kg/ha at 30 x 15 cm spacing at a depth of 5 cm below the soil surface. Chandrashoor, local selection was sown at the end of the October of two consecutive years with the fertilizer dose 80:60:40 kg/ha of N, P and K. The half dose of N and full dose of P and K was applied as basal and remaining dose of N was applied with first irrigation. Herbicides were sprayed with knapsack sprayer using flat fan nozzle with 600 liters of water/ ha. Weed density (number per square meter) recorded just before the execution of first-hand weeding or before the application of post-emergence herbicides during both years by using a quadrat of size 0.5 x 0.5 m (0.25 m^2). Weed dry matter (weed biomass) of all the weed species (grasses, broad-leaved weeds and sedges) was recorded just before the execution of first-hand weeding or before application of post-emergence herbicides within an area of quadrat of 0.5 x 0.5 m (0.25 m^2) were cut closed to ground surface, separated species wise and sun dried for first 4-5 days thereafter placed into an oven at $70 \pm 1\ ^{O}C$ temperatures till a constant weight was obtained. Later on, weed dry weight was measured by balance. The dry weight of weeds was expressed as weed biomass (g/m^2).

RESULTS AND DISCUSSION

Weed flora

The weed flora in the experimental field consisted of grasses: *Cynodon dactylon, Asphodelus tenuifolius, Phalaris minor, Spergula arvensis;* sedge: *Cyperus rotundus* and broad-leaved weeds: *Chenopodium murale, Chenopodium album, Melilotus indica, Anagallis arvensis, Pluchea lanceolata, Convolvulus arvensis, Phyllanthus niruri, Cirsium arvense, Launaea asplenifolia, Coronopus didymus, Rumex dentatus*. The weed flora was more pronounced during second year of study due to adequate soil moisture.

The herbicides significantly reduced the weed density (no./m^2). The lowest total weed density was recorded with imazethapyr + pendimethalin at 1.0 kg/ha (24) being at par with imazethapyr + imazamox at 100 g/ha PoE (26) followed by imazethapyr at 75 g/ha as PoE (30) and significantly superior over fenoxaprop-p-butyl 100g/ha (59) and quizalofop-p-ethyl 50 g/ha (52). Similar results were observed of weed biomass (g/m^2), which was significantly lower in imazethapyr + pendimethalin at 1.0 kg/ha (3.22) closely followed by imazethapyr + imazamox 100g/ha PoE (10.41) followed by imazethapyr 75 g/ha as PoE (47.25), followed byfenoxaprop-p-butyl 100 g/ha (55.75) and quizalofop-p-ethyl at 50 g/ha (60.56).

The highest weed control efficiency (80%) was attained with the application of imazethapyr + pendimethalin 1.0 kg/ha PoE, which was closely followed by imazethapyr + imazamox at 100 g/ha PoE andimazethapyr 75 g/ha PoE (**Table 2**). Weed index indicates the loss of yield caused by weeds under particular treatment as compared to weed free plot. The minimum loss in yield *i.e.* weed index was with post-emergence herbicides *i.e.* fenoxaprop-p-butyl (17.55 and 17.34 during 2018-19 and 2019-20, respectively) followed by quizalofop-p-ethyl (24.30 and 24.50 during 2018-19 and 2019-20, respectively) compared to weed free plot. The loss of yield, as measured in terms of weed index, was recorded maximum under weedy check due to heavy infestation of weeds, while application of imazethapyr + pendimethalin, imazethapyr + imazamox, imazethapyr also recorded reduction in yield due to phytotoxic effect of these herbicide on chandrashoor plants as compared to other post-emergence herbicides.

Chandrashoor growth, yield attributes and yield

At harvest stage the maximum plant height was recorded in weed free, but it was at par with fenoxaprop-p-butyl 100 g/ha (57.12) and quizalofop-p-ethyl 50 g/ha (**Table 2)**. Significantly higher seed yield was recorded in plots treated with fenoxaprop-p-butyl 100 g/ha and quizalofop-p-ethyl 50 g/ha (678 and 622 kg/ha, respectively in 2018-19 and 693 and 633 kg/ha, respectively in 2019-20) (**Table 3**). Significantly highest harvest index was recorded with fenoxaprop-p-butyl 100 g/ha and quizalofop-p-ethyl 50g/ha (25.80 and 25.51%, respectively in 2018-19 and 25.89% and 25.41%, respectively in 2019-20). Similar trend was also found with respect to the stover yield. It might be due to lesser infestation of weeds that encourage proper translocation of photosynthates from source to sink. Such condition may increase the seed production ratio in total produce.

Table 1. Effect of weed management treatments on weed density and biomass in standing chandrashoor crop

Treatment	Weed density (no./m^2)						Weed biomass (g/m^2)					
	Before spray			7 Days after spray			Before spray			7 Days after spray		
	2018-19	2019-20	Pooled	2018-19	2019-20	Pooled	2018-19	2019-20	Pooled	2018-19	2019-20	Pooled
Quizalofop-p-ethyl (50 g/ha) PoE	12.63 (159.0)	12.44 (154.7)	12.53 (156.8)	7.22 (51.7)	7.08 (49.7)	7.15 (50.7)	8.64 (74.4)	8.54 (72.4)	8.59 (73.4)	7.86 (61.5)	7.73 (59.6)	7.79 (60.6)
Fenoxaprop-p-butyl 100 g/ha PoE	13.11 (171.7)	12.86 (165.3)	12.99 (168.5)	7.75 (59.7)	7.67 (58.3)	7.71 (59.0)	8.77 (76.6)	8.62 (73.9)	8.70 (75.2)	7.59 (57.1)	7.41 (54.4)	7.50 (55.7)
Imazethapyr 75 g/ha PoE	12.82 (164.0)	12.56 (157.3)	12.69 (160.7)	5.52 (30.0)	5.45 (29.3)	5.49 (29.7)	9.08 (82.1)	8.96 (79.8)	9.02 (81.0)	6.99 (48.7)	6.81 (45.8)	6.88 (47.2)
Imazethapyr + imazamox 100 g/ha PoE	12.94 (167.0)	12.87 (165.3)	12.90 (166.2)	5.18 (26.3)	5.15 (26.0)	5.16 (26.2)	8.33 (69.3)	8.06 (64.8)	8.21 (67.1)	3.39 (11.2)	3.13 (9.6)	3.26 (10.4)
Imazethapyr + pendimethalin 1.0 kg/ha PoE	13.15 (172.3)	12.98 (168.7)	13.06 (170.5)	4.98 (24.3)	4.91 (23.7)	4.95 (24.0)	8.53 (72.4)	8.29 (68.4)	8.42 (70.4)	1.99 (3.5)	1.86 (3.0)	1.93 (3.2)
Weed free (using hand weeding twice)	0.71 (0.0)	0.71 (0.0)	0.71 (0.0)	0.71 (0.0)	0.71 (0.0)	0.71 (0.0)	0.71 (0.0)	0.71 (0.0)	0.71 (0.0)	0.71 (0.0)	0.71 (0.0)	0.71 (0.0)
Weedy check	12.99 (168.3)	12.89 (166.0)	12.94 (167.2)	10.93 (119.0)	10.90 (118.3)	10.92 (118.7)	9.76 (94.8)	9.49 (89.5)	9.62 (92.2)	9.57 (91.2)	9.23 (85.0)	9.40 (88.1)
LSD (p=0.05)	0.51	0.82	0.56	0.33	0.34	0.31	0.64	0.54	0.38	0.65	0.68	0.48

Original values given in parentheses was subjected to square root $(\sqrt{x+1})$ transformation before analysis

Table 2. Effect of weed management practices on weed index, weed control efficiency and crop plant height in chandrashoor crop

Treatment	Weed index		Weed control efficiency				Plant height (cm) at harvest		
			Before spray		After spray				
	2018-19	2019-20	2018-19	2019-20	2018-19	2019-20	2019-20	2018-19	Pooled
Quizalofop-p-ethyl (50 g/ha) PoE	24.30	24.50	5.54	6.83	56.58	58.03	95.00	97.59	96.30
Fenoxaprop-p-butyl 100 g/ha PoE	17.55	17.34	-1.98	0.40	49.86	50.70	96.33	98.30	97.32
Imazethapyr 75 g/ha PoE	88.51	88.46	2.57	5.22	74.79	75.21	69.33	71.47	70.40
Imazethapyr + imazamox 100g/ha PoE	81.41	81.42	0.79	0.40	77.87	78.03	63.67	66.84	65.26
Imazethapyr + pendimethalin 1.0 kg/ha PoE	87.83	87.43	-2.38	-1.61	79.55	80.00	74.00	75.43	74.72
Weed free (using hand weeding twice)	0.0	0.0	100.00	100.00	100.00	100.00	96.67	102.93	99.80
Weedy check	54.72	52.67	0.00	0.00	0.00	0.00	92.67	94.36	93.51
LSD (p=0.05)	-	-	-	-	-	-	8.40	8.37	8.16

Table 3. Effect of weed management treatments on yield attributes and yield of chandrashoor crop

Treatment	Grain yield (kg/ha)			Stover yield (kg/ha)			Harvest index (%)		
	2018-19	2019-20	Pooled	2018-19	2019-20	Pooled	2018-19	2019-20	Pooled
Quizalofop-p-ethyl (50 g/ha) PoE	622	633	627	1825	1840	1832	25.51	25.41	25.54
Fenoxaprop-p-butyl 100 g/ha PoE	678	693	685	1947	1970	1958	25.80	25.89	25.91
Imazethapyr 75 g/ha PoE	94	97	96	318	331	325	22.79	22.71	22.75
Imazethapyr + imazamox 100 g/ha PoE	153	156	154	446	456	451	25.43	25.38	25.41
Imazethapyr + pendimethalin 1.0 kg/ha PoE	100	105	103	308	336	322	24.41	23.44	24.09
Weed free (using hand weeding twice)	822	838	830	2069	2092	2081	28.49	28.67	28.58
Weedy check	372	397	384	1173	1218	1196	24.11	24.64	24.37
LSD (p=0.05)	60.94	65.16	48.49	138.75	135.85	127.54	3.53	3.70	2.84

Table 4. Economics of weed management treatments in standing chandrashoor crop

Treatment	Cost of cultivation (x10^3 `/ha)		Gross returns (x10^3 `/ha)			Net returns (x10^3 `/ha)			B:C ratio		
	2018-19	2019-20	2018-19	2019-20	Pooled	2018-19	2019-20	Pooled	2018-19	2019-20	Pooled
Quizalofop-p-ethyl 50 g/ha PoE	34.01	34.55	62.20	63.27	62.73	33.15	33.67	33.41	2.14	2.14	2.14
Fenoxaprop-p-butyl 100 g/ha PoE	34.28	34.83	67.78	69.27	68.52	38.46	39.40	38.93	2.31	2.32	2.32
Imazethapyr 75 g/ha PoE	34.32	34.86	9.43	9.67	9.55	-19.92	-20.24	-20.08	0.32	0.32	0.32
Imazethapyr + imazamox 100g/ha PoE	35.64	36.19	15.27	15.57	15.42	-15.41	-15.66	-15.54	0.50	0.50	0.50
Imazethapyr + pendimethalin 1.0 kg/ha PoE	38.54	39.09	10.00	10.50	10.25	-23.58	-23.63	-23.61	0.30	0.31	0.30
Weed free (using hand weeding twice)	45.20	46.40	82.22	83.83	83.03	48.59	49.37	48.98	2.44	2.43	2.44
Weedy check	33.06	33.58	37.22	39.67	38.44	9.13	11.05	10.09	1.32	1.39	1.36
LSD (p=0.05)	0.00	0.00	6.10	6.52	4.85	6.10	6.52	4.85	0.3	0.3	0.3

Economics

The lowest cost of cultivation was in weedy check treatment (₹ 33055/ha during 2018-19 and ₹ 33578/ha during 2019-20) as no weed control measure was undertaken and it was highest in weed free treatment. Weed free treatment recorded higher gross returns (₹ 48589/ha during 2018-19 and ₹ 49365/ha during 2019-20). Among herbicide treatments, higher gross return was observed with fenoxaprop-p-butyl 100 g/ha PoE (₹ 67778/ha during 2018-19 and ₹ 69267/ha during 2019-20) followed by quizalofop-p-ethyl 50 g/ha PoE (₹ 62200/ha during 2018-19 and ₹ 63267/ha during 2019-20) when compared to other herbicide treatments. Fenoxaprop-p-butyl 100 g/ha PoE resulted in higher net returns (₹ 48589/ha during 2018-19 and ₹ 49365/ha during 2019-20) followed by quizalofop-p-ethyl 50 g/ha PoE (₹ 38457/ha during 2018-19 and ₹ 39399/ha during 2019-20) when compared to other herbicide treatments. The highest B:C was also recorded with fenoxaprop-p-butyl 100g/ha PoE treatment (2.31 during 2018-19 and 2.32 during 2019-20) followed by quizalofop p ethyl at 50 g/ha PoE as compared to rest of the treatments (**Table 4**). Therefore, fenoxaprop-p-butyl 100 g/ha PoE and quizalofop-p-ethyl 50 g/ha PoE may be used for managing weeds in chandrashoor, when labour availability is scarce, as they proved to be safe to chandrashoor and gave higher chandrashoor yield with higher net income.

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Utilization of weeds in rice ecosystem by farmers in Odisha, India

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ABSTRACT

The aim of this study was to compile an inventory of the weeds in a rice ecosystem as livelihood support to farmers of Bhadrak district, Odisha, India. Information was collected from 165 local inhabitants during 2017-2019, using standard procedures. In the rice fields, altogether 37 plant species belonging to 30 genera and 24 families were recorded. Amaranthaceae was the dominant family. The systematic documentation of the weed flora in the Bhadrak district showed that the area is rich in plants with edible, fodder and ethnomedicinal value and that the inhabitants of the area had significant knowledge about the use of such plants. Ethnobotanical indices like relative frequencies of citation (RFC) and use value (UV) were calculated for each of the recorded weeds. The commonly used weed/plant species are: *Ipomoea aquatica* Forssk. (UV: 0.588) and *Glinus oppositifolius* (L.) Aug. DC. (UV: 0.576) as vegetables; *Echinochloa crus-galli* (L.) P.Beauv. (UV: 0.552) and *Echinochloa stagnina* (Retz) P. Beauv. (UV: 0.527) as fodder; *Centella asiatica* (L.) Urb. (UV: 0.41) followed by *Bacopa monnieri* (L.) Penn.(UV: 0.37) and *Commelina benghalensis* L. (UV: 0.364) for medicinal purposes. The leaves of the herbaceous plant/weed species are the most used by farmers. The reported ethnomedical wisdom of farmers could contribute to basic primary health care and balanced diets for the benefit of local farming community posterity.

INTRODUCTION

An evolved field knowledge arising from conscious 'hit and trail' methods have resulted in selection of certain plants as edible choices (Sharma *et al.* 2018). The world's agriculture can be regarded as one of the great successes of human civilization. Agricultural biodiversity is the first link in the food chain, developed and safeguarded by indigenous people throughout the world (Nakhauka 2009). Rice fields are rich in biodiversity and playing multifunctional role. It is widely accepted that intensive agriculture plays a decisive role for loss of biodiversity and environmental sustainability in rice agro-ecosytem (Jose-Maria *et al.* 2010). Accordingly, in the ecological and socio-economic context, the protection of diversity of agro-ecosystems is considered to be of immense significance in modern agriculture (Firbank *et al.* 2008). It is well documented that weeds are aggressive, troublesome, compete with crops for water, nutrients and light, reducing detrimentally crop yield and quality, encourage disease problems, reduce the efficiency of agricultural apparatus, decline the germination potential of crops seed, enhance the cost of production and decrease the market value of crops (Rao *et al.* 2014; Gharde *et al.* 2018). However, limited attention has been devoted to understanding their potential use as food, animal fodder, medicine and erosion control (Marcelino *et al.*2005; Bilaliset *al.* 2014, Chandrasena 2014). Moreover, one cannot ignore the importance of weeds in agro-ecosystem food web (Bastiaans *et al.* 2000).

In the context of man-plant interactions (Upadhaya *et al.*2016), the significance of rice ecosystems for food security and the maintenance of biodiversity has been recognized in various Asian countries (Kosaka *et al.*2013, Cruz-Garcia and Price 2014), whereas the role of weeds in rice fields in the provision of foods is underestimated and undervalued (Halwart and Bartley 2007). Furthermore, scientists affianced in agricultural research usually recommend for eradication of weeds, but the same plant referred as weed is considered as wild food plants by local farmers (Cruz-Garcia and Price 2012), consequently most research on weed diversity in rice field is focused on weed management. But, the fact is that 89% of the 18 most widespread and aggressive weeds in the world are edible (Rapoport *et al.*1995) and many of these species have a high nutritional value and medicinal properties (Duke 1992). As it is known that some arable weeds have declined since the 1950s (Lososova 2003) and some alien weeds have threatened the indigenous flora of ecosystems (Panda *et al.* 2018a), therefore, the continued availability of weeds depend on the maintenance of cooperation between farming and wild biodiversity (Pretty 2007).

The change of cropping system from diversified to simplified (cereal-based systems) has contributed to micronutrient malnutrition in many developing countries (Demment *et al.* 2003). Globally, an estimated 1.02 billion people are undernourished (FAO 2009). In India, about 60% of malnutrition cases are from states which also rank high in poverty. Along with a few other states, Odisha ranks high on both poverty and malnutrition scales (World Bank 2016). There are relatively few studies about weeds based on its usability (Sinha and Larka 2007). Review of literature reveald that no attempts have been made to assess quantitatively the potential value of weeds to farmers of Bhadrak district, Odisha, India. Hence this study was carried out, to evaluate quantitatively the traditional ethnobotanical knowledge of common weeds in rice and to assess its significant role for farmers as supplement to food and primary health care.

MATERIALS AND METHODS

Study area

Bhadrak district (20°43′-21°13′N and 86°6′-87° E) is located in north east Odisha and covers an area of 2505 km^2,with a population of 1.507 million (2011 Census). It borders the Balasore district in the north, Jajpur in the south, Bay of Bengal and Kendrapara district in the east and Koenjhar in the west. The district accounts for 1.61% of the state's territory and shares 3.62% of the state's population. The climate of the district is warm and humid. The maximum and minimum temperatures ranged from 37.4°C to 17.7°C, respectively, and the annual average rainfall is approximately 1428 mm (Anonymous 2019) of which about 71% occurs in the monsoon season. The varying intensities of cyclones, drought and flood are the characteristic feature of the district. More than 70% of the people are involved in agriculture. Rice is cultivated in two seasons namely *Kharif* (rainy season, June–Nov) and *Rabi* (winter season, January–April). Both traditional and hybrid rice cultivars are cultivated in the surveyed area. Rice cultivation in Bhadrak district during *Kharif* season depends mostly on monsoon rains. South-West monsoon sets in the district and the state during 2nd fortnight of June and continues up to 1st week of October. Rainfall pattern is highly unpredictable in timing, amount and distribution and therefore, the district suffers either from drought or flood.

Data Collection

The method employed was designed with the purpose of providing base line information on the use of plant species in rice ecosystem by farmers, through literature survey and field visits in seven blocks of the district *i.e.* Basudevpur, Bhadrak, Bhandaripokhari, Bonth, Chandbali, Dhamnagar and Tihidi. The field study was carried out monthly during June 2017 to July 2019 following established and standard procedures (Martin 1995). The information on the use of weed flora was obtained through structured questionnaires, complemented by free interviews and informal conversations (Martin 1995; Huntington 2000). Elderly persons were considered key informants in the study, and the selection process was based on the knowledge base, experience, and current practices in ethnoedible/ ethnomedicine and fodder plant species. The interviews and discussions were carried out individually with members of the inhabitants of the each of the villages visited ,in the local language. During repeated visits to the study site, further group (8-12 people) discussions were held with: i) old-aged key informants, and ii) women key-informants known to be especially skilled in the use of uncultivated plants. The valuable and specific information about the plants obtained during personal interviews and group discussions with local inhabitants was further compared and authenticated by cross-checking (Cunningham 2001). In total 165 (98 women and 67 men) persons of different blocks in the district (Basudevpur: 24 farmers, Bhadrak:18 farmers, Bhandaripokhari: 23 farmers, Bonth: 19 farmers, Chandbali: 29 farmers, Dhamnagar: 27 farmers and Tihidi: 25 farmers) were interviewed. The household surveys were also carried out to get information on farming practices used, use of uncultivated plants and their management and personal demographic features. In addition, field visits were made with the respondents to the areas where the respondents normally collect the uncultivated species. During the visits, harvesting methods, parts used, harvest quantity, treatment for which they are used and storage of different species for their future use were discussed. The collected specimens were processed, dried, herbarium specimens were prepared and identified by referring to Saxena and Brahmam (1996). Voucher specimens of the collected plant species were deposited in the herbarium of the Department of Botany, Chandbali College, Chandbali.

Quantitative analysis

Relative frequency of citation (RFC): This index determines the local importance of each species and is calculated by the following formula:

$$RFC = \frac{FC}{N} \quad (0 < RFC < 1)$$

Where FC is the number of informants reporting the use of a particular species and N is the total number of informants.RFC value varies from 0 (when nobody refers to a plant as a useful one) to 1 (when all informants mention it as useful) (Tardio and PardodeSantayana 2008).

Use value (UV): The use value demonstrates the relative importance of plants known locally. It is calculated using the following formula (Gazzaneo *et al.*2005).

$$UV =” \frac{Ui}{N}$$

Where Ui is the number of uses mentioned by each informant for a given species and N is the total number of informants.

RESULTS AND DISCUSSION

Many weeds are edible, serving as traditional food every day for people all over the world (Duke 1992, Lee *et al.* 2007, Maneechote 2007). In India, more than 3000 wild plant species are used as subsidiary food and vegetable by indigenous people, and at least 250 plants can be developed as a new source of food in the near future (Anonymous 1994). At the end of our two year study, 37 rice field weeds belonging to 24 botanical families were considered as edible plants, (**Table 1**) as reported earlier from other states of India (Sinha and Lakra 2007; Parameswaran and Kumar 2017) and different countries of the world (Díaz-Betancourt *et al.* 1999, Cruz-Garcia and Price 2012, Kosaka *et al.* 2013). All these species appear in the Global Compendium of Weeds (HEAR 2007] and were reported as weed in rice (Moody 1989). Halwart (2006) also emphasized the importance of wild foods from rice-based aquatic ecosystems for food and nutritional security. In the Asian-Pacific region, more than 150 weed species are considered edible (Kim *et al.*2007). The importance of wild food plant diversity from agricultural ecosystems has been highlighted by Cruz-Garcia and Price (2012). In this study, Amaranthaceae was the most common family represented by six species, followed by Asteraceae and Poaceae with three species each. Both reproductive (flowers and fruits) and vegetative parts (shoots, leaves, tuber *etc*.) were used for vegetables. Leaves (42.1%) and shoots (33.3%) were eaten most frequently (**Table 1**). However, in most cases the fruit was not eaten as a vegetable.

The most important species according to their use value with highest RFC and used for vegetable purposes were: *Ipomoea aquatica* (UV 0.588;UR 160), *Glinus oppositifolius* (UV 0.576; UR 155) and *Marsilea minuta* (UV 0.558; UR 149) (**Table 2**). The importance of edible weeds was emphasized in India (Datta and Banerjee 1978, Sinha and Lakra 2007 and Mishra *et al.* 2012), Philippines (Marcelino *et al.* 2005), Korea and China (Pemberton and Lee 1996), Thailand (Maneechote 2007) and in Laos (Kosaka *et al.*2013) of Asia; and also in Africa, America and Europe (Grivetti *et al.* 1987, Duke 1992, Pemberton and Lee 1996, Díaz-Betancourt *et al.* 1999, Turner *et al.* 2011). The three top edible weeds in Asian culinary delights are: *Alternanthera sessilis*, *Centella asiatica* and *Ipomoea aquatica* (Chandrasena 2007). These edible weeds of Bhadrak district are also consumed in other Asian countries, for example: *Centella asiatica* in China (Hu 2005), *Glinus oppositifolius* in Thailand (Cruz-Garcia and Price 2012), *Alternanthera sessilis* and *Ipomoea aquatica* in the Philippines and China (Marcelino *et al.* 2005; Hu 2005) and *Coccinia grandis* in Vietnam (van Chin 1999). The reported weeds such as *Glinus oppositifolius*, *Ipomoea aquatica* and *Marsilea minuta* were found, during the survey period, to be sold in the local markets particularly by poor and economically marginalised families, thereby generating a supplementary income to their household economy. Village farmers stated that these food plants are being sold in market for 50 or 60 years, and that demand for these foods has increased with time. The selling of *Glinus oppositifolius*, *Ipomoea aquatica* and *Marsilea minuta* in the local markets was also reported by Srivastava *et al.* (2018).

In addition to food, vegetables usage, the weeds were also used for fodder purpose (**Table 1**). The study considered as important sources for animal well being because, many weed species are utilized as fodder for buffaloes and cattle as reported elsewhere

Table 1. List of weeds consumed as vegetables and used for various purposes in Bhadrak district, Odisha, India

Weed	Family	Vernacular name	Edible part(s) as mentioned by respondents	Uses*
Alternanthera philoxeroides (Mart.) Griseb.	Amaranthaceae	Ghodamadaranga	Leaf, shoot	F, FD
Alternanthera sessilis (L.) R. Br. Ex DC.	Amaranthaceae	Madaranga	Shoot, leaf	F, FD M
Amaranthus viridis L.	Amaranthaceae	Leutia	Leaf, shoot	F, FD
Amaranthus spinosus L.	Amaranthaceae	Kantaneutia	Leaf	F, FD, M
Amaranthus tricolor L.	Amaranthaceae	Nautia	Leaf	F
Aponogeton natans (L.) Engl. & Krause	Aponogetonaceae	Ghechu	Bulbil	F, FD
Argemone mexicana L.	Papaveraceae	Kantakusuma	Leaf	F, FD, M
Bacopa monnieri (L.) Penn.	Scrophulariaceae	Brahmi	Shoot	F, FD, M
Boerhavia diffusa L.	Nyctaginaceae	Puruni	Leaf, shoot	F, FD, M
Centella asiatica (L.) Urb.	Apiaceae	Thalkudi	Leaf, petiole	F, FD, M
Chenopodium album L.	Amaranthaceae	Bathuasaga	Leaf, shoot	F, FD, M
Coccinia grandis (L.) Voigt.	Cucurbitaceae	Kundri	Fruit	F
Colocasia esculenta (L.) Schott.	Araceae	Saru	Leaf, tuber	F, FD, M
Commelina benghalensis L.	Commelinaceae	Kansiri	Leaf, shoot	F, M
Crinum asiaticum L.	Amaryllidaceae	Panikenduli	Rhizome	F, M
Echinochloa crus-galli (L.) P. Beauv.	Poaceae	Dhera	Grain	F, FD
Echinochloa stagnina (Retz) P. Beauv.	Poaceae	Jhipa	Grain	F, FD
Eclipta alba (L.) Hassk.	Asteraceae	Bhrungaraj	Shoot	F, FD, M
Emilia sonchifolia (L.) DC.	Asteraceae	Sarkara	Shoot	F
Enydra fluctuans Lour.	Asteraceae	Hidimicha	Leaf, shoot	F, FD, M
Glinus oppositifolius (L.) Aug. DC.	Molluginaceae	Pitasaga	Leaf, shoot	F, FD, M
Hydrolea zeylanica (L.) Vahl	Hydrophyllaceae	Langulia	Whole plant	F, FD, M
Hygrophila auriculata (Schumach)Heine	Acanthaceae	Koelikhia	Leaf	F, M
Ipomoea aquatica Forssk.	Convolvulaceae	Kalamasaga	Leaf, shoot	F, FD, M
Limnophila indica (L.) Druce.	Scrophulariaceae	Keralata	Leaf	F
Ludwigia adscendens (L.) H. Hara	Onagraceae	Jagal	Shoot, leaf	F, FD, M
Ludwigia prostrata Roxb.	Onagraceae		Shoot, leaf	F
Marsilea minuta L.	Marsileaceae	Sunsunia	Leaf, petiole	F, FD, M
Monochoria hastata (L.) Solms	Pontederiaceae		Leaf, shoot, flower	F, FD
Nymphaea nouchali Burm. f.	Nymphaeaceae	Nilakain	Fruit	F, M
Nymphaea pubescens Willd.	Nympaeaceae	Rangakain	Fruit	F
Ottelia alismoides (L.) Pers.	Hydrocharitaceae	Panikundri	Shoot, flower	F, FD, M
Oryza rufipogon Griff.	Poaceae	Balunga	Grain	F, FD
Oxalis corniculata L.	Oxalidaceae	Ambiliti saga	Leaf	F, FD, M
Polygonum plebeium R.Br.	Polygonaceae	Muthisaga	Leaf, shoot	F
Portulaca oleracea L.	Portulacaceae	Badabalbaula	Leaf, shoot	F, FD, M
Portulaca quadrifida L.	Portulacaceae	Balbaula	Leaf, shoot	F, FD

*F= Food; FD= Fodder; M= Medicinal use

by Marcelino *et al.* (2005). The most significant species according to their use value for fodder were *Echinochloa crus-galli* (0.552), *Echinochloa stagnina* (0.527) and *Alternanthera. philoxeroides* (0.436). The rice fields are abundant sources of forage production for dairy cattle (Zahra *et al.*2014) and weeds such as *E. crus-galli* and *E. stagnina* are considered as a source of protein as well as additives to the fodder for animals (Sherag *et al.*2014). The use of *Alternanthera philoxeroides* as forage for animals was also reported (Banerjee and Matai 1990, Sushilkumar and Vishwakarma) in addition to its reported use as medicine (Panda and Misra 2011) and food (as leafy vegetables) for human consumption (Sarma and Saikia 2010).

The plant species with use value (UV) for medicinal purposes were *Centella asiatica* (L.)Urb. (UV: 0.41) followed *by Bacopa monnieri* (L.) Penn. (UV: 0.37) and *Commelina benghalensis* L. (UV: 0.364) (**Table 2**). *Centella asiatica* use, for the treatment of various ailments such as stomach disorders, irregular menstruation, maternal health care, has been reported (Prakash *et al.* 2017, Panda *et al.* 2018b). In Ayurveda, *Bacopa monnieri* is recommended for improvement of memory, variety of diseases like anti-inflammatory, analgesic, antipyretic and sedative (Russo and Borrelli 2005). Aguiar and Borowski (2013) and Kongkeaw *et al.* (2014) stated that *Bacopa monnieri* targets the CNS and manage conditions such as memory, lack of concentration, and anxiety. Similarly, *Glinus oppositifolius* has been used in the treatment of skin disease, increase appetite, cures kapha, piles, leukoderma, tonic to intestine, urinary infections, fever, cough, liver problem and also used as antioxidant due to its excellent properties and potent phytoconstituents (Sheu *et al.* 2014). Likewise, *Ipomoea aquatica* is effectively used against

Table 2. Quantitative analysis of weeds use in Bhadrak district, Odisha, India

Weed	Number of respondents* using the weed as			Relative frequency of citation	Use value		
	Food	Fodder	Medicine		Food	Fodder	Medicinal use
Alternanthera sessilis	52	51	22	0.824	0.315	0.309	0.133
Alternanthera philoxeroides	11	72	02	0.552	0.067	0.436	0.012
Amaranthus viridis	87	11	NR	0.612	0.527	0.067	-
Amaranthus spinosus	18	11	33	0.418	0.109	0.067	0.2
Amaranthus tricolor	57	NR	NR	0.412	0.345	-	-
Aponogeton natans	17	12	NR	0.188	0.103	0.072	-
Argemone mexicana	06	13	36	0.455	0.036	0.079	0.218
Bacopa monnieri	37	05	61	0.661	0.224	0.03	0.37
Boerhavia diffusa	51	34	44	0.83	0.309	0.206	0.27
Centella asiatica	33	14	67	0.709	0.2	0.085	0.41
Chenopodium album	53	9	15	0.497	0.321	0.054	0.09
Coccinia grandis	47	NR	NR	0.333	0.284	-	-
Colocasia esculenta	85	03	32	0.733	0.515	0.018	0.193
Commelina benghalensis	19	NR	60	0.491	0.115	-	0.364
Crinum asiaticum	22	NR	30	0.352	0.133	-	0.182
Echinochloa crus-galli	14	91	NR	0.666	0.084	0.552	-
Echinochloa stagnina	09	87	NR	0.624	0.054	0.527	-
Eclipta alba	24	33	51	0.672	0.145	0.2	0.309
Emilia sonchifolia	19	NR	NR	0.158	0.115	-	-
Enydra fluctuans	41	16	34	0.618	0.248	0.097	0.206
Glinus oppositifolius	95	13	47	0.976	0.576	0.079	0.284
Hydrolea zeylanica	03	56	03	0.388	0.018	0.34	0.018
Hygrophila auriculata	31	NR	29	0.484	0.188	-	0.176
Ipomoea aquatica	97	14	49	0.982	0.588	0.084	0.297
Limnophila indica	35	18	11	0.461	0.212	0.109	0.067
Ludwigia adscendens	48	34	24	0.715	0.291	0.206	0.145
Ludwigia prostrata	24	15	08	0.309	0.145	0.091	0.048
Marsilea minuta	92	16	41	0.945	0.558	0.097	0.248
Monochoriahastata	17	06	11	0.212	0.103	0.036	0.067
Nymphaea nouchali	28	05	29	0.412	0.17	0.03	0.176
Nymphaea pubescens	39	NR	22	0.43	0.236		0.133
Ottelia alismoides	28	17	23	0.473	0.17	0.103	0.139
Oryza rufipogon	09	33	NR	0.345	0.055	0.2	
Oxalis corniculata	72	20	15	0.661	0.436	0.121	0.091
Polygonum plebeium	83	NR	NR	0.558	0.503		
Portulaca oleracea	26	27	17	0.436	0.158	0.164	0.103
Portulaca quadrifida	19	13	NR	0.206	0.115	0.079	

***Total number of respondents =165);** RFC = Relative frequency of citation *i.e.* use range - 0: when nobody refers to a plant as a useful one, to 1: when all informants mention it as useful Medicinal use; NR= Not reported

nosebleed, high blood pressure, leukoderma, leprosy, jaundice, liver complaints and as anthelmintic (Malakar and Choudhury 2015). Thus, the weeds in rice are an important resource for farmers of Bhadrak district, not only as food (vegetables) but also because of the multiple additional uses they have.

Our results indicated that the distribution of weed species varies seasonally within rice ecosystems. Abundance and distribution of weed flora in rice field is inclined to interaction multiple factors of local environmental conditions (Travlos *et al.* 2018, Kurniadie *et al.* 2019). In this study, a higher number of weeds were observed during *Kharif* (Rainy-wet) (June–Nov) than the *Rabi* (Post-rainy -dry) (January–April) season. Rainfall and flooding were the 'major drivers' of this variability. Species diversity increases in the monsoon with bund (levee) being the most diverse; whereas in the dry season the greatest diversity was in the rice field as observed by Halwart (2006), Kosaka *et al.* (2013) and Subudhi *et al.* (2015).

It may be concluded that traditional knowledge and usage of weeds as supplementary food and primary health care is intimately linked to the livelihood needs of the local communities. However, most of this traditional use of weed is now in danger of vanishing. Therefore, it is important to preserve as much of this traditional knowledge as possible in written form. Hopefully, such knowledge may some day constitute the special heritage of the people of Bhadrak to the world. The reported edible weeds could contribute to basic primary health care and balanced diets for the benefit of posterity.

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Comparative efficacy and economics of weed management treatments in upland rice at western mid hill of Nepal

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ABSTRACT

Weeds cause drastic reduction of rice yield and quality. The weeds problem is more severe in upland rice system. The efficiency and economics of different weed management treatments on weed dynamics, yield and economics of upland rice were evaluated by carrying out field experiment during rainy season of 2017 at NARC research station, Dasarathpur, Surkhet, Nepal. The experiment consisted of six treatments, *viz*: control, farmers' practice of hand weeding (HW) twice at15 and 30 days after seeding (DAS), manually running dry land weeder twice 15 and 30 DAS, one HW at 15 DAS *fb* bispyribac-sodium post-emergence application (PoE) at 0.4 g/ha 30 DAS, pre-emergence application (PE) of pendimethalin 1.5 g/ha *fb* 1 HW 15 DAS and pendimethalin PE at 1.5 g/ha *fb* bispyribac-sodium PoE 0.4 g/ha 15 DAS, were tested in one factor RCBD design with four replications. Pendimethalin PE 1.5 g/ha *fb* bispyribac-sodium PoE 0.4 g/ha 15 DAS was found to be most efficient and economical weed management option in upland rice with the highest rice grain yield (2.63 t/ha), net returns and B:C ratio.

Upland rice is grown in rainfed, fields and grown as dry direct-seeded rice, much like wheat or maize cultivation. The ecosystem is extremely diverse, including fields that are levelled, gently rolling or steep, at altitudes up to 2,000 meters and with rainfall ranging from 1,000 to 4,500 mm annually. Soils range from highly fertile to highly weathered, infertile and acidic, but only 15 percent of total upland rice grows where soils are fertile, and the growing season is long. Many upland farmers plant local rice that do not respond well to improved management practices—but these are well adapted to their environments and produce grains that meet local needs (Joshi *et al.* 2001).

The productivity of upland rice continues to remain low about 0.8 t ha^{-1}(MOALD 2019) Climatic and soil conditions are the major physical constraints of the upland rice productivity (Gupta and O'Toole 1986). The upland soil is acidic in nature and deficient in nitrogen, phosphorus with aluminum and manganese toxicity. Weeds and drought in upland rice are also the severe problems. Upland rice environments vary widely among the locations (Tommar 2001). Cultivar improvement, use of farmer participatory methods to reduce erosion, and weed management are areas where research advances are needed and being made.

Though the upland rice has lots of prospective for food security especially in remote area but at the same time it suffers from different problem like disease, pest, climatic adversity, lower fertility and weed infestation. Among these, weed menace is the main problem as it causes losses from 10-90% (Ehsanullah *et al.* 2014). Direct-seeded rice is likely to have high level of weed infestation than transplanted rice and with greater difficulty to manage (Begum *et al.* 2006, Rao *et al.* 2007, Chauhan and Johnson 2009). Traditionally, weeds are being controlled through manual weeding. Manual weeding, though effective, is getting increasingly difficult and costly due to labor scarcity and rising wages rates. With the availability of herbicides and associated weed management technology, it is possible to improve the yield of dry direct-seeded upland rice using herbicides (Mishra and Singh 2008, Khaliq *et al.* 2011). Thus, this study was conducted to evaluate different weeds management treatments, understand the weed dynamics and identify effective and economical weed management methods in the upland rice.

This study was conducted in mid-western Nepal in Surkhet district, Lakhbesi municipality at the experimental field of Agriculture Research Station field in collaboration with CIMMYT, Nepal. The experiment was laid out in randomized complete block design (RCBD) with six weed management treatments: Weedy check (no weeding)/ control, manually running dry land weeder twice (15 and 30 days after seeding [DAS]), farmers' practice of hand weeding (HW) twice (15 and 30 DAS), one HW at 15 DAS followed by (*fb*) bispyribac-sodium post-emergence application (PoE) at 0.4 g/ha 30 DAS, pendimethalin pre-emergence application (PE) at 1.5 g/ha *fb* one HW 15 DAS, pendimethalin PE at 1.5 g/ha *fb* bispyribac-sodium PoE at 0.4 g/ha15 DAS, replicated four times. The size of individual plot was 16.2 m^2 (4.5 m x 3.6 m) with the total experimental area of 388.8 m^2 (18 x 21.6 m).

Local upland rice variety Kalanathre (locally known as Gajale) was selected because of its adaptive nature and popularity among the farmers of this area. Seed rate used was 100 kg/ha. Seeds were sown continuously in line manually with row spacing of 20 cm on June 12, 2017. The pre-emergence herbicides were sprayed uniformly in the field at 3 DAS. Recommended dose of inorganic fertilizers *i.e.* nitrogen, phosphorus, and potash 60:30:20 kg/ha were applied using Urea (46%N), DAP (18% N, 46% P) and MOP (60% K). In the weedy check plot, throughout the crop duration weed growth was allowed along with the rice, whereas the respective methods of weed control treatments were implemented in other treatments as described. From the net plot, the weed biomass, weed species and grain yield were recorded and economic efficiency was calculated. The recorded data on various observed parameters were compiled and arranged treatment wise systematically in four replications. MS Excel was used for simple statistical analysis. Compiled data related to weed species density and biomass was transformed by square root transformation before analysis of variance. GenStat and R package were used for data analysis. ANOVA was constructed and significant data were subjected to DMRT for mean separation with reference to Gomez and Gomez (1984).

Effect on weeds

During harvesting of crop, weed density was more in control plot (2.646) which was statistically at par with density in dry land weeder plot (2.654) and farmer practice HW (2.699) which was followed by pendimethalin *fb* HW (2.521) and HW *fb* bispyribac-sodium (2.31) respectively with lowest density in pendimethalin *fb* bispyribac-sodium (1.92) treated plot (**Table 1**). Weed density at different time interval was also found significant to different weed management practices.

Weed biomass at 1st weeding was found to vary significantly amongst different weed management practices. The highest weed biomass was found in farmer's practices (108 g/m^2) followed by HW *fb* bispyribac-sodium (85.7 g/m^2). Similarly, the weed biomass in dry weeder used plot was 48.8 g/m^2, 50.8 g/m^2 in control plot and lowest with pendimethalin *fb* HW (7.6 g/m^2) and in pendimethalin *fb* bispyribac-

Table 1. Effect of different weed management treatments on weed control efficiency, total weed density and weed biomass at different growth stages in upland rice

Treatment	Weed control efficiency (%)			Weed density (no./m^2)			Weed biomass (g/m^2)		
	15 DAS	30 DAS	99 DAS	15 DAS	30 DAS	99 DAS	15 DAS	30 DAS	99 DAS
Weedy check (no weeding)/ control	0^c (1.9)	0^c (0)	0^d (0)	2.73^b (542)	2.885^a (767.5)	2.646^a (500.8)	50.8^c	230.8^a	211.2^b
Manually running dry land weeder twice (15 and 30 DAS)	-1.14^c (9.4)	3.09^b (3.2)	-0.28^d (-5.6)	2.76^b (576)	2.795^b (632)	2.654^a (452)	48.8^c	165^b	293.5^a
Farmers' practice of HW twice (15 and 30 DAS)	-5.64^d (-3.8)	5.58^b (21.8)	-1.98^d (32.1)	2.88^a (764)	2.724^b (530)	2.699^a (444)	108.8^a	46.3^{cd}	39.5^c
One HW at 15 DAS *fb* bispyribac-sodium PoE at 0.4 g/ha 30 DAS	-7.85^e (-10.1)	14.79^a (29)	12.65^b (34.4)	2.94^a (880)	2.458^c (289)	2.31^c (206.5)	85.7^b	27.7^{de}	35.8^c
Pendimethalin PE 1.5 g/ha *fb* 1 HW 15 DAS	41.06^a (62.3)	17.33^a (39)	4.72^c (34.8)	1.60^d (41)	2.385^c (243.5)	2.521^b (332.5)	7.6^d	17.5^e	40.6^c
Pendimethalin PE 1.5 g/ha *fb* bispyribac-sodium PoE 0.4 g/ha 15 DAS	33.94^b (46.4)	15.42^a (24.6)	27.43^a (42.7)	1.80^c (64)	2.440^c (279)	1.92^d (83.5)	15.2^d	59.4^c	22.8^c
LSD (p=0.05)	2.115**	2.895**	1.913**	0.061**	0.083**	0.051	10.97**	26.47**	36.30**
Gran mean	10.06	9.37	7.09	2.45	2.614	2.459	52.8	91.1	107.2

Note: Mean separated by DMRT and columns represented with same letter (s) are non-significant at 5% level of significance, *mean significant and **mean highly significant and the value in parenthesis is original value sodium (15.2 g/m^2). Similarly, during second weeding, the weed biomass was highest under control plot (230.8 g/m^2) and lowest in the pendimethalin *fb* HW (17.5 g/m^2). During harvesting, weed biomass was found to be statistically same under framer's practice, HW *fb* bispyribac-sodium, pendimethalin *fb* HW and pendimethalin *fb* bispyribac-sodium which was lower than that of control and dry land weeder plot. This was attributed to the weed free environment provided by different weed control treatments (Gaire *et al.* 2019).

The different combination of weed management practices have significant effect in the weed control efficiency. At 15 DAS, the highest weed control efficiency was found with pendimethalin *fb* HW (41.06) followed by pendimethalin *fb* bispyribac-sodium (33.94), dry land weeder plot (-1.14), control plot (-1.14), farmer practice (-5.64) and least of HW and bispyribac-sodium (-7.85) respectively. Similarly, the highest weed control efficiency was found under pendimethalin *fb* HW (17.33) which was statistically at par with and pendimethalin *fb* bispyribac-sodium (15.52) and HW *fb* bispyribac-sodium (14.79) being lowest efficiency of control plot. During harvesting, it was found highest under pendimethalin *fb* bispyribac-sodium (27.43) followed by hand weeding *fb* bispyribac-sodium (12.65), pendimethalin *fb* HW (4.72) respectively.

Weed dynamics

Sedges: During the 1st weeding time, the infestation of the sedge was significantly high in upland rice. The highest sedge density was found in HW *fb* bispyribac-sodium (2.113) while the lowest was in pendimethalin *fb* HW (1.572) indicating pendimethalin efficacy in suppressing these weeds emergence (**Table 2**). During the second weeding the highest sedge infestation was found in pendimethalin *fb* bispyribac-sodium (2.321), and least in HW *fb* bispyribac-sodium (1.773) indicating reduced efficacy of pendimethalin on sedges with the passing of time after its application.

Broad-leaved weeds (BLW): The highest infestation of BLW was found in dry land weeder used plot (0.96) at 1st weeding; in pendimethalin *fb* HW (2.19) 2nd weeding and in farmer practice (2.66) at harvesting. The least BLW density was found with HW *fb* bispyribac-sodium (0.38) and pendimethalin *fb* HW (0.38) at 15 DAS, with HW *fb* bispyribac-sodium (0.619) at 30 DAS and with pendimethalin *fb* bispyribac-sodium (1.406) at rice harvest. The bispyribac-sodium was proved to control the BLW, hence lowest BLW density was found in bispyribac-sodium treated plot at rice harvest.

Grasses: During the 1st weeding time highest grasses density was found with farmer's practice and HW fb bispyribac-sodium followed by control and dry land weeder and the lowest density of grasses was with pendimethalin *fb* HW. During the 2nd weeding, the highest grass density was found with weedy check control (2.77) followed by dry weeder (2.5), farmer practice (2.573), HW *fb* bispyribac-sodium (2.348), pendimethalin *fb* bispyribac-sodium (1.494) and least in pendimethalin + HW (1.190). At rice harvest, the weedy check control (2.59) and dry weeder plot (2.58) had highest grass density followed by HW *fb* bispyribac-sodium (1.99), farmer practice (1.59), pendimethalin *fb* HW (1.57) and was least in pendimethalin *fb* bispyribac-sodium (1.517).

Table 2. Effect of different weed management treatments on density (no./ m^2) of grasses, broad-leaved weeds and sedges at 15, 30 and 99 days after seeding (DAS) in upland rice

Treatment	15 DAS (at first weeding)			30 DAS (at second weeding)			99 DAS (at harvest)		
	Grasses	Broad-leaved	Sedges	Grasses	Broad-leaved	Sedges	Grasses	Broad-leaved	Sedges
Weedy check (no weeding)/ control	2.664^{b} (464.5)	0.376^{c} (2.5)	1.879 (74.5)^{c}	2.770a (589)	1.186^{d} (16)	2.070 (162.5)^{b}	2.586^{a} (386.5)	1.608^{e} (41)	2.2070 (16.50)^{b}
Manually running dry land weeder twice (15 and 30 DAS)	2.667^{b} (466)	0.964^{a} (9.50)	1.99 (100.5)^{b}	2.575b (382)	1.776^{b} (60)	2.275 (190)^{ab}	2.582^{a} (384)	1.715^{d} (52)	2.27 (16)^{b}
Farmers' practice HW twice (15 and 30 DAS)	2.817^{a} (657.5)	0.736^{ab} (5.50)	2.003 (101)^{b}	2.573b (376)	1.744^{b} (55.5)	1.989 (98.5)^{c}	1.59^{c} (39.5)	2.655^{a} (452.5)	1.989 (8.75)^{c}
One HW at 15 DAS *fb* bispyribac-sodium PoE at 0.4 g/ha 30 DAS	2.871^{a} (747)	0.376^{c} (2.50)	2.113 (130)^{a}	2.348c (225)	0.619^{e} (4.5)	1.773 (59.5)^{e}	1.990^{b} (99)	1.981^{c} (96)	1.773 (11.50)^{b}
Pendimethalin PE 1.5 g/ha *fb* 1 HW 15 DAS	0.075^{d} (0.5)	0.376^{c} (2.75)	1.572 (37.5)^{e}	1.190e (15.5)	2.190^{a} (156.5)	1.854 (71.5)^{d}	1.570^{cd} (37.5)	2.446^{b} (279.5)	1.854 (15.50)^{b}
Pendimethalin PE 1.5 g/ha *fb* bispyribac-sodium PoE 0.4 g/ha 15 DAS	0.806^{c} (6.5)	0.537^{bc} (3.5)	1.728 (53.5)^{d}	1.494d (32)	1.522^{c} (33.5)	2.321 (213.5)^{a}	1.517^{d} (33)	1.406^{f} (26)	2.321 (24.50)^{a}
LSD (p=0.05)	0.1161**	0.256**	0.10**	0.105**	0.167**	0.078**	0.063**	0.086**	0.078*
Grand mean	1.984	0.559	1.879	2.158	1.506	2.07	1.973	1.969	2.07

Note: Mean separated by DMRT and columns represented with same letter (s) are non-significant at 5% level of significance, *mean significant and **mean highly significant and the value in parenthesis is original value

Effect on rice

Rice plant height at all recorded growth stages was not significantly affected by various weed management treatments (**Table 3**) except at 75 DAS at which rice plant height with pendimethalin *fb* HW (106.4 cm) was significantly higher than that of other treatments. Maximum number of effective tillers per m^2 was recorded in pendimethalin *fb* bispyribac-sodium which was statistically higher than all the remaining treatments (**Table 4**). Statistically similar result was obtained for grain per panicle for all the treatments except weedy check control plot.

The highest straw yield was observed in pendimethalin *fb* bispyribac-sodium (2.95 t/ha) and was statistically at par with pendimethalin *fb* HW, HW *fb* bispyribac-sodium and farmer's practice of hand weeding twice (**Table 4**). The lowest straw yield was observed in weedy check plot and was statistically similar to that in dry land weeded plot. Parameswari and Srinivas (2014) stated that the huge amount of nitrogen, phosphorous and potassium was removed by the weeds in weedy check resulting in lower uptake of nutrients by rice and hence low rice biomass yield. The highest grain yield was recorded in pendimethalin PE *fb* bispyribac-sodium PoE (2.63

Table 3. Effect of different weed management treatments on plant height of upland rice

Treatment	Rice plant height (cm)				
	30 DAS	60 DAS	45 DAS	75 DAS	90 DAS
Weedy check (no weeding)/ control	32.0	68.9	65.0	85.2^b	101.6
Manually running dry land weeder twice (15 and 30 DAS)	32.7	76.3	66.2	90.5^b	108.1
Farmers' practice HW twice (15 and 30 DAS)	31.3	74.8	67.3	94.0^b	110.0
One HW at 15 DAS *fb* bispyribac-sodium PoE at 0.4 g/ha 30 DAS	38.6	71.3	62.6	93.1^b	107.9
Pendimethalin PE 1.5 g/ha *fb* 1 HW 15 DAS	33.1	81.9	72.1	106.4^a	115.4
Pendimethalin PE 1.5 g/ha *fb* bispyribac-sodium PoE 0.4 g/ha 15 DAS	34.5	70.4	65.6	93.9^b	101.6
LSD (p=0.05)	NS	NS	NS	10.95*	NS

Note: Mean separated by DMRT and columns represented with same letter (s) are non-significant at 5% level of significance, * means significant, NS means non- significant

Table 4. Effect of different weed management treatments on rice yield attributes, straw yield, grain yield and harvest index

Treatment	No. of effective tiller/m^2	Grain per panicle	Sterility (%)	Straw yield (t/ha)	Grain yield (t/ha)	Harvest index
Weedy check (no weeding)/ control	238^b	73.9^b	31.4^a	1.88^b	0.989^c	0.35^c
Manually running dry land weeder twice (15 and 30 DAS)	210^b	80.2^a	18.1^a	1.91^b	1.453^{bc}	0.431^{ab}
Farmers' practice HW twice (15 and 30 DAS)	240^b	87.9^a	13.4^{ab}	2.29^{ab}	1.783^b	0.442^{ab}
One HW at 15 DAS *fb* bispyribac-sodium PoE at 0.4 g/ha 30 DAS	238^b	98.1^a	11^{ab}	2.33^{ab}	1.919^b	0.452^{ab}
Pendimethalin PE 1.5 g/ha *fb* 1 HW 15 DAS	245^b	83.6^a	15.9^{ab}	2.65^{ab}	1.616^b	0.387^{bc}
Pendimethalin PE 1.5 g/ha *fb* bispyribac-sodium PoE 0.4 g/ha 15 DAS	369^a	109.4^a	9.5^b	2.95^a	2.628^a	0.471^a
LSD (p=0.05)	80.9*	23.15*	15.52*	0.825**	0.465**	0.067*
Grand mean	257	88.9	16.5	2.33	1.731	0.423

Note: Mean separated by DMRT and columns represented with same letter (s) are non-significant at 5% level of significance, *mean significant and **mean highly significant

Table 5. Economics of different weed management treatments in upland rice

Treatment	Cost of cultivation (`/ha)	Gross return (`/ha)	Net return (`/ha)	B:C ratio
Weedy check (no weeding)/ control	20140^c	27696^c	7556^{bc}	1.375^{bc}
Manually running dry land weeder twice (15 and 30 DAS)	27758^b	40678^{bc}	12920^{bc}	1.462^{bc}
Farmers' practice HW twice (15 and 30 DAS)	50885^a	49935^b	-950^c	0.985^c
One HW at 15 DAS *fb* bispyribac-sodium PoE at 0.4 g/ha 30 DAS	47765^a	53726^b	5962^{bc}	1.139^{bc}
Pendimethalin PE 1.5 g/ha *fb* 1 HW 15 DAS	28758^b	45235^b	16478^b	1.588^b
Pendimethalin PE 1.5 g/ha *fb* bispyribac-sodium PoE 0.4 g/ha 15 DAS	23014^c	73572^a	50558^a	3.197^a
LSD (p=0.05)	4486.9*	13038.6*	14093.6*	0.457**
Grand mean	33053	48474	15421	1.624

Note: Mean separated by DMRT and columns represented with same letter (s) are non-significant at 5% level of significance, *significant and **mean highly significant t/ha) which was statistically higher than that of the remaining treatments (**Table 4**). The lowest grain yield from control plot (0.99 t/ha) which was statistically same as in dry land weeder used plot. Any reduction in weed pressure can be expected to promote yield as it lessens the strength of the competition for resources between the crop and the weeds (Phuong *et al.* 2005). The lowest yield was obtained under weedy check might be due to competition from weeds that reduced LAI, allowed less light transmission producing less photosynthates and ultimately low dry matter production (Parameswari and Srinivas 2014). Harvest index was highest with pendimethalin PE *fb* bispyribac-sodium PoE and lowest under weedy check control.

Economics

The cost of cultivation was higher for farmers' practice of hand weeding twice. Significantly higher gross return, net return and B:C ratio were obtained with pendimethalin *fb* bispyribac-sodium (**Table 5**).

Among the tested weed management treatments, highest yield (2.65 t/ha), net return (₹ 50558/ha) and B:C ratio (3.197) with lowest weed density and biomass was observed with pendimethalin PE 1.5 g/ha *fb* bispyribac-sodium PoE 0.4 g/ha 15 DAS and may be used for managing weeds and attaining maximum profitability of upland rice.

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Weed management in transplanted finger millet with pre-and post-emergence herbicides

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ABSTRACT

A field experiment was conducted during *Rabi* (winter season), 2020-21 at wetland farm of S.V. Agricultural College, Tirupati campus of Acharya N.G. Ranga Agricultural University, Andhra Pradesh, India to identify suitable pre-and post-emergence herbicide for managing weeds and enhancing productivity and profitability of transplanted finger millet. The hand weeding (HW) twice at 20 and 40 days after transplanting (DAT) resulted in lower density and biomass with higher weed control efficiency, grain yield, and benefit-cost ratio. It was closely followed by pre-emergence application (PE) of pretilachlor 500 g/ha or pyrazosulfuron-ethyl 15 g/ha. Post-emergence application (PoE) of penoxsulam 20 g/ha resulted in higher grain yield and benefit-cost ratio with broad-spectrum weed control among the post-emergence herbicides. The weeds in unweeded check reduced the grain yield by 64.39% compared to HW twice.

Finger millet [*Eleusine coracana* (L.) Gaertn] is a staple food crop for millions of people, who thrive under subsistence farming in dry areas like Eastern Africa, India and Sri Lanka. The grain of finger millet has an outstanding nutritional properties, *viz.* calcium (8.3%), iron (0.017%), dietary fibers and polyphenols (0.3 to 3%). Among different constraints that limit the productivity of finger millet, weed menace is one of the serious problems. Finger millet is a high stature crop with slower initial growth which remains under smothering due to the infestation of weeds at early stages of growth (Dhanapal *et al.* 2015). Generally, small millets are relatively poor competitors for growth resources than weeds, especially during the early stages of the crop. This severe competition due to uncontrolled weeds may result in drastic reduction in the yield up to 34 to 61% in finger millet depending on crop cultivars, nature and intensity of weeds, spacing, duration of weeds infestation, management practices and environmental conditions (Nanjappa and Hosamani 1985 and Mishra *et al*. 2018). Critical period for crop-weed competition of finger millet was 25-45 days after sowing (Yathisha *et al*. 2020). The research on chemical weed management in small millets is very meagre. Only limited pre-and post-emergence herbicides are selective in nature to control weeds in small millets with small seed size and sown at shallow depths (Mishra *et al.* 2018). Thus, there is need to have an alternate herbicides with different modes of action for obtaining broad-spectrum weed control coupled with low dose and high-efficacy herbicide for control of mixed weed flora in transplanted finger millet. Hence, the present study was undertaken to assess the performance of pre-and post-emergence herbicides for broad-spectrum weed control in transplanted finger millet.

A field experiment was conducted during *Rabi* (winter season), 2020-21 at wetland farm of S.V. Agricultural College, Tirupati campus of Acharya N.G. Ranga Agricultural University, Andhra Pradesh. The soil of experimental site was sandy loam in texture, neutral in reaction, low in organic carbon and available nitrogen, medium in available phosphorus and potassium. The total rainfall received during crop period was 574.4 mm with 28 rainy days. The experiment was laid out in a randomized block design with tentreatments and replicated thrice. The treatments consisted of pre-emergence application (PE) of alachlor 1000 g/ha, isoproturon 750 g/ha, pyrazosulfuron-ethyl 15 g/ha, pretilachlor 500 g/ha, post-emergence application (PoE) of bispyribac-sodium 20 g/ha, topramezone 20 g/ha, penoxsulam

20 g/ha, ethoxysulfuron 20 g/ha, and hand weeding twice at 20 and 40 days after transplanting (DAT) and unweeded check. (**Table 1**). Phytotoxicity scoring was done at 6th and 7th days after herbicide application of pre-and post-emergence herbicides, respectively as per the method suggested by Singh and Rao (1976). Finger millet was transplanted at 30 x 10 cm spacing on 12th October, 2020. Pre-and post-emergence herbicides were applied to transplanted finger millet at two and 20 DAT by using power operated knapsack sprayer fitted with flat fan nozzle and spray volume of 500 L/ha. The crop was fertilized with 60 kg N, 30 kg P and 30 kg K/ha. Nitrogen was applied in two splits, *viz*. ½ as basal and the remaining ½ as top dressing at 30 DAT and entire dose of phosphorous and potassium was applied as basal at the time of sowing itself. The rest of the packages of practices were adopted as per the recommendations of the Acharya N.G. Ranga Agricultural University. Weed density and biomass were recorded randomly at harvest with the help of 0.25 m^2 quadrat and subjected to square root transformation ($\sqrt{x+0.5}$) to normalize their distribution as suggested by Gomez and Gomez (1984). Weed control efficiency was computed as per the method suggested by (Mani *et al.* 1973). Growth parameters, *viz*. plant height and dry matter production yield attributes, *viz*. productive tillers/m^2, weight of ear head and weight of grains/ head were recorded at harvest from the randomly selected plants from net plot area. The crop was harvested on 9th January, 2021. Grain and straw yield of transplanted finger millet were recorded based on the yield obtained from net plot. Net returns were calculated by subtracting the cost of cultivation from the gross returns. Benefit-cost ratio was calculated after dividing gross returns with cost of cultivation.

Effect on weeds

The predominant weed flora associated with transplanted finger millet was *Digitaria sanguinalis* (L.) Scop. (35%), *Dactyloctenium aegyptium* (L.) (21%), *Cyperus rotundus* L. (17%), *Trichoderma indicum* (L.) Lehm. (12%), *Celosia argentea* L., (6%), *Commelina benghalensis* L., (5%) and others (4%). All the weed management practices significantly influenced weed density and biomass (**Table 1**). Among the weed management treatments, the lowest density and biomass of grasses, broad-leaved weeds and total weeds as well as higher weed control efficiency were obtained with pretilachlor 500 g/ha PE, which was comparable with pyrazosulfuron-ethyl 15 g/ha PE and penoxsulam 20 g/ha PoE. The HW twice at 20 and 40 DAT was superior than all other treatments tested. Pretilachlor 500 g/ha as PE found effective in suppressing the density and biomass of grasses, sedges and broad-leaved weeds followed by pyrazosulfuron-ethyl 15 g/ha. These results are in agreement with findings of Tuti *et al.* (2016) and Banu *et al.* (2016). Among the post-emergence herbicides, penoxsulam 20 g/ha was effective in suppressing density and biomass of total weeds including grasses, sedges and broad-leaved weeds. Topramezone 20 g/ha PoE resulted in higher density and biomass of total weeds as this herbicide was unable to control heavy infestation of weeds and it caused phytotoxicity on crop, which in turn created vacant spaces due to stand loss and reduced crop competitiveness against weeds that led to rampant growth of weeds.

Effect on finger millet growth and yield

Different weed management treatments tested in transplanted finger millet exerted significant and

Table 1. Weed density, weed biomass and weed control efficiency (%) as influenced by different treatments in transplanted finger millet

Treatment	Weed density (no./m^2)				Weed biomass (g/m^2)				WCE (%)
	Grasses	Sedges	BLW	Total	Grasses	Sedges	BLW	Total	
Alachlor (1000 g/ha) 2 DAT	5.55(30.3)	5.49(29.7)	6.43(41.0)	10.05(101.0)	5.02(24.8)	5.00(24.5)	5.37(28.4)	8.84(77.7)	55.13
Isoproturon (750 g/ha) 2 DAT	6.92(47.3)	6.70(44.3)	7.20(51.3)	11.97(143)	5.70(32.0)	5.65(31.4)	5.91(34.6)	9.92(98.0)	43.42
Pyrazosulfuron-ethyl (15 g/ha) 2 DAT	4.81(22.7)	4.56(20.3)	5.02(24.7)	8.24(67.7)	4.34(18.4)	4.21(17.2)	4.52(19.9)	7.48(55.5)	67.93
Pretilachlor (500 g/ha) 2 DAT	4.67(21.3)	4.26(17.7)	4.81(22.7)	7.86(61.7)	4.24(17.5)	4.18(17.0)	4.49(19.8)	7.40(54.3)	68.66
Bispyribac-sodium (20 g/ha) 20 DAT	5.51(29.8)	5.46(29.3)	6.22(38.3)	9.89(97.5)	4.99(24.4)	4.75(22.1)	5.32(27.8)	8.65(74.3)	57.07
Topramezone (20 g/ha) 20 DAT	6.87(46.7)	6.27(39.0)	7.18(51.2)	11.71(136.8)	5.60(30.9)	5.45(29.3)	5.82(33.4)	9.70(93.6)	45.93
Penoxsulam (20 g/ha) 20 DAT	4.83(22.9)	4.71(21.7)	5.21(26.7)	8.46(71.2)	4.44(19.3)	4.24(17.5)	4.62(20.9)	7.61(57.7)	66.68
Ethoxysulfuron (20 g/ha) 20 DAT	4.85(23.0)	4.64(21.0)	5.46(29.3)	8.58(73.3)	4.45(19.3)	4.23(17.4)	4.81(22.6)	7.71(59.3)	65.73
Hand weeding 20 and 40 DAT	4.02(15.7)	3.46(11.5)	3.58(12.3)	6.32(39.5)	2.65(6.5)	2.70(6.8)	3.17(9.6)	4.85(23.0)	86.71
Unweeded check (control)	7.70(59.5)	7.37(54.3)	7.92(62.7)	13.30(176.5)	7.05(49.3)	7.96(63.0)	7.83(60.8)	13.2(173.2)	-
LSD (p=0.05)	0.60	0.59	0.68	1.08	0.38	0.40	0.44	0.81	-

Figures in parentheses indicates square root transformed values, WCE: Weed control efficiency; DAT: Days after transplanting

Table 2. Yield components and yield as influenced by different weed management treatments in transplanted finger millet

Treatment	Plant height (cm)	Dry matter production (t/ha)	Productive tillers/m^2	Weight of ear head (g)	Weight of grains ear/head (g)	Grain yield (t/ha)	Straw yield (t/ha)	Net returns (`/ha)	B:C ratio
Alachlor (1000 g/ha) 2 DAT	88	5.68	55	8.00	6.75	2.34	3.25	37285	2.08
Isoproturon (750 g/ha) 2 DAT	75	3.60	40	6.33	5.08	1.24	2.16	4280	1.13
Pyrazosulfuron-ethyl (15 g/ha) 2 DAT	102	6.76	68	10.40	9.05	2.82	3.84	53189	2.60
Pretilachlor (500 g/ha) 2 DAT	105	7.30	70	10.42	9.12	2.86	3.88	54075	2.61
Bispyribac-sodium (20 g/ha) 20 DAT	85	5.72	53	7.90	6.65	2.20	2.99	30864	1.84
Topramezone (20 g/ha) 20 DAT	71	2.95	34	5.66	4.41	0.85	1.72	-10315	0.72
Penoxsulam (20 g/ha) 20 DAT	100	6.71	68	9.82	8.42	2.81	3.80	51563	2.49
Ethoxysulfuron (20 g/ha) 20 DAT	89	5.95	60	8.70	7.44	2.39	3.32	39567	2.17
Hand weeding 20 & 40	116	8.12	80	11.36	9.96	3.29	4.37	53958	2.15
Unweeded check (control)	74	3.46	37	5.67	4.42	1.17	1.90	4180	1.13
LSD (p=0.05)	10	0.73	7	0.83	0.79	0.40	0.47	9609	0.33

positive influence on finger millet growth and yield components as well as yield. The highest values of growth parameters, *viz.* plant height and dry matter production and yield components *viz.*, productive tillers/m^2, weight of ear head, weight of grains/ear head and grain yield of transplanted finger millet were obtained with HW twice and it was closely followed by pretilachlor 500 g/ha PE due to reduced competition for growth resources from weeds as they were effectively controlled (**Table 2**). The reduction in grain yield due to topramezone 20 g/ha PoE treatment might be due to inhibition of 4-Hydroxyphenyl-pyruvate dioxygenase (HPPD) enzyme in finger millet. Among all the weed management practices, the highest net returns and benefit-cost ratio were obtained with pretilachlor 500 g/ha PE and it was closely followed by pyrazosulfuron ethyl 15 g/ha PE and penoxsulam 20 g / ha PoE. Hand weeding twice even though effective in managing weeds, it recorded lesser benefit-cost ratio than effective pre-and post-emergence herbicides treatments, due to increased cost of manual weeding.

Thus, broad-spectrum weed control, higher finger millet grain yield and monetary returns can be obtained with pre-emergence application of pretilachlor 500 g/ha or pyrazosulfuron-ethyl 15 g/ha on sandy loam soils.

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Effect of different post-emergence herbicides on weeds, crop yield and economics of greengram grown in rainy season

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ABSTRACT

A field experiment was conducted at field unit of AICRP on Agro-forestry, University of Agricultural Sciences, GKVK, Bengaluru during *Kharif* (rainy season) 2018 to study the effect of different post-emergence herbicides on weeds, crop yield and economics of *Kharif* greengram. Eleven treatments including the application of three post-emergence herbicides (fomesafen, propaquizafop and imazethapyr) and their combinations at 25 days after seeding (DAS), hand weeding (HW) twice at 15 and 30 DAS, weed free check and un-weeded control were replicated thrice in randomized complete block design. The post-emergence application (PoE) of fomesafen + propaquizafop 294 + 91 g/ha and fomesafen + propaquizafop 252 + 78 g/ha resulted in significantly lower weed biomass at 45 DAS (11.65 and 12.78 g/m^2, respectively) and at harvest (15.59 and 18.69 g/m^2, respectively) due to reduced weed density at 45 DAS (21.5 and 23.4 no./m^2, respectively) and at harvest (15.90 and 18.01 no./m^2, respectively). These treatments have recorded higher weed control efficiency and lower weed index (71.6%, 6.21% and 69.09%, 10.73%, respectively). Among the various herbicide treatments, significantly, highest greengram seed yield (1058 kg/ha) was recorded with post-emergence application of fomesafen + propaquizafop 294 + 91 g/ha.

Greengram is second most important pulse crop in India after pigeon pea in the acreage. Weed infestation is one of the major biotic factor which is limiting growth and productivity of greengram crop. Yield reduction in greengram ranges from 35% (Raman and Krishnamoorthy 2005) to 80 % (Talnikar *et al.* 2008) depending on the type and weed flora associated with the crop. Critical period of crop weed competition for *Kharif* (rainy season) greengram crop is 20-40 DAS (Sheoran *et al*. 2008). In greengram, weed problem can be successfully managed by utilizing mechanical practices like hand weeding and inter-cultivation. But in the present scenario, timely availability of labour is a major constraint and continuous rainfall during the rainy season obstructs timely manual operations. Mechanical method being expensive, tedious and thus making farmers choose chemical weed control. Pendimethalin is the most widely used pre-emergence herbicide. Its effectiveness for late emerging weeds in *Kharif* greengram is less due to frequent rains of south- west monsoon. Moreover, the late emerged weeds pose severe competition to the crop and infest the land with weed seeds making it less productive in the successive seasons. Hence, post-emergence herbicide application (PoE) is alternative for effective weed control and increasing the growth and productivity of greengram. Herbicides like fomesafen and propaquizafop are characterized by broad spectrum weed control with an environmental benefit derived from their low application rates in the field (Tiwari and Mathew 2002).

A field experiment was conducted during *Kharif* 2018 to study the effect of different post-emergent herbicides on weed dynamics of *Kharif* greengram at field unit of AICRP on Agro-forestry, University of Agricultural Sciences, GKVK, Bengaluru. Eleven treatments including the application of three post-emergence herbicides and their combinations (fomesafen, propaquizafop and imazethapyr) at 25 days after seeding (DAS), hand weeding (HW) twice at 15 and 30 DAS, weed free check and unweeded control. A randomized complete block design with three replications was used. The soils of experimental site belongs to ferric luvisols. The soil was red sandy loam with slightly acidic in reaction (pH 6.2) with medium electrical conductivity (0.34 dS/m) and medium organic carbon content (0.55%). Greengram variety *'KKM-3'* was sown at a spacing of 30 x 10 cm and the recommended dose of fertilizer *i.e*., 25:50:25 kg of N, P and K was applied at the time of sowing. All the post-emergence herbicides were applied using high volume spray to the weeds as per the treatment at 25 DAS.

Number of weeds (grasses, broad-leaved, sedges) per 1 m^2 in net plot was recorded at 45 DAS and at harvest. Weeds cut up to ground level and were oven dried for 48 hrs at 60 ^{0}C until obtaining a constant weight and total dry weight of the weeds (biomass) were recorded at 45 DAS and at harvest.

Weed control efficiency shows how effectively the treatment controlled the weeds. The weed control efficiency of treatments was worked out using the formula given by Mani *et al.* (1973).

$$\text{Weed control efficiency} = \frac{X - Y}{X} \times 100$$

Where,

X = weed biomass in unweeded check plot

Y = weed biomass in the treated plot

Weed index indicates to what extent yield is reduced with respect to crop weed competition and for different treatments it was worked out by using the formula stated by Gill and Kumar (1969).

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

Where,

X = Yield from weed free plot

Y = Yield from treated plot

First the border plants were harvested and separated. Later, the crop from each net plot was harvested and sun dried for 3 days, bundled, tagged, weighed and transported to threshing floor. Threshing was done for each plot and yield was computed to kg/ha basis. The value of return on investment was calculated by converting increased seed yield over the weed control into monetary equivalent with market prices and cost involved for weed control operations.

The collected weed data on different traits was statically analyzed using the standard procedure and the results were tested at five per cent level of significance as given by Gomez and Gomez (1984).

Effect on weeds

Major weed species observed in the experimental field were *Borreria articularis, Alternanthera sessilis, Euphorbia geniculata, Acanthospermum hispidum, Parthenium hysterophorus, Amaranthus viridis* among broad leaved weeds, *Eleusine indica, Dactyloctenium aegyptium* and *Echinochloa colona* among the grassy weeds and *Cyperus rotundus* among sedges (**Table 1**).

The density and biomass of sedge, grasses and broad-leaf weeds differed significantly with tested weed management treatments. All the weed management treatments had significantly lower weed density and biomass than unweeded check at different stages of crop growth. The magnitude of reduction in weed biomass and density varied depending upon the weed control efficiency of the herbicide treatments.

Among the herbicide treatments, the density and biomass of sedges and grasses was observed to be the lowest with application of propaquizafop when compared to fomesafen and imazethapyr (**Table 2**

Table 1. The density (no./m^2) of dominant grasses, sedge and broad-leaved weeds and total weed density at 45 DAS in greengram as influenced by treatments tested

Treatment	Sedge	Grasses				Broad-leaved weeds							Total weed density
	Cr	Ei	Da	Ec	Total	Ba	As	Eg	Ah	P	Av	Total	
Fomesafen 250 g/ha	5.6	9.0	6.0	3.3	18.4	7.3	1.8	1.7	2.3	1.2	2.3	16.5	40.4
Propaquizafop 100 g/ha	3.9	2.5	2.7	0.8	6.0	14.9	2.1	3.5	3.5	1.8	2.3	28.3	38.1
Imazethapyr 100 g/ha	3.8	4.5	3.2	2.0	9.6	20.3	1.5	1.3	2.7	1.3	1.2	28.3	41.7
Fomesafen + propaquizafop 168 + 52 g/ha	3.1	3.9	2.1	1.3	7.3	11.8	0.9	2.4	2.3	0.4	3.1	20.9	31.3
Fomesafen + propaquizafop 210 + 65 g/ha	2.2	4.0	1.1	2.0	7.0	8.7	1.7	1.8	1.0	1.1	1.4	15.7	24.9
Fomesafen + propaquizafop 252 + 78 g/ha	2.2	3.6	1.3	1.7	6.6	6.8	1.3	1.5	1.7	2.0	1.2	14.6	23.4
Fomesafen + propaquizafop 294 + 91 g/ha	2.5	3.2	1.2	0.5	5.0	5.3	2.1	2.3	1.1	1.5	1.7	14.1	21.5
Propaquizafop + imazethapyr 50 + 75 g/ha	2.6	2.4	3.3	1.2	7.0	13.7	2.6	2.5	1.3	1.2	2.2	23.6	33.1
Hand weeding twice at 15 and 30 days after seeding	1.9	1.1	1.0	1.0	3.1	0.9	0.4	1.3	0.6	1.2	0.2	4.7	9.7
Weed free check	0.0	0.0	0.0	0.0	0.0	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Unweeded check	7.5	12.5	5.1	2.8	20.4	28.6	7.4	2.5	3.7	3.7	1.9	47.8	75.7

Cr- *Cyperusrotundus,* Ei- *Eleusine indica,* Da- *Dactylocteniumaegyptium,* Ec- *Echinochloacolona,* Ba- *Borreriaarticularis,* As- *Alternanthera sessilis,* Eg- *Euphorbia geniculate,* Ah- *Acanthospermumhispidum,* P- *Parthenium hysterophorus,* Av- *Amaranthus viridis* and **3**). At 45 DAS and at harvest, significantly lower density and biomass of grasses and sedges were recorded with post-emergence application of fomesafen + propaquizafop 294 + 91 g/ha, fomesafen + propaquizafop 252 + 78 g/ha and propaquizafop 100 g/ha compared to the unweeded check. Similar observations were made in soybean by Kumar *et al.* (2018) and Bhimwal *et al.* (2018).

Density and biomass of broad-leaved weeds was observed to be the lowest with the application of fomesafen when compared to propaquizafop and imazethapyr. At 45 DAS and at harvest significantly lower density and biomass of broad-leaved weeds were recorded with post-emergence application of fomesafen + propaquizafop 294 + 91 g/ha, fomesafen + propaquizafop 252 + 78 g/ha and fomesafen 250 g/ha as compared to the unweeded check and were statistically on par with hand weeding at 15 and 30 DAS. Similar observation was also reported in common bean (Santos 2006) and in tomato (Mohsen and Doohan 2017).

Post-emergence application of fomesafen + propaquizafop 294 + 91 g/ha and fomesafen + propaquizafop 252 + 78 g/ha resulted in significantly lower total weed biomass at 45 DAS (11.65 and 12.78 g/m^2, respectively) and at harvest (15.59 and 18.69 g/m^2, respectively) due to reduced total weed density at 45 DAS (21.5 and 23.4 no./m^2, respectively) and at harvest (15.90 and 18.01 no./m^2, respectively). This is due to control of broad-spectrum weeds as a result of different mode of action of herbicides *i.e.*, fomesafen which inhibited the protoporphyrinogen oxidase (PROTOX) enzyme was effective in controlling the dicot weeds and propaquizafop, which inhibits fatty acid synthesis (ACCase) was effective in killing the monocot weeds (Tiwari and Mathew, 2002). Hence, combined application of fomesafen + propaquizafop was more effective for weed control in greengram as compared to application of fomesafen or propaquizafop alone. Whereas, application of fomesafen alone controlled only the broad-leaved weeds and application of propaquizafop alone controlled only the grassy weeds. Combination

Table 2. Weed density and biomass at 45 days after seeding (DAS) in greengram as influenced by weed management treatments

Treatment	Weed density (no./m^2)				Weed biomass (g/ m^2)			
	BLW	Grasses	Sedges	Total	BLW	Grasses	Sedges	Total
Fomesafen 250 g/ha	4.18(16.5)	4.40 (18.4)	2.56(5.6)	6.44 (40.4)	3.52(11.39)	4.44(18.71)	1.15(0.32)	5.61(30.42)
Propaquizafop 100 g/ha	5.41(28.3)	2.64(6.0)	2.21(3.9)	6.25 (38.1)	4.62(20.86)	2.07(3.28)	1.07(0.15)	5.02(24.29)
Imazethapyr 100 g/ha	5.41(28.3)	3.26(9.6)	2.17(3.8)	6.53 (41.7)	4.88(22.61)	2.38(4.77)	1.31(0.29)	5.35(28.67)
Fomesafen + propaquizafop 168 + 52 g/ha	4.67(20.9)	2.87(7.3)	2.36(3.1)	5.68 (31.3)	4.40(18.38)	2.19(3.82)	1.19(0.42)	4.85(22.56)
Fomesafen + propaquizafop 210 + 65 g/ha	4.07(15.7)	2.83(7.0)	1.79(2.2)	5.09(24.9)	3.97(14.62)	2.41(4.85)	1.16(0.34)	4.56(19.81)
Fomesafen + propaquizafop 252 + 78 g/ha	3.95(14.6)	2.76(6.6)	1.78(2.2)	4.83 (23.4)	3.41(10.35)	1.77(2.13)	1.13(0.29)	3.71(12.78)
Fomesafen + propaquizafop 294 + 91 g/ha	3.88(14.1)	2.38(5.0)	1.86(2.5)	4.74 (21.5)	3.28(9.46)	1.76(2.09)	1.05(0.10)	3.56(11.65)
Propaquizafop + imazethapyr 50 + 75 g/ha	4.96(23.6)	2.82(7.0)	2.22(2.6)	5.84(33.1)	4.43(18.05)	2.11(3.45)	1.21(0.47)	4.79(21.97)
Hand weeding twice at 15 and 30 DAS	2.38(4.7)	2.03(3.1)	1.69(1.9)	3.27(9.7)	2.60(5.43)	1.42(1.07)	1.02(0.06)	2.79(7.09)
Weed free check	1.00(0.0)	1.00(0.0)	1.00(0.0)	1.00(0.0)	1.00(0.00)	1.00(0.00)	1.00(0.00)	1.00(0.00)
Unweeded check	6.99(47.8)	4.62(20.4)	2.92(7.5)	8.76(75.7)	6.13(37.21)	2.79(6.71)	1.24(0.56)	6.74(44.48)
LSD (p=0.05)	0.35	0.75	0.51	1.72	0.94	0.65	0.12	1.11

Data within parentheses are original values; DAS: Days after seeding

Table 3. Weed density and biomass at harvest in greengram as influenced by weed management treatments

Treatment	Weed density (no./m^2)				Weed biomass (g/ m^2)			
	BLW	Grasses	Sedges	Total	BLW	Grasses	Sedges	Total
Fomesafen 250 g/ha	3.90 (14.22)	3.84 (13.78)	2.08 (3.36)	5.69 (31.36)	4.60 (20.22)	3.97(14.76)	1.89(2.57)	6.20(37.55)
Propaquizafop 100 g/ha	5.98 (34.78)	2.39 (4.69)	1.66 (1.77)	6. 50 (41.25)	3.95 (14.60)	2.18(3.75)	1.71(1.89)	4.6 (20.24)
Imazethapyr 100 g/ha	5.32 (27.35)	2.96 (7.76)	1.76 (2.12)	6.18 (37.22)	5.39 (28.08)	2.84(7.34)	1.78(2.17)	6.21 (37.59)
Fomesafen + propaquizafop 168 + 52 g/ha	4.50 (19.29)	2.54 (5.46)	1.71 (1.94)	5.26 (26.69)	4.67 (20.88)	2.91 (7.46)	1.59(1.57)	5.56 (29.91)
Fomesafen + propaquizafop 210 + 65 g/ha	3.97 (14.80)	2.46 (5.06)	1.70 (1.88)	4.77 (21.73)	4.14 (16.15)	2.19(3.98)	1.57(1.47)	4.75 (21.6)
Fomesafen + propaquizafop 252 + 78 g/ha	3.64 (12.29)	2.33 (4.44)	1.51 (1.28)	4.36 (18.01)	3.90 (14.20)	2.07(3.31)	1.47(1.18)	4.43 (18.69)
Fomesafen + propaquizafop 294 + 91 g/ha	3.52 (11.39)	2.15 (3.63)	1.39 (0.98)	4.11 (15.90)	3.68 (12.58)	1.91(2.75)	1.12(0.26)	4.07 (15.59)
Propaquizafop + imazethapyr 50 + 75 g/ha	4.68 (20.96)	2.34 (4.47)	1.73 (2.07)	5.34 (27.50)	4.91 (23.10)	2.17(3.76)	1.35(0.82)	5.35 (27.68)
Hand weeding twice at 15 and 30 DAS	2.97 (7.80)	2.04 (3.18)	1.33 (0.87)	3.60 (11.95)	3.05 (8.31)	1.57(1.58)	1.35(0.83)	3.42 (10.72)
Weed free check	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00(0.00)	1.00(0.00)	1.00 (0.00)
Unweeded check	7.32 (52.78)	4.45 (18.82)	3.02 (8.31)	8.99 (79.9)	7.59 (56.59)	3.12(8.94)	2.62(5.89)	8.51 (71.42)
LSD (p=0.05)	0.95	0.4	0.35	0.85	0.9	0.56	0.12	1.08

Data within parentheses are original values; DAS: Days after sowing of these both herbicides have longer effect on controlling weeds and brought significant reduction in weed biomass as compared to weedy check as also observed in field pea (Singh *et al.* 2014) and soybean (Kadam *et al.* 2018).

The unweeded check recorded the highest weed biomass at 45 DAS (44.48 g/m^2) and at harvest (71.42 g/m^2) as a result of higher weed density of 75.4 and 79.9 no./m^2, respectively. This could be attributed to higher density and biomass of grasses, sedges and broad-leaved weeds.

Among the treatments tested, weed free check recorded complete control of weeds with weed control efficiency of 100 per cent at all the stages when compared to all other treatments (**Table 4**). The crop yield is directly proportional to weed control efficiency (WCE) and inversely related to weed index (WI). At harvest, higher weed control efficiency was observed in hand weeding twice at 15 and 30 DAS (87.19%) followed by post-emergent application of fomesafen + propaquizafop 294 + 91 g/ha (71.60%) and fomesafen + propaquizafop 252 + 78 g/ha (69.09%) due to reduction in the weed biomass as a result of effective weed management in these treatments.

Effect on greengram

The new herbicide molecules like fomesafen and propaquizafop did not cause any phytotoxic symptoms on greengram. In the present study, significant differences were noticed in yield of greengram as a consequence of weed control treatments involving post-emergence application of herbicides. All the herbicide treatments resulted in significantly higher seed yield compared to the unweeded check. Significantly, higher seed yield was recorded with post-emergence application of fomesafen + propaquizafop 294 + 91 g/ha (1058 kg/ha) and fomesafen + propaquizafop 252 + 78 g/ha (1007 kg/ha) and were statistically on par with hand weeding at 15 and 30 DAS (1094 kg/ha) (**Table 4**). The reduction in yield of unweeded check was mainly attributed to the reduction in the leaf area, which is an important factor that determines the photosynthetic ability, growth and dry matter production (Algotar *et al.* 2014, Mamatha *et al.* 2017).

Weed index, an indicator of yield reduction due to weed competition, was higher in unweeded control (64.6%). The lower weed index was noticed in hand weeding twice at 15 and 30 DAS (3.01%) followed by post- emergence application of fomesafen + propaquizafop 294 + 91 g/ha (6.21%) and fomesafen + propaquizafop 252 + 78 g/ha (10.73%) due to satisfactory control of weeds and reduction in the crop weed competition which enabled the crop to utilize available resources like light, nutrients, moisture and space resulting in higher yield (Gupta *et al.* 2013 and Kewat *et al.* 2014).

Return on investment on weed control

By manual hand weeding operations, yield loss can be minimized in the crop but it's costly due to increased labour wages. The manual weeding method of weed management generated, on an average, 4 rupees returns over single rupee investment. While post-emergence herbicides use resulted in 22.5 rupees return over single rupee investment, on an average. Post-emergence application of fomesafen + propaquizafop 294 + 91 g/ha recoded highest greengram seed yield. However, the application of fomesafen + propaquizafop 168 +52 g/ha recorded higher return on investment of 34 rupees.

Table 4. Weed control efficiency and weed index at harvest in greengram as influenced by weed management treatments

Treatment	Seed yield (kg/ha)	Weed control efficiency (%)	Weed index (%)	Return on investment
Fomesafen 250 g/ha	728	46.63	35.46	11.4
Propaquizafop 100 g/ha	717	49.67	36.44	14.6
Imazethapyr 100 g/ha	681	44.91	39.63	21.6
Fomesafen + propaquizafop 168 + 52 g/ha	937	58.65	16.93	34.0
Fomesafen + propaquizafop 210 + 65 g/ha	959	67.11	14.98	28.3
Fomesafen + propaquizafop 252 + 78 g/ha	1007	69.09	10.73	25.6
Fomesafen + propaquizafop 294 + 91 g/ha	1058	71.60	6.21	23.8
Propaquizafop + imazethapyr 50 + 75 g/ha	844	56.27	25.18	20.6
Hand weeding twice at 15 and 30 DAS	1094	87.19	3.01	4.8
Weed free check	1128	100.00	0.00	4.2
Unweeded check	402	0.00	64.36	-
LSD (p=0.05)	72.00	-	-	-

Inputs cost (Rs./kg): seeds (KKM-3)= 120.00; FYM = 0.50; Urea = 5.62; MOP = 7.8; Fomesafen = 2000; Fomesafen + Propaquizafop = 1230; Propaquizafop + imazethapyr = 750; Carbendazim = 325.00; Carbandizim = 325; Output: greengram (Rs./Kg.) = 69.75

Conclusion

Post-emergence application of fomesafen + propaquizafop 294 + 91 g/ha recoded significantly lower weed density and biomass, higher weed control efficiency and highest greengram yield due to its efficacy in controlling broad spectrum of weeds with no crop phytotoxicity. Hence, it can be used for managing weeds and increasing greengram yield of *Kharif* greengram under current labour constraint conditions.

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Weed management in groundnut with diclosulam herbicide

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ABSTRACT

The efficacy of diclosulam herbicide in managing weeds and improve groundnut yield was tested in this study on weed management in groundnut (*Arachis hypogaea* L.). The diclosulam pre-plant incorporation (PPI) and pre-emergence application (PE) significantly reduced the sedges density. The diclosulam 27 g/ha PE followed by (*fb*) hand weeding (HW) at 50 days after seeding (DAS) recorded highest weed control efficiency (80.44%) and lowest (92) weed density (number /m^2) at 80 DAS. Number of groundnut pods per plant and pod yield was significantly higher with diclosulam 27 g/ha PE *fb* HW at 50 DAS and also gave the highest net return of ₹ 1,07,335/ha and B:C ratio of 2.32 followed by hand weeding twice at 30 DAS and 50 DAS and diclosulam 27 g/ha PPI *fb* HW at 50 DAS.

Groundnut is widely cultivated in the tropics and sub-tropics in between 40°N to 50°S latitudes. It is an important oilseed crop ranked 2nd with respect to production and 1st with respect to area in India (GOI 2020). In spite of this, India didn't achieve self-sufficiency in vegetable oils production and this leads to largest imported agricultural commodity in the country (DGCIS 2018). Among several factors for the reduction of productivity in groundnut, weed infestation play major role and reduces the yield up to 35.8% (Gharde *et al*. 2017, 2018). Therefore, an experiment was conducted to evaluate the efficacy of new herbicide, diclosulam, in managing weeds in groundnut.

The field experiment was conducted in the agronomy experiment research farm of School of Agricultural Sciences and Rural Development (SASRD), Nagaland University, Medziphema campus during *Kharif* season, of 2019.The climate of the experimental site lays in a humid subtropical zone with moderate temperature with medium to high rainfall. The soil of the field experimental field was having pH (4.8), organic carbon (1.09%), available N (228.8 kg/ha), P (19.96 kg/ha) and K (220.26 kg/ha). The experiment consisted of eight weed control treatments, *viz.* weedy check; hand weeding twice at 30 days after seeding (DAS) and 50 DAS; diclosulam 84% WDG (diclosulam) 17 g/ha pre-plant incorporation (PPI) followed by (*fb*) hand weeding (HW) at 50 DAS; diclosulam 27 g/ha PPI *fb* hand weeding at 50 DAS; diclosulam pre-emergence application (PE) 17 g/ha *fb* hand weeding at 50 DAS; diclosulam 27 g/ha PE *fb* hand weeding at 50 DAS; hand weeding at 30 DAS *fb* diclosulam 17 g/ha post-emergence application (PoE) at 50 DAS and hand weeding at 30 DAS fb diclosulam 27 g/ha PoE at 50 DAS. The experiment was laid out in randomized block design with three replications. Groundnut variety '*ICGV 87141* (*ICGS 76*)' was sown. The crop was fertilized with 20 kg N, 40 kg P and 30 kg K/ha through urea, single super phosphate and muriate of potash respectively. For spraying herbicides as per the treatment, hand sprayer is used by adopting a spray volume of 400 L/ha. Weed count (density) and dry weight (biomass) were recorded at 40 and 80 DAS at two spots using a quadrat of 50 × 50 cm and expressed as number/m^2 and g/m^2, respectively. The data on weed density and biomass were subjected to square root transformation $(\sqrt{x+1})$ before statistical analysis. Economics of the treatments was computed based upon prevalent prices.

The dominant weeds present in the experimental field were *Sonchus asper, Mimosa pudica, Marsilea quadrifolia, Leucas aspera, Amaranthus spinosus, Celosia argentea, Eleusine indica, Axonopus compressus, Digitaria sanguinalis, Cynodon dactylon, Fimbristylis miliacea* and *Cyperus iria.* The application of diclosulam herbicides resulted in lower density and biomass of all categories of weeds (**Table 1** and **Table 2**), which is due to its broad spectrum of action of herbicide. At 80 DAS, the diclosulam 27 g/ha PE *fb* hand weeding at 50 DAS resulted in effective control of grasses, broad-leaved weeds and sedges at 40 and 80 DAS and also recorded lower weed

Table1. Effect of weed management treatments on the density of grass, broad-leaved and sedge weeds and weed control efficiency in groundnut

Treatment	Weed density (no./m^2)						WCE (%) at 80 DAS
	Grassy weeds		Broad-leaved weeds		Sedges		
	40 DAS	80 DAS	40 DAS	80 DAS	40 DAS	80 DAS	
Diclosulam 17g/ha PPI *fb* HW at 50 DAS	12.75 (162)	7.46 (58)	7.03 (56)	6.44 (46)	4.51 (20)	3.75 (14)	73.15
Diclosulam 27 g/ha PPI *fb* HW at 50 DAS	11.25 (126)	6.75 (48)	6.62 (46)	5.87 (42)	3.23 (10)	3.39 (12)	77.18
Diclosulam 17g/ha PE *fb* HW at 50 DAS	12.10 (146)	7.23 (52)	5.80 (38)	6.87 (50)	4.04 (16)	3.75 (14)	75.06
Diclosulam 27 g/ha PE *fb* HW at 50 DAS	10.12 (102)	6.55 (44)	5.63 (32)	5.92 (38)	2.86 (8)	3.23 (10)	80.44
HW at 30 DAS *fb* diclosulam 17g/ha PoE at 50 DAS	9.51 (90)	11.73 (138)	9.40 (88)	9.73 (98)	6.52 (42)	7.47 (56)	42.90
HW at 30 DAS *fb* diclosulam 27 g/ha PoE at 50 DAS	9.30 (86)	11.30 (128)	9.29 (86)	9.58 (92)	6.04 (36)	7.38 (54)	46.56
HW twice at 30 DAS and 50 DAS	9.16 (84)	7.06 (50)	9.08 (82)	6.15 (40)	5.87 (34)	4.26 (18)	74.95
Weedy check	14.67 (215)	14.16 (200)	9.82 (96)	10.22 (104)	8.74 (76)	10.02 (100)	0.00
LSD (p=0.05)	0.47	2.28	2.57	1.77	0.49	0.81	5.59

Table 2. Effect of weed management treatments on weed biomass at harvest, groundnut pod yield, and economics

Treatment	Grassy weeds biomass (g/m^2)	Broad-leaved weeds biomass (g/m^2)	Sedge weeds biomass (g/m^2)	Groundnut pod yield (t/ha)	Economics		
					Cost of cultivation (x103 `/ha)	Net returns (x103 `/ha)	B:C ratio
Diclosulam 17g/ha PPI *fb* HW at 50 DAS	5.52(30)	5.41(29)	4.52(20)	2.23	45.58	68.48	1.50
Diclosulam 27 g/ha PPI *fb* HW at 50 DAS	5.29(27)	5.22(27)	3.71(13)	2.63	46.11	88.20	1.91
Diclosulam 17g/ha PE *fb* HW at 50 DAS	5.41(29)	5.52(30)	4.27(18)	2.42	45.58	77.99	1.71
Diclosulam 27 g/ha PE *fb* HW at 50 DAS	4.61(21)	4.87(24)	3.71(13)	3.00	46.11	107.33	2.32
HW at 30 DAS *fb* diclosulam 7g/ha PoE at 50 DAS	8.54(72)	5.92(35)	6.53(43)	2.04	45.58	58.74	1.28
HW at 30 DAS *fb* diclosulam 27 g/ha PoE at 50 DAS	8.17(66)	5.71(32)	6.17(38)	2.01	46.11	56.81	1.23
HW twice at 30 DAS and 50 DAS	4.52(22)	5.12(25)	5.62(31)	2.75	49.76	90.53	1.81
Weedy check	10.48(109)	7.94(63)	8.12(67)	1.27	37.76	27.34	0.72
LSD (p=0.05)	1.15	072	1.34	0.89			

Figures in the parentheses indicated original values which are subjected to square root transformation; HW: Hand weeding; PPI: Pre-plant Incorporation; PE: Pre-emergence application; PoE: Post-emergence application; DAS = days after seeding; *fb* = followed by

biomass. Highest weed control efficiency achieved at 80 DAS of observation with hand weeding at 30 and 50 DAS and diclosulam 27 g/ha PE *fb* hand weeding at 50 DAS respectively. Application of diclosulam either as a pre-plant incorporation or pre-emergence is more effective on broad-leaved weeds and sedges as it resulted in lowest weed biomass with this treatment. The greater efficacy of higher dose (20 and 26 g/ha) of diclosulam, in controlling all type of weeds, when compared to low dose (18 g/ha) was reported earlier (Singh *et al.* 2009, Naveen *et al.* 2019).

The highest pod yield was recorded with diclosulam 27 g/ha PE *fb* hand weeding at 50 DAS (**Table 2)** which may be attributed due to low crop-weed competition throughout crop growth. Price *et al.* (2002) reported that among different doses diclosulam herbicides, 17.5, 27 and 52 g/ha PE recorded highest groundnut pod yield (3.50-5.25 t/ha). The cost of cultivation was maximum of ₹ 49,765/ha with hand weeding twice at 30 DAS and 50 DAS. The net return (₹ 1,07,335) and B:C ratio (2.32) were maximum with diclosulam 27 g/ha (PE*)* *fb* hand weeding at 50 DAS, due to higher pod and haulm yields.

The results of the study indicated that pre-emergence application of diclosulam at 27 g/ha recorded higher groundnut yield attributes and seed yield with lower weed density and biomass; higher weed control efficiency and higher B:C ratio.

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Bio-efficacy of ready and tank mixed herbicides in chickpea

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ABSTRACT

A field experiment was conducted at Agricultural Research Institute, Main Farm, Professor Jayashankar Telangana State Agriculture University, Rajendranagar, Hyderabad, India during *Rabi* (winter season) 2020 to evaluate the efficacy of herbicides in chickpea (*Cicer arietinum* L.) variety *'JG-11'*. The experiment was conducted in RBD with three replications. The application of pendimethalin 30% EC + imazethapyr 2% EC (ready mix [RM]) 1.0 kg/ha as pre-emergence application (PE) followed by (*fb*) mechanical weeding at 30 days after seeding (DAS) recorded lowest weed density and biomass at 20 and 40 DAS. Pendimethalin 1.0 kg/ha PE *fb* mechanical weeding at 20 and 40 DAS, oxyfluorfen 140 g/ha PE *fb* mechanical weeding at 20 and 40 DAS, pendimethalin + imazethapyr (RM) 1.0 kg/ha PE *fb* mechanical weeding at 30 DAS registered 1.95, 1.94 and 2.08 t/ha seed yield, respectively as against seed yield of 1.11 t/ha in weedy check. The maximum net returns of ₹ 72093/ha were recorded in pendimethalin + imazethapyr (RM) 1.0 kg/ha PE *fb* mechanical weeding at 30 DAS with B-C ratio of 3.27, which was closely followed by oxyfluorfen 140 g/ha PE *fb* mechanical weeding at 20 and 40 DAS with net returns of ₹ 64980/ha and B:C ratio of 2.99.

Chickpea, the most important *Rabi* (winter season) pulse crop in India, accounts for about 44.5% of total pulse production from 35.1% of total pulse area. Its production is about 10.13 mt from an area of 8.4 mha with productivity of 1.07 t/ha during 2019-20 (Anonymous 2019). Among the constraints faced in chickpea cultivation, the most crucial one is competition from weeds as chickpea is not a weed competitive crop, due to slow growth especially at early stages. The yield losses in chickpea due to weeds range from 30-54% (Mukherjee 2007) if weed growth remains unchecked at critical period of crop weed competition. Weeds in chickpea are generally controlled by conventional methods (cultural manipulation either by hand weeding or hoeing) which is very effective but, it is laborious and expensive. Herbicides are effective but offer limited choice in chickpea, hence an attempt was made to study the efficacy of ready and tank mix herbicides in managing weeds in chickpea.

A field experiment was carried out at Agricultural Research Institute, Main Farm, Professor Jayashankar Telangana State Agriculture University, Rajendranagar, Hyderabad during *Rabi* 2020 to evaluate efficacy of ready mix and tank mix herbicides and herbicide mixtures in chickpea. The experiment consisted of 12 treatments and 3 replications (**Table 1**). The soil of experimental site was clay in texture, slightly alkaline in reaction (pH, 8.2), high in organic carbon (0.98 %) available N, P and K were 290.5 (high), 17.4 (high) and 332.6 kg/ha (high) respectively.

Chickpea variety *'JG-11'* was sown on 6th November, 2020 in 30 cm inter-row spacing and 10 cm intra-row spacing using seed rate of 75 kg/ha and was harvested on 13th February, 2021. Recommended dosage of fertilizers 20 kg N/ha of which 50% was applied at basal along with 21.5 kg P/ha, 16.6 kg/ha and remaining 50% N was applied at 25 days after seeding (DAS). Pre-emergence herbicides application (PE) was done after sowing of crop and post emergence herbicides application (PoE) was done at 25 DAS. Herbicides were sprayed with knapsack sprayer using 500 liters of water per hectare. Weed density was recorded by using 0.25 m^2 quadrat at different intervals in all the treatments and then converted into number/m^2. Weeds were dried in oven till constant weight was attained and transformed to g/m^2 (weed biomass) by square root transformation. The data on weed density and biomass were subjected to square root transformation to normalize their distribution Gomez and Gomez 1984).

Effects on weeds

The experimental field was infested with *Physalis minima, Alternanthera sessilis, Abelmoschus* spp., *Corchorus acutangulus, Parthenium hysterophorus, Phyllanthus niruri, Euphorbia geniculata, Trianthema portulacastrum, Cynodon dactylon, Panicum* spp. and *Cyperus rotundus.* The weed density at 20 DAS (**Table 1**) was lowest with pendimethalin 30 % + imazethapyr 2% EC (RM) 1000 g/ha PE *fb* mechanical weeding at 30 DAS. Pendimethalin 1000 g PE followed by (*fb)* mechanical weeding at 20 and 40 DAS and oxyfluorfen 140 g/ha PE *fb* mechanical weeding at 20 and 40 DAS were equally effective. Weed density at 40 DAS (**Table 1**) was lowest in pendimethalin + imazethapyr (RM) 1000 g/ha PE *fb* mechanical weeding at 30 DAS and was at par with pendimethalin 1000 g/ha PE *fb* mechanical weeding at 20 and 40 DAS, oxyfluorfen 140 g/ha PE *fb* mechanical weeding at 20 and 40 DAS. At 60, 90 DAS and at harvest (**Table 1)** lowest weed density was recorded by topramezone 25.2 g/ha (PoE) *fb* mechanical weeding at 40 DAS. The data on weed density at 20,40, 60, 90 DAS and at harvest (**Table 1**) revealed that weed density was decreased in the effective treatments within 20 days of sowing due to application of pre-emergence herbicides and thereafter, between 20 and 40 DAS weed count decreased in all the treatments except, weedy check due to effect of post-emergence herbicide application coupled with mechanical weeding. Similar findings in chickpea were reported by Poonia and Pithia (2013) and Parihar *et al.* (2019). At 60, 90 DAS and at harvest the weed density increased in all the treatments except with topramezone 25.2 g/ha as (PoE) *fb* mechanical weeding at 40 DAS due to residual effect of topramezone which has half-life of >120 days (Lavanya *et al.* 2021).

The lowest weed biomass at 20 DAS, weed index (6.00 %) and highest weed control efficiency (88.09%) were registered with pendimethalin + imazethapyr (RM) 1000 g/ha PE *fb* mechanical weeding at 30 DAS which was equally effective as pendimethalin 1000 g/ha PE *fb* mechanical weeding at 20 and 40 DAS (**Table 1** and **2**). At 40 DAS, the lowest weed biomass was observed with pendimethalin + imazethapyr (RM) 1000 g/ha PE *fb* mechanical weeding at 30 DAS and pendimethalin 1000 g/ha as PE *fb* mechanical weeding at 20 and 40 DAS and oxyfluorfen 140 g/ha PE *fb* mechanical weeding at 20 and 40 DAS. At 60, 90 DAS and at harvest, the lowest weed biomass was recorded with topramezone 25.2 g/ha PoE *fb* mechanical weeding at 40 DAS. It may be inferred that weed biomass was less in effective treatments at 20 DAS because of pre-emergence application of herbicides in those

Table 1. Weed density and biomass in chickpea as influenced by weed control treatments

Treatment	Total weed density (no./m^2)					Total weed biomass (g/m^2)				
	20 DAS	40 DAS	60 DAS	90 DAS	At harvest	20 DAS	40 DAS	60 DAS	90 DAS	At harvest
Pendimethalin 1000 g/ha PE followed by (*fb)* mechanical weeding at 20 and 40 DAS	8.2 (67.0)	4.8 (22.0)	7.6 (57.3)	8.1 (65.8)	8.34 (68.66)	1.45 (1.10)	2.57 (5.62)	3.43 (10.73)	3.76 (13.12)	3.89 (14.16)
Pendimethalin + imazethapyr 1000 g/ha PE *fb* mechanical weeding at 30 DAS	7.2 (51.0)	4.7 (21.3)	6.7 (44.0)	7.3 (53.3)	7.68 (58.00)	1.28 (0.64)	2.35 (4.51)	3.28 (9.78)	3.61 (12.00)	3.79 (13.33)
Oxyfluorfen 140 g/ha PE *fb* mechanical weeding at 20 and 40 DAS	7.3 (52.0)	5.2 (25.6)	7.9 (60.6)	8.4 (70.6)	8.77 (76.00)	1.95 (2.81)	2.67 (6.15)	3.45 (10.91)	4.05 (15.43)	4.18 (16.43)
Imazethapyr 60 g/ha as (PoE) *fb* mechanical weeding at 40 DAS	11.2 (125.3)	9.0 (79.3)	13.1 (171.3)	13.9 (194.7)	14.10 (198.00)	3.07 (8.40)	3.66 (12.43)	5.89 (33.67)	6.17 (37.10)	6.33 (39.10)
Topramezone 25.2 g/ha (PoE) *fb* mechanical weeding at 40 DAS	11.5 (131.7)	5.5 (29.3)	5.5 (29.3)	5.3 (27.3)	5.25 (26.66)	3.09 (8.55)	2.91 (7.45)	2.93 (7.60)	1.79 (2.20)	1.70 (1.90)
Imazethapyr + imazamox 70 g/ha (PoE) *fb* mechanical weeding at 40 DAS	11.0 (121.0)	9.2 (84.0)	13.2 (173.6)	14.5 (211.3)	14.70 (215.33)	3.05 (8.28)	3.96 (14.7)	6.30 (38.67)	6.40 (39.97)	6.48 (40.97)
Propaquizafop + imazethapyr (62.5 + 60) g/ha PoE *fb* mechanical weeding at 40 DAS	11.5 (130.7)	7.2 (50.7)	8.9 (77.3)	13.1 (172.6)	13.22 (174.00)	3.11 (8.69)	3.05 (8.29)	5.06 (24.63)	5.39 (28.03)	5.48 (29.03)
Quizalofop-ethyl + imazethapyr (50+ 60) g/ha (PoE) *fb* mechanical weeding at 40 DAS	11.6 (133.3)	7.4 (54.0)	10.5 (109.3)	13.7 (186.8)	13.79 (189.33)	3.00 (8.02)	3.27 (9.69)	5.19 (25.90)	5.60 (30.37)	5.78 (32.37)
Acifluorfen + clodinafop-propargyl 245 g/ha (PoE) *fb* mechanical weeding at 40 DAS	11.7 (135.3)	8.7 (74.0)	12.6 (158.6)	13.8 (190.3)	13.89 (192.00)	3.06 (8.36)	3.61 (12.05)	5.71 (31.60)	6.04 (35.50)	6.12 (36.50)
Fluazifop-p-butyl + fomesafen 250 g/ha PoE *fb* mechanical weeding at 40 DAS	11.5 (130.7)	8.5 (71.2)	11.9 (139.9)	13.7 (189.0)	13.94 (193.33)	3.09 (8.56)	3.42 (10.70)	5.35 (27.60)	5.67 (31.18)	5.85 (33.18)
Mechanical weeding at 20 and 40 DAS	11.5 (130.9)	5.5 (29.9)	8.1 (64.0)	12.6 (160.0)	12.74 (161.33)	3.07 (8.43)	2.79 (6.78)	3.64 (12.27)	4.64 (20.57)	4.75 (21.57)
Weedy check	11.5 (130.2)	15.8 (250)	16.0 (255.6)	17.4 (302.6)	17.46 (304.00)	3.10 (8.63)	6.24 (37.88)	7.47 (54.77)	7.76 (59.20)	7.82 (60.20)
LSD (p=0.05)	1.95	2.30	2.30	0.54	0.51	0.17	0.35	0.47	0.58	0.61

Figures in parentheses are the original values; square root transformation ($\sqrt{x+1}$) used for statistical analysis

Table 2. Seed yield and economics of chickpea as influenced by weed control treatments

Treatment	WCE at 40 DAS	WI (%)	Seed yield t/ha	Haulm yield t/ha	Net returns `/ha	B:C
Pendimethalin 1000 g/ha PE followed by (*fb)* mechanical weeding at 20 and 40 DAS	85.17	6.0	1.95	2.18	64757	2.99
Pendimethalin + imazethapyr 1000 g/ha PE *fb* mechanical weeding at 30 DAS	88.09	0.0	2.08	2.62	72093	3.27
Oxyfluorfen 140 g/ha PE *fb* mechanical weeding at 20 and 40 DAS	83.76	6.5	1.94	2.08	64980	3.05
Imazethapyr 60 g/ha as (PoE) *fb* mechanical weeding at 40 DAS	67.19	39.1	1.26	1.42	32870	2.09
Topramezone 25.2 g/ha (PoE) *fb* mechanical weeding at 40 DAS	80.33	21.0	1.64	1.90	47828	2.41
Imazethapyr + imazamox 70 g/ha (PoE) *fb* mechanical weeding at 40 DAS	61.19	39.3	1.26	1.41	32018	2.04
Propaquizafop + imazethapyr (62.5 + 60) g/ha PoE *fb* mechanical weeding at 40 DAS	78.11	27.7	1.50	1.71	44416	2.46
Quizalofop-ethyl + imazethapyr (50+ 60) g/ha (PoE) *fb* mechanical weeding at 40 DAS	74.41	28.2	1.49	1.71	43577	2.42
Acifluorfen + clodinafop-propargyl 245 g/ha (PoE) *fb* mechanical weeding at 40 DAS	68.20	35.6	1.34	1.43	35651	2.15
Fluazifop-p-butyl + fomesafen 250 g/ha PoE *fb* mechanical weeding at 40 DAS	71.75	33.9	1.37	1.57	38235	2.27
Mechanical weeding at 20 and 40 DAS	82.10	16.4	1.73	1.97	55612	2.80
Weedy check	0.00	46.4	1.11	1.36	27937	2.01
LSD (p=0.05)		-	0.26	0.16	12617	0.41

Figures in parentheses are the original values; square root transformation ($\sqrt{x+1}$) used for statistical analysis; WCE- Weed control efficiency, WI- Weed index

treatments, thereafter between 20 and 40 DAS the weeds biomass has increased but the rate of increase was less in all the treatments compared to weedy check due to the effect of post-emergence application of herbicides coupled with mechanical weeding (**Table 1**) (Gupta *et al.* 2017). The results are in agreement with Indu *et al.* (2021). At 60, 90 DAS and at harvest the weeds biomass increased in all the treatments except topramezone 25.2 g/ha PoE *fb* mechanical weeding at 40 DAS because of the residual effect of topramezone. These results are in concurrence with those of Singh *et al.* (2020).

Effect on chickpea

Pendimethalin + imazethapyr (RM) 1000 g/ha PE *fb* mechanical weeding at 30 DAS gave significantly higher seed yield (2.08 t/ha) and was at par with pendimethalin 1000 g/ha PE *fb* mechanical weeding at 20 and 40 DAS and oxyfluorfen 140 g/ha PE *fb* mechanical weeding at 20 and 40 DAS which registered seed yield of 1.95 t/ha and 1.94 t/ha, respectively (**Table 2**). Pendimethalin + imazethapyr (RM) 1000 g/ha PE *fb* mechanical weeding at 30 DAS recorded maximum haulm yield (2.62 t/ha) which was followed by pendimethalin 1000 g/ha as PE *fb* mechanical weeding at 20 and 40 DAS (2.18 t/ha). Improvement in seed yield and straw yield in these treatments was due to the significant reduction in weed density and biomass that resulted in less crop weed competition.

The economic analysis revealed highest benefit-cost ratio of 3.27 with pendimethalin + imazethapyr (RM) 1000 g/ha PE *fb* mechanical weeding at 30 DAS (3.27), which was equally superior to oxyfluorfen 140 g/ha PE *fb* mechanical weeding at 20 and 40 DAS (3.05) and pendimethalin 1000 g/ha PE *fb* mechanical weeding at 20 and 40 DAS (2.99). Net returns with highest with pendimethalin + imazethapyr (RM) 1000 g/ha PE *fb* mechanical weeding at 30 DAS due to higher seed yield on account of low crop weed competition as evident from the higher weed control efficiency and lower weed index.

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Integrated weed management in mustard

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ABSTRACT

A field experiment was conducted in the experimental farm of Department of Agriculture, Himgiri Zee University, Dehradun, Uttarakhand, India during winter season (*Rabi*) 2018-19. The experiment was conducted in randomized block design (RBD) with 7 treatments, *viz.* pre-emergence application (PE) of pendimethalin 750 g/ha, pendimethalin 750 g/ha PE followed by (*fb*) one hand weeding (HW) at 30 days after seeding (DAS), post-emergence application of (PoE) clodinafop 60 g/ha, clodinafop 60 g/ha (PoE) *fb* one hand weeding (HW) 60 days after seeding (DAS), hand weeding twice at 30 and 60 DAS, weed free and weedy check. All the weed control treatments significantly reduced the weed density and biomass. Hand weeding twice at 30 and 60 DAS recorded highest weed control efficiency and minimum weed index. The integrated weed management treatment including pendimethalin 750 g/ha PE *fb* 1 HW was superior than other treatments in recording highest plant height, plant population, dry matter, seed/siliqua, siliqua/plant, length of siliqua, seed weight, seed, stover and biological yield of Indian mustard.

Edible oil crops have an important role in agriculture and industrial economy of India. Despite leading producer of vegetable oil in the world, India has dubious distinction of largest producer, consumer and importer of edible oil in the world. For India, the attainment of self-sufficiency in edible oil is possible if the production potential of our annual edible oilseed crops is harnessed through improved technologies of managing nutrients and weeds. In India, mustard occupies an area of 6.8 mha with production of 9.1 million tonnes and average yield of 1.34 t/ha (GOI 2020). Rajasthan is the largest rapeseed and mustard producing state with 4.22 m tonnes followed by Haryana with 1.15 m tonnes and Uttar Pradesh with 0.96 m tonnes (GOI 2020).

Mustard (*Brassica juncea* (L.) Czern.) belongs to Cruciferae or Brassicaceae family. Mustard is one of the major Rabi oilseed crops of India. It is also known as Rai or Laha. India is one of the largest producer of mustard in the world. The oil content in mustard seeds varies from 37-49 % (Bhowmik *et al. 2014)*. The seed and oil are used as condiment in the preparation of pickles and for flavouring curries and vegetables. Among numerous constraints of mustard production technology, weed infestation is one of the major causes of low productivity (Singh *et al.* 2013*)*. Competition by weeds at initial stages is a major limiting factor to its productivity. Approximately, 15-30% yield reduction is caused by weeds in mustard crop (Mishra *et al.* 2016). Weed control in Indian mustard needs due attention as this crop is grown in poor soils with poor management practices. Manual weeding at 3-4 weeks after sowing is the most common practice to control weeds in Indian mustard. But increasing wages and scarcity of labour compel to search for other alternatives. The pre-emergence application of pendimethalin was found effective in managing weeds (Mukherjee 2014, Rao and Chauhan 2015) and hence is most common herbicidal weed control measure recommended in Indian mustard. In the situations where weeds are not controlled completely by pre-emergence herbicides, the post-emergence herbicides or other non-chemical method will be helpful in managing weeds and increasing mustard production. Therefore, it is imperative to find out an alternative weed management strategy for achieving season long weed control in Indian mustard. therefore, the present study was conducted to identify effective weed control method for season long weed management in Indian mustard.

A field experiment was conducted during winter season (*Rabi*) 2018-19 at the experimental field, Himgiri Zee University, Dehradun (Uttarakhand). The soil of experimental site was sandy loam in texture, alkaline in reaction, (pH 8.27) and low in available N (165.30 kg/ha), medium in available P (24.88 kg/ha) and available K (164.43 kg/ha). The experiment was conducted in randomized block design (RBD) with 7 treatments *i.e*. pre-emergence application (PE) of pendimethalin 750 g/ha, pendimethalin 750 g/ha PE followed by (*fb*) one hand weeding (HW) at 30 days after seeding (DAS), post-emergence application of (PoE) of clodinafop 60 g/ha, clodinafop 60 g/ha PoE *fb* one hand weeding (HW) at 60 days after seeding (DAS), hand weeding twice at 30 and 60 DAS, weed free and weedy check. Mustard variety '*Pusa Bahar*' was sown at row spacing of 30 cm apart on 11 October 2018 using 6 kg/ha. A uniform dose of 60 kg N/ha, 40 kg P/ha and 40 kg K/ha was applied through Urea, DAP and MOP respectively. The recommended cultural practices and plant protection measures were followed to raise the healthy crop. The post-emergence herbicide was applied on 30 DAS. Weeding was done manually in weed free check plots with help of hand tool '*Khurpi*', as required. Species wise number of weeds (weed density) was recorded at random in each plot by using quadrat of 50 x 50 cm size. The herbicides were sprayed with the help of hand operated knapsack sprayer. The mustard yield was estimated by using standard procedures. Economics of the treatment was computed based on the prevalent market prices.

Effect on weeds

The weed flora in the experimental field consisted of mixed population of broad-leaved weeds, *viz. Chenopodium album* and *Fumaria parviflora*; grassy weed, *viz. Cynodon dactylon* and sedge, *viz. Cyperus rotundus*, as reported in mustard by Sharma and Jain (2002) and Bazaya *et al.* (2004). The field was dominated with broad-leaved weeds at all the crop growth stages. All weed control treatments significantly reduced weed density than the weedy check. Among the integrated weed management treatments, pendimethalin 750 g/ha PE *fb* one HW was effective against grassy, broad-leaved and sedge weeds. Lowest weed density and biomass, weed index and highest weed control efficiency was recorded with hand weeding twice at 30 and 60 DAS. The integrated weed management treatment involving pendimethalin 750 g/ha PE *fb* one HW at 30 DAS (**Table 1**.) also recorded the lowest weed density and biomass, weed index and highest weed control efficiency as reported earlier by Sharma *et al.* (2001) and Sharma and Thakur (2001).

Effect on mustard

Significantly taller plants were recorded with hand weeding twice at 30 and 60 DAS. Among the herbicide-based treatments taller plants were observed with pendimethalin 750 g/ha PE *fb* one HW due to the effective control of weeds that created favourable environment for the growth of mustard. The highest seed, straw yield of mustard was recorded under the weed free conditions (**Table 2)**. Among the weed management treatments tested, hand weeding twice at 30 and 60 DAS was most effective in achieving significantly higher mustard seed and straw yield (1.55 and 3.16 t/ha) and it was at par with pendimethalin 750 g/ha PE *fb* one HW. This could be attributed to decreased crop-weed competition at the critical stages due to these treatments, which facilitated better growth and development resulting in better response of yield attributing characters, *viz*. seed/siliqua, length of siliqua and test weight resulting in higher seed yield (**Table 2)** as reported by Bamboriya *et al.* (2016). Weedy check had the lowest yield due to higher weed density and biomass. The test weight was not affected significantly due to different weed control treatments as it is directly related with yield in the same manner. The seed yield of mustard linearly decreased as the weed biomass increased.

Table 1. Effect of various weed control treatments on weed density and biomass, weed control efficiency (WCE), weed index, mustard plant height, seeds/ siliqua, length of siliqua and test weight at mustard harvest

Treatment	Weed density (no./m^2)	Weed biomass (g/m^2)	WCE (%)	Weed index (%)	Plant height (cm)	Seed / siliqua	Length of siliqua (cm)	Test weight (g)
Pendimethalin 750 g/ha pre-emergence application (PE)	3.74 (4.60)	2.36 (4.60)	40.09	17.48	126.06	10.33	4.96	3.53
Pendimethalin 750 g/ha PE *fb* one hand weeding at 30 DAS	2.92 (4.16)	2.27 (4.16)	45.71	9.11	155.63	12.00	5.13	3.53
Clodinafop 60 g/ha post-emergence application (PoE)	4.58 (6.46)	2.73 (6.46)	15.60	26.99	108.93	10.33	4.73	3.40
Clodinafop 60 g/ ha PoE *fb* one hand weeding 60 DAS	4.28 (5.56)	2.56 (5.56)	25.43	20.91	114.86	10.33	4.90	3.53
Hand weeding twice at 30 and 60 DAS	2.68 (3.06)	2.01 (3.06)	60.31	5.16	180.16	12.66	5.36	3.53
Weed free	1.00 (0.00)	1.00 (0.00)	100.00	0.00	186.33	14.33	5.70	3.56
Weedy check	5.03 (7.66)	2.94 (7.66)	0.00	33.69	90.80	9.66	4.16	3.43
LSD (p=0.05)	0.68	0.15	8.99	0.17	6.50	0.98	0.20	NS

Table 2. Effect of different weed management treatments on economics, seed yield and straw yield of mustard cultivation

Treatment	Gross return (x10^3 `/ha)	Cost of cultivation (x10^3 `/ha)	Net return (x10^3 `/ha)	Seed yield (t/ha)	Straw yield (t/ha)	B:C ratio
Pendimethalin 750 g/ha pre-emergence application (PE)	56.60	25.08	31.52	1.35	2.78	1.25
Pendimethalin 750 g/ha PE *fb* one hand weeding at 30 DAS	62.34	29.58	32.76	1.48	2.98	1.10
Clodinafop 60 g/ha post-emergence application (PoE)	50.08	24.55	25.53	1.19	2.35	1.03
Clodinafop 60 g/ ha PoE *fb* one hand weeding 60 DAS	54.25	28.75	25.50	1.29	2.57	0.88
Hand weeding twice at 30 and 60 DAS	65.06	33.30	31.75	1.55	3.16	0.95
Weed free	68.60	37.80	30.80	1.63	3.39	0.81
Weedy check	45.49	24.30	21.18	1.08	2.20	0.87
LSD (p=0.05)				0.03	0.04	

Economics

The viability of any practice depends on its economic feasibility. A better treatment in terms of weed control if not fetched good return may not be acceptable to the farmers. Among all the weed control treatments tested, the highest cost of cultivation and gross return was observed with weed free followed by hand weeding twice at 30 and 60 DAS (**Table 2**). However, highest net return was obtained with pendimethalin 750 g/ha PE *fb* hand weeding at 30 DAS which might be attributed to higher seed yield of mustard because of better weed control and the low cost of cultivation due to herbicide use when compared to hand weeding twice and weed free. Thus, the integrated weed management treatment comprising of pendimethalin 750 g/ha PE *fb* one HW at 30 DAS may be used for effective weed management and higher yield of mustard with higher net income.

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Non-chemical weed management to improve fruit yield and net income in ladies-finger

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ABSTRACT

A field experiment was conducted at Coconut Research Station, Balaramapuram, Thiruvananthapuram, India during winter (*Rabi*) season of 2020-21 to study the effect of stale seedbed and different non-chemical weed management practices on weed control in ladies-finger. The experiment was conducted in randomized block design with treatment combination of two methods of seedbed preparation and six methods of weed management. . Stale and non-stale seedbed were two seedbed preparation methods. Six non-chemical weed management treatments were tested. The uncontrolled weed growth caused 59.20% reduction in fruit yield in ladies-finger, locally called okra. Compared to non-stale seedbed, stale seedbed registered significantly lower weed density (35.67 no./m^2) and biomass (7.81 g/m^2) and significantly higher weed control efficiency (WCE) (81.13%), fruits per plant (36.5) and fruit yield (3.29 t/ha), higher net return (₹ 54520/ha) and B:C ratio (1.69). Among different non-chemical weed management practices, the mechanical weeding with wheel hoe weeder (MWHW) at 15, 30 and 45 DAS recorded the lowest total weed density (26.67 no./m^2) and biomass (2.54 g/m^2); and the highest WCE (93.86%), number of fruits/plant (38.8), fruit weight (6.98/g), fruit yield (4.41 t/ha), higher net return (₹ 97804/ha) and B:C ratio (2.25). Interaction between seedbed preparation and weed management practice was found to be significant only for absolute density of broad-leaved weeds (BLW), weed biomass and WCE. Among seedbed preparation, stale seedbed can be recommended for reducing the weed density and biomass in ladies-finger. The mechanical weeding with wheel hoe thrice at 15, 30 and 45 DAS can be recommended as a cost-effective weed management to attain higher weed control efficiency, ladies-finger yield and net returns in ladies-finger.

Ladies-finger locally called okra (*Abelmoschus esculentus* (L.) Moench) is regarded as one of the most important warm season vegetable crops all over the world. India is the world's leading producer of ladies-finger accounting for roughly 74% of global output. From a total area of 5.85 million hectares, India produced 6.34 million tonnes (AGRICOOP 2021). The major ladies-finger growing states in India are West Bengal, Uttar Pradesh, Bihar, and Orissa. Ladies-finger is a rich source of proteins, carbohydrates, vitamins and minerals. Other than being an essential component in human diet, it is effective in curing ulcers, genitourinary disorders, and useful as a plasma replacement or blood volume expander. The dry seed has an edible oil content of 13 to 22% and a protein content of 20 to 24%. Weed infestation is a major problem in ladies-finger cultivation, due to wider spacing and slow initial growth. Crop weed competition in ladies-finger is at its peak during the early stages of growth, owing to the crop's slow initial growth rate and resulting poor competitive ability (Narayan *et al*. 2020). Season long weed competition causes significant reduction in fruit yield of ladies-finger upto 43.84 to 45.90% (Sah *et al*. 2018). Hand weeding is the commonly adopted method. Non-availability of labour for weeding at right time, high wage rate, high cost of production *etc*. are some of the problems faced by farmers for adopting manual method of weed control. Mulching is considered to be an effective non-chemical method of weed control in crops as it effectively controls both annual and perennial weeds (Chacko *et al*. 2021). Mulching aids in weed control by inhibiting the weed seed germination, smothering weeds and encouraging crop growth by retaining soil moisture and maintaining soil temperature. The application of grass mulch (5 t/ha) one week after germination (Baraiya *et al*. 2017) was very effective in reducing the weed infestation in ladies-finger.

Stale seedbed (SSB) technique is a cultural weed management practice in which weed seeds present on the top layer of soil (2-5 cm) were allowed to germinate and killed prior to seeding. The SSB with glyphosate *fb* mulching with black polyethene cover was the best method for the management of purple nutsedge in ladies-finger (Ameena *et al*. 2013). Herbicides were proven to be effective method of weed control, but due to environmental impacts and health concerns, non-chemical weed management practices have gained importance. Hence, the present study was conducted to find out a cost-effective non-chemical weed management method to manage weeds and increase productivity of ladies-finger.

A field experiment was carried out at Coconut Research Station, Balaramapuram, Thiruvananthapuram, Kerala during winter season (*Rabi*) of 2020-21 to identify a cost-effective seedbed preparation method and non-chemical weed management treatment. The experiment was conducted in randomized block design with treatment combination of two methods of seedbed preparation and six methods of weed management. Two methods of seedbed preparation comprised of stale seedbed (SSB) and non-stale seedbed (NSSB). The six non-chemical weed management treatments tested include: mulching with dried banana leaf (MBL)10 t/ha; MBL10 t/ha followed by (*fb*) mechanical weeding with wheel hoe weeder (MWHW) at 30 and 45 days after seeding (DAS) (MBL *fb* WHW); MBL 10 t/ha *fb* hand weeding (HW) at 30 and 45 DAS (MBL *fb* HW); MWHW at 15, 30 and 45 DAS; HW thrice at 15, 30 and 45 DAS (THW) and weedy check (WC). The soil texture was sandy loam acidic in reaction (4.71), normal in EC (0.1dS/m), low in available N (163.1 kg/ha), high in available P (33.5 kg/ha) and medium in available K (134.4 kg/ha). The variety used for the study was *Anjitha*, a high yielding yellow vein mosaic resistant variety of 120 days duration released from Kerala Agricultural University. The rainfall received during the experimental period was 248.4 mm. The site was previously under nendran banana (Chengazhikodan Nendran Banana, also known Chengazhikode Banana, is among the most popular traditional fruits cultivated in Thrissur district, Kerala, India. The mature fruits are pale yellow and on ripening, turn golden yellow with red patches.). Stale seedbed (SSB) was prepared by ploughing with a power tiller twice and 12 experimental plots each measuring 6.0 × 4.05 m were laid out. Small bunds were taken around each treatment plot. After ploughing irrigation was applied and the experimental plots were left alone for 14 days to allow the weeds to germinate. Weeds that emerged were uprooted by gentle raking with minimum soil disturbance. Field preparation of non-stale seedbed was started 10 days after the SSB. Twelve treatment plots with a gross plot size of 6.0 × 4.05 m were taken. Lime 250 kg/ha and farm yard manure (FYM) 20 t/ha were uniformly applied to all plots. Crop was fertilized with 120 kg/ha N, 35 kg/ha P and 70 kg/ha K. Half N, full P and half K were applied as basal dose and remaining N and K were applied in three equal splits at 30, 45 and 60 DAS. Two seeds were dibbled at a spacing of 60 × 45 cm. A light irrigation was given after sowing.

Total weeds density and biomass were recorded by randomly placing a quadrat of size 0.25 × 0.25 m in two different locations in each treatment plot at 60 DAS, outside the net plot area. Weeds present inside the quadrat were counted and reported as weed density (number/m^2). Weeds uprooted from the quadrat area were shade dried for two days and dried in a hot air oven at 65 ± 5° C till constant weight was obtained and weed dry weight (weed biomass) was expressed as g/m^2. Weed control efficiency (WCE) at 60 DAS and weed index were worked out using the standard formula. For calculating WCE, the treatment NSSB × WC was taken as the weedy check and to calculate the weed index (WI), SSB × MWHW was taken as the control treatment which recorded the minimum weed biomass and the highest fruit yield. Number of fruits per plant and fruit weight was recorded from the five tagged plants from each treatment and the mean value was recorded. Fruit yield per hectare was worked out from the fruits harvested from the net plot area. Economics was worked out based on the market price of the fruit and the cost of inputs. Data on absolute density of grasses, broad-leaved weeds (BLW), total weed density, weed biomass, WCE and weed index were subjected to square root transformation to normalize the distribution. Data were statistically analyzed using ANOVA and the treatments were compared at 5 per cent probability.

Effect on weeds

Grasses and BLW were the predominant weed flora of the experiment field. However, more diversity was observed in broad-leaved weeds (BLW). *Setaria barbata* (Lam.) Kunth and *Digitaria sanguinalis* (L.) Scop. were the two grasses present in the experimental field. *Synedrella nodiflora* (L.) Gaertn, *Phyllanthus niruri* L., *Boerhavia diffusa* L., *Mimosa pudica* L. and *Tridax procumbens* L. were the BLW present in the experimental field.

The stale seedbed recorded lower absolute density of grasses (33.11 no./m^2) and BLW (2.55 no./m^2) than normal seedbed (**Table 1)**. At 60 DAS, stale seedbed (SSB) significantly reduced the total weeds density and biomass and consequent higher WCE compared to normal seedbed method (NSSB) as demonstrated by Ameena *et al.* (2013).

Weed management treatments significantly influenced the absolute density of grasses and BLW and total weed density and weed biomass at 60 DAS. Mechanical weeding with wheel hoe weeder (MWHW) at 15, 30 and 45 DAS recorded significantly lower absolute density of grasses (21.33 no./m^2) which was statistically at par with MBL *fb* WHW and THW. MWHW recorded the lowest weed biomass (2.54 g/m^2). The WCE was higher (81.13%) with stale seedbed method than non-stale seedbed (WCE of 68.51%). Among the weed management treatments, MWHW recorded the highest WCE (93.86 %) which was statistically at par with MBL *fb* WHW, MBL *fb* HW and THW.

Mechanical weeding with wheel hoe weeder (MWHW) at 15, 30 and 45 DAS very effectively destroyed the weeds and created a condition congenial for the crops to grow vigorous and smother the weeds that resulted in significantly lower weed density and biomass and higher WCE (**Table 1**). The efficacy of mechanical weeding in reducing the weed density and biomass was also reported in other crops (Mynavathi *et al*. (2008). Mulching with dried banana leaf mulch alone (MBL) or MBL *fb* WHW at 30 and 45 DAS also registered lower total weed density and biomass as reported by Baraiya *et al*. (2017), Shamla *et al*. (2017), Sinchana (2020). This was due to the fact that banana leaf mulch on the soil surface prevented the germination of weed seeds by obstructing the solar radiation from reaching the soil and smothering the weed seedling that emerged during the initial growth stages of crop growth and the effective removal of latter emerged weeds by wheel hoe weeder.

Interaction was found to be significant only for absolute density of BLW, total weed biomass and WCE (**Table 2**). The treatment combination SSB × WC registered the lowest density of BLW. The treatment combination SSB × MWHW recorded significantly lower total weed biomass (1.03 g/m^2) and the highest WCE (97.57%) due to the favourable effect of SSB in exhausting the weed seed bank before sowing of seeds and better killing of weeds at the latter growth stages of the crop growth by MWHW at 15, 30 and 45 DAS as observed by Reimens *et al*. (2006) in lettuce.

Effect on ladies-finger

The adoption of stale seedbed technique resulted in significantly higher number of fruits per plant (36.50) and fruit weight (6.49 g) and higher yield (3291 kg/ha) and lower weed index (27.68 %) compared to the non-stale seedbed as observed by Sinchana (2020).

Among the weed management treatments, MWHW at 15, 30 and 45 DAS recorded the highest number of fruits per plant (38.8/plant) and fruit

Table 1. Effect of seedbed preparation and weed management on absolute density and total weed density and biomass and weed control efficiency in ladies-finger at 60 DAS

Treatment	Absolute density of grasses (no./m^2)	Absolute density of BLW (no./m^2)	Total weed density (no./m^2)	Total weed biomass (g/m^2)	Weed control efficiency (%)
Seedbed preparation method					
Stale seedbed	5.37^a (33.11)	1.80^a (2.55)	5.65^a (35.67)	2.67^a (7.81)	8.97^a (81.33)
Non-stale seedbed	6.98^b (54.11)	3.13^b (9.11)	7.73^b (63.22)	3.40^b (13.05)	7.53^b (68.51)
LSD (p=0.05)	0.269	0.211	0.282	0.114	0.640
Weed management					
Mulching with dried banana leaf (MBL) 10 t/ha	6.22^b (39.33)	2.36^b (4.67)	6.60^d (44.00)	3.99^c (15.13)	8.11^b (63.34)
Mulching with dried banana leaf 10 t/ha *fb* mechanical weeding with wheel hoe weeder at 30 and 45 DAS	4.80^a (22.67)	2.63^b (7.00)	5.42^{ab} (29.67)	2.12^b (3.59)	9.56^a (91.36)
MBL 10 t/ha *fb* HW twice at 30 and 45 DAS	5.21^a (26.67)	3.09^c (9.33)	5.99^c (36.00)	2.23^b (4.07)	9.49^a (90.18)
Mechanical weeding with wheel hoe weeder at 15, 30 and 45 DAS	4.64^a (21.33)	2.35^b (5.33)	5.13^a (26.67)	1.83^a (2.54)	9.69^a (93.86)
Hand weeding thrice at 15, 30 and 45 DAS	5.11^a (26.67)	2.45^b (5.33)	5.66^{bc} (32.00)	2.23^b (3.99)	9.50^a (90.37)
Weedy check	11.19^c (125.0)	1.88^a (3.33)	11.33^e (128.33)	5.80^d (33.23)	3.14^c (19.81)
LSD (p=0.05)	0.467	0.366	0.488	0.196	0.903

Values in parentheses are original values, data are subjected to square root transformation, absolute total weed density and weed dry weight $(\sqrt{x+1})$ and weed control efficiency and weed index $\sqrt{x}$; DAS: Days after seeding; HW: Hand weeding

Table 2. Interaction effect between seedbed preparation and weed management methods on absolute broad-leaved weeds (BLW) density, total weed biomass and weed control efficiency at 60 DAS in ladies-finger

Treatment	Absolute BLW density (no./m²)	Total weed biomass (g/m²)	Weed control efficiency (%)
Stale seedbed × mulching with dried banana leaf	2.49^de (5.33)	3.62^d (12.13)	8.73^b (70.56)
Stale seedbed × mulching with dried banana leaf *fb* mechanical weeding with wheel hoe weeder	1.66^bc (2.00)	1.80^b (2.25)	9.72^a (94.54)
Stale seedbed × mulching with dried banana leaf *fb* HW twice at 30 and 45 DAS	2.24^cd (4.00)	1.96^bc (2.86)	9.64^a (93.09)
Stale seedbed × mechanical weeding with wheel hoe weeder at 15, 30 and 45 DAS	1.40^ab (1.33)	1.41^a (1.03)	9.88^a (97.57)
Stale seedbed × hand weeding thrice at 15, 30 and 45 DAS	1.90^bc (2.67)	2.14^cd (3.57)	9.55^ab (91.38)
Stale seedbed × weedy check	1.00^a (0.00)	5.09^h (24.99)	6.28^d (39.61)
Non-stale seedbed × mulching with dried banana leaf	2.24^cd (4.00)	4.37^g (18.12)	7.48^c (56.13)
Non-stale seedbed × mulching with dried banana leaf *fb* mechanical weeding with wheel hoe weeder	3.60^gh (12.00)	2.43^e (4.93)	9.39^ab (88.18)
Non-stale seedbed × mulching with dried banana leaf *fb* HW twice at 30 and 45 DAS	3.95^h (14.67)	2.51^e (5.29)	9.34^ab (87.28)
Non-stale seedbed × mechanical weeding with wheel hoe weeder at 15, 30 and 45 DAS	3.20^fg (9.33)	2.25^de (4.07)	9.49^ab (90.14)
Non-stale seedbed × hand weeding thrice at 15, 30 and 45 DAS	3.00^ef (8.00)	2.33^de (4.41)	9.45^ab (89.36)
Non-stale seedbed × weedy check	2.77^ef (6.67)	6.51^i (41.46)	0.00^e (0.00)
LSD (p=0.05)	0.518	0.278	0.905

Values in parentheses are original values, data are subjected to square root transformation, absolute total weed density and weed dry weight ($\sqrt{x+1}$) and weed control efficiency and weed index $\sqrt{x}$; DAS: Days after seeding; HW: Hand weeding

Table 3. Effect of seedbed preparation and weed management methods on yield attributes, fruit yield and weed index in ladies-finger

Treatment	No. of fruits per plant	Fruit weight (g/fruit)	Fruit yield (kg/ha)	Weed index (%)
Seedbed preparation				
Stale seedbed	36.5^a	6.49^a	3291^a	4.63^a (27.68)
Non-stale seedbed	31.9^a	6.16^b	2963^b	5.58^b (34.90)
LSD (p=0.05)	3.23	0.333	187.6	0.411
Weed management				
Mulching with dried banana leaf 10 t/ha	31.5^cd	6.15^b	2513^d	6.68^d (44.81)
Mulching with dried banana leaf 10 t/ha *fb* mechanical weeding with wheel hoe weeder at 30 and 45 DAS	37.8^ab	6.53^a	3936^b	3.61^b (13.52)
Mulching with dried banana leaf 10 t/ha *fb* HW twice at 30 and 45 DAS	36.5^abc	6.39^ab	3337^c	5.14^c (26.66)
Mechanical weeding with wheel hoe weeder at 15, 30 and 45 DAS	38.8^a	6.98^a	4412^a	1.22^a (3.08)
Hand weeding thrice at 15, 30 and 45 DAS	32.7^bcd	6.35^ab	2711^d	6.31^d (40.46)
Weedy check	28.0^d	5.54^c	1852^e	7.68^e (59.20)
LSD (p=0.05)	5.59	0.578	324.9	0.741

Values in parentheses are original values, data are subjected to square root transformation $\sqrt{x}$; DAS: Days after seeding; HW: Hand weeding

weight (6.98/g) and fruit yield (4.41 t/ha) (**Table 3**) due to lower crop weed competition during all stages of crop growth. Similar results were also reported by Daramola *et al*. (2020). The treatment, MWHW was followed by MBL *fb* WHW, MBL *fb* HW and THW. Mechanical weeding with wheel hoe not only reduced the crop weed competition but also improved the soil aeration, root development, nutrient availability and ultimately resulted in increased dry matter production with higher number of fruits per plant, fruit weight and higher fruit yield.

Among the treatment combinations, SSB × MWHW recorded the highest gross return, net return and B:C ratio (₹ 1, 82, 113/ha, ₹ 1, 02, 255/ha and 2.28, respectively) and it was followed by NSSB × MWHW which registered the gross return, net return and benefit cost ratio of ₹ 1, 70, 811/ha, ₹ 93, 353/ha and 2.21, respectively (**Table 4**). This was due to better weed control and reduced crop weed competition (**Table 1 and 2**). Higher fruit yield coupled with low cost of cultivation resulted in higher B:C ratio in SSB × MWHW and NSSB × MWHW. The reduced cost of cultivation by mechanical weeding was reported earlier (Remesan *et al.* 2007).

It may be concluded that the best cost-effective eco-friendly weed management in ladies-finger with higher ladies-finger productivity and net returns can be obtained by the combination of stale seedbed method with mechanical weeding with wheel hoe weeder at 15, 30 and 45 DAS.

Table 4. Effect of seedbed preparation and weed management on economics in ladies-finger

Treatment	Gross return (x10^3 `/ha)	Net return (x10^3 `/ha)	B:C ratio
Stale seedbed × mulching with dried banana leaf	106.59	38.43	1.56
Stale seedbed × mulching with dried banana leaf *fb* mechanical weeding with wheel hoe weeder	161.46	83.10	2.06
Stale seedbed × mulching with dried banana leaf *fb* HW twice at 30 and 45 DAS	140.02	56.26	1.67
Stale seedbed × mechanical weeding with wheel hoe weeder at 15, 30 and 45 DAS	182.11	102.25	2.28
Stale seedbed × hand weeding thrice at 15, 30 and 45 DAS	121.07	33.12	1.37
Stale seedbed × weedy check	78.51	13.95	1.22
Non-stale seedbed × mulching with dried banana leaf	94.44	28.68	1.44
Non-stale seedbed × mulching with dried banana leaf *fb* mechanical weeding with wheel hoe weeder	153.46	77.51	2.02
Non-stale seedbed × mulching with dried banana leaf *fb* HW twice at 30 and 45 DAS	126.95	45.59	1.56
Non-stale seedbed × mechanical weeding with wheel hoe weeder at 15, 30 and 45 DAS	170.81	93.35	2.21
Non-stale seedbed × hand weeding thrice at 15, 30 and 45 DAS	95.77	10.21	1.12
Non-stale seedbed × weedy check	69.64	7.48	1.12

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Phyto-allelopathic effect of different trees leaves' aqueous extracts on seed germination and seedling growth of *Echinochloa crus-galli* (L.) Beauv

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ABSTRACT

Echinochloa crus-galli (L.) Beauv is the most frequently reported troublesome weed in rice fields as it is aggressive, difficult to control and reduces rice yields significantly. An experiment was conducted during 2021 with an objective to assess the allelopathic effect of ten trees' leaves aqueous extracts on the seed germination and seedling growth of *E. cruss-galli.* Leaves of ten tree species were separately dried and the aqueous extracts of each of them were diluted to obtain the three concentrations *i.e.* 5, 10 and 15% of each. Three concentrates of each of the tree leaves extract were used as treatments. The 15% concentration of the leaves extracts of all tree species exhibited highest efficacy in reducing germination and growth of *E. crus-galli*. Amongst all tree species studied, *Aegle marmelos* (L.) Corrêa tree leaves aqueous extract, at all concentrations caused greater allelopathic effect and maximum seedling root and shoot inhibition with lowest vigour index and seedling weight of *E. crus-galli*.

Echinochloa crus-galli (L.) Beauv is known to be one of the worst weeds occurring in rice fields (Rao 2021) as it causes severe rice yield losses by depleting 60–80% of soil nitrogen. It is a plant with C_4 photosynthetic pathway which makes it physiologically advantageous when it is grown as a weed in C_3 crops like rice. *Echinochloa* species seedlings look very similar to rice plants which make it difficult to manage by manual weeding as farmers sometimes unknowingly transplant these weeds onto rice field (Rao and Moody 1988) and causing huge rice yield losses (Rao and Moody 1987). The use of plants with strong allelopathic properties for weed control has shown promising results (Duke *et al.* 2000). Leaf extracts of tree species are a potent source of metabolites and toxic effects of these are species specific (Krumsri *et al.* 2020). The phytochemicals have the ability to reduce and delay germination, induce mortality of seedling leading to reduction in growth and yield. Thus, incorporating allelopathy in agricultural weed management programs may reduce the usage of herbicides (Kaur *et al.* 2017). Hence, the present study was conducted to assess the allelopathic potential of various tree species' leaves aquous extracts against *E. cruss-galli*.

The study was conducted during 2021 in Department of Botany, Punjab Agricultural University (PAU), Ludhiana, Punjab. The seeds of *E. crus-galli* were procured from the Department of Agronomy, PAU, Ludhiana and stored under optimum storage conditions till use. The ten trees selected for the study include: *Aegle marmelos* (L.) Corrêa, *Albizia lebbeck* (L.) Benth., *Azadirachta indica* A. Juss., *Eucalyptus tereticornis* Sm., *Leucaena leucocephala (*Lam.) de Wit, *Murraya koenigii* (Linn.) Spreng, *Populus deltoides* W. Bartram ex Marshall, *Salix alba* L., *Syzygium cumini* (L.) Skeels. and *Toona ciliata* M. Roem. Healthy and fully expanded leaves of selected tree species were collected from the trees growing in the Research Farm of Department of Forestry and Natural Resources, PAU during the months of March to August. The collected leaves were dried in hot-air oven at 60°C for one week and then grinded in electric grinder so as to obtain fine powder and sieved through 40 mesh sieve. The extracts were obtained by adding dry powdered tissues in distilled water at 1:1 w/v proportion for 48 hours. Then the extract was filtered through double layered muslin cloth; centrifuged at 4000 g for 30 min and the supernatant was filtered through Whatman No. 1 filter paper. The obtained extracts served as the crude extract (100 % concentration) and it was used as a stock solution for the study (Hussain *et al.* 2012). Three diluted concentrations (5, 10 and 15%) were prepared from stock solution through dilution of 100% concentrate.

E. crus-galli seeds were surface sterilized with 5% sodium hypochlorite solution for 5 minutes and then rinsed twice with running tap water for 3-5 minutes prior to the germination test to avoid fungal contamination. Twenty-five *E. crus-galli* seeds were placed in a 9-cm diameter Petri dish lined with two pieces of Whatman no. 1 filter paper. The Petri dishes were sealed with parafilm and placed at 30^{0}C in an environmental chamber. Different concentrations of leaf extracts were applied on the inner side of the cover of Petri dish. The number of germinated seeds was counted at 15 days after sowing (DAS) or until there was no further germination. A similar set up with distilled water served as control.

The *E. crus-galli* seed germination percentage was calculated based on the number of normal seedlings on 15th day of germination.

$$\text{Germination percentage} = \frac{\text{Number of seeds germinated}}{\text{Total no. of seeds placed in petri dish}} \times 100$$

The percentage inhibition of germination, per cent root inhibition and per cent shoot inhibition were calculated using the equation:

$$I = 100-(E2\times 100/ E1)$$

Where, I represents percentage inhibition, E1 represents response of control and E2 represents response of treatment. Ten *E. crus-galli* seedlings were selected at random, gently blotted dry and then fresh weight was recorded and expressed in milligrams. For dry weight determination, *E. crus-galli* seedlings which were used for recording fresh weight were dried in oven at 60^{0}C for 3 days and their dry weight was recorded. The *E. crus-galli* seedling vigour index I and II were calculated as per Abdul-baki and Anderson (1973).

Seed germination was calculated following formula stated by Association of Official Seed Analysts (1983). $=\sum n1/d1 + n2/d2 + n3/d3+$ ----------, where 'n' is the number of germinated seeds; 'd' is the number of days.

Primary root length and shoot length were measured at the end of 15th day. Ten normal *E. crus-galli* seedlings from each replication were taken at random. The root length and shoot length of *E. crus-galli* seedlings were measured from point of attachment to cotyledon till the tip of root and shoot, respectively. Mean root length and shoot length was computed and expressed in centimetres. Total seedling length was measured as length from shoot tip to the root tip from seedlings selected at random. The mean of ten seedlings was computed and expressed in centimetres.

Total phenolic content was assayed following the procedures given by Bray and Thorpe (1954). The method of Balabaa *et al*. (1974) was used for total flavonoid content. Total alkaloid content was estimated following the procedures given by Shamsa *et al.* (2008) and total tannins content was determined following the procedures given by Sadasivam and Manickam (1992). Total terpenoid content was determined using standard protocol of Ghorai *et al.* (2017). Total soluble sugars were assayed using standard methodology of Dubois *et al.* (1956). They are expressed in units mg/g dry weight (DW).The experiments were carried out using completely randomised design (CRD). The statistical analysis of data was performed using duncan multiple (DMRT) range test through SPSS statistical software. All the differences were considered statistically significant at the probability levels of ($p < 0.05$).

Phytochemical content of leaves

The maximum phenol content was recorded in the extract of *E. tereticornis* (32.91 mg/g DW) and *S. cumini* (30.90 mg/g DW), followed by *A. marmelos* extracts with 24.00 mg/g DW of total phenols (**Table**

Table 1. Secondary metabolites composition in leaves of selected tree species

Tree species	Total soluble sugars (mg/g DW)	Total phenols (mg/g DW)	Total flavonoids (mg/g DW)	Total tannins (mg/g DW)	Total alkaloids (mg/g DW)	Total terpenoids (mg/g DW)
Salix alba	6.39^{bcd}	14.57^{b}	5.94^{bcd}	4.2^{bc}	4.77^{bcd}	1.93^{b}
Populus deltoides	6.67^{bcd}	21.35^{ab}	5.4^{bcd}	6^{abc}	12.43^{a}	15.04^{a}
Eucalyptus tereticornis	6.33^{bcd}	32.91^{a}	9.23^{a}	1.75^{c}	9.91^{ab}	3.67^{b}
Sygyzium cumini	8.01^{abc}	30.9^{a}	6.67^{abcd}	2.36^{bc}	4.54^{bcd}	5.38^{b}
Aegle marmelos	11.04^{a}	24^{ab}	8.33^{ab}	10.38^{a}	8.96^{abc}	5.96^{b}
Murraya koenigii	4.15^{cd}	11.35^{b}	5.08^{cd}	7.01^{ab}	6.13^{bcd}	4.71^{b}
Azadirachta indica	3.61^{d}	11.23^{b}	4.47^{cd}	4.2^{bc}	7.15^{abcd}	7.09^{b}
Toona ciliata	9.06^{ab}	12.94^{b}	3.79^{d}	2.6^{bc}	6.86^{abcd}	3.92^{b}
Luecaena leucocephala	6.79^{bcd}	18.99^{ab}	7.11^{abc}	4.58^{bc}	1.86^{d}	2.67^{b}
Albizia lebbeck	7.3^{abcd}	19.81^{ab}	6.26^{abcd}	4.18^{bc}	2.7^{cd}	3.97^{b}

Values depicted by same letter are not significantly different as per DMRT ($p < 0.05$)

1), while, minimum levels of total phenols were recorded in the extracts of *A. indica* (11.23 mg/g DW) which was statistically at par with the phenol levels in the extracts of *M. koenigii* (11.35 mg/g DW), *T. ciliata* (12.94 mg/g DW) and *S. alba* (14.57 mg/g DW). The recorded total flavonoids were significantly higher in *E. tereticornis* extracts (9.23 mg/g DW) followed by *A. marmelos* (8 mg/g DW) while, the lowest flavonoid levels were recorded in *T. ciliata* (3.79 mg/g DW) and *A. indica* (4.47 mg/g DW). Polyphenols and flavanoids were reported to cause strong inhibitory effects on seed germination and early seedling growth of *E. crus-galli* (Poonpaiboonpipat and Jumpathong 2019). Higher total soluble sugars were recorded in *A. marmelos* (11.04 mg/g DW), followed by *T. ciliata* (9.06 mg/ml) and *S. cumini* (8.01 mg/g DW) with lowest sugar content in *A. indica* (3.61 mg/g DW) closely followed by *M. koenigii* extracts (4.15 mg/g DW).

Significantly higher tannins were recorded in *A. marmelos* (10.38 mg/g DW) and lowest in *E. tereticornis* (1.75 mg/g DW), among all tree species leaf aqueous extracts. Alkaloids are the metabolites chiefly responsible for the medicinal and allelopathic properties among plant species. Significantly maximum alkaloid content was recorded in the leaves aqueous extracts of *P. deltoids* at 12.43 mg/g DW and lowest in those of *L. leucocephala* at 1.86 mg/g DW, among all tree species extracts. Total terpenoids were found to be significantly highest in the leaves extracts of *P. deltoids* at 15.04 mg/g DW, while all other leaf extracts terpenoid levels were statistically at par amongst each other. Terpenoids are essential allelochemicals as they are highly potent leading to electrolyte leakage, lipid peroxidation, loss of cell water, disruption of respiration which adversely affected seed germination (Araniti *et al.* 2013). The trees which leaves extracts were screened for phytochemical constituents seemed to have the potential to act as a source of allelopathic chemicals that may be used to improve the current weed management practices.

Table 2. Effect of aqueous leaf extracts of selected tree species on *E. crus-galli* seed germination related parameters

Tree species	Concentration	Germination (%)	Germination inhibition (%)	Germination speed
	Water (control)	89.67^{a}	0^{f}	18.46^{a}
Salix alba	5%	81.67^{abcd}	8.92^{cdef}	15.16^{ab}
	10%	72.05^{abcdef}	20.76^{abcdef}	12^{bcdef}
	15%	64.88^{cdef}	27.66^{abcd}	10.08^{bcdefg}
Populus deltoides	5%	81.96^{abcd}	8.58^{cdef}	15.25^{ab}
	10%	70.51^{abcdef}	21.36^{abcdef}	13^{bcd}
	15%	64.97^{cdef}	27.57^{abcd}	10.67^{bcdef}
Eucalyptus tereticornis	5%	78.67^{abcd}	12.33^{cdef}	11.33^{bcdef}
	10%	72.67^{abcdef}	18.93^{abcdef}	9^{cdefg}
	15%	54.33^{f}	39.42^{a}	7.37^{efg}
Sygyzium cumini	5%	82.27^{abcd}	8.22^{cdef}	13^{bcd}
	10%	73.71^{abcde}	17.79^{bcdef}	12^{bcdef}
	15%	66.77^{bcdef}	25.48^{abcde}	10.03^{bcdefg}
Aegle marmelos	5%	65.76^{bcdef}	26.65^{abcde}	9^{cdefg}
	10%	58.2^{ef}	35.09^{ab}	7.33^{efg}
	15%	53.95^{f}	39.85^{a}	4.99^{g}
Murraya Koenigi	5%	84.82^{ab}	5.37^{ef}	12.67^{bcde}
	10%	82.78^{abc}	7.64^{def}	11^{bcdef}
	15%	72.73^{abcdef}	18.84^{abcdef}	9^{cdefg}
Azadirachta indica	5%	84.28^{abc}	5.99^{def}	9.33^{cdefg}
	10%	76^{abcde}	15.24^{bcdef}	7.85^{defg}
	15%	62.71^{def}	30.05^{abc}	6.82^{fg}
Toona ciliata	5%	86.57^{a}	3.43^{f}	13.33^{abcd}
	10%	83.4^{abc}	6.98^{def}	11.67^{bcdef}
	15%	74.04^{abcde}	17.43^{bcdef}	9.09^{cdefg}
Lucaena leucocephala	5%	83.18^{abc}	7.24^{def}	13.33^{abcd}
	10%	75.37^{abcde}	15.9^{bcdef}	12.42^{bcde}
	15%	66.93^{bcdef}	25.33^{abcde}	11.58^{bcdef}
Albizia lebbeck	5%	88.55^{a}	1.23^{f}	13.61^{abc}
	10%	85.03^{ab}	5.17^{ef}	11^{bcdef}
	15%	80.06^{abcd}	10.7^{cdef}	10.33^{bcdefg}

Values depicted by same letter are not significantly different as per DMRT ($p < 0.05$)

Effect on germination

The tested leaf extracts were very effective in decreasing seed germination of *E. crus-galli* (**Table 2**). The inhibition of *E. crus-galli* seeds germination showed a concentration dependent trend with the degree of inhibitory proportional to the leaves aqueous extract concentration (**Table 2**). The highest per cent seed germination inhibition was with 15% formulation followed by 10 and 5%. Among ten tree species, *A. marmelos* leaves aqueous extract caused the maximum germination inhibition (**Table 2**). The inhibitory effect could be due to interference of leaf extracts on seed physiological processes like cell division and enlargement (Chowhan *et al.* 2011) which confirm reports of Nadeem *et al.* (2021) and Mondal *et al.* (2020). Lower rate of seed germination could be attributed to the presence of phytotoxic metabolites in the leaf aqueous extracts of trees which reduced *E. crus-galli* seeds germination index. These findings support the results of Khan *et al.* (2016) who reported that the germination kinetics of weed seeds were significantly reduced due to extracts of different species. The phytotoxicity of plant extracts affected weed seed germination and seedling growth. This study revealed that the magnitude of inhibition on seed germination traits, seedling growth and biomass increased with incremental extract intensity and showed linear dose dependent variation as reported by Phuwiwat *et al.* (2012) and Akacha *et al.* (2013), while examining the effect of aqueous leaf extracts of *Melia azedarach* on *E. crus-galli.*

Effect on seedlings growth parameters

The minimum *E. crus-galli* seedling length was observed when treated with *A. marmelos* extracts followed closely by *S. cumini* and *E. tereticornis* (**Table 3**). Minimum *E. crus-galli* seedling root length (0.65 cm) and minimum shoot length (1.27 cm) was recorded with 15% extracts of *E. tereticornis* and *Aegle marmelos,* respectively. These observations indicated that allelopathic aqueous extracts generally have rather significantly more pronounced effect on

Table 3. Effect of aqueous leaf extracts of selected tree species on seedling growth related parameters and percentage root and shoot inhibition of *E. crus-galli*

Tree species	Concentration	Root length (cm)	Shoot length (cm)	Total seedling length (cm)	Root inhibition (%)	Shoot inhibition (%)
	Water (control)	2.28^{a}	6.79^{a}	9.08^{a}	0^{f}	0^{h}
Salix alba	5%	1.83^{ab}	5.32^{abc}	7.16^{abc}	19.61^{ef}	21.72^{fgh}
	10%	1.63^{abcd}	5.14^{abcd}	6.77^{abcd}	28.65^{cdef}	24.45^{efgh}
	15%	1.13^{bcdef}	4^{bcdefg}	5.13^{bcdefgh}	50.72^{abcde}	40.76^{bcdefg}
Populus deltoides	5%	1.26^{bcdef}	4.76^{abcde}	6.02^{bcdefg}	44.48^{abcde}	29.97^{defgh}
	10%	1.09^{bcdef}	3.9^{bcdefg}	4.99^{bcdefghi}	52.15^{abcd}	42.68^{bcdefg}
	15%	0.96^{def}	3.4^{bcdefgh}	4.36^{cdefghi}	57.72^{abc}	49.81^{abcdefg}
Eucalyptus tereticornis	5%	1.08^{cdef}	3.43^{bcdefgh}	4.51^{bcdefghi}	52.67^{abcd}	49.28^{abcdefg}
	10%	0.92^{def}	2.97^{cdefgh}	3.89^{defghi}	59.75^{abc}	56.11^{abcdef}
	15%	0.65^{f}	2.38^{efgh}	3.03^{ghi}	71.62^{a}	64.93^{abcd}
Sygyzium cumini	5%	1.21^{bcdef}	3.67^{bcdefg}	4.88^{bcdefghi}	46.91^{abcde}	46.06^{bcdefg}
	10%	1^{cdef}	2.86^{defgh}	3.86^{defghi}	56^{abcd}	57.76^{abcde}
	15%	0.81^{ef}	2.06^{fgh}	2.86^{hi}	64.56^{ab}	69.37^{abc}
Aegle marmelos	5%	0.93^{def}	2.54^{efgh}	3.47^{efghi}	59.11^{abc}	62.76^{abcd}
	10%	0.82^{ef}	1.79^{gh}	2.61^{hi}	63.76^{ab}	73.72^{ab}
	15%	0.69^{f}	1.27^{h}	1.96^{i}	69.6^{a}	81.29^{a}
Murraya Koenigi	5%	1.07^{cdef}	4.13^{bcdefg}	5.2^{bcdefgh}	53.17^{abcd}	39.27^{bcdefg}
	10%	0.89^{def}	3.63^{bcdefgh}	4.52^{bcdefghi}	60.98^{abc}	46.11^{bcdefg}
	15%	0.77^{f}	2.66^{efgh}	3.42^{fghi}	66.42^{a}	60.71^{abcd}
Azadirachta indica	5%	1.55^{bcde}	4.43^{bcdef}	5.98^{bcdefg}	32.53^{bcdef}	34.55^{cdefgh}
	10%	1.26^{bcdef}	3.67^{bcdefg}	4.93^{bcdefghi}	45.56^{abcde}	45.97^{bcdefg}
	15%	1.1^{bcdef}	2.63^{efgh}	3.73^{efghi}	52.68^{abcd}	60.79^{abcd}
Toona ciliata	5%	1.33^{bcdef}	5.13^{abcd}	6.46^{abcde}	42.6^{abcde}	24.64^{efgh}
	10%	0.87^{ef}	4.16^{bcdefg}	5.02^{bcdefgh}	62.18^{ab}	38.66^{bcdefg}
	15%	0.64^{f}	3.47^{bcdefgh}	4.11^{defghi}	71.3^{a}	48.72^{abcdefg}
Lucaena leucocephala	5%	1.74^{abc}	5.67^{ab}	7.41^{ab}	23.99^{def}	16.65^{gh}
	10%	0.68^{f}	4.58^{abcde}	5.26^{bcdefgh}	69.11^{a}	32.37^{defgh}
	15%	0.81^{ef}	3.33^{bcdefgh}	4.14^{cdefghi}	64.27^{ab}	50.73^{abcdefg}
Albizia lebbeck	5%	1.24^{bcdef}	5.11^{abcd}	6.35^{abcdef}	46.08^{abcde}	24.63^{efgh}
	10%	1.54^{bcde}	3.99^{bcdefg}	5.53^{bcdefgh}	32.96^{bcde}	40.94^{bcdefg}
	15%	1.16^{bcdef}	3.46^{bcdefgh}	4.62^{bcdefghi}	49.31^{abcde}	48.96^{abcdefg}

Values depicted by same letter are not significantly different as per DMRT ($p < 0.05$)

inhibition of seedlings root growth than the shoot growth (Randhawa *et al*. 2002, Singh *et al.* 2009, Aslani *et al.* 2014, Scavo *et al.* 2019, Saad *et al*. 2019). Such an outcome is expected because plant root is often the first tissue to be in contact with allelochemicals present in them (Singh *et al.* 2009). All the leaf extracts were found to have an inhibitory effect on the root and shoot growth (**Table 3**). Roots were most sensitive to these extracts and exhibited highest degree of inhibition with extracts of *E. tereticornis* (71.62%), followed closely by *T. ciliata* (71.3%) and *A. marmelos* (69.6%) (**Table 4**). Highest root inhibition was recorded with *A. marmelos* and *E. tereticornis* extracts and lowest with *S. alba* extracts at all concentrations. Among various tree species extracts, *A. marmelos* recorded highest and *Salix alba* recorded lowest degree of shoot inhibition at all concentration levels. The chemicals present in these extracts inhibit shoot and seedling growth by inhibiting cell division and elongation and interferes with enzymes involved in mobilization of nutrients necessary for seedling emergence (Kong *et al.* 2019).

Effect on seedlings vigour and biomass

The highest vigour index I (616.26) and II was recorded with *L. leucocephala* at 5% concentration (**Table 4**). Among treatments, *E. crus-galli* seeds treated with *S. alba* and *A. lebbeck* extracts were most vigorous while, *E. crus-galli* seeds treated with *A. marmelos* and *E. tereticornis* extracts were least vigorous as they have the highest and lowest values of seed vigour index I and II, respectively. Similar trends were recorded for the *E. crus-galli* seedling fresh and dry weight (**Table 5**). Among treatments, *E. crus-galli* seeds treated with *S. alba* recorded highest fresh weight and dry weight of *E. crus-galli* seedlings followed by *A. lebbeck* while, *E. crus-galli* seeds treated with *A. marmelos* extracts recorded lowest fresh and dry weight of *E. crus-galli* seedlings at all concentration levels followed by *E. tereticornis* extracts. Minimum *E. crus-galli* seedling dry weight observed with the leaf aqueous extract application may be attributed to phytotoxic compounds released in higher concentration from their leaves which imparted growth inhibitory action (Ding *et al.* 2007).

Table 4. Effect of aqueous leaf extracts of selected tree species on vigour and biomass of *E. crus-galli*

Tree species	Concentration	Vigour index I	Vigour index II	Fresh weight (mg)	Dry weight (mg)
	Water (control)	814.12^{a}	523.89^{a}	9.04^{a}	5.84^{a}
Salix alba	5%	585.11^{abc}	339.17^{b}	7.42^{abc}	4.16^{b}
	10%	481.28^{bcdef}	210.84^{bcdefgh}	6.65^{abcd}	2.96^{bcde}
	15%	332.74^{bcdefgh}	163.38^{bcdefgh}	5.03^{cdefgh}	2.53^{bcde}
Populus deltoides	5%	493.49^{bcdef}	324.76^{bc}	7.99^{ab}	3.96^{bc}
	10%	352.2^{bcdefgh}	272.27^{bcd}	6.48^{abcde}	3.86^{bc}
	15%	283.92^{cdefgh}	146.24^{cdefgh}	4.81^{cdefgh}	2.24^{cde}
Eucalyptus tereticornis	5%	355.05^{bcdefgh}	214.92^{bcdefgh}	5.43^{bcdef}	2.74^{bcde}
	10%	282.17^{cdefgh}	124.05^{defgh}	3.58^{fgh}	1.7^{de}
	15%	165.57^{gh}	66.04^{h}	2.54^{gh}	1.22^{e}
Sygyzium cumini	5%	401.38^{bcdefgh}	250.67^{bcdefg}	6.02^{bcdef}	3.05^{bcde}
	10%	284.5^{cdefgh}	184.7^{bcdefgh}	4.65^{cdefgh}	2.51^{bcde}
	15%	190.79^{fgh}	114.56^{defgh}	3.83^{defgh}	1.72^{de}
Aegle marmelos	5%	228.46^{efgh}	170.82^{bcdefgh}	4.56^{cdefgh}	2.6^{bcde}
	10%	151.92^{gh}	85.35^{efgh}	3.61^{efgh}	1.47^{de}
	15%	105.46^{h}	71.04^{gh}	2.36^{h}	1.32^{e}
Murraya Koenigi	5%	439.85^{bcdefg}	232.19^{bcdefgh}	5.59^{bcdef}	2.74^{bcde}
	10%	374.96^{bcdefgh}	234.09^{bcdefgh}	5.2^{bcdefgh}	2.83^{bcde}
	15%	249.41^{efgh}	190.33^{bcdefgh}	4.43^{defgh}	2.61^{bcde}
Azadirachta indica	5%	503.89^{bcde}	206.55^{bcdefgh}	4.67^{cdefgh}	2.46^{bcde}
	10%	376.18^{bcdefgh}	161.77^{bcdefgh}	4.07^{defgh}	2.12^{cde}
	15%	236.38^{efgh}	82.07^{fgh}	3.49^{fgh}	1.31^{e}
Toona ciliata	5%	559.22^{abcd}	255.7^{bcdef}	5.81^{bcdef}	2.96^{bcde}
	10%	418.95^{bcdefg}	227.04^{bcdefgh}	5.53^{bcdef}	2.72^{bcde}
	15%	304.95^{cdefgh}	169.28^{bcdefgh}	4.41^{defgh}	2.3^{bcde}
Lucaena leucocephala	5%	616.26^{ab}	265.85^{bcde}	6.23^{bcdef}	3.19^{bcd}
	10%	397.12^{bcdefgh}	174.35^{bcdefgh}	4.94^{cdefgh}	2.3^{bcde}
	15%	277.27^{defgh}	178.04^{bcdefgh}	4.69^{cdefgh}	2.66^{bcde}
Albizia lebbeck	5%	561.87^{abcd}	326.02^{bc}	6.25^{bcdef}	3.68^{bc}
	10%	471.54^{bcdef}	213.91^{bcdefgh}	5.25^{bcdefg}	2.52^{bcde}
	15%	370.13^{bcdefgh}	191.89^{bcdefgh}	4.5^{defgh}	2.4^{bcde}

Values depicted by same letter are not significantly different as per DMRT ($p < 0.05$)

On the basis of this study, it was concluded that *Aegle marmelos* leaves aqueous extract at all concentrations tested, has greater phyto allelopathic effect on *E. crus-galli*

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