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REVIEW ARTICLE

Mechanical weed management technology to manage inter- and intra-row weeds in agroecosystems - A review

Satya Prakash Kumar*, V.K. Tewari[1], C.R. Mehta, C.R. Chethan[2], Abhilash Chandel[3], C.M. Pareek[1] and Brajesh Nare[4]

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ABSTRACT

Traditional manual weed management is one of the tedious and costly operations in the complete cycle of crop production, reasons being high labor costs, time and tedium. The herbicide use contributes to environmental pollution in addition to other disadvantages of concern. The increasing demand for toxicant free food has become a challenge for weed control. Hence, the mechanical weeding is gaining importance. Automation in agriculture has also improved the mechanization input in weed management. The rapid entry of sensors, microcontroller and computing technologies in the field has formed a foundation of agricultural autonomous guidance systems. An automated system is time effective for field operations, avoids huge labor requirement and health drudgery issues to provide an efficient farm operation. Generally manual tools such as khurpi (hand operated small hoe), grubber, spade, wheel hoe, push pull type of weeder are used by farmers for the removal of inter- and intra-row weeds with higher weeding efficiency in the range of 72 to 99% but field capacity is very low in the range of 0.001 to 0.033 ha/h. This review deliberates on the latest work being done on mechanical weed management such as tractor operated finger weeder, torsion weeder, ECO weeder, flame weeder, harrow and sensor-based technologies for management of inter- and intra-row weeds in crops with wider rows.

Key words: Automation, Crops, Inter- and intra-row weeder, Mechanical weed management, Microcontroller, Sensors

INTRODUCTION

Weed infestation is a major concern in agriculture worldwide. Weeds germinate and grow substantially in a random and ununiform manner across the crop field and compete with main crops for water, nutrients and sunlight, resulting in a significant deterioration of production quality and quantity (Berge *et al.* 2008, Slaughter *et al.* 2008, Hamuda *et al.* 2016). The weed management in India, involves an average expense of ₹ 6000/ha for rainy *(Kharif)* season crops and ₹ 4000/ha for winter *(Rabi)* season crops amounting to 33% and 22% of the total production costs, respectively (Yaduraju and Mishra 2018). Several studies have also demonstrated a strong impact of weed infestations on crop yield loss (Slaughter *et al.* 2008, McCarthy *et al.* 2010). Even with traditional methods of weed control, an average yield loss of 15-20% occur and thus weed management remains critical for effective crop loss management and quality production (Chethan *et al.* 2022).

Weeds that emerged with the crop should be controlled during critical period (Rao and Nagamani 2010). Weed management is a strategy for ensuring the success of a targeted weed population in a crop area by employing weed ecology and management technical knowledge (Ghersa *et al.* 2000). An integrated approach for weed management is required evolving (i) Cultural methods, (ii) Physical methods, (iii) Chemical methods and (iv) Biological methods (Buhler 2002, Rao and Nagamani 2010). Even though soil steaming, laser radiation, and flame are among intra-row weed management techniques (Raffaelli *et al.* 2013, Fontanelli *et al.* 2015) are available, they are successful under certain soil and plant conditions and they necessitate additional steam and flame generation systems, which result in excessive fuel consumption and are costly (Melander and Kristensen 2011, Marx *et al.* 2012).

Physical force either manual, animal, or mechanical strength is used to tug out or kill weeds under physical strategies of weed management. One or combinations of these methods are employed to

ICAR - Central Institute of Agricultural Engineering, Bhopal, Madhya Pradesh 462038, India

[1] Indian Institute of Technology, Kharagpur, West Bengal 721302, India

[2] ICAR-Directorate of Weed Research, Jabalpur, Madhya Pradesh 482004, India

[3] Biological Systems Engineering, Washington State University, Pullman, 99164, WA, USA

[4] ICAR - Central Potato Research Station, Jalandhar, Punjab 144026, India

* Corresponding author email: satyaprakashkumar27@gmail.com

control the weed population depending on weed and crop. Major operations of physical control are hand weeding, hand hoeing, digging, mowing, cutting, tillage, burning, inter cultivation, and use of mulches. Hand weeding is also very popular amongst the farmers in India where weeds are pulled out by hand or uprooted by small hand tools. The weeds are eliminated through digging it in deeper layers to remove the underground storage organs. Nowadays, physical weed control techniques are compelling very quick and effective solution which does not leave any chemical deposits on crop or plants. The objective of the current review is to review the research efforts on mechanical weed management to provide a synthesis and some thoughts on weed management tactics that could be useful in developing sustainable solutions.

OVERVIEW OF MECHANICAL WEED MANAGEMENT TECHNOLOGY

Conventional methods of weed control system

The weeding tools basically can be categorized based on power sources such as manual, animal-drawn, and power or tractor operated. Popular weeding tools are khurpi (hand hoe), spades, and long handle tools. Animal drawn equipment or implements are suitable for intercultural and weeding operations. They may be accomplished weeding fast and successfully by way of the advanced mechanism. A wider row spacing (above 30 cm) is provided for the movement of animal-drawn weeders which preserve proper row spacing and that are beneficial for successful weeding operation. The cost of operation and time can be reduced by animal-drawn tools. Animal weeding tools are single and multi-row hoes. The farmers of various states in India have extensively used the animal-drawn single row hoes. The blade shape like straight or slightly curved is typically used in animal-drawn single row hoes. According to crop spacing, the size of the blade can be modified. Multi-row units are famous for weeding operations in Gujarat and other states for more coverage and timely operation. Some new designs in animal-drawn weeders are three tine cultivators (Triphali), Akola hoe, Bardoli hoe and animal-drawn sweeps of different designs (Singh *et al.* 2018). A power-operated weeder for inter-row cultivation is costlier for small farm operations compared with the push-pull type weeder. The work rate of different weeding implements varies due to variation in a row and plant spacing, crop canopy size, weeding depth, soil conditions and other different factors. The typical work rate might vary from 300-500 man-h/ha with the use of a hand hoe (khurpi). But, a khurpi demanded much less energy expenditure than a three-time hoe accompanied with the aid of a spade (Tewari *et al.* 1991). The labor requirement in hand hoeing varies from 200-300 man-h/ha within rows using chopping hoe. Push-pull type weeder requires 100-125 man-h/ha along the row in typical conditions. The labor requirement varies from 6-20 man-h/ha for animal-drawn weeding tools (blade hoe and blade harrow) (Anonymous 2017). Some advanced weeding tools are suitable for the reduction in the human attempt, reduction in time, compared to manual weeding and effectiveness in operation.

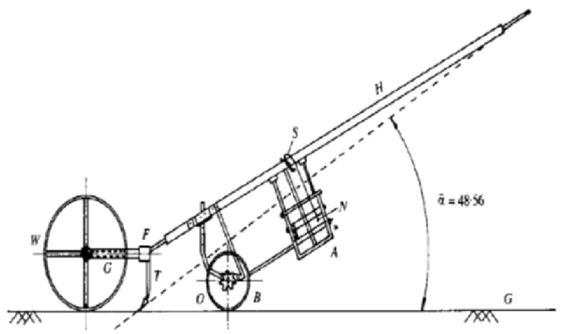
The manual weed management technique has been taken into consideration because of the smoothest and earliest among all techniques. Farmers with their bare hands used to uproot the weeds earlier without the use of hand tools including khurpi (hand-hoe). The manual method which is the simple but it is labour and cost intensive and consumes a huge human effort and energy (Cloutier *et al.* 2007). Humans work in a bending posture for longer durations with this practice, which poses health hazards and has thus been abandoned (Tewari *et al.* 1993, Tu *et al.* 2001, Weide *et al.* 2008, Tewari *et al.* 2014a and b, Chandel *et al.* 2018). Slaughter *et al.* (2008) reported that around 65 – 85% of the weeds only were removed from cotton field by hand-weeding, due to human inaccuracy or missing. It was also stated that, the usage of long-treated hoes would damage the crops and leaving behind some weeds in the field (Gianessi and Reigner 2007). A manually operated weeder, was developed and tested ergonomically for relative weeding performance, consisted of a pull-push recorder to measure the force of five different blades during the weeding operation (**Figure 1**) (Tewari *et al.* 1993). Each of the blades has width of cut 20 cm, cutting angle 20° and sharpness angle 15°. The quality of work of B_1 was superior (84%) compared to all other blades. Another manual weeder was developed and when its performance was studied in the groundnut field by operating at 30 mm depth had field capacity of 0.048 ha/h with weeding performance up to 92.5% (Yadav *et al.* 2007). Another manual weeder developed and ergonomically evaluated in groundnut crop (Goel *et al.* 2008) had the highest performance index (3690) at 11.63% moisture content with the lowest plant damage (2.46 to 7.96%) and the lower energy consumption rate (8.34 to 40.05 kJ/min) when compared with other weeders such as wheel finger weeder, wheel hoe, and traditional weeding. Manual weeding has always faced a problem during cultivation in a timely manner. Different manual weeding tools with its performance parameters is shown in **Table 1.**

Mechanical weed management systems for inter-row weed management

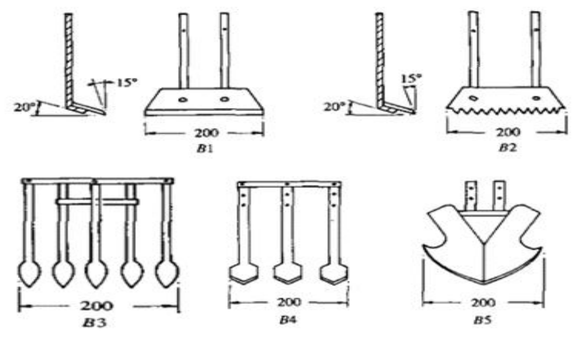
Mechanical inter-row weeders can remove weeds completely or partially. Many mechanical weeders have been developed for cutting, uprooting and burying the weeds in soil. The weeding equipment developed earlier had been pulled by draft animals, which include bullocks and buffaloes. As time progressed, the shift to tractors as the power source was observed (Gianessi and Sankula 2003). Mechanical weed management, alone, is practiced mostly by farmers who avoid usage of herbicides. Inter-row weeding eliminates weeds within the inter-row region without adverse the crop. Mechanical weed management is effective only at the initial stage of crop growth. At a later stage, tractors and cultivators damage the crop foliage due to less ground clearance compared to crop plant height (Cloutier *et al.* 2007). The basket weeder, that consisted of rolling rectangular-shaped round baskets (Bowman *et al.* 1997), is ground driven and did not require any power other than a draft from the tractor. It is capable of removing weeds from the top surface of the soil with the least amount of soil sport into the crop row and is suitable only for soil with high moisture content and a speed range of 6.4 to 12.9 km/h.

A three-row tractor-mounted rotary weeder, with four “L” shaped blades per flange, was developed at TNAU, Coimbatore, under the ICAR- AICRP on Farm Implement and Machinery (FIM) Scheme (Anonymous 2006). In a sugarcane field (at 2-4 km/h speed of operation, 2-2.4 m width of machine, row spacing of 67.5-90 cm) its weeding efficiency was 61-82% with damage of less than 3% with labour saving of > 70% and cost-saving > 50%. Another weeder, with three rows coil spring full sweep tine (Sutthiwaree *et al.* 2015), had the field capacity, weeding efficiency, and fuel consumption were 0.54 ha/h, 94.66% and 5.58 L/ha, respectively, when tested in sugarcane field. A tractor-mounted rotary weeder designed and developed at PAU, Ludhiana under ICAR-AICRP on FIM scheme. (Anonymous 2018), had the field capacity of the machine was 0.24 ha/h with a weeding efficiency of 83-87%. Three commercially available power weeders for weeding operation and inter cultivation were evaluated in the sweet sorghum crop in Andhra Pradesh (Srinivas *et al.* 2010). Power weeder consisted of three types of blades *i.e.*, C, L and Sweep type of blades. The weeding efficiency of C, L and Sweep type of blades was found to be 91, 87 and 84%, respectively. The performance index with C, L and Sweep type of blades was observed as 169.84, 153.23 and 114.30, respectively.

Inter-row weeding using precision hoe showed good results for vegetable farming in Italy (Peruzzi *et al.* 2007, Fontanelli *et al.* 2009, Raffaelli *et al.* 2009). The developed machine is a modular machine which was constructed for different working depths



(a) Push-Pull weeder



(b) Different type of weeding blades

B1: A straight flat blade, B2: A straight flat blade with a serrated edge, B3: A five tines blade, B4: A sweep type blades, and B5: A double plough type blade

Figure 1. Manual operated push-pull weeder and different types of blades

Table 1. Manual weeding tools

Device	Width of cut (mm)	Field capacity (ha/h)	Weeding efficiency (%)	Work rate (man-h/ha)	Energy requirement (MJ/ha)
Khurpi	80	0.001-0.002	92-99	300-500	567.62
Grubber		0.004-0.008	82-96	109	212.62
Spade	220	0.0002	75.7-92	120-226	326.62
Wheel hoe	230	0.008-0.009	72-94	86	167.30
Push-pull type weeder (V shape blade)	150-250	0.026-0.033	80-90	100-125	140.5

Ref: Tewari *et al.* 1993, Mandal *et al.* 2002, Yadav *et al.* 2007, Shekhar *et al.* 2010, Sarkar *et al.* 2017, Chethan *et al.* 2018 adapting to the distinct soil conditions (Raffaelli *et al.* 2009). The working width is adjustable as every device is fixed on an articulated parallelogram ready with a small wheel that allows adjustments. The precision hoe working equipment, mounted on a rectangular draw frame, comprises of rigid elements that include a 9 cm wide triangular horizontal blade each, pairs of concave discs, and two types of elastic tines- vibrating and torsion). The steering is manually completed by way of a back-seated operator. This system can provide a more selective weed control inside the rows for vegetable plants such as cabbage, cauliflower and tomato. The rolling harrow for weed control was utilized for the shallow tillage and performed efficient weed control methods.

Split-hoe is used to control weeds in the inter-row area of herbaceous, horticultural, and greenhouse plants in Germany (Asperg Gartnereibedarf, Germany) (Pannacci and Tei 2014). Split-hoe has the advantages of hoe, rotary tilling cultivator and brush weeder, while it does not have their negative aspects. Weeds present in the inter-row area ranging from 0.4 - 0.5 m to 0.2- 0.25 m can be removed using a split-hoe. A shield is provided for covering the crop plants. As a result, an uncultivated soil band of 80 mm gets left. Weeding was achieved by the gangs of spike-wheels mounted on a horizontal axis that gets power from the tractor PTO (Power take off) . A spike wheels system was provided for the cutting and pulling of the weed plants simultaneously at the same time (Pannacci *et al.* 2017).

The majority of previous weeders have been horizontal, and there has been little investigation into vertical axis rotating weeders and weeding unit energy considerations. A non-powered self-propelling vertical axis rotary weeder was designed to eliminate the external powering mechanism that delivers the energy to remove the weeds and soil (Kumar *et al.* 2019). The designed weeder was tested in a maize crop, with operational depths of 2 and 4 cm and crop growth stages of 15 and 30 DAS. The invented weeder functioned well at all stages of crop development, with weeding efficiency ranging from 65 to 70% and plant damage from 1.98 to 5.88%.

The evaluation of self-propelled rotary weeder and a tractor-operated sweep weeder for weed management in cotton (Dixit *et al.* 2011) recorded weeding efficiency of 94 - 95% and plant damage 1-4 % with the field capacity 0.11 ha/h to 0.13 ha/h for self-propelled weeder and 0.2 ha/h to 0.4 ha/h for tractor operated weeder. Several mechanical weeders capable of removing inter-row weeds at different depths and speeds with high weeding efficiency were developed and demonstrated **(Table 2)**.

Mechanical weed management systems for intra-row weed management

The intra-row weeds remain uncontrolled after the management of the inter-row weeds with mechanical weeders. Hence, intra-row weeders were also developed from time to time. The spring-tine harrow weeder could be worked at a speed of around 6 to 8 km/h and at a working width of 6 to 24 m (Kouwenhoven 1997). The level of weed control relies on weed types and crops. The duration of operation, forward speed, angle of the tines, weed composition, difference between growth phases, and plant height differential between the crop and weeds all had an impact on the weed/crop (Rasmussen 1990).

A brush weeder was developed (Kouwenhoven 1997, Melander *et al.* 1997**)** which was manually directed and consisted of flexible brushes made of fiberglass or nylon that revolved around vertical or horizontal axes (**Figure 2a**). This weeder is capable of uprooting weeds, besides, to bury and destroy them. A protecting guard was provided to avoid the crop from damage. An operator was preferred to manually guide the brushes to eliminate weeds closest to crop plants without detrimental them. The torsion weeder is a gadget for weed management inside vegetable rows and is frequently used along with any other inter-row cultivation blade (Weide *et al.* 2008). Torsion weeder was fabricated that consisted of pair of spring tines linked to a rigid frame angled downward or backward within the row so that the two quick segments can work very close to each other and parallel to the soil surface (**Figure 2b**). The tines control the intra-row weeds. However, any imprecision in steering distracts the output and damages the main crop. The work is also supposed to perform on relatively low forward velocities, and hence it has a very low working capacity (Bleeker *et al.* 2002, Melander 2004, Cloutier *et al.* 2007, Weide *et al.* 2008).

A finger weeder is a basic mechanical intra-row weeder that consists of two pairs of truncated metal cones that are ground-driven by metallic tines oriented vertically. The cone has rubber spikes, or

Table 2. The inter-row weed control devices developed and their features

Devices	Depth of operation (mm)	Speed of operation (Km/h)	Field capacity (ha/h)	Weeding efficiency (%)
Rotary weeder	40-50	2-4	0.24-0.5	61-87
Sweep cultivator	20-40	2-4	0.54	84-94
Chemical weeding	On surface	2.9-9.7	2 -5	90
Self-propelled rotary power weeder	20-50	1.3-2.5	0.08-0.09	91-95

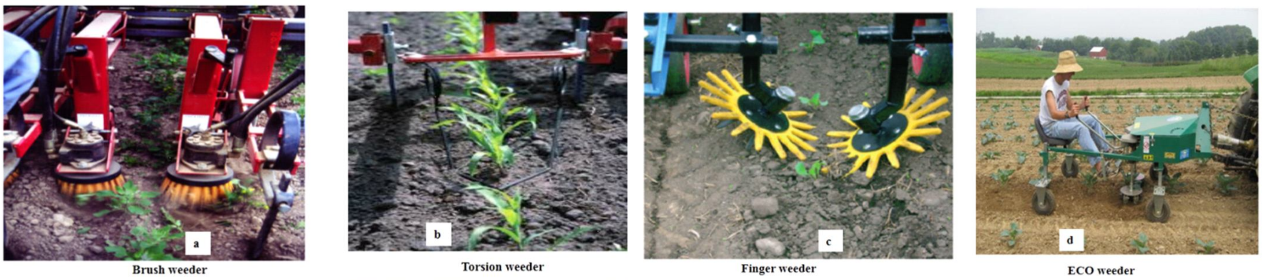
weeder fingers pointed horizontally outwards while the crop row is in between the cones **(Figure 2c)**. Finger weeder is a great performer in loose soils; however, it performs poorly incrusted or compacted soils or while the long-stemmed residue is present in the area (Van der Schans *et al.* 2006, Weide *et al.* 2008). Small weeds near the fingers are removed by the rubber fingers that penetrate below the soil surface.

An ECO-weeder is a mechanical intra-row weeding equipment with a three-point hitch system that was operated behind a tractor (**Figure 2d**). The weeding unit was powered by tractor Power take-off (PTO). The ECO-weeder could reduce the weeding costs by up to 60% compared to manual weeding. The field performance of intra-row weed management devices and effect of speed on weed control is shown in **Table 3** and **Table 4** respectively. A mechanical inter- and intra-row weeding system for row crops was developed at ICAR-Central Institute of Agricultural Engineering, and was evaluated in field grown crops (Chandel *et al.* 202). The optimal intra-row tine rotary speed to forward speed (u/v) ratios were in the range of 0.8–1.3, resulting in weed mortality of 88.4% (Buried: 8.5%, Uprooted: 79.9%), negligible intact weeds, and plant damage (Pd) of less than 6%. At recommended operating speeds of 0.50–0.56 m/s, the machine's field capacity was found to be 0.22–0.26 ha/h.

Automated technology for intra-row weeding

Manual guidance is the most common techniques, either by the input of a second operator seated on the hoe or by highly accurate tractor steering, both demand high levels of concentration. Weed management can overcome the limitation in manual and mechanical methods through automation which helps in differentiating crop plants and weeds and remove the weeds precisely by mechanical device in an automotive mode without intervention of human and without causing plant damage (Bakker 2009). Automation incorporates major innovations such as guidance, detection and identification, in-row precise weed control and mapping (Slaughter *et al.* 2008). It helps to reduce the operator stress and restricts operators from continuous steering of agricultural equipment. It allows in focusing on implement performance and reduce resources through use of electronic hardware, sensors, actuators and software (Kocher *et al.* 2000).

Enormous importance was given to vision systems and image processing techniques for weed identification based on plant characteristics and visual structure (Gonzales *et al.* 2004). A computer vision guiding system can detect the location of a tool, the center of the seed line, the ridge edges, and calculate the offset distance from the crop's center line. Slaughter *et al.* (1999) built up a machine vision guidance framework utilizing an ongoing color segmentation of direct-seeded crops in seed lines



(**Source:** Dedousis *et al.* 2006, Dedousis 2007, Weide *et al.* 2008, Anonymous 2011, Ahmad 2012)

Figure 2. Mechanical intra-row weeders

Table 3. Field performance of intra-row weed management devices

Devices	Weed control	Depth of operation (mm)	Field capacity (ha/h)	Weeding efficiency (%)
Finger weeder	Intra-row	10-40	0.3-0.6	55-60
Torsion weeder	Intra-row	10-25	0.1-1.4	60-80
ECO weeder	Intra-row	25-50	0.05-0.15	60-80
Flame weeder	Intra-row	On surface	0.1-0.5	80-90

Table 4. Effect of speed on intra-row weeds management

Devices	Weed control	Depth of operation (mm)	Speed (km/h)	Weeding efficiency (%)
Brush weeder	Inter-/Intra-row	20-30	<3.5	60-80
Harrow	Inter-/Intra-row	20-30	7	70-80
Hoe ridger	Inter-/Intra-row	25-40	7	80-90
Sensor based vertical axis rotor weeder	Inter-/Intra-row	20-60	1-2.58	75-90

where the crop is missing because of poor germination. They utilized two cameras and a framework was tried in the field at a speed of 16 km/h. The general RMS position error was from 4.2 mm (no weed condition) to 12 mm (under high weed condition). A row guidance system dependent on machine vision just as global positioning systems (GPS) for crop row recognition was described (Slaughter *et al.* 2008). The machine can identify crop rows with minimal errors from 12 to 27 mm at travel speeds of 2.5 to 10 km/h and GPS precision with RMS error at 6 cm and 13 cm maximum error in horizontal direction. Simultaneously, the lateral movement of the electromechanical/hydraulic steering system was controlled in this system (Tillett *et al.* 2008, Sogaard and Olsen 2003, Bakker *et al.* 2008).

There are numerous guidance systems proposed for weed control in agriculture (Tillett 1991, Hague *et al.* 2000) using which high-level accuracy is expected for intra-row cultivation. The most appropriate guidance techniques are to sense the crop directly and operate the weeding system on time. Sukefeld *et al.* (2000) utilized Fourier descriptors and shape parameters to distinguish more than 20 weed species. About 69.5% of weeds with only cotyledons were correctly identified, while 75.4% of weeds with one or two pairs of leaves were correctly identified. In wider row crops, this detecting system distinguishes between crop and weeds by working constantly with a camera image and under uncontrolled illumination and movement conditions (Guerrero *et al.* 2017).

High-level accuracy is expected for intra-row cultivation. There are numerous guidance systems proposed for weed control in agriculture (Tillett 1991, Hague *et al.* 2000). The most appropriate guidance techniques are to sense the crop directly and operate the weeding system on time. Manual guidance is also the most common techniques, either by the input of a second operator seated on the hoe or by highly accurate tractor steering, both demand high levels of concentration.

For detection of weed and subsequent control, Astrand and Baerveldt (2002) developed an autonomous mobile agricultural robot using a system that includes two cameras: one gray-scale camera for distinguishing crop rows and another for weeds rows. The robot works along with the columns, and the subsequent camera utilize a color-based vision system to recognize a single crop among weeds and thus it focuses on a perceptual system for crop row recognition rather than weed management specifically. The weeding device was guided with the assistance of a pneumatic chamber for some tilling action in inter row plant area. At a speed of 0.2 m/s and a camera error of +2 cm, machine performance was acceptable. Using picture segmentation algorithms, the color-based camera effectively spotted crops. It uses colour and shape characteristics to classify weeds and crops. The machine's weed-control effectiveness, however, was not reported.

A robotic weed control machine was developed for transplanted lettuce (Blasco *et al.* 2002) by which weeding was done using a high voltage electric current (15 kV electrical current discharge). Two vision-based machines were used, one to detect the weeds in the field based on size and another to position the electrical probe to destroy those weeds. The autonomous platform and record device was capable of gathering pix automatically. Maps and images of weeds and crops were also acquired. The detection accuracy of the system was 84% for the weeds and 99% for the lettuce plants.

For the guidance of an implement at the side of a pre-stored electronic area map through satellite, Real-Time Kinematics (RTK) DGPS (Differential Global Positioning gadget) was inspected by Zuydam (1999). The field map was based on a coordinate system that describes the path of an implement. It was observed that the real direction of the implement deviated using less than ± 20 mm from a straight line. A rover and a base DGPS were used for the guidance of the weeding machine. This base station must stay close to the rover unit for best results. The implement was guided through GPS the use of a side-shift mechanism to control lateral position.

An intra-row weeder, developed by Griepentrog *et al.* (2006) on the RTK base, used crop seed maps created at the time of sowing to remove the weeds. This rotary weeder consisted of eight tines rotated with the help of an electro-hydraulic motor describing cycloid curves. The rotary tine cultivator (the cycloid hoe) can be guided within the crop rows by RTK-GPS (Norremark 2008). It was tested in the field for its accuracy. By using a plastic stick, instead of crop, a violation of the uncultivated region (10 mm from the center of sticks) by tines was seen in less than 2% of the observations. The effectiveness of weed eradication and crop–weed discrimination, on the other hand, was not assessed. The research findings highlight that the rotor weeding mechanism could control weeds and cut the soil without destructive crop plants. The weeding mechanism can uproot and cut weeds and cover them with soil. The cycloid pattern is visible in the hoeing system. The novel idea is that, the tines may be retracted to the interior of the cylinder, causing the tine tip to trace a smaller cycloid. Griepentrog *et al.* (2007) examined the identical machine at a speed of 1.44 km/h; they mentioned that it induced immoderate damage to the crop and resulted in very low weed control efficacy. Moreover, cycle hoe has some disadvantages that make it unsuitable for mechanical weed control. One of the most reported constraints is its design complexity, which causes the increased maintenance and capital price. An undisturbed circle around the plant (18 mm) also makes the system difficult to adapt. The soil type is another crucial factor. When soil clods engage with crops, it will become tough to control crop damage. In cotyledons plants (at the true leaf stage), the mechanical design of the system is tough for use due to potential damage.

The rotary tine cultivator (the cycloid hoe) guided within the crop rows by RTK-GPS was tested in the field for its accuracy (Norremark 2008). by using a plastic stick, instead of crop. A violation of the uncultivated region (10 mm from the center of sticks) by tines was seen in less than 2% of the observations. The effectiveness of weed eradication and crop–weed discrimination was not assessed.

Zuydam and Sonneveld (1994) explored the accuracy of a laser directing system that is guided to a tool to control the weed. A side moving unit, a transmitter, and a second operator with a hand-held receiver made up the guidance system. An electro-hydraulic valve was used to convert a lateral error indication into hydraulic cylinder activation. It assists with moving the laser guidance system towards an exact side. The maximum distance for the selected laser can work at 500 m with an average steering accuracy of ± 6 mm over a length of 250 m. The maximum deviation was no longer exceeded 19 mm. An alternative non-contact system was developed by Andersen (2003). To measure the furrow's extreme value points, he used a vertically placed laser light source. Following that, the implement was guided to produce the proper lateral alignment. Kise *et al.* (2005) created a weed-free detection system using near-infrared stereovision. The system represented an error of 30–50 mm RMSE relying on speed and row arc. Astrand and Baerveldt (2002) developed a machine based on vision steering to distinguish between direct-seeded crop plantings, crop plant length and the presence of weeds at densities up to 200 weeds/m^2. This machine was primarily based on the Hough transform, which uses a couple of rectangular regions for crop size to estimate the row position.

The rotating disk and the cycloid hoe for Intra row weeder was developed (Cavalieri *et al.* 2001) whose working was based on real-time or map-based. The rotating disk, developed at Wageningen University, comprised of a vertical rotating disc with two spring-loaded knives that are actuated by a hydraulic motor. Its speed was controlled by a hydraulic controller. The disc rotates with a steady speed of 850 rev/min, and the knives fold-out due to the significance of both the forces, which is the centrifugal force that is larger than the spring force. The disc decelerates to 700 rev/min when a plant is detected, and because of the inertia forces, the knives fold in, letting the disc to keep away from the plant contact (Bontsema *et al.* 1998, Home 2003). The plant detection sensor, along with three infrared transmitters and three infrared receivers, are placed in front of the disc at a constant height along the crop row (Bontsema *et al.* 1998). Plant detection signals are sent to a digital signal processor. The weeding efficiency is low due to one mode of cutting action above the soil surface. Weed killing efficacy was reduced due to three possibilities *i.e.*, uproot, cut, and cover. Additionally, the detection device couldn't differentiate between the plants and weeds appropriately, hence making it a system suitable only for transplanted crops (Jones *et al.* 1995).

Radis Mechanism developed an intra-row weed management system with blades mounted on a pivoting arm. Light sensors detect the plants, and this information is used to control the disc's position. When no plants are visible, the rotating arm enters the intra-row area through an air pressure chamber, eradicating the intra-row weeds.

Bakker (2003) reported that weeds were removed only up to 20 mm at a driving speed of 5 km/h. Bleeker (2005 and 2007) reported a maximum speed of 3 km/h limited for weeding operation in case of Radis weeder, due to the plant damage by the intra-row hoe mechanical transition. This technique is best suited to vegetables with a wider spacing between rows and a minimum intra-row spacing of 220 mm (Bakker 2003). The system's challenge was detecting the plant in a wide row crop and limiting the speed of the intra row weeding operation.

Tillett (1991) reported that a high accuracy of 99% can be obtained from ultrasonic guidance in the distance range of 100 mm to 10 m. He also said that stray foliage poses issues because the distance is calculated based on the time it takes for the ultrasonic signal to reach, hit, and reflect back off the target, which means that the signals are reflected back from weeds rather than crops.

A weeding machine using computer vision was tested to detect plants by Tillett *et al.* (2008). A rotating half circle disc was provided in this automated intra-row weeder to protect the crops at the time of weeding (**Figure 3a**). A digital camera was fixed at mid-position of the weeder for looking forward and down. The camera was vertically above the base of the field of view and it covered the length of about 2.5 m over a time of view. Weeding treatments were conducted at 16, 23, and 33 days after transplanting (DAP). Weeding conducted after

16 and 23 days of planting gave the best results as it resulted in a decrease in the number of weed plants by 77 and 87%, respectively.

Another novel inter and intra-row mechanical weeder can operate at a speed of 1.2 m/s in transplanted intra-row spacing (**Figure 3b**) (Home 2003). It consists of a duck foot and reciprocating blades for inter and intra-row weeding, respectively. The plants are identified by using a camera and differentiated from the weeds based on computer vision. It is possible to operate at a speed of 2.2 m/s. Excessive damage to the plants was reported.

A rotating tine mechanism for an automated mechanical intra-row weeder with rotating tine mechanism powered by a brushless DC (BLDC) motor was developed (Ahmad *et al.* 2012) which detects crop location using a machine vision system. The weeding actuator was controlled using a controller. At travel speeds ranging from 0.8 to 2.4 km/h and working depths of 25.4 mm and 50.8 mm, they discovered a substantial difference in weed canopy area.

A weeding tool developed by Gobor *et al.* (2013), comprised of number of arms holders and integrated on horizontal axis of rotating arms, placed directly above the crop row. A concept of integration of the weeding tool on an autonomous platform, in the form of a prototype was used. The guiding principle was based on the hoeing tool's rotating speed. The tool must be fine-tuned in real time, taking into account the tool carrier's forward speed, the estimated in-row distance between consecutive plants, and the observed angular position of the arms. For the validation of the geometrical equations, a model was built and a virtual prototype of the system was created in Pro/Engineer. For testing the system behaviour for various weeding techniques and considering distances inside adjacent crops, a virtual model of the weeding tool was used. Different weeding approaches were simulated for less plant damage and examined for one, two, and three consecutive trajectories tools inside nearby plant, with and without changing the angular position. The sensor guided system and accuracy of intra row weeding system is shown in **Table 5**.

(a) Disc weeder (b) Autonomous vehicle for intra-row

Source: Home 2003, Tillett *et al.* (2008)

Figure 3. Autonomous hydraulic operated weeder

A weed identifying robot was developed by Sujaritha *et al.* (2017), consisting of a Raspberry Pi microprocessor with appropriate input-output subsystems, such as cameras, small light sources, and motors, as well as an electric device. Raspbian working gadgets and python programming were used for the weed detection mechanism. Among nine different weed species, the built robot prototype was able to correctly locate the sugarcane plantation. The developed system identified the 92.9% weeds correctly and had a handling time of 0.02 s. Jakasania *et al.* (2019) developed an intra row weeding unit and evaluated at soil bin laboratory for determining percentage of plant damage. The minimum plant damage was observed at plant spacing of 35 cm and speed of operation of 1.0 km/h.

Kumar *et al.* (2020) developed a fuzzy logic algorithm integrated autonomous system for weed eradication in the intra-row crop zone. The system incorporates time of flight and inductive sensing into a fuzzy logic algorithm for electronic control of a four-bar linkage mechanism (FBLM). A prototype of intra-row weeder was developed as a combined arrangement of mechanical linkage actuator system and various electrical sensing and control systems (Kumar *et al.* 2019a and b). The prototype consisted of an intra-row vertical axis rotor, FBLM, sensor, permanent magnate direct current (PMDC) motor, microcontroller circuit box and virtual plants. Intra row weeding system was evaluated at soil bin laboratory at varied conditions of soil compaction, forward speed, depth of operation and plant spacing. The developed system very well accounted for the numerous parameters that could exist in field operations. With faster forward speeds and smaller plant spacings, plant damage increased significantly (p=0.05). The device's sensing accuracy was also evaluated during preliminary tests, and encountered plant damage. The overall operating efficiency varied within 80 to 96% when evaluated under different plant spacing.

Machine vision-based sensing systems for managing inter- and intra-row weeds by other weed management methods

The machine vision-based sensing system was integrated with an existing sprayer for selective herbicide control (Steward *et al.* 2002). A finite state machine (FSM) model was utilised to construct the controller, and generic design specifications were created to determine the travel distance between states. Artificial targets were used to test the system's spatial application accuracy in the field. The system has a 91% overall hit accuracy with no statistical evidence that the mean pattern length was affected by vehicle speed. Home-made system for spatially

Table 5. Sensor guided system for intra-row weeding operation

Device	Guidance type	Accuracy/limitation	Source
Hoe	Laser guidance steering system	±6 mm	Zuydam & Sonneveld 1994
	Ultrasonic	99% over range 0.1-10 m	Tillett 1991; Kumar *et al.* 2020
	Real Time Kinematics (RTK) DGPS	± 20 mm to ± 60 mm	Zuydam 1999; Griepentrog 2006; Buick 2007; Slaughter *et al.* 2008
Cycloid hoe	Hydraulic side-shift system	Geo-positioning expensive maintenance	Griepentrog 2007; Cavalieri *et al.* 2001
Field Robot or Autonomous vehicle for weeding	Machine Vision guidance system	±12 mm to ± 45 mm	Tillett *et al.* 1999; Keicher and Seufert 2000; Astrand and Baerveldt 2002; Home 2003; Aastrand and Baerveldt 2005; Tillett *et al.* 2008; Lee *et al.* 1999; Slaughter *et al.* 2008
Vertical rotating disk weeder	Rotating disc with a cut-out sector	Angular error of the disc less than 10°	Dedousis *et al.* 2006
Rotating disc tine	Infrared	Error on discrimination between plants and weeds	Cavalieri *et al.* 2001; Bontsema *et al.* 1998; Jones *et al.* 1995 and 1996
Radis moving tine	Light sensors	Error due to natural light interference	Bakker 2003; Bleeker 2007

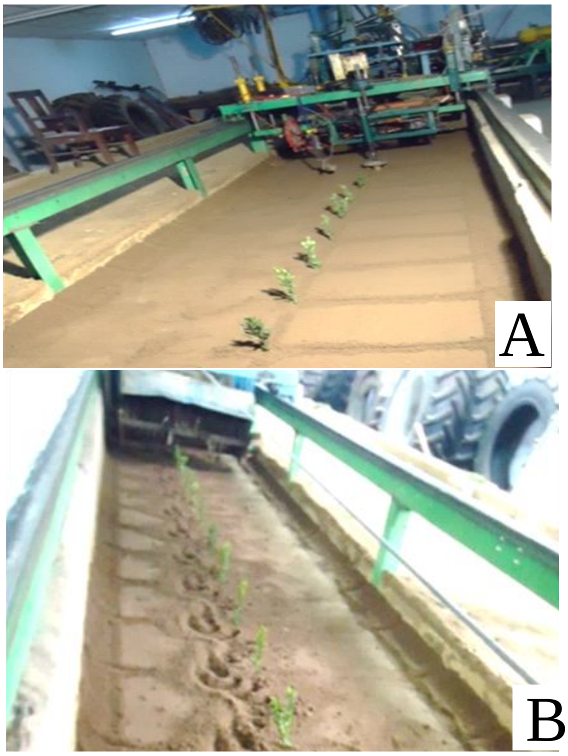
variable rate herbicide applicator was used to weed control (Carrara *et al.* 2004). This system consists of a differential global positioning system (DGPS), a portable computer, custom-developed software, and a device that applies rates proportional to the machine forward speed. The herbicide application at a spatially varying rate allowed for an almost uniform grain production across the entire field. In comparison to the levels generally used in conventional farming, the technique saved 29% of herbicides.

Another real-time robotic weed control system useful for the cotton field (Lamm *et al.* 2002) was able to distinguish between weeds and cotton plants, allowing for precise application of the chemical spray. Weeds were targeted at a travel speed of 0.45 m/s and the system was correctly sprayed at 88.8% weeds at this speed.

Tewari *et al.* (2014a) developed a three-row contact type microcontroller-based herbicides applicator to control the weeds population from the inter-row crop (**Figure 5a**.). The system was based on real-time image processing. The system automatically computes and applies the amount of herbicide through contact sponge rollers depending on the amount of weed estimated by real-time image processing. Field experiments demonstrated that there was a 40% herbicides reduction having an application efficiency of 90%. Chandel *et al.* (2018) developed a tractor-operated contact type weed eradicator for row crops using a microcontroller-based position sensor and an integrated digital image processing system (**Figure 5b** and **c**). The weed density within the crop rows was detected using an image analyzer developed in the Visual Studio Open computer vision platform, which was employed under varied illumination conditions. In addition, a graphic user interface was designed for parametric adjustments of the image analyzer. The micro-controller acquires the data from the image analyzer, processes the data and sends the signal to the solenoid valve to release the chemical over the contacting roller (Figure 5d). They reported an average weeding efficiency of 90% in maize and groundnut crops with plant damage of 5 and 8%, respectively. They observed a saving of 79.5% of herbicides by using the digitally developed embedded system. The use of chemical herbicides in the field is causing an increase in health risks, environmental issues, and herbicide-resistant weed species, all of which are driving demand for low-cost, chemical-free production. Many researchers have been challenged to investigate and develop alternate weed management technologies (Astrand and Baerveldt 2002, Kurstjens 2007, Dedousis *et al*, 2007, Tillett *et al*.2008, Norremark *et al*. 2008).

A real-time robotic weed control system can be utilized for exact application of herbicide applications on weeds utilizing machine vision (Lee *et al.* 1999). Weeds can also be controlled by a high voltage (15-60 kV) electrical current to small weeds utilizing a precise control system (Diprose and Benson, 1984, Blasco *et al.* 2002). Weeds can be detected and burnt precisely using infrared sensors and flame nozzle spray (Merfield 2011). The flame weeder is also used for weeding operation. The important thing to know about flame weeder is it can be used either before weeding or pre-emergence. It can also destroy under soil surface weeds (Kirchoff 1999).

Flame weeders were precisely impacted the weeds growing in the "in-row" space at strip of 0.25 m wide. This weeder was used for onion and maize crop precisely and that plants can tolerate flaming (Parish 1990, Ascard 1990). A computer vision guiding system can detect the location of a tool, the



(Source; Kumar *et al.* 2020)

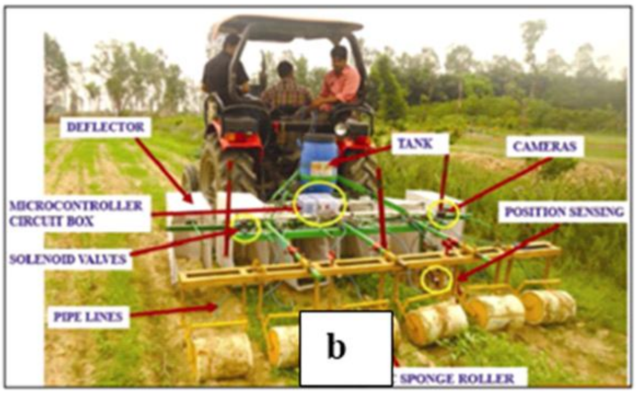
Figure 4. Soil bin profile (a) before and (b) after operation of prototype intra-row weeder

centre of the seed line, the ridge edges, and calculate the offset distance from the crop's centre line. Simultaneously, the lateral movement of the electromechanical/hydraulic steering system was controlled in this system (Tillett *et al.* 2008, Sogaard and Olsen, 2003 and Bakker *et al.* 2008). Sukefeld *et al*. (2000) utilized Fourier descriptors and shape parameters to distinguish more than 20 weed species. About 69.5% of weeds with only cotyledons were correctly identified, while 75.4% of weeds with one or two pairs of leaves were correctly identified. In wider row crops, this detecting system distinguishes between crop and weeds by working constantly with a camera image and under uncontrolled illumination and movement conditions (Guerrero *et al.* 2017).

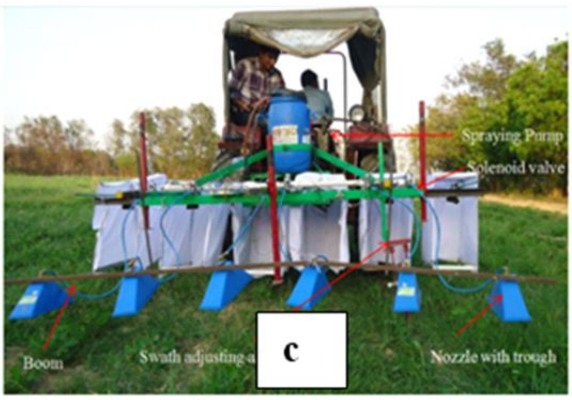
Conclusions

Mechanical weeding has seen a lot of innovation over the previous few decades, but more is needed to develop and use precision agricultural technology for mechanical weed management in India. There are presently no commercial approaches available to effectively control intra-row weeds, and the accuracy of the tool's lateral positioning in intra row is restricted to the guidance system. The challenges for dynamic synchronization of electronic control,

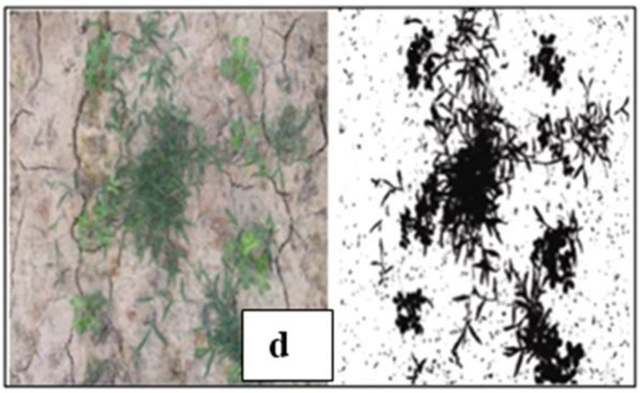
(a) Manual drawn



(b) Tractor drawn roller based herbicides applicator



(c) Herbicideds applicator



(d) Image processing of weeds

Source: Tewari *et al.* 2014a, Chandel *et al.* 2018

Figure 5. Image processing and microcontroller based herbicide applicators

mechanical tool actuations, and plantation characteristics need to be consistently explored and optimized for effective weeding options in row crops.

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RESEARCH ARTICLE

Effect of tillage and weed management on weed dynamics and yield of rice in rice-wheat-greengram cropping system in vertisols of central India

Nisha Sapre*, M.L. Kewat, A.R. Sharma and Priya Singh

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ABSTRACT

A field experiment on effect of tillage and weed management on weed dynamics and yield of rice in rice-wheat-greengram cropping system in vertisols of central India was conducted during *Kharif* 2014 to 2015 at ICAR-DWR, Jabalpur. The experiment consisted of total 15 treatments. A split plot design having three replications was used with five tillage practices in main plots and three weed control treatments in subplots. The maximum weed density and biomass were found when zero tillage was done in rice in the presence of *Sesbania* (S) and greengram residues (ZT+S+GG); under zero tillage in rice in the presence of *Sesbania* and green gram residues-zero tillage in wheat in the presence of rice residues- zero tillage in greengram in the presence of wheat residues system [ZT+S+GG(R)-ZT+RR(W)-ZT+WR(GG)] followed by zero tillage done in rice in the presence of only *Sesbania* residues (ZT+S) under ZT+S(R)-ZT(W)-ZT(GG) system. Whereas the minimum was recorded when conventional tillage was done in transplanted rice under CT(TPR)-CT(W)-fallow system which also recorded higher grain and straw yields as well as gross monetary returns but had higher cost of cultivation followed by (ZT+S) under ZT+S(R)-ZT(W)-ZT(GG) system. This system also has the maximum net monetary returns and B:C along with the reduced cost of cultivation. Rotational application of chlorimuron + metsulfuron-methyl 4 g /ha during previous year and post-emergence application (PoE) of bispyribac-sodium 25 g/ha during next year in rice as well as regular application of bispyribac-sodium 25 g/ha PoE in rice during both the years gave similar weed control and recorded the higher crop yield, net monetary returns and B:C. Among different treatment combinations, rotational application of chlorimuron + metsulfuron-methyl 4 g/ha PoE during previous year and bispyribac-sodium 25 g/ha PoE during next year after conventional tillage in transplanted rice under CT(TPR)-CT(W)-fallow system and ZT+S in rice under ZT+S(R)-ZT(W)-ZT(GG) system has resulted lower weed density and biomass along with higher weed control efficiency, higher grain and straw yields and economic returns than other combinations.

Keywords: Bispyribac-sodium, Chlorimuron + metsulfuron-methyl, Conventional tillage, Economics, Productivity, Weed management, Rice, Zero tillage

INTRODUCTION

Rice is a major food crop in India and rice-wheat is one of the valuable and popular cropping system in India as well as most of the regions in the world. It occupies about 13.5 million ha (Mha) of cultivable land in South Asia (Nawaz *et al*. 2019), particularly in India, Bangladesh, Pakistan and Nepal. In most of the part of central India, rice is grown by transplanting method in puddled conditions. This type of cultivation requires a large quantity of water, huge labour and energy; declines crop productivity; causes ill effects on soil health as well as increases cost of cultivation and ultimately lowers the net income. Sowing direct-seeded rice (DSR) is a better choice to overcome the problem of water scarcity and labour shortage (Weerakoon *et al.* 2011). Similarly, sowing of DSR with zero or minimum tillage conserves the soil and water and ensures sustainable crop production. It also abridges the cost of cultivation as well as energy consumption to sustain productivity and secure good earnings for the farmers (Singh *et al.* 2006). Hence, conservation agriculture (CA) become popular among many countries and they are shifting from conventional agriculture to CA. About 157 Mha area has come under CA in which 15 Mha occupied in India during, 2013 (FAO 2014). Sowing of DSR gives almost equal yield to transplanted rice and it has higher net monetary returns due to lower cost of cultivation (Singh *et al.* 2005). Weeds are the major constraint in DSR it causes yield reduction. Uncontrolled weeds in DSR cause 85 to 98% yield loss especially in zero tillage system (Chauhan and Johnsos 2011). It was assessed that 10 to 32 days after sowing (DAS) in wet-seeding and up to 83 DAS in dry-seeding were more critical for weed control (Sharma *et al.* 2006). In DSR, weed management is a very difficult task as weeds and crop plants emerge at the same time (Khaliq and

ICAR-PC Unit (Sesame & Niger), JNKVV, Jabalpur, Madhya Pradesh, 482004, India

* Corresponding author email: toughysingh@gmail.com

Matloob2011). On the flip side after the harvesting of rice with a combiner huge quantity of residues remain left over the soil surface and create problem in tillage operation as well as application of pre-emergence herbicides. Hence patchy emergence of weeds and crops has been shown due to improper distribution and absorption of herbicides which results in lower crop yield. Hence, timely weed management in DSR especially under CA is very necessary for getting higher productivity, economic returns and effective weed control (Jaya-Suria *et al.* 2011).

Different weed control methods are available for rice crop such as differential tillage practices (Mohler and Galford 1997, Chauhan *et al.* 2006), mechanical, manual, chemical, competitive cultivars, seeding density, water management, fertilizer management, seed invigoration and straw mulching and all these weed control strategies are proved to increase rice yield (Sana *et al.* 2017). The weed flora also shifts with change from conventional to conservation tillage practices, which require a suitable weed management method that involves proper tillage practices, use of crop residues as mulch, inclusion of pulse crop in cropping system, use of suitable broad-spectrum herbicides *etc*. Chemical weed management has appeared as a promising approach for weed control in rice under CA because it is easy, effective and economically feasible method. Through proper time and a combination of pre- and post-emergence applications of herbicides, weeds can be effectively suppressed and allow a competition-free environment for the direct-seeded fine rice (Khaliq *et al.* 2012). Because of the importance of rice and losses due to weeds in DSR, the present study was taken to see the effect of tillage and weed management on weed dynamics and yield of rice in rice-wheat-greengram cropping system in vertisols of central India

MATERIALS AND METHODS

This experiment was conducted at Research Farm, ICAR-Directorate of Weed Research, Maharajpur, Jabalpur (M.P.) during *kharif* 2014 to 2015. The experimental site is situated at 23° 11' 9.1824" North latitude and 79° 58' 27.7680" East longitude with an altitude of 411.78 meters above the mean sea level. It is classified under “Kymore Plateau and Satpura Hills” agro- climatic zone as per norms of National Agricultural Research Project (NARP), New Delhi. The soil of the experimental field was clay (27% sand, 29% silt and 44% clay), neutral in reaction (pH 7.18), normal in EC (0.40 ds/m), medium in organic carbon content (0.60%), medium in available nitrogen (250.56 kg/ha), medium in available phosphorus (17.83 kg/ha) and potassium (280.16 kg/ha) with 1.37 Mg/m^3 bulk density. During the *Kharif* 2014 about 1290 mm rainfall was received on 56 rainy days. But in the next year (2015), the rainfall was quite low (1029 mm) which was received in 44 rainy days.

Experiment was conducted using split-plot design with three replications. The experiment consisted of fifteen treatments comprising of five tillage practices as main plot treatments, *viz*. conventional tillage (CT) in rice (R)+ Sesbania (S)-conventional tillage in wheat (W)-zero tillage (ZT) in greengram (GG) [CT+S(R)-CT(W)-ZT(GG)], conventional tillage in rice+ Sesbania+ greengram residues-conventional tillage in wheat + rice residues (RR)-zero tillage in greengram+ wheat residues (WR) [CT+S+GG (R)-CT+RR(W)-ZT+WR(GG)], zero tillage in rice+ Sesbania -zero tillage in wheat-zero tillage in greengram, [ZT +S(R)-ZT+S(W)-ZT(GG)], zero tillage in rice + Sesbania + greengram residues [GG(R)]-zero tillage in wheat + rice residue-zero tillage in greengram + wheat residues (WR)-[ZT+S+GG(R)-ZT+RR(W)-ZT+WR(GG)], conventional tillage in transplanted rice (TPR)-conventional tillage in wheat fallow [CT(TRP)-CT(W)-fallow] and sub plot treatments, *viz.* weedy check, bispyribac-sodium 25 g/ha in rice as post-emergence application (PoE) in both the years and rotational application of chlorimuron + metsulfuron-methyl (ready mix) 4 g/ha PoE during (2014) and bispyribac-sodium 25 g/ha PoE during 2015 in rice. Weed count, for estimating weed density at 60 days after sowing/transplanting was recorded with the help of a quadrat (0.5 x 0.5 m) placed randomly at four spots in each plot. To record weed biomass weeds were cut at ground level, washed with tap water, sun-dried in hot air oven at 70°C for 48 hrs and then weighed. For the statistical analysis weed density and biomass were converted to 1 m^2 and imposed square root transformation to normalize their distribution. Further weed control efficiency (WCE) was calculated by using the formulae given by Mani *et al.* 1973. The grain yield was taken from 10 m^2 area in the center of each plot and expressed in t/ha at 14% moisture content. Economic analysis was done as per the prevailing cost of inputs and selling price of output as per the concerning years.

RESULTS AND DISCUSSION

Weed density and biomass

The higher density and biomass of *Echinochloa colona* and *Dinebra retroflexa* were observed with ZT+S in rice under ZT+S(R)-ZT(W)-ZT(GG) system, followed by ZT+S+GG under ZT+S+GG

(R)-ZT+RR(W)-ZT+WR(GG) system (**Table 1**). However, a reverse trend was observed in case of *Cyperus iria* and *Caesulia axillaris*. Whereas, all the weeds have minimum density and biomass when conventional tillage was done in transplanted rice under CT (TPR)-CT(W)-fallow system. The higher density and biomass of *Echinochloa colona* and *Dinebra retroflexa* in ZT+S in rice under ZT+S(R)-ZT(W)-ZT(GG) system may be attributed to minimum disturbance, which left a large number of weed seeds on upper soil layer. These weed seeds germinated just after the sowing of rice and consequently acquired more density and biomass than the high soil disturbance (conventional tillage) system (Feldman *et al.*1997). Mishra and Singh (2012) also observed more emergence of above weeds under zero tillage in rice but the presence of rice residues up to 6 t/ha can suppress the emergence and growth of *E. colona* (Chauhan, 2012). Similarly, *Cyperus iria* is a prolific seed producer, and produces more than 5000 seeds out of which 60% of seeds germinate after 75 days of shedding in moist soil at 20 to 30°C temperature under optimum dryland condition (Das 2008). This species also reproduces from underground plant storage structure (rhizomes), which were not killed or removed in minimum or zero tillage (Sharma *et al.* 2015). The previous crop residues were present on the soil surface under conservation tillage system which influences soil temperature and moisture regimes and affects the weed germination and emergence patterns throughout the growing season (Bullied *et al.* 2003). *Caesulia axillaris* also produces a huge number of seeds and plant develops abundant adventitious roots at the base of the stem (Srivastava *et al.*1983) and their propagation is also facilitated by more available moisture regime throughout the season. Seed germination of *Caesulia axillaris* was manifested by absolute light requirement. As a consequence, more population and biomass of *C. axillaris* was exhibited with ZT+S+GG in rice under ZT+S+GG(R)-ZT+RR(W)-ZT+WR(GG) system. Further, the lower density and biomass of these weeds in conventional tillage might be due to the region that light can penetrate only in the weeds that are commenced on surface layer of soil but most of the seeds were deeply buried which could not germinate due to insufficient supply of oxygen to the deeper soil layer (Egley 1986). The minimum weed density and biomass in CT (TPR) might be because of a reduction in oxygen diffusion rate below 20 x10^{-8} g O_2/cm^2/minute in puddled soil against normal value 40 x 10^{-8} g O_2 /cm^2/ minute. Hence, seeds failed to germinate due to lack of oxygen under puddled condition in transplanted rice (Benech *et al.* 2000). Chauhan *et al.* (2010) also reported lower emergence and growth of *Cyperus iria* due to continuous shallow flooding. Ismail *et al.* (1995) reported no emergence of *E. colona* when rice was flooded for 5 days after seedling/transplanting. It was noticed that long-term cropping of DSR followed

Table 1. Weed density (no./m²) and biomass (g/m²) in rice as affected by tillage and weed control practices at 60 DAS (mean of two years)

Treatment	*Echinochloa colona*		*Cyperus iria*		*Dinebra retroflexa*		*Caesulia axillaris*		Total	
	Density	Biomass	Density	Biomass	Density	Biomass	Density	Biomass	Weed density	Weed biomass
Tillage										
CT+S(R)-CT(W)-ZT(GG)	3.14 (9.36)	4.90 (23.61)	2.26 (4.59)	2.25 (4.57)	1.59 (2.03)	1.85 (2.93)	0.92 (0.35)	1.08 (0.67)	4.14 (16.64)	5.46 (32.64)
CT+S+GG(R)-CT+RR(W)-ZT+WR(GG)	2.72 (6.87)	4.01 (15.60)	2.76 (7.11)	2.62 (6.39)	1.42 (1.52)	1.60 (2.06)	1.02 (0.54)	1.05 (0.61)	4.13 (16.52)	5.07 (25.25)
ZT+S(R)-ZT(W)-ZT(GG)	3.89 (14.66)	5.30 (27.62)	2.95 (8.21)	2.98 (8.41)	2.18 (4.24)	2.15 (4.12)	1.80 (2.75)	1.82 (2.82)	5.57 (30.55)	6.76 (45.24)
ZT+S+GG(R)-ZT+RR(W)-ZT+WR(GG)	3.52 (11.90)	5.55 (30.36)	4.25 (17.56)	3.99 (15.39)	2.00 (3.51)	2.04 (3.66)	2.07 (3.77)	2.64 (6.46)	6.28 (38.93)	7.65 (57.98)
CT(TPR)-CT(W)	2.24 (4.51)	2.88 (7.77)	1.96 (3.33)	1.98 (3.41)	1.31 (1.22)	1.43 (1.55)	0.74 (0.05)	0.75 (0.07)	3.16 (9.50)	3.70 (13.17)
LSD (p=0.05)	0.56	0.50	0.42	0.52	0.61	0.25	0.31	0.77	0.69	0.47
Weed management										
Weedy check	4.73 (21.88)	7.71 (58.95)	5.31 (27.60)	5.31 (27.74)	2.21 (4.39)	2.30 (4.78)	1.86 (2.95)	2.21 (4.38)	7.69 (58.06)	9.95 (98.44)
Bispyribac-sodium 25 g/ha (in both the years)	2.07 (3.80)	2.65 (6.50)	1.78 (2.67)	1.68 (2.33)	1.48 (1.69)	1.67 (2.28)	1.24 (1.05)	1.33 (1.26)	3.16 (9.50)	3.68 (13.08)
Chlorimuron + metsulfuron-methyl in 2014 and bispyribac-sodium 25 g/ha in 2015	2.50 (5.76)	3.23 (9.94)	1.41 (1.49)	1.30 (1.18)	1.41 (1.50)	1.48 (1.69)	0.83 (0.18)	0.90 (0.31)	3.11 (9.18)	3.73 (13.42)
LSD (p=0.05)	0.27	0.60	0.34	0.34	0.47	0.15	0.19	0.54	0.36	0.59

*Value presented in the parentheses are original by zero-till sown wheat provided an excellent opportunity for severe weed infestation. The present findings are in close conformity with Jha (2010).

Different weed control practices caused significant variation in density and biomass of weeds in rice. All weeds had higher density and biomass in weedy check plots where no weed control practices were done. But, weed infestation appreciably declined due to herbicides application. Hoffman *et al.* (1998) reported a reduction in density and biomass of weeds due to application of herbicides. It was noticed that *C. iria, D. retroflexa* and *C. axillaries* were effectively controlled by rotational application of chlorimuron + metsulfuron-methyl 4 g/ha during 2014 and bispyribac-sodium 25 g/ha PoE during 2015 than continuous application of bispyribac-sodium 25 g/ha PoE in rice during both the years. On the contrary, *E. colona* had minimum density and biomass in plots receiving regular application of bispyribac-sodium during both the years as compared to rotational application of herbicides. Effective control of *C. iria, D. retroflexa* and *C. axillaris* due to rotational application of herbicides might be because chlorimuron + metsulfuron-methyl showed better efficacy against these weeds and rotational application of herbicides also prevented early development of resistance in weeds (Das 2008). Singh *et al.* (2003) reported that chlorimuron + metsulfuron-methyl was more capable to kill the broad-leaved weeds and sedges as compared to other herbicides. The above results are in line with Sreelakshmi *et al.* (2016). *E. colona* had taller and more vigorous plants as compared to other weeds and crop. If the targeted plants are taller than the other non-targeted plants, a greater amount of herbicide was intercepted by these plants. In addition, bispyribac-sodium is absorbed by both roots as well as shoots and it is translocated in the plant simultaneously through apoplast and simplast movement (Antralina *et al.* 2015). As a result of more absorption and faster translocation of bispyribac-sodium to the site of action in lethal concentration, density and biomass of *E. colona* were reduced when regular application of bispyribac-sodium was done in rice during both years. Chauhan (2012) also reported 97% reduction in of population of *E. colona* with application of bispyribac-sodium 25 g/ha at four leaf stage.

Density and biomass of weeds were affected due to the interaction of tillage and weed control practices. The total weed density and biomass were the maximum when no weed control was done in ZT+S or ZT+S+GG in rice under ZT+S(R)-ZT(W)-ZT(GG) or ZT+S+GG(R)-ZT+RR(W)-ZT+WR (GG) being minimum in no weeding was done after conventional tillage in transplanted rice and proved superior to other tillage practices. It might be due to poor germination and emergence of weeds in transplanted rice due to anaerobic conditions. However, in case of zero tillage old as well as newly dropped weed seeds were left over on or uppermost layer of the soil, which germinated and emerged out due to zero soil disturbances. Besides this, no herbicidal or other weed control practices were adopted for weed control. Therefore, all weeds had higher density and biomass under zero tillage system. Further, higher weed density and biomass were recorded when the regular application of bispyribac-sodium was done during both years after zero tillage in rice in the presence or absence of greengram and *Sesbania* residues as compared to other combinations. Because 15-80% of applied herbicides are intercepted by anchored crop residues, the herbicides were not absorbed and translocated at site of action in lethal concentration so that higher density and biomass of weeds were recorded under above treatment combinations. Even so greater reduction in weed density and biomass was observed in plots receiving rotational application of chlorimuron + metsulfuron-methyl during previous year and bispyribac-sodium during next year in transplanted rice. Poor emergence of weeds took place in transplanted rice due to anaerobic conditions and the late-emerged weeds were effectively controlled by rotational application of herbicides.

Weed control efficiency in rice

Weed control efficiency (WCE) was significantly influenced due to different tillage practices and weed management practices in rice. The minimum WCE was recorded in ZTR under ZT+S+GG(R)-ZT+RR(W)-ZT+WR(GG). However, the maximum WCE was recorded when conventional tillage was done in transplanted rice under CT (TPR)-CT (W)-fallow system (Table 2.). When rice was sown as direct on zero tillage in presence of greengram and *Sesbania* residues under ZT+S+GG(R)-ZT+RR(W)-ZT+WR(GG) system, the weeds produced higher dry matter. When rice was transplanted after conventional tillage in puddled conditions weeds shows poor germination and result in lower density and biomass. Thus, lower WCE was exhibited under ZT+S+GG(R)-ZT+RR(W)-ZT+WR (GG) system but higher in CT(TPR)-CT(W) system. Numerically the higher WCE was recorded with rotational application of herbicides as compared to the regular application of the same herbicides during both the years of experimentation, but statistically, it was at par. All the weeds except *E. colona* attained lower density and biomass with rotational application of herbicides. Consequently, both herbicides had almost similar WCE but lower than weedy check plots. The results are in close conformity with Teja *et al*. (2015). The WCE was also affected due to the interaction of tillage and weed control practices. The minimum WCE was recorded when weed control was not done after zero tillage in rice in the presence of greengram and *Sesbania* residues, which was higher when no weed control was done after conventional tillage in transplanted rice. It might be attributed to decrease in weed biomass production in conventional tillage contrary to zero tillage when weed biomass production was not checked appreciably. From the foregoing observations we can say that transplanting could check weed growth without adoption of any weed management practice. However, WCE was enhanced with bispyribac-sodium 25 g/ha PoE after zero as well as conventional tillage. The maximum WCE was registered in case of rotational application of chlorimuron + metsulfuron-methyl 4 g/ha during 2014 and bispyribac-sodium 25 g/ha during 2015 in conventional tillage in transplanted rice due to lower dry matter production of weeds.

Grain and straw yields of rice

Grain and straw yields were lower in ZT+S+GG in DSR under ZT+S+GG(R)-ZT+RR(W)-ZT+WR (GG). However, both were increased in conventional tillage in DSR under CT+S(R)-CT(W)-ZT(GG) and CT+S+GG(R)-T+RR(W)-ZT+WR(GG) being maximum in conventional tillage in transplanted rice under CT(TPR)-CT(W)-fallow system. Plots receiving zero tillage in rice in presence of greengram and *Sesbania* residues had more weed density and biomass compared to other tillage practices. This affected the yield attributing traits adversely and finally had poor values of yield attributes, grain and straw yields. However, further increment in grain and straw yields was observed in conventional tilled DRS because of better yield attributes as compared to zero tillage in DSR under ZT+S+GG(R)-ZT+RR(W)-ZT+WR(GG) system. Whereas maximum grain and straw yields was obtained in conventional tilled transplanted rice under CT(TPR)-CT(W)-fallow system since, transplanted rice had sufficient space for each plant/hill for better growth and development under weed-free environment. Henceforth, lower inter and intra species competition under transplanted rice had superior yield attributing traits, which ultimately resulted in the maximum grain and straw yields.

The minimum grain and straw yields were obtained in weedy check plots, due to inferior yield attributes. However, a slight increment in grain and straw yields was recorded in case of regular application of same herbicides being maximum in rotational application of herbicides. This might be due to better weed-free environment provided to crop for optimum growth and under rotational application of herbicides from early stage of crop. Higher yield attributes and yields were recorded because of better weed control by the application of chlorimuron +metsulfuron-methyl was also reported by Heisnam *et al*. (2015). The results are also agreement with Kaikkhura *et al.* (2015). The interaction of tillage and weed control practices caused significant effects on grain and straw yields of rice. All the plots in which weeds were not controlled after each tillage practice had long and thin plants. Other growth and yield attributes were also poor in this situation. It might be attributed to higher density and biomass of weeds in these plots, which suppressed the growth of crop plants and led to inferior yield attributes. Finally, lower yields were recorded in weedy plots under each tillage practice as compared to other combinations of tillage and weed management practices. The values of above parameters were enhanced with the regular application of bispyribac-sodium in all tillage practices. Thus, yields were also increased due to the positive effect of weed control on yield attributes. Further, the maximum value of growth and yield attributes were registered when rotational application of herbicides was done in transplanted rice. In case of transplanting plants were properly spaced, as well as weeds were also very less and post emerged weeds were effectively controlled by rotational application of herbicides. Thus, plants got sufficient space, light and nutrients for their optimum growth and development on accounts of zero inter and intra species competition. This led to superior yield attributes, which ultimately resulted in the maximum grain as well as straw yields in these treatment combinations.

Economics

The minimum cost of cultivation was recorded in ZT+S in DRS under ZT+S(R)-ZT+(W)-ZT+(GG) system. It was gradually increased in conventional tillage in DSR being maximum when rice was transplanted after conventional tillage in puddled condition under CT(TPR)-CT(W)-fallow system. Transplanting of rice after conventional tillage was more costly because it involved use of several implements including puddling to obtain suitable sowing condition and also involve manual transplanting which increases the cost of cultivation. But in case of sowing of DSR under zero tillage systems, the establishment costs reduced considerably. Consequently, it had lower cost of

Table 2. Weed control efficiency, grain and straw yields and economics of rice as affected by tillage and weed control practices (mean of two years)

Treatment	WCE (%)	Grain yield (t/ha)			Straw yield (t/ha)			Cost of cultivation (x10^3 `/ha)	GMR (x10^3 `/ha)	NMR (x10^3 `/ha)	B:C
		2014	2015	Pooled	2014	2015	Pooled				
Tillage											
CT+S(R)-CT(W)-ZT(GG)	78.65	4.11	3.89	4.01	7.04	6.34	6.69	28.26	57.43	26.284	1.84
CT+S+GG(R)-CT+RR(W)-ZT+WR(GG)	82.88	4.35	3.94	4.14	7.00	6.56	6.78	28.46	59.32	27.971	1.89
ZT+S(R)-ZT(W)-ZT(GG)	71.46	4.66	4.08	4.37	7.96	6.48	7.22	27.81	62.56	31.858	2.04
ZT+S+GG(R)-ZT+RR(W)-ZT+WR(GG)	59.76	3.70	3.69	3.69	7.77	5.17	6.47	28.01	53.09	22.192	1.72
CT(TPR)-CT(W)	92.04	4.81	4.61	4.71	8.31	7.77	8.04	35.77	67.65	31.746	1.88
LSD (p=0.05)	-	0.23	0.16	0.10	0.48	1.21	0.51	-	-	-	-
Weed management											
Weedy check	45.25	2.79	2.75	2.77	6.84	5.11	5.97	28.55	40.38	9.498	1.31
Bispyribac-sodium 25 g/ha (in both the years)	92.77	4.93	4.79	4.86	7.52	7.36	7.44	30.51	69.33	36.485	2.11
Chlorimuron + metsulfuron-methyl in 2014 and bispyribac-sodium 25 g/ha in 2015	92.85	5.26	4.59	4.92	8.48	6.92	7.70	29.94	70.33	38.048	2.18
LSD (p=0.05)	-	0.10	0.14	0.07	0.28	0.63	0.32	-	-	-	-

cultivation (Bullock 2004). Sowing of DSR (ZT+S+GG) under ZT+S+GG (R)-ZT+RR(W)-ZT+WR(GG) system had minimum gross monetary returns (GMRs) and net monetary returns (NMRs) as well as B:C. However, conventional tillage in transplanted rice under CT(TPR)-CT(W)-fallow system recorded the highest GMRs but NMRs and B:C were higher in ZT+S in rice under ZT+S(R)-ZT-(W)-ZT(GG) system followed by CT(TPR)-CT(W)-fallow system. Economic returns were influenced by the yields of crop and cost of cultivation. Due to higher yields of rice in transplanting under CT(TPR)-CT(W)-fallow system gets higher GMRs but due to lower cost of cultivation in ZT+S(R)-ZT-(W)-ZT(GG) system as compared to transplanted rice fetched higher NMRs and B:C. No weed control in rice fetched the minimum cost of cultivation GMRs, NMRs and B:C. The higher cost of cultivation was recorded with regular application of bispyribac-sodium 25 g/ha in rice during both the years it was at par with rotational application of chlorimuron + metsulfuron-methyl 4 g /ha during 2014 and bispyribac-sodium 25 g/ha PoE during 2015 in rice. However reverse trend was observed in case of GMRs, NMRs and B:C due to a proportionate increment in profit in per rupee investment in weed control. Interaction between tillage and weed control practices also caused marked influence on economics of rice. The GMRs, NMRs and B:C were lower in plots where weed control practices were not adopted after each tillage. However, cost of cultivation was higher when regular application of bispyribac-sodium 25 g/ha in rice during both the years after conventional tillage in transplanted rice. GMRs and NMRs were higher when rotational application of chlorimuron + metsulfuron-methyl 4g/ha during 2014 and bispyribac-sodium 25 g/ha PoE during 2015 was done after conventional tillage in transplanted rice and B:C was higher in rotational application of chlorimuron + metsulfuron-methyl 4 g/ha during 2014 and bispyribac-sodium 25g/ha PoE during 2015 was done after zero tillage was done in rice in presence of *Sesbania*.

Thus, it was concluded that zero tillage in presence of *Sesbania* residues as well as conventional tillage in transplanted rice along with rotational application of chlorimuron + metsulfuron-methyl 4g/ha during 2014 and bispyribac-sodium 25g/ha PoE during 2015 found effective for weed control in rice and attained higher productivity and profitability of rice.

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RESEARCH ARTICLE

Integration effect of drip irrigation and mulching on weeds and spring maize productivity

Ritu Mohanpuria, Simerjeet Kaur*, Tarundeep Kaur, K.B. Singh, A.S. Brar and J.S. Deol

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ABSTRACT

A field experiment was carried out at Research Farm, Department of Agronomy, Punjab Agricultural University, Ludhiana during spring season of 2020 and 2021. The experimental design was split-plot with three replications. The main plots included the combination of two methods of drip irrigation, *viz.* surface drip irrigation (SD) and sub-surface drip irrigation (SSD) and three mulch treatments, *viz.* plastic mulch (PM), straw mulch 6 t/ha (SM) and no mulch (NM) along with furrow irrigation (FI) as a control treatment. The sub-plots consisted of four weed control treatments, *viz.* pre-emergence application (PE) of atrazine 1000 g/ha, hand weeding twice at 30 and 60 days after seeding (DAS), weed free and weedy check. The dominant weed species were *Cyperus rotundus, Oenothera laciniata, Chenopodium album, Coronopus didymus, Rumex dentatus, Digitaria sanguinalis,* and *Dactyloctenium aegyptium.* The maize emergence was 6 days earlier under plastic mulch than the crop under straw mulch. The SD-PM, SD-SM, SSD-PM, SSD-SM and SSD-NM resulted in maximum maize plant height when compared to FI. SD-PM, SD-SM, SSD-PM and SSD-SM treatments recorded significantly lower total weed density and biomass at 30 DAS than the atrazine treated FI treatment. Maximum weed control efficiency of 88.89% was recorded under integration of drip irrigation with plastic mulch. Integration of drip irrigation and mulches resulted in significantly increased maize grain yield as compared to FI. Crop raised under SD-SM treatment resulted in 20.62% higher grain yield than FI. The integration of drip irrigation with mulching resulted in effective weed management and higher maize grain yield than furrow irrigation method.

Keywords: Drip irrigation, Irrigation methods, Maize, Mulches, Weed control efficiency, Weed management

INTRODUCTION

Maize (*Zea mays* L.) is the third most versatile cereal grain crop having worldwide significance after rice and wheat. It can be successfully grown under different seasons such as *Kharif* (summer), *Rabi* (winter) and spring season as it can sustain itself in varied agricultural ecosystems. Spring maize is becoming more popular among potato farmers in semi-arid sub-tropical regions of Punjab. This is due to the less or no incidence of insect-pest and diseases and its high productivity (8.0 t/ha) compared to the *Kharif* maize (6.0 t/ha). Spring sown maize also helps to meet the increasing green ear demands during summer and provides excellent profits (Verma and Mishra 1998).

Water is an extremely vital resource for crop growth and yield. However, its increasing paucity has raised concerns about its efficient utilization, management, and sustainability. Spring maize has high evapo-transpiration rates often exceeding 10 mm/day and experience water stress especially at flowering and pollination stages leading to inferior yields (Singh and Vashist 2016). Therefore, uniform, and continuous supply of irrigation water need to be ensured in Punjab due to absence of rainfall during spring season. However, Punjab's water resources are depleting at a distressing rate due to continuous cultivation of water-devouring paddy. The mean annual water balance in Punjab exhibits a deficit of 1.6 m ha which is met through over-utilization of groundwater (Brar *et al.* 2018). Therefore, it is necessary to devise effective in-situ water management methods to increase crop productivity with same or comparably less amount of water applied. Drip irrigation method have the highest water use efficiency of more than 90% making it the most efficient method among all other irrigation systems.

Amongst biotic constraints, weed-induced competition is a serious threat to spring maize productivity as it encounters both *Kharif* (summer) and *Rabi* (winter) season weeds. Severe weed infestation has been reported to reduce maize yield by 35 to 80% (Oerke and Dehne 2004). The practice of

Punjab Agricultural University, Ludhiana 141004, India
* Corresponding author email: simer@pau.edu

hand weeding is becoming less common currently due to soaring labour costs and migration of labour to urban areas. Thus, farmers are preferring the use of herbicides. However, excessive reliance on herbicides having similar mechanism of action has led to the evolution of herbicide resistance in weeds and hence, the focus should be shifted on using more economically viable and environmental-friendly weed management options. Mulching is a promising method for reducing weed infestation in maize (Bhatt and Khera 2006). Mulching effectively reduces soil evaporation losses and improves root growth leading to soil moisture conservation, thereby enhancing the crop yield (Chaudhary and Prihar 1974). There is a need to quantify the coupled effect of drip irrigation methods and mulching on weeds and spring maize productivity. Thus, the present study was conducted with an objective to assess the weed composition and management under integration of drip irrigation and mulches and compare it to the standard furrow irrigation method.

MATERIALS AND METHODS

Field trial was conducted during two successive spring seasons of 2020 and 2021 at Research farm of Department of Agronomy, Punjab Agricultural University, Ludhiana (30° 56' N, 75° 52' E, 247 m above mean sea-level), Punjab. This region is located in the central plain region of Punjab under Trans-Gangetic agro-climatic zone of India. The climate of the region is sub-tropical and semi-arid with very hot and dry summer from April to June, hot and humid conditions from July to September, cold winters from November to January and mild climate during February and March. Soil of the experimental field was sandy loam with a normal pH of 7.6, low available nitrogen (175.4 kg/ha), high in available phosphorous (25.7 kg/ha) and available potassium (345.6 kg/ha). Maize hybrid 'PMH 10' was sown on February 11, 2020 and February 12, 2021 at a spacing of 60 cm × 20 cm using 25 kg seed per ha on the southern side of east-west ridges. The experiment was laid out in split plot design with three replications. The main plot consisted of seven treatments including combination of two drip irrigation treatments *viz.* surface drip (SD) and subsurface drip (SSD) irrigation and three mulch treatments *viz.* black plastic mulch of 25µ thickness (PM), paddy straw mulch 6 t/ha (SM) and no mulch (NM); and one standard (control) treatment of furrow irrigation (FI) without mulch in the main plots. In the sub-plots, four weed management treatments were taken *viz.* pre-emergence application (PE) of atrazine 1000 g/ha, hand weeding twice at 30 and 60 days after seeding (DAS), weed-free and weedy check. To prevent the interflow of water between plots, the buffer area of 1.0 m was maintained between the main plots. Atrazine was sprayed with knapsack sprayer using flat fan nozzle before laying down of mulches in straw mulched plots. Herbicide was sprayed before laying plastic mulch and dibbling was done afterwards by making punching holes in the plastic mulch. Days taken to 100% emergence under different treatments were noted to see the effect of treatment combinations on the crop emergence. Weed density (species wise) was recorded at 30 DAS by placing a quadrat (0.5 × 0.5 m). Weed biomass (group wise) was recorded at 30 DAS by cutting weeds at the ground level and then dried in the hot air oven at 60±2^{0}C till constant weight was obtained. Plant height was taken at harvest by recording height of randomly selected five maize plants. Total number of cobs per plot was counted and divided by total number of plants per plot to calculate number of cobs per plant. Cob diameter of five representatives randomly selected cobs were measured with the help of a vernier caliper from the base, center, and the top, and the mean value was multiplied with the value of ð (=3.14) to get the average cob girth. The grain yield from the net plot was recorded and computed as yield per hectare. Data of weed density and biomass were subjected to square root transformation $(\sqrt{x+1})$ before statistical analysis. Weed control efficiency (WCE) was calculated as per standard formulas (Mani *et al.* 1973). Data was analysed using the two-way ANOVA (given below) to evaluate the difference between treatments. Significance of treatment means were evaluated at 5% level of significance with Fisher's Protected Least Significance Difference Test. Another post-hoc test, Dunnett's Multiple Comparison was computed to compare means of groups of main-plot treatments (SD-PM, SD-SM, SD-NM, SSD-PM, SSD-SM, SSD-NM) with mean of one control, furrow irrigation so that the integrative effect of drip irrigation and mulching on weeds and crop growth can be compared with conventional furrow irrigation method.

RESULTS AND DISCUSSION

Days taken to crop emergence: The number of days taken to crop emergence were recorded to determine whether different irrigation methods and mulches had a significant impact on seedling germination and emergence (**Table 1**). The minimum number of days were taken to achieve 100% emergence by crop under plastic mulch followed by crop sown under no mulch treatment whereas crop sown under straw mulch treatment took maximum number of days for complete emergence. The complete emergence under plastic mulch has occurred 6 days earlier than the crop under straw mulch. Similarly, crop with no mulch took 3 days less for complete emergence than crop under straw mulch. Plastic mulch elevates soil temperature which accelerates the crop emergence and growth in order to achieve the desired population structure at an early growth stage (Liu *et al.* 2014). More number of days taken for 50% emergence and 100% emergence under straw mulch 6 t/ha was possibly due to high mulch load.

Effect on weeds: The dominant weed species observed at the experimental field comprised of *Digitaria sanguinalis, Dactyloctenium aegyptium* (grass weeds); *Oenothera laciniata, Chenopodium album, Coronopus didymus* and *Rumex dentatus* (broad-leaved weeds) and *Cyperus rotundus* as sedge (**Table 2**). The integration of drip irrigation and mulches, including drip irrigation with no mulch treatments recorded significantly lower density of *Digitaria sanguinalis, O. laciniata* and *C. rotundus* at 30 DAS as compared to FI treatment. The lower weed density of *Chenopodium album* and *Rumex dentatus* was observed under SD-PM, SSD-PM, SSD-SM and SD-PM, SSD-PM, SSD-SM, SSD-NM treatments respectively when compared to FI. Treatment combinations *i.e.*, SD-PM, SD-SM, SSD-PM and SSD-SM significantly reduced density of *Coronopus didymus* in comparison to FI. The SD-PM, SD-SM, SSD-PM, SSD-SM and SSD-NM led to significantly less weed biomass of grass and broad-leaved weeds as compared to FI (**Table 3**). Thus, the drip irrigation resulted in effective control of weeds when integrated with mulches as compared to furrow irrigation method. Retention of crop residue on soil surface coupled with subsurface drip irrigation resulted in reduced weed seed germination due to less sunlight and moisture on the soil surface (Jat *et al.* 2019). Sub-surface drip irrigation showed significant reduction in density and biomass of grass weeds and broadleaf weeds mainly *O. laciniata, Chenopodium album, R. dentatus*. Application of plastic mulch led to significant reduction in weed density and biomass followed by straw mulch as compared to no mulch treatment. Application of atrazine significantly reduced the weed density and biomass as compared to weedy check. Application of high dose of atrazine PE resulted in lower weed density and biomass of grass weeds in maize (Gopinath and Kundu 2008). All the treatment combinations resulted in remarkable reduction in sedge weed biomass in comparison to FI. The maximum WCE of 88.89% was recorded under integrated use of drip irrigation with plastic mulch (SD-PM and SSD-PM) whereas lowest WCE of 11.11% was recorded under FI treatment. Sub-surface drip irrigation resulted in higher WCE owing to less weed emergence. Use of plastic mulch resulted in maximum WCE. The integrated use of drip irrigation and mulches (SD-PM, SD-SM, SSD-PM and SSD-SM) results in significant reduction in total weed density and biomass even under weedy conditions as compared to the atrazine treated FI treatment at 30 DAS (**Table 4**) suggesting that the use of herbicides and/or hand weeding may be avoided with the integrated use of drip irrigation and mulches.

Table 1. Effect of irrigation methods, mulching and weed control treatments on days taken to emergence, crop growth and yield of spring maize (pooled data of 2020 and 2021)

Treatment	Days taken to 100% emergence	Plant height at harvest (cm)	Cob girth (cm)	No. of cobs/plant	Grain yield (t/ha)		
					2020	2021	Pooled
Furrow irrigation v/s other main-plot treatments (FI v/s others)							
SD-PM	10.67	187.40*	14.77*	1.56	8.68	8.46	8.57*
SD-SM	16.79*	191.50*	15.70*	1.89*	8.83	8.61	8.72*
SD-NM	13.88*	165.13	13.62	1.30	7.35	7.24	7.30
SSD-PM	10.92	190.10*	15.02*	2.00*	8.88*	8.67*	8.78*
SSD-SM	16.88*	193.51*	15.54*	2.18*	9.06*	8.83*	8.95*
SSD-NM	14.46*	168.41*	13.68	1.55	7.75	7.54	7.64
FI	11.79	162.33	13.76	1.55	7.54	7.31	7.42
d-crit. (p=0.05)	0.70	5.43	0.33	0.12	1.51	1.40	0.35
Drip irrigation (D)							
Surface drip	13.78	181.34	14.71	1.59	8.30	8.10	8.20
Sub-surface drip	14.08	184.01	14.76	1.91	8.56	8.35	8.46
LSD (p=0.05)	NS	2.51	NS	0.07	NS	NS	0.21
Mulching (M)							
Plastic mulch (25µ)	10.79	188.75	14.90	1.79	8.78	8.56	8.67
Straw mulch (6 t/ha)	16.83	192.50	15.63	2.04	8.94	8.72	8.83
No mulch	14.17	166.77	13.66	1.43	7.57	7.39	7.47
LSD (p=0.05)	0.47	3.07	0.22	0.08	0.45	0.41	0.25
Weed Control treatments (W)							
Atrazine 1000 g/ha as pre-emergence	13.86	176.62	14.62	1.67	8.12	7.92	8.02
Hand weeding twice at 30 and 60 DAS	13.38	183.85	14.49	1.76	8.56	8.33	8.44
Weed free	13.55	193.68	15.13	1.93	8.91	8.69	8.80
Weedy check	13.71	164.92	14.10	1.52	7.63	7.43	7.53
LSD (p=0.05)	NS	4.95	0.34	0.10	0.41	0.39	0.30

*Denotes significant difference from furrow irrigation

Table 2. Effect of different irrigation methods, mulching and weed control treatments on weed density at 30 DAS in spring maize (pooled data of 2020 and 2021)

Treatment	Weed density (no./m^2)						
	Grasses		Broad-leaved weeds				Sedge
	D. sanguinalis	*D. aegyptium*	*O. laciniata*	*C. album*	*R. dentatus*	*C. didymus*	*C. rotundus*
Furrow irrigation v/s other main-plot treatment							
SD-PM	1.20 (1)*	1.08 (0)*	2.51 (8)*	1.29 (1)*	1.13 (0)*	1.08 (0)*	2.72 (10)*
SD-SM	1.74 (3)*	1.35 (1)	2.85 (11)*	1.67 (2)	1.59 (2)	1.15 (0)*	3.71 (21)*
SD-NM	2.03 (4)*	1.53 (2)	3.53 (18)	1.72 (3)	1.74 (3)	1.36 (1)	4.28 (28)*
SSD-PM	1.13 (0)*	1.05 (0)*	1.82 (4)*	1.23 (1)*	1.00 (0)*	1.09 (0)*	2.68 (9)*
SSD-SM	1.60 (2)*	1.26 (1)*	2.23 (6)*	1.38 (1)*	1.31 (1)*	1.25 (1)*	3.37 (17)*
SSD-NM	1.86 (3)*	1.37 (1)	3.16 (15)*	1.57 (2)	1.42 (1)*	1.33 (1)	4.26 (29)*
FI	2.25 (6)	1.50 (2)	3.77 (22)	1.84 (3)	1.74 (3)	1.42 (1)	4.89 (38)
d-crit. (p=0.05)	0.15	0.16	0.43	0.19	0.16	0.14	0.31
Drip irrigation							
Surface drip	1.66 (2)	1.32 (1)	2.96 (12)	1.56 (2)	1.48 (2)	1.20 (1)	3.57 (20)
Sub-surface drip	1.53 (2)	1.22 (1)	2.40 (8)	1.39 (1)	1.24 (1)	1.22 (1)	3.44 (18)
LSD (p=0.05)	0.08	0.08	0.17	0.10	0.08	NS	NS
Mulching							
Plastic mulch (25µ)	1.16 (0)	1.06 (0)	2.16 (6)	1.26 (1)	1.06 (0)	1.08 (0)	2.70 (9)
Straw mulch (6 t/ha)	1.67 (2)	1.30 (1)	2.54 (8)	1.53 (2)	1.45 (1)	1.20 (1)	3.54 (19)
No mulch	1.94 (4)	1.45 (1)	3.34 (17)	1.64 (2)	1.58 (2)	1.34 (1)	4.27 (29)
LSD (p=0.05)	0.10	0.10	0.20	0.11	0.10	0.09	0.22
Weed control treatment							
Atrazine 1000 g/ha as pre-emergence	2.13 (4)	1.49 (1)	4.12 (19)	1.87 (3)	1.56 (2)	1.34 (1)	6.15 (39)
Hand weeding twice at 30 and 60 DAS	1.00 (0)	1.00 (0)	1.00 (0)	1.00 (0)	1.00 (0)	1.00 (0)	1.00 (0)
Weed free	1.00 (0)	1.00 (0)	1.00 (0)	1.00 (0)	1.00 (0)	1.00 (0)	1.00 (0)
Weedy check	2.61 (7)	1.72 (2)	5.23 (29)	2.25 (4)	2.11 (4)	1.62 (2)	6.66 (48)
LSD (p=0.05)	0.11	0.13	0.26	0.14	0.11	0.10	0.30

*Denotes significant difference from furrow irrigation; Weed data is subjected to square root transformation (x+1) and means of original values are given in parentheses

Table 3. Effect of irrigation methods, mulching and weed control treatments on weed biomass at 30 DAS and weed control efficiency in spring maize (pooled data of 2020 and 2021)

Treatment	Weed biomass (g/m^2)				Weed control efficiency (%)
	Grasses	Broad-leaved	Sedge	Total	
Furrow irrigation v/s other main-plot treatments					
SD-PM	1.18 (0)*	1.22 (1)*	1.28 (1)*	1.55 (2)*	88.89
SD-SM	1.25 (1)*	1.55 (2)*	1.56 (2)*	2.04 (5)*	72.22
SD-NM	1.89 (4)	2.24 (6)	2.08 (5)*	3.16 (14)	22.22
SSD-PM	1.16 (0)*	1.25 (1)*	1.26 (1)*	1.55 (2)*	88.89
SSD-SM	1.28 (1)*	1.35 (1)*	1.62 (2)*	1.95 (4)*	77.78
SSD-NM	1.50 (2)*	1.83 (3) *	1.98 (4)*	2.62 (9)*	50.00
FI	1.95 (4)	2.28 (6)	2.33 (6)	3.35 (16)	11.11
d-crit. (p=0.05)	0.16	0.19	0.16	0.20	-
Drip irrigation					
Surface drip	1.44 (2)	1.67 (3)	1.64 (2)	2.25 (7)	61.11
Sub-surface drip	1.31 (1)	1.48 (2)	1.62 (2)	2.04 (5)	72.22
LSD (p=0.05)	0.09	0.06	NS	0.07	-
Mulching					
Plastic mulch (25µ)	1.17 (0)	1.24 (1)	1.27 (1)	1.55 (2)	88.89
Straw mulch (6 t/ha)	1.26 (1)	1.45 (2)	1.59 (2)	1.99 (4)	77.78
No mulch	1.70 (3)	2.04 (4)	2.03 (4)	2.89 (11)	38.89
LSD (p=0.05)	0.12	0.07	0.10	0.09	-
Weed control treatment					
Atrazine 1000 g/ha as pre-emergence	1.73 (2)	1.97 (4)	2.31 (5)	3.18 (11)	38.89
Hand weeding twice at 30 and 60 DAS	1.00 (0)	1.00 (0)	1.00 (0)	1.00 (0)	100
Weed free	1.00 (0)	1.00 (0)	1.00 (0)	1.00 (0)	100
Weedy check	2.11 (4)	2.73 (7)	2.62 (7)	4.10 (18)	-
LSD (p=0.05)	0.11	0.13	0.11	0.15	

*Denotes significant difference from furrow irrigation; Weed data is subjected to square root transformation (x+1) and means of original values are given in parentheses

Maize growth, yield attributes and yield: Straw mulch application led to significant increase in plant height of spring maize (**Table 1**). Among weed control treatments, weedy check recorded significantly shorter plant height as compared to atrazine and hand weeding. The number of cobs per plant were higher when crop was grown under SD-SM, SSD-PM and SSD-SM as compared to FI treatment. Higher number of cobs per plant were recorded under sub-surface drip irrigation compared

Table 4. Interactive effect of FI v/s other methods and weed control treatments on total weed density and biomass at 30 DAS in spring maize (pooled data of 2020 and 2021)

Furrow irrigation v/s other methods) × Weed control treatments	SD-PM	SD-SM	SD-NM	SSD-PM	SSD-SM	SSD-NM	FI
	Total weed density (number/m^2)						
Atrazine 1000 g/ha as pre-emergence	6.02 (36)	8.33 (70)	10.27 (105)	5.67 (32)	6.33 (42)	7.72 (59)	11.71 (136)
Hand weeding twice at 30 and 60 DAS	1.00 (0)	1.00 (0)	1.00 (0)	1.00 (0)	1.00 (0)	1.00 (0)	1.00 (0)
Weed free	1.00 (0)	1.00 (0)	1.00 (0)	1.00 (0)	1.00 (0)	1.00 (0)	1.00 (0)
Weedy check	6.52 (42)	9.60 (91)	11.42 (130)	4.94 (24)	8.45 (71)	12.35 (152)	12.78 (163)
LSD (p=0.05)	For comparing two weed control treatments at same main-plot (furrow irrigation v/s other methods) treatment = 0.86						
	For comparing two main-plot (furrow irrigation v/s other methods) treatments at same or different weed control treatments = 0.84						
	Total weed biomass (g/m^2)						
Atrazine 1000 g/ha as pre-emergence	1.96 (3)	2.48 (5)	4.79 (22)	1.88 (3)	2.37 (5)	3.47 (11)	5.26 (27)
Hand weeding twice at 30 and 60 DAS	1.00 (0)	1.00 (0)	1.00 (0)	1.00 (0)	1.00 (0)	1.00 (0)	1.00 (0)
Weed free	1.00 (0)	1.00 (0)	1.00 (0)	1.00 (0)	1.00 (0)	1.00 (0)	1.00 (0)
Weedy check	2.25 (4)	3.68 (13)	5.86 (33)	2.31 (4)	3.43 (11)	5.01 (24)	6.14 (37)
LSD (p=0.05)	For comparing two weed control treatments at same main-plot (furrow irrigation v/s other methods) treatment = 0.40						
	For comparing two main-plot (furrow irrigation v/s other methods) treatments at same or different weed control treatments = 0.39						

to surface drip irrigation and under straw mulch treatment compared to no mulch treatment. SD-PM, SD-SM, SSD-PM and SSD-SM resulted in increased cob girth as compared to FI treatment (**Table 1**). Straw mulch application resulted in significantly higher cob girth followed by plastic mulch treatment. Cob girth and number of cobs per plant recorded under atrazine PE and hand weeding was statistically at par but significantly higher than weedy check. Integration of drip irrigation and mulches resulted in significant increase in maize grain yield as compared to FI (**Table 1**). Crop raised under SD-SM treatment resulted in 20.62% higher grain yield than FI. Shah *et al* (2014) also reported that integration of drip irrigation with paddy straw mulch recorded improvement in grain yield by 14% compared to flood irrigation. Sub-surface drip irrigation recorded higher grain yield than surface drip irrigation treatment. Application of paddy straw mulch resulted in higher maize grain yield by 18.21% than no mulch. Among weed control treatments, hand weeding (twice) resulted in significantly higher maize grain yield.

Thus, it can be concluded that weeds can be managed effectively by integration of drip irrigation (surface or sub-surface) and mulching (with plastic or straw) and maize productivity can be improved, when compared to furrow irrigation.

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RESEARCH ARTICLE

Impact of organic methods of nutrient and weed management on weeds nutrient uptake and maize productivity in sandy loam soils of Rajasthan, India

L.K. Jain*, Ishwar Singh[1], Ramawtar[2], R.K. Sharma[2] and P.L. Maliwal[3]

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ABSTRACT

An experiment was conducted during rainy (*Kharif*) season 2019 and 2020 at Instructional Farm, College of Agriculture, Sumerpur, Rajasthan to study the influence of organic methods of nutrient and weed management on weeds growth and nutrient uptake and maize (*Zea mays* L.) productivity. The experiment comprised of six weed management and five nutrient management treatments arranged in split-plot design with three replications. The stale seedbed + hoeing with power weeder at 20 days after seeding (DAS) + hoeing once at 40 DAS and stale seedbed + hoeing once at 20 DAS + application of 5 t/ha of straw mulch applied at 30 DAS recorded significantly lowest mean weed biomass at 30 DAS and at 50 DAS, respectively. They were found on par with weed free check at harvest in respect of recording mean minimum weed biomass and nutrient uptake by different categories of weeds, higher maize and nutrient uptake by maize on pooled basis. Amongst nutrient management treatments, mean minimum weed biomass and nutrient uptake, significantly higher maize yield, protein content, nutrient content and uptake by the maize was recorded with 75% recommended dose of nitrogen (RDN) using vermicompost (75% as basal + 25% as top dress at 30 DAS) + seed treatment with beejamurt + spray of 500 l/ha of jeevamurt twice (at sowing and 30 DAS). The similar trend was recorded in terms of yield and economics of maize. Next best was 75% RDN through vermicompost as basal + seed treatment with beejamurt + spray of 500 l/ha jeevamurt twice (at sowing and 30 DAS). The organic nutrient management treatments significantly increased the nutrient content in maize grain and stover, while weed management treatments have no significant effect.

Keywords: Beejamurt, Farm yard manure, Jeevamurt, Maize, Organic cultivation, Stale seed bed, Straw mulch, Vermicompost, Weed management

INTRODUCTION

Maize contributes to nearly 9 percent to the national food basket of India with cultivated area of nearly 9.2 Mha area with a production of 27.8 million tons (GOI 2020). In Rajasthan, maize is grown in 8.75 lakh ha during *Kharif* as rainfed and irrigated during *Rabi* season with a production of 11.35 lakh tons (Vital Agricultural Statistics 2020). The initial slow growth, wider crop geometry and congenial environment during *Kharif*, hastens the growth and development of weeds that compete with crop severely resulting in the yield losses of 44.1 to 49.1% in North Western Plain Zone of India (Jat *et al.* 2018). The use of power driven tillage implements and also the manual weeding and application of crop residues as mulch for weed management are popular among conservation agriculture practicing farmers to protect the soil as well as environment. The physico-chemical properties of the soil greatly altered by organic nutrient management practices and by maintaining mulches on soil surface. The crop is highly exhaustive and requires nutrients for extended period *i.e.* up to flowering, and it is not possible to maintain through fertilizers and thus composted materials *i.e.* farm yard manure (FYM) and vermicompost as nutrient sources are being suggested to meet the crop nutrient requirement. Further, the application of fermented products of cow dung and cow urine *i.e.* beejamurt for seed treatment and jeevamurt for soil application were found to boost the crop growth due to the congenial soil environment for multiplying favourable soil micro-organisms (Pawar *et al.* 2012, Shannon *et al.* 2006) to maintain the quality of soil sustainability of an agro-ecosystem (Shukla and Tyagi 2009). The present experiment was conducted to find out the effect of organic weed management practices and composted and fermented nutrient sources on nutrient uptake by various categories of weeds and

* College of Agriculture, Sumerpur, Pali, Rajasthan 306902 India

1 Directorate of Extension Education, Agriculture University, Jodhpur, Rajasthan 342304, India

2 College of Agriculture, Bhilwara, Rajasthan 311001, India

3 Former Director Research, Directorate of Research, MPUAT, Udaipur Rajasthan 313001, India

* Corresponding author email: jainlokesh74@gmail.com

maize crop, productivity and economics of maize cultivation under organic production system to reduce dependency of high cost external inputs.

MATERIALS AND METHODS

A field experiment was conducted for two consecutive rainy (*Kharif*) seasons during 2019 and 2020 at the research farm of College of Agriculture, Sumerpur, Pali situated in the western part of Rajasthan at 25^{0}09' N latitude and 73^{0}04' E longitude with at an elevation of 297.7 m above mean sea level. The region has a typical semi- arid and sub-tropical climate characterized by mild winter and moderate to high summers, associated with mild relative humidity especially during the months of July to September. The total rainfall received during the crop season of the *Kharif* 2019 and *Kharif* 2020 was 636.9 mm and 473.5 mm, respectively. The soil was sandy loam in texture, slightly alkaline in pH, low in organic carbon and available nitrogen, medium in available phosphorus and high in available potassium. A split-plot design with three replications was used. Six organic weed management treatments were assigned to main plots viz., stale seed bed (SS) + hoeing twice at 20 and 40 days after seeding (DAS); SS+ hoeing once with power weeder at 20 DAS (Honda make) +hoeing once manually at 40 DAS; SS +hoeing once manually at 20 DAS + straw mulch 5 t/ha at 30 DAS; SS + black plastic (25 micron) mulch at sowing, weedy check and weed free up to 60 DAS. Five organic nutrient management treatments in sub plots include: 100% recommended dose of nitrogen (RDN) through farm yard manure (FYM); 75% RDN through FYM + seed treatment with beejamrut + jeevamrut 500 l/ha at sowing and 30 DAS; 100% RDN through vermicompost; 75% RDN through spray twice vermicompost as basal + seed treatment with beejamrut + jeevamrut 500 l/ha spray twice at sowing and 30 DAS and 75% RDN through vermicompost (75% as basal + 2% as top dress at 30 DAS) + seed treatment with beejamrut + jeevamrut 500 L/ha spray twice at sowing and 30 DAS. The beejamrut and jeevamrut was prepared by adopting standard methods described by Lunagariya and Zinzala (2017) and Bhadu (2019), respectively The maize crop was cultivated as per recommended package of practices and applied 90 kg N, 60 kg P and 60 kg K/ha using recently notified maize cultivar '*Pratap Hybrid Maize 3*' at the seed rate of 25 kg/ha. The intercultural practices were performed as per treatments while nutrients were applied based on nitrogen requirement. Weeds were collected from two randomly selected spots using a quadrat of 0.25 m^2 at harvest and sun dried for 24 hours followed by oven drying at 65°C till a constant weight was achieved. The final dry weight (biomass) of broad-leaved weeds, grasses and sedges was recorded separately and expressed in kg/ha. The maize grain and stover yield per plot were recorded separately and expressed in kg/ha. After recording weeds biomass at harvest and grain and stover of maize, samples were ground for estimation of N, P and K contents in weeds and maize crop using standard procedures and expressed in percent while uptake was the function of content and dry matter.

RESULTS AND DISCUSSION

Effect on weeds

Two years pooled data **(Table 1)** revealed that broad-leaved weeds, grasses and sedges and total weeds were completely controlled by stale seedbed + plastic mulch up to harvest of the crop and weed free check up to 60 DAS. Among the rest of treatments, stale seedbed + hoeing with power weeder at 20 DAS + hoeing once at 40 DAS, stale seedbed + hoeing once at 20 DAS + application of 5 t/ha of straw mulch at 30 DAS recorded significantly lowest mean biomass of broad-leaved weeds, grasses and sedges and total weeds at 30 DAS and 50 DAS respectively. The weed biomass recorded up to 50 DAS during both the years individually as well as in pooled analysis was not significantly influenced by nutrient management treatments. The organic sources of nutrients with or without fermented organic concoction influenced weed biomass significantly at harvest. The mean minimum weed biomass of broad-leaved and total weeds was recorded with 75% RDN through vermicompost in two splits + seed treatment with beejamurt + spray of jeevamurt twice (**Table 1**). The straw mulching significantly lowered the weeds biomass due to interference with light penetration up to weeds and release of phytotoxins from straw decomposition suppress weed growth and development (Kumar *et al.* 2005, Modak *et al.* 2019). The straw mulch proved very effective in discouraging weed emergence, weed growth and ultimately reduced weed biomass and increased weed control efficiency. The stale seedbed technique was found effective in decreasing the weed biomass in maize production system (Sanbagavalli *et al.* 2016). The use of power weeder as a tool for mechanical hoeing churned well the soil and destroyed the weeds as effectively as manual weeding (Kumar 2020).

Nutrient content and uptake by weeds

Different weed management treatments had no significant effect on nitrogen, phosphorus and potassium content in weeds at harvest during both the years of study (**Table 2**). A significant reduction in nitrogen, phosphorus and potassium uptake by weeds, grasses, sedges and total weeds was recorded in all weed management treatments as compared to weedy check. The uptake of nitrogen, phosphorus and potassium followed the similar pattern as that of weed biomass observed at harvest (**Table 3**) as the uptake of nutrients is the function of dry matter and nutrient contents. The mean minimum nitrogen, phosphorus and potassium uptake was recorded with SS +hoeing once manually at 20 DAS + straw mulch (5 t/ha) at 30 DAS by broad-leaved weeds and at 60 DAS by grasses, sedges and total weeds at harvest in weed free, on pooled basis, as against the mean maximum in weedy check. Further, significant reduction in uptake of nutrients through broad-leaved weeds, grasses, sedges and total weeds at harvest was observed with 75% RDN through vermicompost in two splits + seed treatment with beejamurt + jeevamurt spray twice followed by 75% RDN through vermicompost as basal+ seed treatment with beejamrut + two spray of jeevamrut 500 L/ha at sowing and 30 DAS. Weed management treatments recorded reduced nutrient uptake over weedy check because of less weed dry matter accumulation in treated plots (Malviya and Singh 2007). The higher weed biomass and higher nutrient uptake at harvest

Table 1. Effect of different treatments on weed biomass (kg/ha) at 30 DAS, 50 DAS and harvest in maize (pooled over two years)

Treatment	Broad-leaved weeds			Grasses and sedges			Total weeds		
	30 DAS	50 DAS	At harvest	30 DAS	50 DAS	At harvest	30 DAS	50 DAS	At harvest
*Weed management**									
SS+ HT at 20 and 40 DAS	137.0	63.2	123.2	251.8	253.8	241.7	388.7	317.0	365.0
SS+ H with power weeder at 20 DAS + HO at 40 DAS	69.5	44.6	126.1	191.3	187.4	274.4	260.8	232.0	400.6
SS+ Hoeing once at 20 DAS + Straw mulch at 30 DAS	140.2	15.2	64.9	248.3	44.9	239.7	388.5	60.2	304.5
SS+ Plastic mulch at sowing	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Weedy check	596.7	682.3	409.6	2211.0	2304.4	2724.6	2807.7	2986.8	3134.3
Weed free check up to 60 DAS	0.0	0.0	93.1	0.0	0.0	122.6	0.0	0.0	215.7
LSD (p=0.05)	19.5	8.2	13.1	23.0	40.8	47.6	34.6	44.8	38.2
*Nutrient management ***									
100% RDN FYM	165.5	136.8	177.6	491.1	474.2	756.6	656.6	611.0	934.2
75% RDN FYM + ST B.M + J.M (T)	161.9	135.6	170.6	484.9	462.8	709.4	646.8	598.3	880.0
100% RDN VC	152.0	136.1	163.5	472.5	461.0	760.9	624.5	597.1	924.4
75% RDN VC + ST B.M + J.M (T)	154.6	130.9	169.6	484.0	458.6	678.6	638.5	589.5	848.3
75% RDN VC (2 splits) + ST B.M + J.M (T)	152.2	131.8	135.6	486.2	468.9	697.5	638.4	600.7	833.2
LSD (p=0.05)	NS	NS	10.6	NS	NS	43.6	NS	NS	50.9

*Stale seed bed (SS), hoeing twice (HT), Days after sowing (DAS), hoeing once (HO); ** Recommended dose of nitrogen (RDN), Seed treatment with beejamrut (ST) and two spray of jeevamrut 500 L/ha at sowing and 30 DAS [J.M. (T)], FYM (Farm yard manure, vermicompost (VC), 2 splits (75% as basal + 25% as top dress at 30 DAS).

Table 2. Effect of different treatments on nutrient content in different categories of weeds

Treatment	Nutrient content (%)					
	Broad-leaved weeds			Grasses and sedges		
	N	P	K	N	P	K
*Weed management**						
SS+ HT at 20 and 40 DAS	2.290	0.363	1.418	1.041	0.293	1.328
SS+ H with power weeder at 20 DAS + HO at 40 DAS	2.297	0.364	1.408	1.042	0.294	1.326
SS+ Hoeing once at 20 DAS + Straw mulch at 30 DAS	2.294	0.365	1.419	1.041	0.298	1.319
SS+ Plastic mulch at sowing	-	-		-	-	
Weedy check	2.293	0.362	1.412	1.051	0.294	1.325
Weed free check up to 60 DAS	2.309	0.363	1.421	1.056	0.298	1.343
LSD (p=0.05)	NS	NS	NS	NS	NS	NS
*Nutrient management***						
100% RDN FYM	2.278	0.365	1.417	1.048	0.297	1.340
75% RDN FYM + ST B.M + J.M (T)	2.286	0.363	1.401	1.049	0.292	1.314
100% RDN VC	2.310	0.366	1.430	1.050	0.298	1.340
75% RDN VC + ST B.M + J.M (T)	2.304	0.361	1.407	1.043	0.294	1.320
75% RDN VC (2 splits) + ST B.M + J.M (T)	2.307	0.364	1.423	1.042	0.295	1.327
LSD (p=0.05)	NS	NS	NS	NS	NS	NS

*Stale seed bed (SS), hoeing twice (HT), Days after sowing (DAS), hoeing once (HO); ** Recommended dose of nitrogen (RDN), Seed treatment with beejamrut (ST) and two spray of jeevamrut 500 L/ha at sowing and 30 DAS [J.M. (T)], FYM (Farm yard manure, vermicompost (VC), 2 splits (75% as basal + 25% as top dress at 30 DAS).

with FYM may be attributed to extended nutrients availability in soil profiles due to slow mineralization (Singh and Chouhan 2021).

Effect on maize yield, economics and nutrient uptake

The two years pooled mean data indicated that the weed free situation up to 60 DAS gave maximum grain yield of maize (3.36 t/ha) which was statistically similar to treatment SS + hoeing once manually at 20 DAS + straw mulch (5 t/ha) at 30 DAS (3.24 t/ha) and lowest of 1.96 t/ha in treatment weedy check (**Table 4**). Likewise, weed free check up to 60 DAS and SS +hoeing once manually at 20 DAS + straw mulch (5 t/ha) at 30 DAS have recorded significantly higher stover yield over weed free up to 60 DAS, during both the years. Among the nutrient management treatments, the mean maximum grain yield of 3.17 t/ha was recorded with 75% RDN through vermicompost in two splits + seed treatment with beejamurt + spray of jeevamurt spray twice closely followed by 75% RDN through

Table 3. Effect of treatments on nutrients uptake (kg/ha) by weeds at harvest (pooled of two years)

Treatment	Broad-leaved weeds			Grasses and sedges			Total weeds		
	N	P	K	N	P	K	N	P	K
*Weed management**									
SS+ HT at 20 and 40 DAS	2.82	0.45	1.75	2.52	0.71	3.21	5.34	1.16	4.96
SS+ H with power weeder at 20 DAS + HO at 40 DAS	2.90	0.46	1.78	2.86	0.81	3.64	5.76	1.27	5.41
SS+ Hoeing once at 20 DAS + Straw mulch at 30 DAS	1.49	0.24	0.92	2.49	0.71	3.18	3.98	0.95	4.10
SS+ Plastic mulch at sowing	-	-	-	-	-	-	-	-	-
Weedy check	9.38	1.48	5.79	28.59	8.00	36.11	37.97	9.48	41.90
Weed free check up to 60 DAS	2.15	0.34	1.33	1.30	0.37	1.65	3.45	0.71	2.98
LSD (p=0.05)	0.29	0.04	0.20	0.33	0.17	0.85	0.41	0.14	0.70
*Nutrient management***									
100% RDN FYM	4.01	0.64	2.51	7.87	2.23	10.09	11.89	2.87	12.60
75% RDN FYM + ST B.M + J.M (T)	3.87	0.62	2.40	7.48	2.08	9.30	11.36	2.70	11.70
100% RDN VC	3.78	0.60	2.33	7.79	2.25	10.16	11.57	2.85	12.48
75% RDN VC + ST B.M + J.M (T)	3.93	0.61	2.40	7.10	2.00	8.97	11.03	2.61	11.37
75% RDN VC (2 splits) + ST B.M + J.M (T)	3.14	0.50	1.93	7.52	2.04	9.28	10.66	2.54	11.20
LSD (p=0.05)	0.27	0.04	0.17	0.50	0.14	0.67	0.70	0.16	0.76

*Stale seed bed (SS), hoeing twice (HT), Days after sowing (DAS), hoeing once (HO); ** Recommended dose of nitrogen (RDN), Seed treatment with beejamrut (ST) and two spray of jeevamrut 500 L/ha at sowing and 30 DAS [J.M. (T)], FYM (Farm yard manure, vermicompost (VC), 2 splits (75% as basal + 25% as top dress at 30 DAS).

Table 4. Effect of different treatments on maize yield and economics

Treatment	Yield (t/ha)									Economics	
	Grain			Stover			Biological			Net return (`/ha)	B C ratio
	2019	2020	Pooled	2019	2020	Pooled	2019	2020	Pooled	Pooled	Pooled
*Weed management**											
SS+ HT at 20 and 40 DAS	2.94	3.13	3.04	6.14	6.27	6.20	9.09	9.40	9.24	27599	1.50
SS+ H with power weeder at 20 DAS + HO at 40 DAS	2.83	3.04	2.93	6.09	6.29	6.19	8.92	9.33	9.13	28401	1.55
SS+ Hoeing once at 20 DAS + Straw mulch at 30 DAS	3.14	3.35	3.24	6.01	6.21	6.11	9.14	9.57	9.36	32364	1.59
SS+ Plastic mulch at sowing	3.03	3.14	3.08	5.95	6.12	6.03	8.98	9.25	9.12	15589	1.23
Weedy check	1.91	2.00	1.96	5.14	5.35	5.24	7.05	7.36	7.20	14820	1.36
Weed free check up to 60 DAS	3.24	3.47	3.36	6.19	6.33	6.26	9.43	9.80	9.62	31799	1.55
LSD (p=0.05)	0.19	0.17	0.12	0.36	0.27	0.21	0.52	0.28	0.28	2901	0.05
*Nutrient management***											
100% RDN FYM	2.66	2.84	2.75	5.57	5.79	5.68	8.24	8.63	8.43	22253	1.43
75% RDN FYM + ST B.M + J.M (T)	2.73	2.92	2.83	5.83	6.06	5.95	8.56	8.98	8.77	26602	1.53
100% RDN VC	2.84	3.02	2.93	5.98	6.14	6.06	8.82	9.16	8.99	20750	1.35
75% RDN VC + ST B.M + J.M (T)	2.93	3.08	3.01	6.03	6.20	6.11	8.95	9.28	9.12	26016	1.47
75% RDN VC (2 splits) + ST B.M + J.M (T)	3.08	3.25	3.17	6.18	6.29	6.24	9.27	9.55	9.41	29857	1.54
LSD (p=0.05)	0.12	0.11	0.08	0.25	0.18	0.15	0.28	0.15	0.16	1815	0.03

*Stale seed bed (SS), hoeing twice (HT), Days after sowing (DAS), hoeing once (HO); ** Recommended dose of nitrogen (RDN), Seed treatment with beejamrut (ST) and two spray of jeevamrut 500 L/ha at sowing and 30 DAS [J.M. (T)], FYM (Farm yard manure, vermicompost (VC), 2 splits (75% as basal + 25% as top dress at 30 DAS).

vermicompost as basal + seed treatment with beejamrut + jeevamrut 500 l/ha spray twice at sowing and 30 DAS of 3.01 t/ha and were 15.4 and 9.3 per cent superior, respectively over 100% RDN through FYM (2.75 t/ha).The similar pattern was observed in stover yield. Increase in yield in vermicompost as an organic source of plant nutrients might be due to increase in photosynthetic area, dry matter accumulation per plant, more translocation of photosynthates towards sink and improved yield attributes (Javed *et al.* 2019). The organic concoction produced favorable effects of IAA, GA_3, macro and micronutrients along with beneficial microorganisms present in the liquid organic manures acted as stimulants in the plant system (Majhi *et al.* 2018).

The mean maximum net return of ₹ 32,364/ha was recorded in the integrated weed management practice of stale seedbed + hoeing at 20 DAS + straw mulch at 30 DAS as against the minimum of ₹ 14,820/ha in weedy check. This treatment also gave highest B:C ratio of 1.59 as against the lowest in SS + plastic mulch at sowing (1.23) in pooled study. The treatment 75% RDN through vermicompost in two splits +seed treatment with beejamurt + spray of jeevamurt twice recorded maximum net return of Rs.

Table 5. Effect of different treatments on nutrient content (%) and protein content (%) in maize

Treatment	Nutrients						Protein Grain
	Grain			Stover			
	N	P	K	N	P	K	
*Weed management**							
SS+ HT at 20 and 40 DAS	1.662	0.325	0.370	0.701	0.127	1.326	10.39
SS+ H with power weeder at 20 DAS + HO at 40 DAS	1.655	0.324	0.367	0.701	0.126	1.321	10.35
SS+ Hoeing once at 20 DAS + Straw mulch at 30 DAS	1.670	0.331	0.372	0.709	0.130	1.331	10.44
SS+ Plastic mulch at sowing	1.659	0.324	0.367	0.699	0.127	1.324	10.37
Weedy check	1.646	0.321	0.360	0.686	0.126	1.319	10.29
Weed free check up to 60 DAS	1.674	0.331	0.372	0.714	0.131	1.336	10.46
LSD (p=0.05)	NS	NS	NS	NS	NS	NS	NS
*Nutrient management***							
100% RDN FYM	1.635	0.320	0.363	0.682	0.124	1.313	10.22
75% RDN FYM + ST B.M + J.M (T)	1.649	0.323	0.366	0.691	0.125	1.322	10.31
100% RDN VC	1.658	0.326	0.367	0.703	0.128	1.325	10.36
75% RDN VC + ST B.M + J.M (T)	1.669	0.329	0.369	0.709	0.129	1.331	10.43
75% RDN VC (2 splits) + ST B.M + J.M (T)	1.694	0.333	0.374	0.722	0.131	1.340	10.59
LSD (p=0.05)	0.019	0.006	0.006	0.013	0.003	0.012	0.12

*Stale seed bed (SS), hoeing twice (HT), Days after sowing (DAS), hoeing once (HO); ** Recommended dose of nitrogen (RDN), Seed treatment with beejamrut (ST) and two spray of jeevamrut 500 L/ha at sowing and 30 DAS [J.M. (T)], FYM (Farm yard manure, vermicompost (VC), 2 splits (75% as basal + 25% as top dress at 30 DAS).

Table 6. Effect of organic weed and organic nutrient management practices on nutrients uptake (kg/ha) by maize at harvest (pooled of two years)

Treatment	Grain			Stover			Total		
	N	P	K	N	P	K	N	P	K
*Weed management**									
SS+ HT at 20 and 40 DAS	50.50	9.91	11.27	43.51	7.89	82.27	94.01	17.80	93.53
SS+ H with power weeder at 20 DAS + HO at 40 DAS	48.52	9.50	10.78	43.46	7.79	81.81	91.98	17.29	92.59
SS+ Hoeing once at 20 DAS + Straw mulch at 30 DAS	54.18	10.77	12.10	43.37	7.93	81.34	97.54	18.70	93.44
SS+ Plastic mulch at sowing	51.14	9.99	11.33	42.24	7.66	79.88	93.38	17.65	91.21
Weedy check	32.23	6.29	7.07	36.05	6.60	69.23	68.28	12.89	76.31
Weed free check up to 60 DAS	56.20	11.15	12.52	44.73	8.18	83.66	100.93	19.33	96.18
LSD (p=0.05)	2.30	0.47	0.58	1.88	0.44	3.19	3.31	0.74	3.39
*Nutrient management***									
100% RDN FYM	44.93	8.82	10.01	38.85	7.04	74.62	83.78	15.87	84.63
75% RDN FYM + ST B.M + J.M (T)	46.63	9.13	10.38	41.16	7.47	78.64	87.79	16.60	89.01
100% RDN VC	48.56	9.57	10.80	42.62	7.76	80.32	91.18	17.32	91.12
75% RDN VC + ST B.M + J.M (T)	50.16	9.92	11.13	43.40	7.91	81.32	93.56	17.82	92.45
75% RDN VC (2 splits) + ST B.M + J.M (T)	53.70	10.57	11.90	45.09	8.21	83.60	98.80	18.78	95.50
LSD (p=0.05)	1.43	0.34	0.36	1.45	0.27	2.17	1.82	0.38	2.13

*Stale seed bed (SS), hoeing twice (HT), Days after sowing (DAS), hoeing once (HO); ** Recommended dose of nitrogen (RDN), Seed treatment with beejamrut (ST) and two spray of jeevamrut 500 L/ha at sowing and 30 DAS [J.M. (T)], FYM (Farm yard manure, vermicompost (VC), 2 splits (75% as basal + 25% as top dress at 30 DAS).

29,857/ha and B:C ratio of 1.54 and was statistically superior over 100% RDN through vermicompost (₹ 20,750/ha and B:C ratio of 1.35, respectively). These findings were witnessed due to better uptake of nutrients by crop, lowest weed biomass and higher grain yield (Patil and Udmale 2016 and Virk *et al.* 2019).

Nitrogen, phosphorus and potassium content of maize grain and stover remained unaffected due to various weed management treatments, during both the years (**Table 5**). Nitrogen, phosphorus and potassium content, mean maximum protein content in grain and stover of maize was maximum with 75% RDN through vermicompost in two splits + seed treatment with beejamurt + jeevamurt spray twice followed by 75% RDN through vermicompost as basal + seed treatment with beejamurt + spray of jeevamurt spray twice (**Table 5** and **6**). The marked improvement in N, P and K uptake in grain and stover seems to be on account of more availability of nutrients and their diversion towards the crop and higher grain and stover yields (Gupta 2018). The use of vermicompost along with bio-fertilizers sustain availability of nutrients might be owing to extended supply as per crop requirement and corresponding increase of nutrients uptake by plants (Chhetri and Sinha 2020).

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RESEARCH ARTICLE

Bio-efficacy of nicosulfuron against mixed weed flora in maize and its residual effect on succeeding crops

V. Pratap Singh[1], Arunima Paliwal[2]*, Tej Pratap[1], S.P. Singh[1], Ajay Kumar[2] and Radhey Shyam[3]

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ABSTRACT

A field study was conducted during *Spring* and rainy *(Kharif)* season of 2017 at N.E. Borlaug Crop Research Centre of G.B. Pant University of Agriculture and Technology, Pantnagar U.S. Nagar, Uttarakhand, India to evaluate the effective dose of nicosulfuron for weed control in maize while assessing its effect on growth and yield of maize along with its residual effect on succeeding pea and cowpea fodder. Eight treatments were tested which include: post-emergence application (PoE) of nicosulfuron at different doses (30, 36, 42 and 50 g/ha), tembotrione 120 g/ha PoE, pre-emergence application (PE) of atrazine 1000 g/ha, hand weeding twice at 20 and 40 days after seeding (DAS) and weedy check. The weed community during both the seasons in the experimental area consisted of, grassy weeds: *Phalaris minor, Eleusine indica, Digitaria sanguinalis, Echinochloa colona* and *Panicum maximum,* broad-leaved weeds (BLW): *Trianthema monogyna, Chenopodium album, Phyllanthus niruri, Parthenium hysterophorus* and *Mallugo stricta* and a sedge *Cyperus rotundus*. Nicosulfuron at 50 g/ha resulted in 50-100% weed control, depending on the weed species. Nicosulfuron at 50 and 42 g/ha were equally effective in increasing grain yield of maize when compared with tembotrione and was found superior over atrazine during both the season. No phytotoxic symptoms on maize and no residual effect on succeeding pea and cowpea fodder crop were observed, at any doses of nicosulfuron. Hence, nicosulfuron at 42 g/ha PoE may be safely used for effective weed management and improved yield of maize.

Keywords: Atrazine, Maize, Nicosulfuron, Tembotrione, Weed management

INTRODUCTION

Maize (*Zea mays* L.) is one of the important cereals in the world agricultural economy both as a food and fodder crop. It has higher yield potential than any other cereal. In India, it is grown over an area of 9.7 Mha with total production of 28.6 MT and average productivity of 2.945 t/ha (GOI 2022). Weed infestation at early crop growth create competition for various resources, *viz.* nutrients, water, sunlight and space results reduction in grain yield, which also depends on weeds intensity and type of weed flora. The yield losses varied due to season long weed infestation and range from 30% to complete crop failure in maize (Pandey *et al.* 2001). The manual weeding is expensive, time and energy consuming and timely availability of labors for agricultural operation is a major problem. Hence, herbicides are an appropriate alternative strategy to manage weeds as they control weeds timely and effectively and also offer great scope for minimizing the cost of weed management (Ishrat *et al.* 2012). The pre-emergence herbicide options are available in maize (Singh *et al.* 2015) but the post-emergence herbicides for managing weeds in maize are less. Nicosulfuron, a sulfonylurea is a systemic selective herbicide and a new alternative for post-emergence control of both annual and perennial weeds in maize (Lum *et al.* 2005). It displays genera-selectivity, therefore, ensures its effectiveness for managing weeds associated with the maize – even the grasses that are closely related to maize. Nicosulfuron belonging to sulfonylurea derivatives is an acetolactate synthase ALS inhibitor (EFSA 2012, HRAC 2012), which blocks the production of amino acids, such as valine, leucine and isoleucine, and, as a result, it interferes with the formation of proteins and other functional plant components. This herbicide was registered for post-emergence applications to control grass and some dicot weeds in maize in China (China Pesticide Information Network 2012). Hence, a field study was conducted to assess the effective dose of nicosulfuron

[1] College of Agriculture, G.B. Pant University of Agriculture and Technology, Pantnagar U.S. Nagar, Uttarakhand 263145, India

[2] College of Forestry, VCSG Uttarakhand University of Horticulture and Forestry, Ranichauri Tehri Garhwal, Uttarakhand 249199, India

[3] B. P. S. Agricultural College, Bihar Agricultural University, Sabour, Bihar 813210, India

* Corresponding author email: arunima.28@rediffmail.com

for weed management in maize and quantify its phytotoxic effect on growth and yield of maize along with its residual effect on succeeding pea and cowpea fodder.

MATERIAL AND METHODS

The field study was conducted in *Spring* and *Kharif* (rainy) seasons of 2017. The experimental site was situated at 29^0 N latitude, 79° E longitude at an elevation of 243.8 m above MSL at Norman E. Borlaug, Crop Research Center of G.B. Pant University of Agriculture and Technology, Pantnagar. The soil of experimental area was loamy, medium in organic matter (0.67%), available nitrogen (210 kg/ha), phosphorus (17.5 kg/ha) and potassium (181.2 kg/ha) with having natural reaction (pH 7.5). The climate is very hot in summers and cold in winters.

During the *Spring* season, (Feb to May, 2017) total growing period of crop, the total rainfall received was 38.0 mm and the relative humidity ranged from 20.7-93.0%. The average maximum and minimum temperatures were 31.2^0C and 15.5^0C, respectively. During succeeding cowpea fodder crop growing season (June to July 2017), the total rainfall was received 475.0 mm and the relative humidity ranged from 21.9-93.9%. The average maximum & minimum temperature was 34.9^0C and 25.0^0C, respectively. In the *Kharif* season, (July to October, 2017) the total rainfall was received 1290.2 mm and the relative humidity ranged from 46.1-93.9% during total growing period of maize crop. The average maximum and minimum temperatures were 32.4^0C and 23.8^0C, respectively. During succeeding pea crop growing season (November, 2017 to April, 2018) the total rainfall was received 55.8 mm and the relative humidity ranged from 19.0-96.0%. The average maximum and minimum temperature were 26.1^0C and 10.8^0C, respectively.

The experiment was laid out in randomized complete block design with eight treatments and three replications. The treatments consist of nicosulfuron 60D with four doses (30, 36, 42 and 50 g/ha) as post-emergence (PoE), standard check *i.e.*, tembotrione 120 g/ha PoE and atrazine 1000 g/ha as pre-emergence (PE) along with hand weeding twice at 20 and 40 days after seeding (DAS) and weedy check. The maize varieties *P-1844* (hybrid) and *Gaurav* (composite) was sown as test crop during *spring* and *Kharif* 2017, respectively. The crop was sown on 03.02.2017 during *spring* and 18.07.2017 during *Kharif* at 60 x 25 cm spacing in plot size 15 m^2 as per standard agronomic practices except weed control treatments. It was harvested on 24.05.2017 and 11.10.2017 during *Spring* and *Kharif* 2017, respectively.

All the herbicides except atrazine were sprayed at 3-5 leaf stages of weeds using battery operated knapsack sprayer fitted with flat fan nozzle using 500 l/ha volume of water, whereas, atrazine was applied 1-2 days after sowing of maize crop.

The density (no./m^2) and dry matter (biomass) of dominated weed species, that was categorized in grassy, broad-leaved weeds (BLWs) and sedges, was recorded at 45 days after herbicide application (DAA) using a quadrat (0.25 m x 0.25 m) to assess the weed flora. Collected samples were first sun-dried and then dried in an oven at 60 ± 2^0C for 4-5 days till constant dry weight was achieved. The data on weed density and biomass was subjected to square root transformation $(\sqrt{x+1})$ to normalize their distribution. Visual assessment of herbicide toxicity by phytotoxic symptoms, *viz.* leaf tip injury/ wilting/ vein clearing/ necrosis/ epinasty and hyponasty on maize crop was monitored 3, 7, 14 and 21 DAA. The yield attributing characters were recorded at harvest time. Grain yield was calculated by threshing of total plot biomass and presented in tons per hectare.

To assess the residual effect the herbicide treatments on succeeding crop, germination percentage and grain yield of pea and cowpea fodder were also recorded separately for each plot and converted to per hectare during respective succeeding season. The succeeding cowpea fodder and pea crop was also sown in RBD with 9 treatments, which were used in *Kharif* season, in 3 replications. Cowpea variety, UPC 5286 was sown on 25.05.2017 with seed rate 25kg/ha and pea variety, *Pant Pea 25* was sown with seed rate of 75 kg/ha on 20.11.2017. Cowpea fodder and pea was harvested on 16.07.2017 and 03.04.2018, respectively.

For determining the statistical difference between the treatments and to draw conclusions, the data obtained during the course of investigation were subjected to statistical analysis adapted in statistical package STPR-3 programme for the Randomized Complete Block Design, designed and developed by Department of Mathematics and Statistics of College of Basic Science and Humanities (CBSH), GBPUA&T, Pantnagar.

RESULT AND DISCUSSION

Weed flora

The experimental field was infested with natural population of grassy (33 and 49.3%), BLW (13.1 and

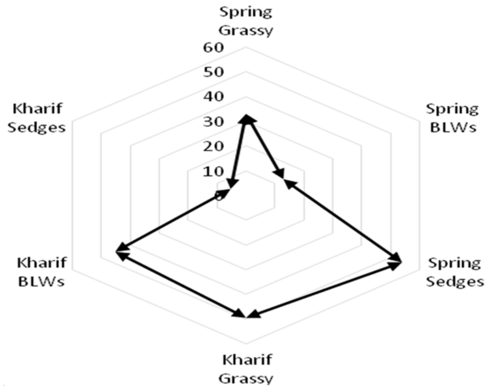

Figure 1. Relative weed composition (%) at 45 DAA

45.4%) and sedges (53.9 and 5.3%), respectively during *spring* and *Kharif*, 2017 (**Figure 1**). The dominant weeds in *Kharif* season were *Eleusine indica, Echinochloa colona, Digitaria sanguinalis* and *Panicum maximum* among grassy weeds and *Parthenium hysterophorus, Mallugo stricta* and, *Trianthema monogyna* among BLW and *Cyperus rotundus* among sedges. During *spring* season, *Eleusine indica, Digitaria sanguinalis* and *Phalaris minor* among grassy, *Trianthema monogyna, Chenopodium album* and *Phyllanthus niruri* among BLW and *Cyperus rotundus*, the sedge were the predominant weeds (**Table 1**).

Effect on weed

The density of all weeds differed significantly amongst tested weed management treatments during both the seasons. The lowest density of all grassy weeds was observed with all the doses of nicosulfuron during both *Spring* and *Kharif*, 2017 (**Table 1**).

Significantly lowest density of *Eleusine indica* was observed with nicosulfuron at 50 g/ha during *spring* 2017, while it was completely controlled with 50 and 42 g/ha during *Kharif* 2017. It was found at par with nicosulfuron at 36 g/ha during *Kharif* 2017. The density of *Digitaria sanguinalis* was also reduced significantly with nicosulfuron at 42 g/ha and was at par with nicosulfuron at 50 g/ha during *spring* 2017. All the doses of nicosulfuron, except 30 g/ha and tembotrione at 120 g/ha were found effective in reducing the density of *Digitaria sanguinalis* during *kharif* 2017 (**Table 1**). Nicosulfuron at 42 and 50 g/ha recorded significantly lowest *Phalaris minor* density in *spring* maize and was found at par with nicosulfuron at 36 g/ha and tembotrione at 120 g/ha. *Echinocloa colona* and *Panicum maximum* were completely controlled with nicosulfuron at 50 g/ha during *Kharif* season.

Among BLW, *Trianthema monogyna*, *Chenopodium album*, *Phyllanthus niruri* were completely controlled with nicosulfuron at 50 g/ha in the *spring* season. The density of broad-leaved weeds during *Kharif* season was found lower with increased dose of nicosulfuron. Nicosulfuron at 50 g/ha and was found superior over tembotrione and atrazine in reducing *Parthenium hysterophorus* and *Mallugo stricta* density in *Kharif* 2017. Thus, the higher dose *i.e.* 50 g/ha of nicosulfuron was found to be more effective to manage BLW in both the seasons. Mitkov *et al.* (2019) also reported the efficacy of nicosulfuron against *Echinochloa crus-galli* and *Chenopodium album* in maize. Zhang *et al.* (2013) observed that nicosulfuron at 40 g per liter was safe to maize in China and its efficacy was greater than tembotrione on broad-leaved weeds.

Table 1. Effect of treatments on weed density (no./m^2) at 45 DAA in maize during *Spring* and *Kharif* 2017

Treatment	Dose (g/ha)	Grassy							BLWs						Sedges	
		E. indica		*D. sanguinalis*		*P. minor*	*E. colona*	*P. maximum*	*T. monogyna*		*C. album*	*P. niruri*	*P. hysterophorus*	*M. stricta*	*C. rotundus*	
		Spring	*Kharif*	*Spring*	*Kharif*	*Spring*	*Kharif*		*Spring*	*Kharif*	*Spring*		*Kharif*		*Spring*	*Kharif*
Nicosulfuron	30	3.2 (9.3)	3.2 (9.3)	3.2 (9.3)	2.1 (3.3)	2.2 (4.0)	3.0 (8.0)	1.7 (2.0)	1.6 (1.7)	3.4 (10.7)	2.2 (4.0)	1.9 (2.7)	3.6 (12.0)	3.1 (8.7)	6.5 (41.3)	2.8 (6.7)
Nicosulfuron	36	2.2 (4.0)	1.5 (1.3)	2.8 (6.7)	1.0 (0.0)	1.9 (2.7)	2.1 (3.3)	1.0 (0.0)	1.5 (1.3)	2.9 (7.3)	1.6 (1.7)	1.0 (0.0)	3.0 (8.0)	2.1 (3.3)	5.1 (25.3)	1.0 (0.0)
Nicosulfuron	42	2.1 (3.3)	1.0 (0.0)	2.1 (3.3)	1.0 (0.0)	1.5 (1.3)	1.2 (0.7)	1.0 (0.0)	1.0 (0.0)	2.6 (6.0)	1.5 (1.3)	1.0 (0.0)	2.8 (6.7)	1.9 (2.7)	4.7 (21.3)	1.0 (0.0)
Nicosulfuron	50	1.2 (0.7)	1.0 (0.0)	2.2 (4.0)	1.0 (0.0)	1.5 (1.3)	1.0 (0.0)	1.0 (0.0)	1.0 (0.0)	2.5 (5.3)	1.0 (0.0)	1.0 (0.0)	2.5 (5.3)	1.9 (2.7)	4.6 (20.0)	1.0 (0.0)
Tembotrione	120	3.2 (9.3)	3.4 (10.7)	3.0 (8.0)	1.0 (0.0)	1.9 (2.7)	1.7 (2.7)	2.8 (6.7)	1.5 (1.3)	2.8 (6.7)	2.1 (3.3)	1.0 (0.0)	2.5 (5.3)	2.9 (7.3)	5.0 (24.0)	1.0 (0.0)
Atrazine	1000	4.0 (14.7)	5.5 (29.3)	4.4 (18.7)	2.1 (3.3)	2.8 (6.7)	4.4 (18.7)	3.9 (14.7)	1.9 (2.7)	2.1 (3.3)	3.2 (9.3)	2.4 (4.7)	3.4 (10.7)	5.9 (34.7)	6.9 (46.7)	3.2 (9.3)
Hand weeding twice	20 & 40 DAS	3.4 (10.7)	3.4 (10.7)	2.6 (6.0)	1.0 (0.0)	2.2 (4.0)	2.0 (3.3)	2.4 (4.7)	1.7 (2.0)	2.2 (4.0)	2.1 (3.3)	1.7 (2.0)	1.9 (2.7)	3.5 (11.3)	5.1 (25.3)	2.4 (4.7)
Weedy check		4.3 (17.3)	9.9 (97.3)	4.4 (18.7)	2.5 (5.3)	3.2 (9.3)	4.1 (16.0)	4.2 (16.7)	2.8 (6.7)	5.9 (34.7)	4.1 (14.7)	2.8 (6.7)	6.2 (37.3)	5.9 (34.7)	9.0 (81.3)	3.4 (10.7)
LSD (p=0.05)		0.49	0.56	0.41	0.29	0.48	1.06	0.27	0.36	0.38	0.49	0.26	0.43	0.54	0.97	0.31

*Data were subjected to square root ($\sqrt{x+1}$) transformation for analysis and original value given in parentheses

Significantly lower density of *Cyperus rotundus* was observed with all doses of nicosulfuron except 30 g/ha during *Spring* season and *C. rotundus* was completely eliminated during *Kharif* season (**Table 1**).

The statistical analysis of total weed density during *Spring* and *Kharif* 2017 revealed that the overall density of all grassy and non-grassy weeds was influenced significantly by herbicidal treatments over weedy check. Among all the herbicide treatments, nicosulfuron at 50 g/ha was found to be best with lowest weed density (**Table 2**).

The total weed biomass of all weeds was significantly reduced with nicosulfuron at 50 g/ha, however it was found statistically similar to nicosulfuron at 42 g/ha except on grassy weeds during *Spring* 2017. Hand weeding twice and atrazine caused reduction in weed biomass at 45 DAA but were not effective as nicosulfuron at 50 g/ha (**Table 3**). Post-emergence application of nicosulfuron, mesotrione and tembotrione applied at V4 stage in maize reduced the monocot and dicot weeds in Brazil (Giraldeli *et al.* 2019). The lower total sedges density and biomass Tembotrione at 120 g/ha also recorded by Kaur *et al.* (2018).

Weed control efficiency

Weed control efficiency with respect to grassy (91.5% and 100%), BLW (100% and 87.1%) and sedges (77.4% and 100%) were highest with

Table 2. Effect of treatments on total weed density at 45 DAA in maize during *Spring* and *Kharif* 2017

Treatment	Dose (g/ha)	Grasses		BLWs		Sedges	
		Spring	*Kharif*	*Spring*	*Kharif*	*Spring*	*Kharif*
Nicosulfuron	30	4.9 (22.7)	4.9 (22.7)	3.1 (8.3)	5.7 (31.3)	6.5 (41.3)	2.8 (6.7)
Nicosulfuron	36	3.8 (13.3)	2.4 (4.7)	2.0 (3.0)	4.4 (18.7)	5.1 (25.3)	1.0 (0.0)
Nicosulfuron	42	3.0 (8.0)	1.2 (0.7)	1.5 (1.3)	4.0 (15.3)	4.7 (21.3)	1.0 (0.0)
Nicosulfuron	50	2.3 (4.7)	1.0 (0.0)	1.0 (0.0)	3.8 (13.3)	4.6 (20.0)	1.0 (0.0)
Tembotrione	120	4.6 (20.0)	4.6 (20.0)	2.3 (4.7)	4.5 (19.3)	5.0 (24.0)	1.0 (0.0)
Atrazine	1000	6.4 (40.0)	8.2 (66.0)	4.2 (16.7)	7.0 (48.7)	6.9 (46.7)	3.2 (9.3)
Hand weeding	20 and 40 DAS	4.7 (20.7)	4.4 (18.7)	2.9 (7.3)	4.4 (18.0)	5.1 (25.3)	2.4 (4.7)
Weedy check	-	6.8 (45.3)	11.7 (162.0)	5.4 (28.0)	10.4 (106.7)	9.0 (81.3)	3.4 (10.7)
LSD (p=0.05)		0.61	0.69	0.55	0.36	0.97	0.31

Data were subjected to square root square root ($\sqrt{x+1}$) transformation for analysis and original value given in parentheses

Table 3. Effect of treatments on total weed dry weight at 45 DAA during *Spring* and *Kharif* 2017

Treatment	Dose (g/ha)	Grasses		BLWs		Sedges	
		Spring	*Kharif*	*Spring*	*Kharif*	*Spring*	*Kharif*
Nicosulfuron	30	3.8(13.6)	3.5(11.5)	2.2(3.9)	4.1(15.8)	2.3(4.1)	2.1(3.6)
Nicosulfuron	36	3.0(8.0)	1.9(2.9)	1.5(1.3)	3.3(9.7)	1.9(2.7)	1.0(0.0)
Nicosulfuron	42	2.4(4.9)	1.2(0.4)	1.2(0.5)	3.0(7.8)	1.8(2.4)	1.0(0.0)
Nicosulfuron	50	1.8(2.3)	1.0(0.0)	1.0(0.0)	2.8(7.0)	1.7(2.1)	1.0(0.0)
Tembotrione	120	3.6(12.0)	3.3(10.1)	1.5(1.3)	3.3(10.2)	1.9(2.5)	1.0(0.0)
Atrazine	1000	4.9(23.6)	5.8(32.9)	2.6(6.0)	5.0(23.7)	2.4(4.7)	2.4(4.7)
Hand weeding	20 and 40 DAS	3.6(12.1)	3.2(9.1)	2.0(3.2)	2.7(6.3)	1.9(2.5)	1.9(2.5)
Weedy check	-	5.3(27.0)	8.3(67.9)	3.5(11.3)	7.4(54.3)	3.2(9.3)	2.7(6.1)
LSD (p=0.05)		0.39	0.44	0.27	0.24	0.26	0.45

Data were subjected to square root square root ($\sqrt{x+1}$) transformation for analysis and original value given in parentheses

Table 4. Effect of treatments on weed control efficiency at 45 DAA during *spring* and *Kharif* 2017

Treatment	Dose (g/ha)	Grasses		BLWs		Sedges	
		Spring	*Kharif*	*Spring*	*Kharif*	*Spring*	*Kharif*
Nicosulfuron	30	49.6	83.1	65.5	70.9	55.9	41.0
Nicosulfuron	36	70.4	95.7	88.6	82.1	71.0	100.0
Nicosulfuron	42	81.9	99.4	95.3	85.6	74.2	100.0
Nicosulfuron	50	91.5	100.0	100.0	87.1	77.4	100.0
Tembotrione	120	55.6	85.1	88.5	81.2	73.1	100.0
Atrazine	1000	12.6	51.6	46.9	56.4	49.5	23.0
Hand weeding twice	20 & 40 DAS	55.2	86.6	71.7	88.4	73.1	59.0
Weedy check	-	-	-	-	-	-	-

Table 5. Yield and yield attributes as influenced by different herbicides treatments in maize during *Spring* and *Kharif* 2017

Treatment	Dose (g/ha)	No. of cob per square meter		Weight/cob (g)		Grain weight/cob (g)		No. of kernels/cob		100 seed weight (g)		Grain yield (t/ha)	
		Spring	*Kharif*	*Spring*	*Kharif*	*Spring*	*Kharif*	*Spring*	*Kharif*	*Spring*	*Kharif*	*Spring*	*Kharif*
Nicosulfuron	30	7.3	8.0	128.0	84.7	103.7	70.7	394	355	26.6	19.9	7.55	5.08
Nicosulfuron	36	8.2	8.9	133.5	91.3	110.2	76.0	404	366	27.2	20.8	9.05	6.70
Nicosulfuron	42	8.4	9.1	134.0	93.3	110.3	77.3	405	372	27.5	20.7	9.11	7.19
Nicosulfuron	50	8.3	9.1	133.9	92.7	111.6	77.0	406	365	27.5	21.1	9.20	6.93
Tembotrione	120	8.2	9.1	134.7	92.7	112.3	77.0	404	366	27.2	21.0	9.14	7.00
Atrazine	1000	8.0	8.7	125.9	85.3	105.2	71.3	388	363	27.1	19.6	8.20	6.19
Hand weeding twice	20 & 40 DAS	8.4	9.2	129.8	87.3	108.2	73.3	397	361	27.7	20.4	8.93	6.73
Weedy check	-	6.5	7.4	101.7	74.7	85.0	62.7	393	328	26.0	19.0	5.54	4.58
LSD (p=0.05)		0.48	0.4	8.2	3.9	6.7	3.8	8.0	7.0	1.2	0.9	0.49	0.44

Table 6. Germination and yield of succeeding crop as influenced by different herbicidal treatment

Treatment	Dose (g/ha)	Cowpea fodder (in *Kharif*)		Pea (in *Rabi*)	
		Germination at 15 DAS (no. of plants/m^2)	Fodder yield (t/ha)	Germination at 15 DAS (no. of plants/m^2)	Grain yield (t/ha)
Nicosulfuron	30	18.7	23.17	63.0	1.19
Nicosulfuron	36	19.5	23.00	60.0	1.23
Nicosulfuron	42	18.8	23.17	65.7	1.27
Nicosulfuron	50	18.3	23.17	61.0	1.24
Tembotrione	120	19.0	23.50	65.5	1.14
Atrazine	1000	19.3	23.17	66.5	1.29
Hand weeding twice	20 and 40 DAS	18.7	23.50	62.8	1.19
Weedy check	-	19.5	23.00	60.2	1.22
Nicosulfuron	82	18.7	23.33	60.8	1.23
LSD (p=0.05)		NS	NS	NS	NS

DAS: Days after sowing, NS- non significant

nicosulfuron at 50 g/ha PoE during *Spring* and *Kharif*, respectively. The next best treatment was nicosulfuron at 42 g/ha (**Table 4**).

Yield parameters and yield

All weed control treatments significantly increased the yield attributing characters and grain of maize over weedy check (**Table 5**) during *Spring* and *Kharif* season.

The maximum grain yield (9.20 t/ha) during *spring* was observed with nicosulfuron at 50 g/ha which was at par with tembotrione at 120 g/ha as well as nicosulfuron at 42 and 36 g/ha which may be attributed to a greater number of cobs per square meter (8.3), grain weight per cob (111.6), number of kernels per cob (406) and 100 seed weight (27.5 g). During *Kharif* season, maximum yield attributes *i.e.*, number of cobs per square meter (9.1), grain weight per cob (77.3 g), number of kernel per cob (372), 100 seed weight (20.7 g) and yield (7.19 t/ha) of maize were observed with nicosulfuron at 42 g/ha which was followed by tembotrione at 120 g/ha and nicosulfuron at 50 g/ha and showed non-significant difference. Nicosulfuron at 50 and 42 g/ha gave 12.2 and 16.3% higher yield as compared to check atrazine during *Spring* and *Kharif* 2017, respectively.

Crop safety and residual effect on succeeding crop

The application of nicosulfuron at single (42 g/ha) or double doses (84 g/ha) resulted in no phytotoxic symptoms on maize crop up to 21 DAA of crop. No phytotoxic effect due to residue of nicosulfuron was recorded on succeeding pea and cowpea fodder crop. The germination of these plants at 15 DAS and final yield were not affected significantly by herbicidal treatments (**Table 6**). This indicated no residual carry-over of nicosulfuron in the soil.

Conclusion

Nicosulfuron at 42 g/ha may be safely used for the effective weed control and achieving higher yield of maize crop as it resulted in lower weed density and biomass, higher weed control efficiency and maize yield without phytotoxicity and residual carry-over.

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RESEARCH ARTICLE

The moisture regimes and herbicides efficacy in improving productivity and profitability of maize-wheat cropping system

Sandeep Rawal, A.S. Dhindwal, Ashok Yadav, Aradhna Bali and Pardeep Sagwal*

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ABSTRACT

Two factorial field experiments were conducted in Haryana in split plot arrangement during 2013-14 and 2014-15 to evaluate moisture regimes and weed control treatments efficacy to managing weeds and improve productivity and profitability in maize-wheat cropping system. Four moisture regimes in main plots were based on cumulative pan evaporation (CPE) at 80-, 120-, 160- and 200-mm CPE interval in maize and at 75, 100, 125 and 150 mm CPE interval in wheat. Weed management treatments included pre-emergence application (PE) of pendimethalin at 1000 g/ha, atrazine at 750 g/ha PE, post-emergence application (PoE) of tembotrione at 120 g/ha in maize and pendimethalin at 1500 g/ha PE, clodinafop + carfentrazone at 60 +20 g/ha PoE and pinoxaden + metsulfuron at 50 + 4 g/ha PoE in wheat, weed free and weedy check. Significantly higher system yield (10.02 and 10.21 Mg/ha) during both years (2013-14 and 2014-15) were recorded at 80 mm CPE interval in maize and CRI+75 mm CPE interval in wheat. The atrazine PE and tembotrione PoE in maize and herbicide mixture viz. clodinafop+ carfentrazone and pinoxaden + metsulfuron PoE in wheat were the most effective weed management treatments.

Keywords: Clodinafop + carfentrazone, maize-wheat cropping system, moisture-weed interaction, Pinoxaden + metsulfuron, Tembotrione, Weed management

INTRODUCTION

Rice-wheat cropping system (RWCS) is crucial for the country's food security, but to ensure sustainability of natural resources and crop production in dark zones (over-exploited groundwater zones), diversification of rice by crops requiring less water, crops such as maize, is essential (Jat *et al*. 2015). Maize (*Zea mays* L.) is one of the most versatile cereal crops having wider adaptability under diverse soil and climatic conditions (Kumar *et al*. 2015) fits best with wheat in cropping system. Weeds are a major biological constraint that limits the production of wheat by 10-60% and maize by 30-40% (Ramesh *et al.* 2017). In India, chemical weed control is the most viable and practical option due to labour scarcity and rising cost coupled with untimely and continuous rainfall that makes timely manual weed control operations difficult. Current rates of agricultural water use are unsustainable, creating an urgent need to identify improved irrigation strategies for water limited areas (Lopez *et al.* 2017). This is especially evident in areas that rely heavily on groundwater resources (Scanlon *et al.* 2012). Among different approaches for scheduling irrigation of field crops; moisture regimes and climatological approach are found to be reliable and dependable (Jaffar *et al.* 2017). The irrigation and weed management at the cropping system level can provide better insight into managing natural resources more efficiently. This will help in optimizing the moisture regimes and weed management practices in maize-wheat cropping sequence under furrow irrigated raised bed system (FIRBS). Thus, an experiment was conducted to identify the optimized moisture regimes and weed management practices in maize-wheat cropping sequence.

MATERIAL AND METHODS

The experiment was conducted in cropping system mode during Kharif and Rabi season of 2013-14 and 2014-15 at CCS Haryana Agricultural University, Hisar research farm situated at $29^0$10' North latitude and $75^0$46' East longitudes at an elevation of 215.2 m above mean sea level. The soil (0-30 cm) of the experimental field was a typic Torripsamments with pH 7.8, 0.51% organic carbon (Walkley and Black 1934), 141.6 kg/ha alkaline $KMnO_4$ oxidizable N (Subbiah and Asija 1956), 16.8 kg/ha Olsen-P (Olsen *et al*. 1954) and 268.4 kg/ha ammonium acetate extractable K. The texture of soil was sandy loam with 1.5 g/cm3 bulk density and

Department of Agronomy, CCS Haryana Agricultural University, Hisar, Haryana 125004, India

* Corresponding author email: pardeepsagwal@gmail.com

basic infiltration rate of 4.3 mm/h. High rainfall (564 mm) was received during 2013 maize crop season (June-September) while second year was comparatively dry with average rainfall daily deficit of 4.29 mm. During wheat season (November-April) rainfall deficit over ET_0 of 1.26 and 1.92 mm/day as observed during 2013-14 and 2014-15 respectively.

Experiment was laid down using split plot design with 20 treatment combinations comprising of four moisture regimes in main plots and five weed control treatments in sub plots, replicated thrice in both maize and wheat. Irrigation was applied at different intervals depending upon cumulative pan evaporation (CPE) as per treatments. In maize, irrigations were applied when value of CPE minus rainfall reached 80 mm, 120 mm, 160 mm and 200 mm. In wheat, after a common irrigation at crown root initiation, irrigations were scheduled at 75 mm, 100 mm, 125 mm and 150 mm CPE. The details of irrigations applied in different treatment is presented in Table A and B.

Five weed control treatments consisted of weed free, weedy check, pre-emergence application (PE) of pendimethalin at 1000 g/ha and atrazine at 750 g/ha and post-emergence application (PoE) of tembotrione at 120 g/ha in maize. While in wheat, treatments consisted of weed free, weedy check, pendimethalin at 1500 g /ha PE, clodinafop + carfentrazone at 60 +20 g /ha PoE and pinoxaden + metsulfuron at 50 + 4 g /ha PoE. Herbicides were sprayed with manually operated knapsack sprayer fitted with flat fan nozzle using 500 litres of water per hectare.

Maize hybrid (HQPM 1) and wheat (WH 1105) were sown on June 23 and November 29 during 2013 and on June 21 and 21 November 21 during 2014. Both crops were sown on top of bed of 45 cm width (one line of maize and three lines of wheat). All other management practices were as per package and practice of maize and wheat in Haryana.

System productivity: Productivity of maize-wheat cropping system was calculated in terms of wheat equivalent yield (WEY) which was calculated by using following expression:

$$\text{WEY of maize} = \frac{\text{Maize yield x maize price}}{\text{Wheat price}}$$

System productivity (Mg/ha) = Grain yield of wheat (Mg/ha) + WEY of maize (Mg/ha)

For water use monitoring soil samples were taken from 0-15, 15-30, 30-60 and 60-90 cm soil depth to monitor the profile moisture status of the active root zone before and after each irrigation. Irrigation water productivity (IWP) of different treatments was computed by dividing the economic yield (kg/ha) by irrigation water applied (cm) in respective treatments.

$$\text{IWP} = \frac{\text{Economic (grains) yield (kg/ha)}}{\text{Irrigation water applied (cm)}}$$

While total water productivity (TWP) was calculated by formula:

$$\text{TWP (kg/m}^3\text{)} = \frac{\text{Grain yield (kg/ha)}}{\text{Total water used (m}^3\text{)}}$$

Total water used = Effective rainfall (m^3) + Irrigation water applied (m^3) + Profile water use including depletion from soil (m^3)

Table A. Date and depth of irrigation water applied in maize

Crop Season	Moisture regimes in maize, irrigation at			
	80 mm CPE	120 mm CPE	160 mm CPE	200 mm CPE
Kharif 2013	02/07/2013			
Total depth	5.70 cm			
Kharif 2014	06/07/2014	11/07/2014	15/07/2014	23/07/2014
	15/07/2014	15/08/2014	27/08/2014	
	15/08/2014			
	27/08/2014			
Total depth	19.30 cm	10.30 cm	10.50 cm	5.90 cm

Table B. Date and depth of irrigation water applied in wheat

Crop Season	Moisture regimes in wheat, irrigation at			
	75 mm CPE	100 mm CPE	125 mm CPE	150 mm CPE
Rabi 2013-14	One common irrigation at CRI state on 21/12/2013			
	26/02/14	20/03/14	31/03/14	
Total depth	9.70 cm	9.90 cm	10.30 cm	4.90 cm
Rabi 2014-15	One common irrigation at CRI state on 12/12/2014			
	01/03/15			
Total depth	9.70 cm	4.80 cm	4.85 cm	4.85 cm

RESULTS AND DISCUSSION

Dry matter partitioning in maize: Leaves and stem dry weight didn't differ significantly owing to well distributed rainfall but cob and total dry weight with irrigation applied at 80 mm CPE interval over other moisture regimes, *viz*. 120 mm, 160 mm and 200 mm CPE observed marked differences during both the years (**Table 1**). During 2014, significant variation in leaf and stem dry weight was observed among various moisture. Highest leaf and stem dry weight (47.4 g and 53.3 g/plant, respectively) being under irrigation applied at an interval of 80 mm CPE. Under the water stressed conditions, there is low nutrient availability and high temperature stress (Chaves *et al.* 2002) which also affects the photosynthesis process adversely, leading to low DMA in lower moisture regimes. Similar pattern was observed in cob and total dry weight during 2014 season.

The weed control treatments effect on partitioning of biosynthates in different maize crop parts was similar during both the years. Atrazine at 750 g/ha PE and Tembotrione at 120 g/ha PoE were at par with weed free in producing significantly higher leaf, stem, cob and total dry weight of maize as compared to weedy check and pendimethalin at 1000 g/ha PE. This may be attributed to less competition from weeds, greater penetration of solar radiation for enhanced rate of photosynthesis and more accumulation of dry matter (Rajcan and Swanton 2001 Rathore *et al*. 2014).

Dry matter partitioning in wheat: The dry weight of leaves (248.4 g/m^2), stem (488.1 g/m^2) and spike (486.6 g/m^2) recorded at maturity during 2013-14 was significantly higher with irrigation at CRI+CPE=75 mm over CRI+CPE=125 mm and CRI+CPE=150 mm but was at par with irrigation at CRI+CPE= 100 mm (**Table 2**). During 2014-15, although leaf and stem dry weight did not vary significantly with varying moisture regimes, but significantly higher dry matter of spike was recorded in CRI+CPE= 75 mm CPE over all other moisture regimes which were at par with each other. In terms

Table 1. Dry matter partitioning of maize at maturity as influenced by different moisture regimes and weed control treatments during 2013 and 2014

Treatment	2013				2014			
	Dry matter (g/plant)			Total	Dry matter (g/plant)			Total
	Leaf	Stem	Cob		Leaf	Stem	Cob	
Moisture regime (Irrigation at an interval of)								
80 mm CPE	48.2	48.9	95.6	192.7	47.4	53.3	106.4	203.1
120 mm CPE	46.4	46.3	87.9	180.6	44.2	49.8	99.7	189.6
160 mm CPE	46.1	45.9	87.7	179.7	42.6	48.3	97.2	184.5
200 mm CPE	46.0	45.8	87.6	179.3	39.7	44.9	91.8	172.4
LSD (p=0.05)	NS	NS	6.1	6.2	2.6	2.7	5.4	5.2
Weed control								
Weed free	49.3	51.0	98.4	198.8	45.8	53.3	105.1	200.2
Weedy check	42.9	42.0	75.2	160.1	38.9	41.1	87.6	163.7
Pendimethalin 1000 g/ha PE	45.1	45.0	83.6	173.7	42.2	47.2	95.1	180.6
Atrazine 750 g/ha PE	48.0	48.0	97.8	193.8	45.7	52.6	104.5	198.7
Tembotrione 120 g/ha POE	47.9	47.6	93.6	191.2	44.7	51.1	101.6	193.6
LSD (p=0.05)	2.4	4.4	6.7	8.1	2.1	3.1	5.9	6.7

Table 2. Influence of different moisture regimes and weed control treatments on dry matter partitioning of wheat at maturity as during cropping season of 2013-14 and 2014-15

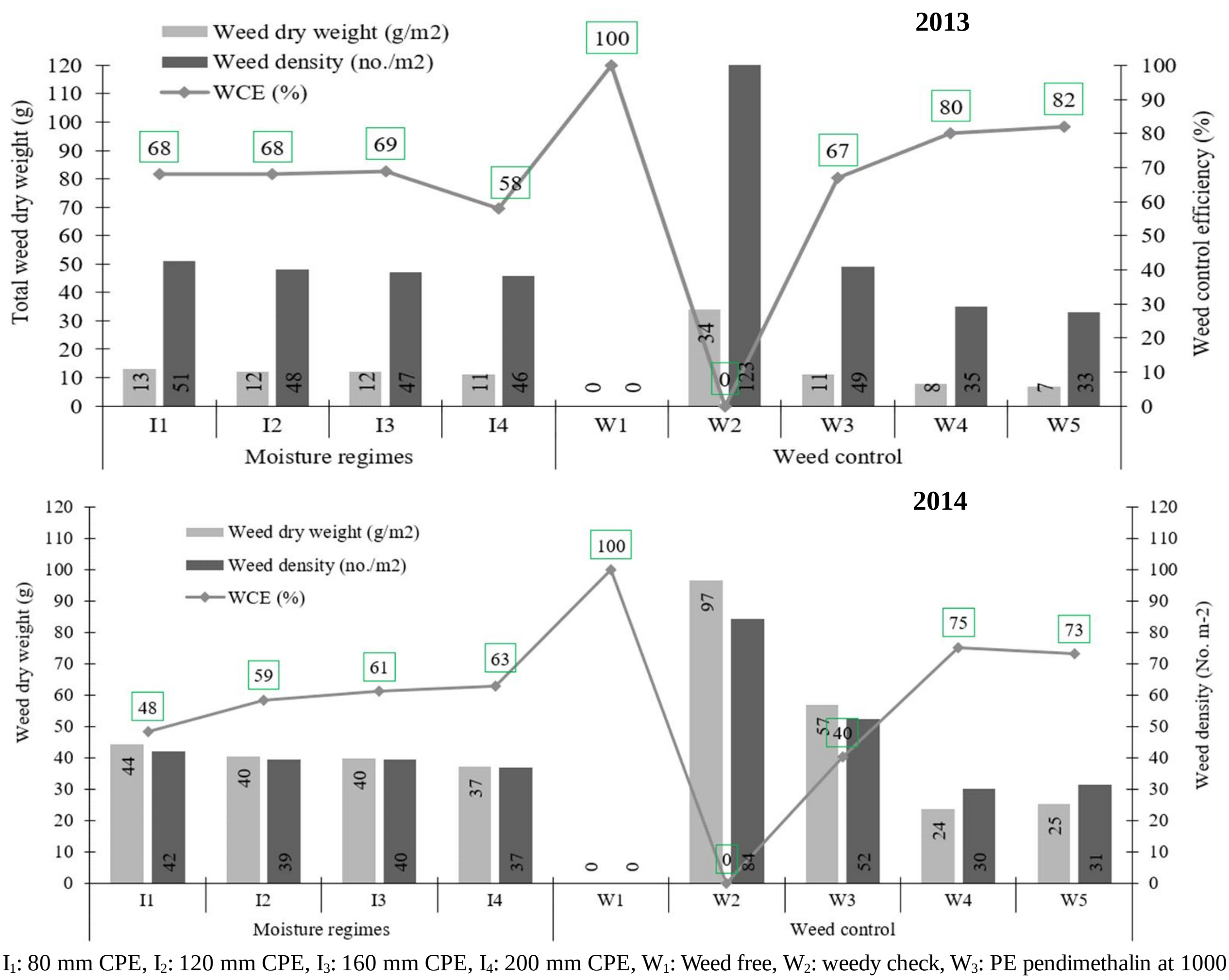
Treatment	2013-14				2014-15			
	Dry matter (g/m^2)			Total	Dry matter (g/m^2)			Total
	leaf	stem	spike		leaf	stem	spike	
*Moisture regime (Irrigation at an interval of) **								
75 mm CPE	248	488	487	1223	252	497	491	1242
100 mm CPE	243	469	478	1190	248	486	483	1220
125 mm CPE	239	457	474	1170	247	485	483	1217
150 mm CPE	228	431	462	1127	246	484	482	1215
LSD (p=0.05)	10.5	24.8	8.7	27	NS	NS	5.2	10
Weed control								
Weed free	246	482	490	1218	259	504	494	1257
Weedy check	230	430	448	1107	221	462	463	1153
Pendimethalin 1500 g/ha PE	238	456	467	1161	249	479	484	1212
Clodinafop+ carfentrazone (60+20 g/ha) PoE	242	468	484	1194	252	495	490	1246
Pinoxaden+ metsulfuron (50+4 g/ha) PoE	244	476	487	1207	254	499	492	1250
LSD (p=0.05)	5.6	25.3	16.3	31	7.6	10.1	5.8	13

of total dry weight, CRI+CPE= 75 mm CPE proved to be significantly superior in producing significantly higher dry matter accumulation during 2013-14, as compared to irrigation applied at CRI + 100-, 125- and 150-mm CPE. Both CRI+CPE 100- and 125-mm CPE irrigations being at par with each other with respect to total dry weight, were significantly superior over CRI+CPE= 150 mm treatment. During 2014-15, highest total dry weight was recorded under CRI+CPE=75 mm over other moisture regimes which were at par with each other, which might be due to better availability of soil water content from the root initiation stage up to the maturity (Fondo *et al*. 2010). This also might be due to enhanced moisture and nutrient, which resulted in higher photosynthetic activity per unit area and hence more dry matter production. (Borrill *et al*., 2015) reported that higher amount of dry matter accumulation in leaves helped the photosynthetic area to remain active for longer period and is responsible for overall better performance of plant under moisture stress condition.

During both the years of study, weed free treatment recorded maximum dry weight which was significantly higher than weedy check and pre-emergence application of pendimethalin at 1500 g/ha but was at par with clodinafop + carfentrazone at 60 + 20 g/ha PoE and pinoxaden + metsulfuron at 50 + 4 g/ha PoE due to less competition for light, space, nutrients and moisture from weeds which were effectively controlled (Mehmood *et al.* 2014).

Weed density, biomass and control efficiency

Maize: Different moisture regimes had not significantly influenced total weed density and dry matter (biomass) during 2013 maize crop season even then significant variation in weed control efficiency was noticed among moisture regimes (**Figure 1**). Maximum weed control efficiency (WCE) of 61.5 % was recorded under irrigation applied at an interval of 80 mm CPE which was significantly higher as compared to other moisture regimes, *viz.* 120 mm, 160 mm and 200 mm CPE treatments which



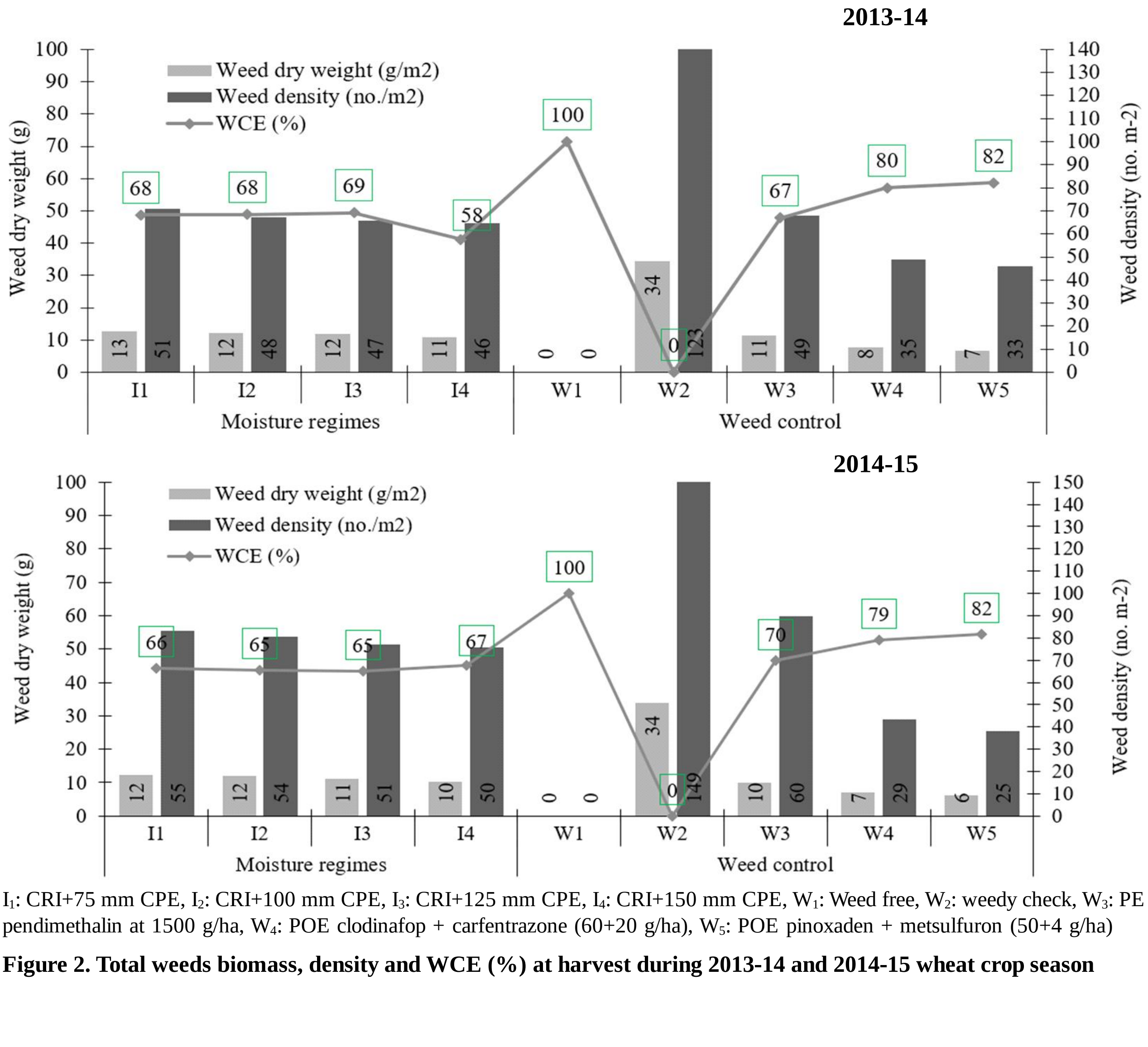
I_1: 80 mm CPE, I_2: 120 mm CPE, I_3: 160 mm CPE, I_4: 200 mm CPE, W_1: Weed free, W_2: weedy check, W_3: PE pendimethalin at 1000 g/ha, W_4: PE atrazine at 750 g/ha, W_5: POE tembotrione at 120 g/ha

Figure 1. Total weed dry weight (biomass), density and weed control efficiency at harvest during maize 2013 and 2014

remained at par with each other. One sole irrigation applied at 9 days after sowing (DAS) in 80 mm CPE treatment may have resulted in better efficacy of herbicides and hence better WCE as compared to other moisture regimes in which no irrigation was applied due to exceptionally high rainfall. During 2014, both weed biomass and density were significantly higher with irrigation application at interval of 80 mm CPE as compared to other moisture regimes, *viz.* 120 mm, 160 mm and 200 mm CPE treatments which remained at par with each other. Irrigation at 160- and 200-mm CPE interval resulted in statistically similar WCE of 61.2 and 62.8 % respectively which was significantly higher over irrigation at 120 (58.5%) and 80 mm CPE (48.4%) interval. Lower moisture availability under 200 mm CPE coupled with scanty rainfall may be reason for lower weed density and dry weight and hence higher WCE as compared to rest of moisture regimes.

Similar trend in total weed density and biomass with different weed control treatments was observed during both the years. Atrazine at 750 g/ha PE and Tembotrione at 120 g/ha PoE resulted in substantially higher WCE of 63.5 and 61.4% during 2013 and 75.3 and 73.1% during 2014 and were at par with each other but resulted in significantly lower weed density and biomass as compared to pendimethalin 1000 g/ha PE and weedy check.

Wheat: Different moisture regimes had not substantially effected total weed density and biomass during both years of study which may be due to almost equal contribution of ground water contribution and the fact that rabi weeds are able to germinate even at low moisture conditions (Steadman *et al.* 2004, Acosta *et al.* 2014) (**Figure 2**). Weed control efficiency (WCE) was statistically similar with irrigation applied at CRI+CPE=75 mm, CRI+CPE=100 mm, CRI+CPE=125 mm but was significantly higher than under CRI+CPE=150 mm. During 2014-15, significant variation in WCE among various moisture regimes was not observed.



I_1: CRI+75 mm CPE, I_2: CRI+100 mm CPE, I_3: CRI+125 mm CPE, I_4: CRI+150 mm CPE, W_1: Weed free, W_2: weedy check, W_3: PE pendimethalin at 1500 g/ha, W_4: POE clodinafop + carfentrazone (60+20 g/ha), W_5: POE pinoxaden + metsulfuron (50+4 g/ha)

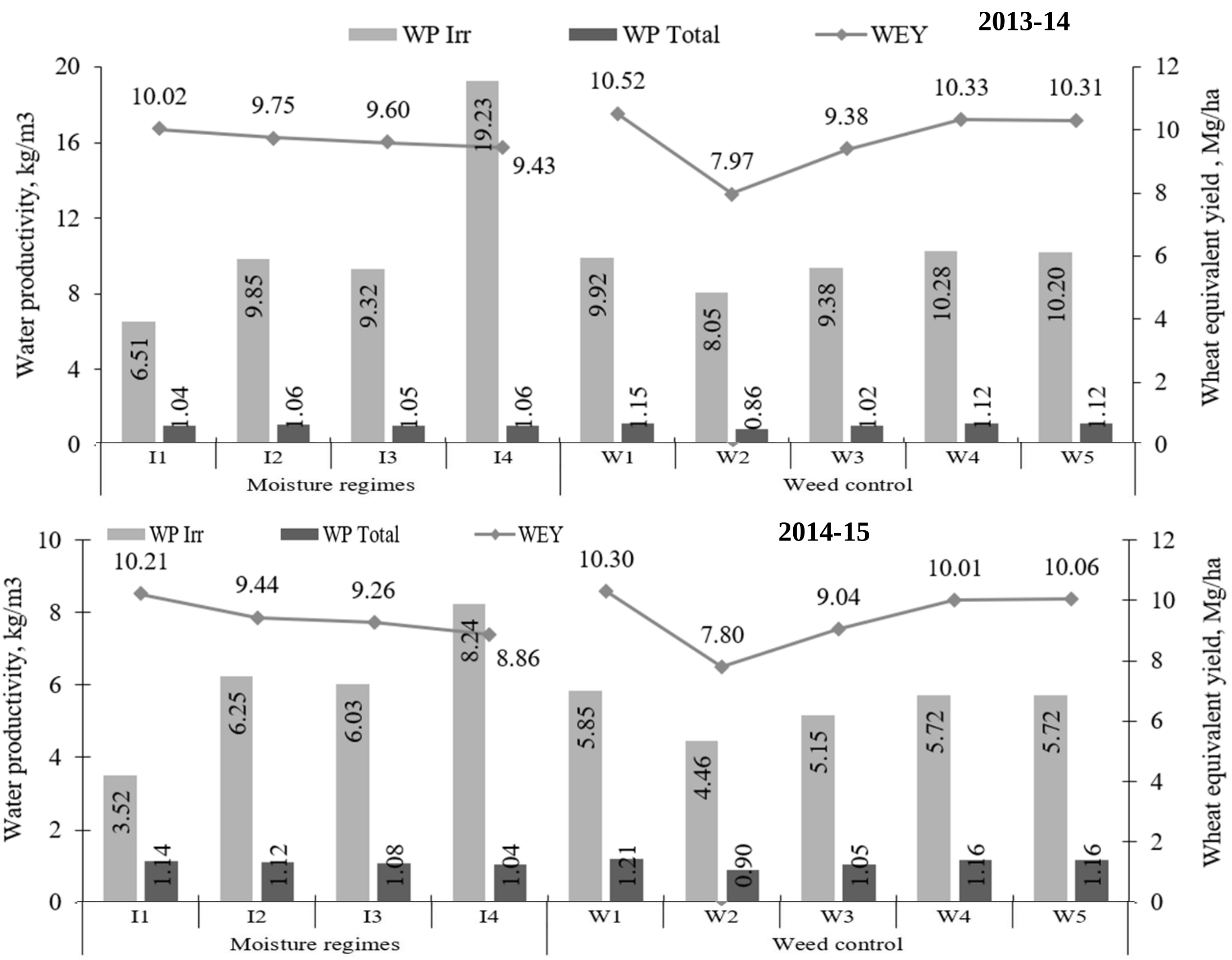
Figure 2. Total weeds biomass, density and WCE (%) at harvest during 2013-14 and 2014-15 wheat crop season

Clodinafop + carfentrazone 60 + 20 g/ha PoE and pinoxaden + metsulfuron 50 + 4 g/ha PoE proved significantly superior in reducing weed biomass and density resulting in significantly higher WCE. Among herbicides, pendimethalin at 1500 g/ha PE, was found to be less effective in reducing total weed biomass as compared to clodinafop + carfentrazone at 60 + 20 g/ha PoE and pinoxaden + metsulfuron at 50 + 4 g/ha PoE but was notably effective over weedy check in term of total weed biomass, density and WCE.

Maize-wheat cropping system: System productivity

Application of irrigation at CPE= 80 mm in maize and CRI+CPE=75 mm in wheat produced significantly highest system productivity of 10.02 and 10.21 Mg/ha during 2013-14 and 2014-15 (**Figure 3**). Difference in system yield between CPE=160 mm in maize and CRI+CPE=125 mm in wheat and at CPE= 200 mm in maize and CRI+CPE=150 mm in wheat, was not significant during 2013-14 while during 2014-15 it was significantly higher under previous as compared to latter. This may due to decreasing trend observed in individual maize and wheat crop yields with decreasing moisture regimes.

Weed free treatment resulted in highest system productivity during both years which was at par with atrazine at 750 g/ha PE in maize and clodinafop + carfentrazone at 60 + 20 g/ha PoE in wheat during 2013-14 and with tembotrione 120 g/ha PoE in maize and pinoxaden + metsulfuron 50 + 4 g/ha PoE in wheat during 2014-15. Among the herbicide treatment, the system yield did not differ between atrazine 750 g/ha PE in maize and clodinafop + carfentrazone 60 + 20 g/ha POE in wheat and with tembotrione at 120 g/ha POE in maize and pinoxaden



I_1: 80 and 75 mm CPE in maize and wheat respectively, I_2: 120 and 100 mm CPE in maize and wheat respectively, I_3: 160 and 125 mm CPE in maize and wheat respectively, I_4: 200 and 150 mm CPE in maize and wheat respectively, W_1: Weed free in maize and wheat, W_2: weedy check in maize and wheat, W_3: PE pendimethalin at 1000 and 1500 g/ha in maize and wheat respectively, W_4: PE atrazine at 750 g/ha in maize and PoE clodinafop + carfentrazone (60+20 g/ha) in wheat, W_5: PoE tembotrione at 120 g/ha in maize and pinoxaden + metsulfuron (50+4 g/ha) in wheat.

Figure 3. Water productivity (WP) and wheat equivalent yield (WEY) of maize-wheat system during 2013-14 and 2014-15

+ metsulfuron at 50 + 4 g/ha POE in wheat but was significantly higher than pendimethalin 1000 g/ha PE in maize and 1500 g/ha PE in wheat during both years.

Water productivity: During 2013-14, highest (19.23 kg/m^3) irrigation water productivity (IWP) of maize wheat system was recorded with irrigation at CPE= 200 mm in maize and CRI+CPE=150 mm in wheat (**Figure 3**). Total water productivity (TWP) of maize wheat system followed the same trend as that of IWP. Higher consumptive use of water was not able to bring the proportional increase in yield in higher moisture regimes as a result of which water productivity of irrigation water decreased although increase in yield was there in higher moisture regimes in comparison to lower moisture regimes. During 2014-15 also, irrigation at CPE= 200 mm in maize and CRI+CPE=150 mm in wheat resulted in highest IWP (8.24 kg/m^3), which decreased with increasing moisture regimes. Reverse trend was observed with respect to system TWP, with highest value (1.14 kg/m^3) in irrigation at CPE= 80 mm in maize and CRI+CPE=75 mm in wheat which decreased with decreasing moisture regimes.

Atrazine at 750 g/ha PE in maize and post emergence application of clodinafop + carfentrazone at 60 + 20 g/ha PoE in wheat and tembotrione at 120 g/ha PoE in maize and pinoxaden + metsulfuron at 50 + 4 g/ha PoE in wheat resulted in substantially higher IWP of maize wheat system than other treatments in maize and wheat during 2013-14. This may be due to lower use of water coupled with higher yield owing to higher weed control efficiency in atrazine 750 g/ha PE in maize and clodinafop + carfentrazone 60 + 20 g/ha POE in wheat and with tembotrione at 120 g/ha POE in maize and pinoxaden + metsulfuron at 50 + 4 g/ha POE in wheat. The TWP of maize wheat system was almost comparable (1.15, 1.12 and 1.12 kg/m^3) under weed free, atrazine at 750 g/ha PE in maize and clodinafop + carfentrazone at 60 + 20 g/ha POE in wheat and with tembotrione at 120 g/ha POE in maize and pinoxaden + metsulfuron at 50 + 4 g/ha POE in wheat, respectively but noticeably higher than weedy check and pendimethalin at 1000 g/ha PE in maize and 1500 g/ha PE in wheat. During 2014-15, highest system IWP (5.85 kg/m^3) was registered under weed free followed by atrazine at 750 g/ha PE in maize and clodinafop + carfentrazone at 60 + 20 g/ha POE in wheat and with tembotrione at 120 g/ha POE in maize and pinoxaden + metsulfuron at 50 + 4 g/ha POE in wheat (5.72 kg/m^3). Similar trend was observed with respect of TWP of maize wheat system.

Conclusion

Irrigation applied either at 80- or 120-mm CPE coupled with atrazine 750 g/ha PE or tembotrione 120 g/ha PoE in maize and CRI + 75 or 100 mm CPE in with of clodinafop + carfentrazone 60+20 g/ha PoE or pinoxaden + metsulfuron 50+4 g/ha PoE in wheat can be used to obtain higher grain yield, enhanced water productivity and profitability.

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RESEARCH ARTICLE

Evaluation of cultural practices for weed management in maize-based cropping system in Palam valley, Himachal Pradesh

Gaytri Hetta, S.S. Rana*, Rahul Sharma and G.D. Sharma

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ABSTRACT

A study was carried out during 2017-19 at Palampur in an ongoing experiment under All India Coordinated Research Project on Weed Management (AICRP-WM). Ten weed control treatments based on hoeing, stale seed bed + hoeing, raised stale seed bed (RSSB) + hoeing, mulch, stale seed bed + mulch, raised stale seed bed (RSSB) + mulch, intercropping, crop rotation, intensive cropping and herbicide check (pendimethalin in pea/garlic and atrazine in maize) were tested during *Rabi* 2017-18 to *Kharif* 2019. There were 22 weed species in garlic and 19 weed species in maize. *Phalaris minor, Daucus carota* and *Anagallis arvensis* were the major weeds, constituting 17.0, 14.0 and 12.0 per cent, respectively of the total weed flora in garlic during 2017-18. *Commelina benghalensis L.*, *Galinsoga parviflora* and *Ageratum* sp. were the major weeds constituting 21.0, 17.0 and 11.0 per cent, respectively of the total weed flora in maize. Maximum bulb yield (3472 kg/ha) was recorded with RSSB + hoeing and was statistically at par with herbicide check and SSB + hoeing. In maize, the highest cob yield was recorded in RSSB + mulch followed by mulch. Maize equivalent yield was higher in intercropping followed by intensive cropping and RSSB + mulch treatments. In 2019, 22 and 13 weed species occurred in pea and maize, respectively. The maximum pea pod yield was with intensive cropping followed by herbicide check in *Rabi* 2018-19. Herbicide check gave highest green cob yield (10323 kg/ha) of maize and was statistically equivalent to RSSB + hoeing (9208 kg/ha green cobs yield). Higher productivity (maize equivalent yield of 11420 kg/ha) was realized with the herbicide check which was at par with RSSB + hoeing (10160 kg/ha). The B:C followed the trend of intensive cropping > intercropping > herbicide check > RSSB + hoeing > RSSB + mulch.

Keywords: Cropping systems, Garlic, Maize, Non-chemical, Pea, Weeds, Weed management

INTRODUCTION

Maize is the third most important food crop after wheat and rice in India. About 80% of maize is cultivated during monsoon season particularly under rainfed conditions. Maize is one of the potential *Kharif* crops of the state and diversification within its cultivation for higher returns is possible through taking it up as green cob depending upon the market demand. In Himachal Pradesh, maize occupied an area of 286.78 thousand hectares producing around 725.55 thousand tons of grain with a productivity of 2.53 t/ha (Anonymous 2019-20). Being a hilly state and owing to unique agro-climatic conditions, most farmers are shifting to vegetables and fetching reasonably good prices. Organic management of maize-vegetable based system may further improve resource use efficiency, family employment and income, besides, achieving the wider national goals of sustainability and overall ecological health. However, weeds are a serious problem in maize, especially during *Kharif* season. They compete with maize for nutrient and causes yield loss up to 70% (Malviya and Singh 2007). Weed menace is one of the numerous constraints lowering the productivity of the cropping systems. Weeds grow rapidly in maize due to slower initial crop growth, wider row spacing and high fertilizers application, favourable soil moisture due to sowing of maize with the commencement of monsoon, and congenial temperature conditions (Sharma and Gautam 2010, Sinha *et al.* 2005). The rapid weed growth leads to severe crop weed competition which culminates in heavy reduction in growth and yield of the crop and lessens the profitability depending upon intensity, type of weed flora and nature of weed growth in relation to environmental conditions at or after sowing. Most of the hill and mountain regions of the Indian Himalayas are organic by default and have tremendous potential to emerge as major suppliers of organic products. Hand weeding, a commonly adopted method of weed control by farmers in the hill state. Many weed management tools used in organic production systems, like diversified rotation of crops, intensive tillage, and mulch, are soil friendly which reduce weed growth and prevent soil erosion (Bond and Lennartsson 1999, Saini *et al.* 2013).

Department of Agronomy, CSK HPKV Palampur, Himachal Pradesh 176062, India

* Corresponding author email: ranassdee@gmail.com

As both public demands for organic produce and the profile of organic farming have increased in recent years, the need has increased for wider range of organic weed control options including cultural methods of weed control such as the use of novel weed-suppressing cover crops, and the identification of specific crop traits for weed suppression (Rana *et al.* 2020, Saini *et al.* 2013). This study was aimed at assessing the effect of different non-chemical weed control measures on weeds and yield of sequentially grown garlic/garden pea and maize under organic farming conditions.

MATERIALS AND METHODS

Field experiments were carried out at Palampur, Himachal Pradesh located at 32°6´ N latitude, 76°3´ E longitude and 1290 m above mean sea level lying in North-West Himalaya in the Palam Valley of Kangra district of Himachal Pradesh, India during *Rabi*, 2017-18 to *Kharif*, 2019. The soil of the experimental field was silty clay loam in texture, low in organic carbon and available N, high in available P and medium in available K.

A randomized block design with three replications was used. Maize variety Kanchan Hybrid was sown during both the years and garlic variety Agrifound Parvati (G-313) and pea variety GS-10 were sown during the successive *Rabi* seasons. A manually operated wheel-hoe was used for hoeing. Lantana (*Lantana camara*) leaves from the nearby wasteland and forests were collected and used as a mulching material at the rate of 5 t/ha, which formed a thickness of about 5–6 cm on the soil surface. The treatment details are given in **Table 1**.

In stale seedbed plots, one irrigation was given 15 days prior to sowing to allow the germination of weeds, and the first flush of emerged weed seedlings were removed by disturbing the surface soil (up to 2 cm) at the time of crop sowing using a manually operated harrow. In case of raised stale seedbed plots, all conditions were like stale seedbed except that the seedbed was raised upto 12-15 cm height for providing proper drainage. Intercropping with soybean in case of maize and fenugreek in pea/garlic was done to check weed growth and get additional yields. The concept of rotating crops with different life cycles was used, as earlier in 2017 -18 *Rabi* season garlic was sown which was later rotated by pea. In case of intensive cropping, incorporation of pulse- soybean, oilseed- brown sarson, green manure crop- buckwheat were taken up. Pendimethalin (1.0 kg/ha) in pea and atrazine (0.75 kg/ha) in maize were used in herbicide check treatments.

Farmyard manure (0.86% N, 0.33% P, and 0.65% K) at the rate of 10 t/ha was applied 15 days before sowing in *Kharif* season and vermicompost at the rate of 15 t/ha during *Rabi* season was thoroughly incorporated into soil (based on availability). During *Rabi* (2017-18) maximum temperature ranged between 16.0 to 29.9°C. The minimum temperature ranged between 3.1 to 15.6°C. Total amount of rainfall received was 466.9 mm and 3132.4 mm in *Kharif* season. In *Kharif* season, the maximum temperature ranged between 20.0 to 30.6°C and minimum temperature ranged between 7.0 to 20.6°C. In 2018-19, the temperature during *Rabi* season ranged from 7.5°C to 25.5°C and during *Kharif* season, from 16.5°C to 35.5°C. A total of 639.6 mm rainfall occurred during the entire *Rabi* season and 1366.8 mm during entire *Kharif* cropping season. In each plot, data on weed count and dry weight were recorded, species-wise at monthly interval and at harvest from 50 × 50 cm quadrate at two places in each plot. The weed count and dry weight so obtained were converted to number and grams per square meter, respectively by multiplying the average count and dry weight of the weeds with factor 4. For weed shifts, the weed count data of the last year *Rabi* 2017-18 and *Kharif* 2018 was compared with the weed count data of 2018-19 *Rabi* and *Kharif* 2019 for the presence or absence of weed species. The yield of the

Table 1. The treatment details

Kharif (Maize green cob)	*Rabi* (Garlic/Peas)	Abbreviation
One hoeing followed by earthing up at knee high stage	Hoeing (twice) at 30 days after seeding (DAS) and 60 DAS	Hoeing
Stale seed bed (SSB) + hoeing + earthing up	SSB + hoeing + hand weeding (HW)	SSB + hoeing
Raised stale seed bed (RSSB)+ hoeing + earthing up	RSSB + hoeing + HW	RSSB + hoeing
Mulch (*Lantana*) 5t/ha	Mulch (*Lantana*) 5 t/ha	Mulch
SSB + mulch 5 t/ha	SSB + mulch 5 t/ha	SSB + mulch
RSSB + mulch 5 t/ha	RSSB + mulch 5 t/ha	RSSB + mulch
Intercropping (with soybean) + hoeing	Intercropping (with fenugreek) + hoeing	Intercropping
*Maize/soybean + hoeing+ earthing up	*Pea/sarson (mustard) + hoeing+ HW	Crop rotation
Maize + mulch + manual weeding *fb* autumn crop of sarson sag	Peas + mulch + manual weeding *fb* summer crop of buckwheat	Intensive cropping
Herbicide + HW	Herbicide + HW	Herbicide check

*Based on crop rotation, maize-peas in the first year and soybean-sarson (mustard) in the second year *i.e.* In *Kharif*, maize/soybean and in *Rabi* peas/ sarson alternatively; intensive cropping was based on intensive cropping; herbicide check was based on recommended dose of fertilizers and herbicides crops obtained from each net plot in the experiment was converted into gross returns in rupees based on prevailing market price of grains and straw. The treatment-wise net returns were obtained by subtracting the cost of cultivation from gross returns.

Benefit:cost ratio (B:C) was calculated by dividing net returns with cost of cultivation as follow:

$$\text{B/C ratio} = \frac{\text{Net returns from treatment (₹/ha)}}{\text{Cost of cultivation of the treatment (₹/ha)}}$$

Data on weeds were analyzed after square-root transformation $\sqrt{x+0.5}$ to account for the non-normality of distribution. All data were analyzed by ANOVA, and the least significant difference (LSD) values at 5% level of significance were calculated and used to test significant differences between treatment means.

RESULTS AND DISCUSSION

Effect on weeds

Weed flora of *Rabi* season: The weed flora composition in 2018-19 differed from that observed during 2017-18. The dominating weeds in garlic crop were *Phalaris minor* Retz. (17.1%), *Daucus carota* L. (14.1%), *Anagallis arvensis* L. (12.5%), *Poa annua* L. (8.9%), *Asphodelus tenuifolius* Cav. (8.9%), *Euphorbia helioscopia* L. (8.5%), *Vicia sativa* L. (7.2%), *Coronopus didymus* (L.) Sm. (4%) and *Tulipa altaica Pall. ex Spreng.* (3.6%). Weeds prevalent during *Rabi* 2017-18 and 2018-19 were *P. minor, A. arvensis, E. helioscopia, V. sativa, C. didymus* and *Tulipa altaica*. Some of the weed species such as *A. tenuifolius*, *Chenopodium murale* L., *Chenopodium album* L., *D. carota, Digitaria sanguinalis* (L.) Scop., *Medicago denticulata* Willd., *Panicum dichotomiflorum* Michx. and *Rumex obtusifolius* L. were absent in the pea crop during 2018-19. *P. minor, Stellaria media* (L.) *Vill., A. arvensis, Poa annua* L., *V. sativa, C. didymus, Allopecurus myosuroides* Huds. and *Artemisia ludoviciana* Nutt. were the major weeds infesting the pea crop. These results are in line with the findings of Mawalia *et al.* (2015), Singh and Angiras (2004). The studied organic systems had the highest population of perennial weeds which could be due to non-use of herbicides, low levels of disturbance of soil and a lower tillage level applied for seed-bed preparation. *Cyperus rotundus L., C benghalensis, P. annua* and *Euphorbia hirta L.* occurred during both the years. Alireza *et al.* in 2008 reported that in the organic systems perennial weeds accounted for 56 and 66% of the total weed population.

Species-wise weed density: Garlic crop was infested with many weeds owing to longer duration, slow initial growth, non-tillering/branching habit, space, canopy development and organic weed control practices. The density of *P. minor* was higher at 120 DAS and decreased in next month owing to manual removal to minimize the soil seed bank (**Table 2**). The density of it again increased due to the emergence of its new flush. SSB + mulch was statistically at par with intensive cropping. Maximum density of *A. arvensis* was recorded at 120 DAS and then decreased later due to manual removal to minimize addition to the seed bank.

Minimum density of *V. sativa* was observed in intensive cropping which was statistically at par with hoeing and SSB + mulch. The density of *Tulipa altaica* was highest at 180 DAS and decreased at harvest. The weed species such as *C. murale, C. album, D. sanguinalis, Galinsoga parviflora* Cav., *Lolium temulentum* L., *M. denticulata, P. dichotomiflorum, Plantago lanceolata* L., *Polygonum alatum D.Don, Ranunculus arvensis* L., *R. obtusifolius, S. media* and *Coriandrum tordylium* (Fenzl) Bornm. were present in very small number and hence were placed under other weeds category.

Table 2. Effect of treatments on species-wise weed density (no./m^2) during *Rabi* season

Treatment	*Phalaris minor*		*Vicia sativa*		*Anagallis arvensis*		*Tulipa altaica*		Other weeds	
	2017-18 (120 DAS)	2018-19 (90 DAS)	2017-18 (120 DAS)	2018-19 (90 DAS)	2017-18 (120 DAS)	2018-19 (120 DAS)	2017-18 (180 DAS)	2018-19 (30 DAS)	2017-18 (At harvest)	2018-19 (At harvest)
Hoeing	7.0(48.1)	2.3(6.7)	1.6(3.7)	3.8(14.0)	5.3(29.6)	0.7(0.0)	1.6(3.7)	2.6(8.0)	8.2(66.7)	8.7(79.1)
SSB + hoeing	6.4(40.7)	4.2(17.3)	2.5(7.4)	4.1(18.0)	5.5(29.6)	0.7(0.0)	0.7(0.0)	4.0(16.0)	8.0(63.0)	7.8(68.9)
RSSB + hoeing	6.7(44.4)	2.6(8.7)	3.4(11.1)	3.6(13.3)	5.1(25.9)	2.7(8.7)	1.6(3.7)	3.7(13.3)	5.1(25.9)	8.4(73.6)
Mulch	6.7(44.4)	4.1(16.7)	7.0(48.1)	3.1(12.7)	6.4(40.7)	3.1(9.3)	4.3(18.5)	4.0(16.0)	9.0(81.5)	7.6(58.7)
SSB + mulch	4.8(22.2)	3.5(13.3)	1.6(3.7)	4.1(17.3)	6.1(37.0)	6.0(36.0)	3.9(14.8)	3.9(14.7)	7.9(63.0)	10.3(105.8)
RSSB + mulch	5.5(29.6)	3.3(14.7)	3.4(11.1)	3.4(12.0)	8.0(63.0)	1.2(1.3)	0.7(0.0)	4.0(16.0)	6.4(40.7)	6.2(43.9)
Intercropping	7.7(59.3)	3.8(20.0)	4.3(18.5)	4.5(20.7)	5.1(25.9)	3.3(14.0)	3.4(11.1)	3.7(13.3)	6.0(37.0)	10.6(112.6)
Crop rotation*	6.1(37.0)	4.0(16.7)	5.1(25.9)	4.5(19.3)	5.3(29.6)	2.1(8.0)	2.5(7.4)	2.7(9.3)	8.2(66.7)	8.5(73.0)
Intensive cropping	5.1(25.9)	4.0(16.7)	0.7(0.0)	2.3(6.0)	6.4(40.7)	4.2(17.3)	5.5(29.6)	2.8(9.3)	10.2(103.7)	8.8(77.9)
Herbicide check	7.5(55.6)	3.0(8.7)	5.1(25.9)	2.9(10.7)	4.7(29.6)	0.7(0.0)	1.6(3.7)	3.7(13.3)	6.0(37.0)	7.0(50.9)
LSD (p=0.05)	0.7	NS	1.7	NS	NS	2.2	1.4	NS	1.1	NS

*Maize-pea and soybean-sarson alternatively. Values in parentheses are means of original values; Data transformed to square root transformation $\sqrt{x+0.5}$

Maize

Effect on weeds: During 2018 *Kharif* season, weeds that dominated the field were *C. benghalensis* (20.5%), *G. parviflora* (17.4%), *Ageratum* sp. (*Ageratum conyzoides* L. and *Ageratum houstonianum Mill.*) (10.7%), *Cyperus* sp. (9.5%), *D. sanguinalis* (7.3%), *Paspalum scrobiculatum* L. (6.6%), *P. alatum* (5.4%), *Phyllanthus niruri* L. (4.7%), *P. dichotomiflorum* (4.5%), *Bidens pilosa* L. (3.7%) and *Aeschynomene indica* L. (2.7%). *Alternanthera philoxeroides* L. also invaded the field but with lesser dominance (0.3%) and might be a potential future threat. In *Kharif* 2019, thirteen weed species were found in association with maize. *Echinochloa colona* (L.) Link (24%) was the most dominant weed followed by *Cyperus* sp. (22%), *C. benghalensis* (17%), *P. alatum* (11%), *G. parviflora* (11%) and *D. sanguinalis* (5%). The other weeds, *Eleusine indica* (L.) Gaertn., *Euphorbia geniculate Ortega, Ipomoea* sp., *Panicum distichum Lam., Physalis minima* L., *A. indica* and *A. philoxeroides,* constituted 10% of the total weed flora. *C. benghalensis, D. sanguinalis, Cyperus* sp., *P. alatum, Panicum* sp. and *A. indica* invaded the field in both seasons. The changes in weed distribution might be due to changes in seed bank density and species composition which often occur when crop management practices and crop rotations are altered. The results are in line with the findings of Chopra and Angiras (2008), Chauhan *et al.* (2006).

Species-wise weed density (no./m²): Weeds data at their respective highest density are presented in **Table 3.** Weed management practices resulted in significant variations in the weed count of *P. alatum*, *D. sanguinalis* during the second year of study and in other weeds during the first year. Higher weed density was recorded during the second year in case of all the weed management practices. The distribution of weeds was random/sporadic rather than uniform and the count of rest of the weeds was not significantly affected inspite of large variations between the treatments. Chopra and Angiras (2008) reported that raised stale seed bed had significantly lowest weed density and biomass at 60 days after sowing and at harvest in maize crop. The density of *P. alatum* significantly varied among different weed control treatments during the second year. The density of this weed was maximum in RSSB + mulch followed by mulch, intensive cropping and hoeing treatments. In the beginning at juvenile stage, the species of *Cyperus* was unidentifiable and were taken together. However, at the reproductive stage, two species *Cyperus iria* L. and *C. esculentus* were observed. The count of *Cyperus* sp. (*C. iria* and *C. esculentus)* was in general higher at 60 DAS. Maximum count of *Cyperus* sp. was observed in

Table 3. Effect of treatments on species-wise weed density (no./m²) at maximum population stage of respective weed during *Kharif* season

Treatment	*Commelina benghalensis*		*Echinochloa colona*		*Polygonum alatum*		*Cyperus* sp.		*Digitaria sanguinalis*		Other weeds	
	2018 (30 DAS)	2019 (60 DAS)	2018 (60 DAS)	2019 (90 DAS)	2018 (60 DAS)	2019 (60 DAS)	2018 (60 DAS)	2019 (60 DAS)	2018 (60 DAS)	2019 (60 DAS)	2018 (At harvest)	2019 (60 DAS)
Hoeing	3.8 (18.5)	3.8 (18.7)	2.1 (7.4)	7.7 (66.7)	3.0 (11.1)	5.0 (24.7)	5.4 (29.6)	8.9 (125.3)	3.8 (18.5)	1.4 (2.7)	3.0 (11.1)	7.7 (87.3)
SSB + hoeing	7.4 (70.4)	7.5 (62.7)	2.1 (7.4)	3.5 (28.0)	2.7 (14.8)	0.7 0.0	6.2 (44.4)	0.7 (0.0)	4.4 (25.9)	0.7 (0.0)	2.5 (7.4)	4.2 (18.7)
RSSB + hoeing	6.3 (40.7)	5.6 (40.0)	2.1 (7.4)	4.8 (30.7)	2.4 (11.1)	1.6 (3.3)	0.7 (0.0)	5.8 (38.0)	3.9 (22.2)	3.8 (32.7)	0.7 (0.0)	7.0 (49.3)
Mulch	5.4 (29.6)	3.4 (14.7)	2.4 (11.1)	6.5 (81.3)	1.6 (3.7)	6.0 (38.0)	2.1 (7.4)	4.1 (24.7)	1.6 (3.7)	0.7 (0.0)	5.5 (29.6)	6.3 (42.0)
SSB + mulch	4.3 (25.9)	1.2 (1.3)	4.6 (29.6)	4.9 (33.3)	3.4 (14.8)	13.3 (6.0)	3.0 (11.1)	7.4 (57.3)	4.3 (18.5)	2.3 (6.0)	1.6 (3.7)	3.7 (13.3)
RSSB + mulch	6.6 (44.4)	5.1 (36.0)	2.4 (11.1)	9.0 (116.0)	0.7 (0.0)	9.2 (86.7)	3.4 (11.1)	9.1 (102.0)	3.8 (18.5)	2.5 (7.3)	0.7 (0.0)	2.8 (9.3)
Intercropping	3.4 (14.8)	5.7 (40.0)	2.7 (14.8)	3.1 (20.0)	2.1 (7.4)	4.8 (32.0)	3.8 (18.5)	9.5 (90.7)	1.6 (3.7)	2.1 (8.0)	4.3 (18.5)	3.6 (14.0)
Crop rotation*	3.4 (14.8)	6.7 (64.0)	2.7 (14.8)	5.1 (38.7)	2.4 (11.1)	2.7 (10.7)	4.1 (22.2)	1.8 (5.3)	2.4 (11.1)	8.8 (78.7)	4.7 (22.2)	5.3 (52.7)
Intensive cropping	4.3 (25.9)	7.2 (52.0)	4.1 (22.2)	4.5 (26.7)	4.1 (22.2)	5.6 (43.3)	2.1 (7.4)	11.3 (160.0)	1.6 (3.7)	0.7 (0.0)	0.7 (0.0)	3.8 (15.3)
Herbicide check	3.8 (18.5)	7.0 (61.3)	0.7 (0.0)	9.7 (94.7)	2.1 (7.4)	2.6 (13.3)	3.8 (18.5)	4.6 (50.7)	2.4 (11.1)	0.7 (0.0)	9.8 (96.3)	9.3 (86.7)
LSD (p=0.05)	NS	NS	NS	NS	NS	4.3	NS	NS	NS	3.7	1.8	NS

*Maize-garlic and soybean-peas alternatively; Data transformed to square root transformation $\sqrt{x+0.5}$, Values given in parentheses are the means of original values intensive cropping followed by hoeing, RSSB + mulch and intercropping. Least count of the species was seen in SSB + hoeing and crop rotation treatments. Density of this weed was initially low, then increased and later on showed a decline due to inter or intra-specific competition with broad-leaved weeds and maize crop for space, nutrients and light. Khan and Haq (2004) reported the similar trend in the population of this weed. The weed species such as *A. philoxeroides, E. indica, P. minima, A. indica, D. sanguinalis, E. helioscopia, Ipomea* sp. and *Panicum distichum* were present in lesser numbers, therefore, they were grouped under the category of other weeds.

Effect on yield attributes of garlic and peas in *Rabi*

The garlic plant population/m^2 was not significantly affected by weed control treatments (**Table 4**). Maximum number of bulbs/m^2 (45) was found under RSSB + hoeing being statistically at par with herbicide check, SSB + hoeing and hoeing. Maximum number of bulbs/m^2 under RSSB + hoeing was recorded which may be due to less competition by weeds. Minimum number of bulbs/m^2 was found in mulch. This may be due to the presence of higher number of weeds which competed with garlic for light, water, space and nutrients.

Maximum weight of bulb (g) was recorded in RSSB + hoeing which was statistically at par with herbicide check and SSB + hoeing. Thus, the treatments having lowest weed density were having better bulb weight due to less competition for growth factors among crop and weeds. In garlic, very close spacing and a shallow root system make mechanical method of weed control difficult and sometimes causes damage to developing bulbs (Lawande *et al.* 2009). Hence, the use of pendimethalin 2.5 kg/ha is recommended for getting higher garlic yield (Rahman *et al.* 2012). Therefore, garlic in herbicide check treatment showed significantly higher cloves per bulb and higher bulb weight compared to other treatments. Maximum number of cloves per bulb was recorded in RSSB + hoeing which was statistically at par with herbicide check, SSB + hoeing, hoeing and RSSB + mulch. Again, number of cloves/bulb was higher in the treatments having lowest crop weed competition. The highest garlic bulb yield in RSSB + hoeing was due to the low weed population and weed growth throughout the crop growth especially during earlier days which reduced crop-weed competition to greater extent and improved growth and development.

Yield attributes were adversely affected in plots where weed competition was high. This might be due to the shading effect caused by taller weeds like wild oat which reduced the availability of light for the photosynthesis. Akhter *et al.* (2009), Rana *et al.* (2004), Sajid *et al.* (2012) also reported decrease in yield attributes of field pea under the reduced photosynthetically active radiation. Plant population in general was significantly higher in treatments where hoeing was done (SSB + hoeing) and low in treatments (mulch) where mulching was done. However, hoeing alone and RSSB + hoeing was at par to herbicide check and intercropping treatments. This may have occurred because the mulch spread was quite thin to suppress weeds *i.e.* organic mulch (*Lantana camara* 5 t/ha), which allowed weed germination and enhanced weed growth by conserving soil moisture. Similar results were obtained by Mohler (1993). Highest number of pods were observed in herbicide check followed by RSSB + hoeing and SSB + hoeing. This was owed to effective weed control due to quick knockdown effect of the herbicide before the commencement of critical period of competition under the former treatment and elimination of one or two flushes before the sowing of the crop in the latter. Raised/stale seedbeds were as effective as that of herbicide check in improving the number of pods. In stale seedbeds, about 200/m^2

Table 4. Effect of weed control treatments on yield attributes of garlic and peas (*Rabi*)

Treatment	Effective plant population (no/m^2)		Cloves/bulb in a plant	Pods/ plant	Yield/plant (g)	
					Weight of onion bulbs	Peas pod yield/plant
	2017-18	2018-19	2017-18	2018-19	2017-18	2018-19
Hoeing	46.1	14.3	8.8	10.8	18.2	30.1
SSB + hoeing	47.8	15.3	8.9	12.5	21.8	34.9
RSSB + hoeing	47.8	14.8	9.4	13	22.8	36.3
Mulch	41.8	11.8	6.7	8.6	14.2	24.0
SSB + mulch	41.9	12.3	6.8	10.3	17.1	28.7
RSSB + mulch	47.2	12.3	8.5	12.5	19.0	34.9
Intercropping	45.5	13.3	7.7	10.9	17.8	30.4
Crop rotation*	-	-	-	-	-	-
Intensive cropping	44.1	12.8	7.0	10.6	17.2	29.6
Herbicide check	47.8	13.3	9.3	14.3	22.9	39.9
LSD (p=0.05)	NS	1.9	1.6	2.0	2.7	2.7

*Maize –pea and soybean- sarson alternatively weeds had germinated that were removed before crop sowing. The initial crop growth and development in stale seedbeds was, therefore, better due to absence of weed-crop competition. The superiority of RSSB in controlling weeds and increasing yield of pea has been reported by Tehria *et al.* (2015). SSB + hoeing followed by herbicide check and RSSB + hoeing showed higher pod weight per plot. This may be because of efficient weed management in these treatments due to lesser weed infestation and longer pods in these plots. The highest number of pods/plant were observed in herbicide check followed by RSSB + hoeing and SSB + hoeing. The pod yield was maximum with intensive cropping followed by herbicide check.

Effect on yield attributes of *Kharif* maize

All the yield attributes varied significantly during the second year (**Table 5**). The yield improved significantly in the second year. Maximum plant population/m^2 was recorded under RSSB + mulch at harvest during both the years. However, during 2018 RSSB + mulch was statistically at par with mulch, intercropping, intensive cropping and herbicide check whereas in the second year, mulch and intercropping didn't gave comparable yields. The higher plant population in this treatment could be attributed to improved weed control and comparatively more warming up of the seed bed and efficient drainage of the excess water. This improvement in crop growth and yield components was due to the consequence of lower crop weed competition, which shifted the balance in favour of crop in utilization of available resources (Saini *et al.* 2013, Sharma and Gautam 2010). Besides plant population, number of cobs/plant is the most important yield determination parameters. In the first year, number of cobs/plant in maize could not be significantly affected due to different weed management treatments. During the second year, weed control treatments resulted in significant variation in the number of cobs per plant. RSSB + hoeing and herbicide check each showed 1.9 cobs/plant. During 2018 hoeing was the next superior treatment. The rest of the treatments did not differ significantly in influencing average cob weight. Highest average cob weight was recorded with herbicide check followed by intercropping and RSSB + hoeing during 2019. This was because of efficient weed control in herbicide check and intercropping treatment which led to more uptake of nutrients by the crop and hence more cob weight.

Maize equivalent yield

The economic yields of crops (cob, greens, or pod) under different treatments were converted to their maize equivalents based on the prevailing market price of each product to facilitate the overall comparison among cultural weed management treatments (**Table 6**). During the first year, intercropping followed by intensive cropping gave the higher yields during *Rabi* season compared to other weed management treatments. It may be due to inclusion of more crops in the system. However during *Kharif* season in maize crop, higher yields were obtained in RSSB + mulch treatment followed by intensive cropping. Raised stale seedbed does not allows water to stagnate in the beds during heavy rains and thus might have resulted in higher yield. During the successive year intensive cropping where short duration crop of buckwheat greens was grown in the summer resulted in comparable maize equivalent yield as the herbicide check in the *Rabi* season. However, RSSB + hoeing, intercropping, RSSB + mulch and SSB + hoeing were equally good as the herbicide check. Similarly the additional crop of mustard greens after the harvest of maize in the autumn resulted in significantly higher maize equivalent yield under intensive cropping in the *Kharif* season. Herbicide check was the next superior treatment and RSSB + hoeing and intercropping were at par to it. Intensive cropping because of more yield from additional crops resulted in 10.4% higher overall system's maize cob equivalent yield than the herbicide check. RSSB + hoeing and intercropping resulted in comparable yields as herbicide check. The

Table 5. Effect of treatments on yield attributes of maize

Treatment	Effective plant population/m^2		Cobs/plant		Avg. wt./cob (g)	
	2018	2019	2018	2019	2018	2019
Hoeing	6.2	9.0	1.1	1.6	166.4	337.5
SSB + hoeing	6.2	8.5	1.0	1.3	163.2	314.4
RSSB + hoeing	6.7	10.4	1.2	1.9	178.3	410.7
Mulch	7.5	8.7	1.3	1.0	189.0	353.0
SSB + mulch	6.2	8.0	1.3	1.2	194.7	336.1
RSSB + mulch	7.7	9.0	1.4	1.2	203.4	337.5
Intercropping	7.3	8.0	1.0	1.1	153.4	430.6
Crop rotation*	-	-	-	-	-	-
Intensive cropping	7.0	9.7	1.2	1.3	179.5	388.2
Herbicide check	6.8	9.5	1.1	1.9	167.4	445.4
LSD (p=0.05)	0.7	1.4	NS	0.3	20.4	2.0

*Maize –pea and soybean- sarson alternatively

Table 6. Effect of treatments on Maize equivalent yield from 2017-19

Treatment	Maize equivalent yield (t/ha) 2017-18			Maize equivalent yield (t/ha) 2018-19		
	Rabi	*Kharif*	System's	*Rabi*	*Kharif*	System's
Hoeing	3.6	3.94	7.30	5.09	5.76	10.85
SSB + hoeing	3.12	2.55	5.67	12.27	5.78	18.05
RSSB + hoeing	4.26	3.96	8.22	13.55	9.21	22.75
Mulch	2.90	5.45	8.35	3.41	5.23	8.64
SSB + mulch	2.73	3.11	5.84	8.86	4.29	13.15
RSSB + mulch	3.96	6.94	10.90	12.48	6.51	18.99
Intercropping	5.04	4.92	9.96	12.75	9.33	22.08
Crop rotation	4.07	2.63	6.70	6.37	8.04	14.41
Intensive cropping	4.63	5.48	10.11	15.38	12.82	28.20
Herbicide check	4.25	4.25	8.51	15.23	10.32	25.55
LSD(p=0.05)	0.95	1.28	1.90	3.02	1.69	3.74

other treatments owing to lower crop yields were having low maize green cob equivalent yield as compared to the herbicide check. Hugar and Palled (2008) found that vegetable crops (cowpea, French-bean, coriander) intercropped with maize reduced the weed density and dry weight accumulation by weeds which resulted in higher maize equivalent yield at Dharwad, Karnataka.

Conclusion

In the organically managed production system, greater weeds floristic diversity was seen. Intensive cropping because of more yield from additional crops resulted in 10.4% higher overall system's maize cob equivalent yield than the herbicide check. RSSB + hoeing and intercropping resulted in comparable yields as herbicide check. The stale seedbed, hoeing and organic amendments application minimized the incidence and severity of weeds.

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RESEARCH ARTICLE

Performance and economical evaluation of two row self-propelled narrow crop rotary weeder for managing weeds in mustard crop

Gatkal Narayan Raosaheb, Vijaya Rani[2], Rahul pannu[2], Naresh[2] and Mukesh Jain[3]

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ABSTRACT

The conventional manual weed management is one of the labour intensive and expensive operation in crop production as it involves low efficiency, time consuming, human drudgery and higher cost of operation. The use of self-propelled rotary weeder for mechanical weeding reduces the drudgery and ensures a comfortable posture of operator or farmer during weeding operation. Hence, a self-propelled narrow crop rotary weeder was developed by department of Farm Machinery & Power Engineering, COAE&T, CCS HAU, Hisar during the winter *(Rabi)* season of 2016 and was evaluated for its performance in mustard crop having row to row spacing of 45 cm. Three forward speeds (1.6, 1.8 and 2 km/h), two blade lengths (180 and 195 mm) and three speeds of rotor (330, 360 and 390 rpm) were selected for its evaluation and results were compared with manual hand weeding using Kasola (tool smaller than spadi in size). The effective field capacity of 0.09 ha/h, field efficiency of 67.98%, weeding efficiency of 80.12% and plant damage of 2.9% were observed at the best combination of operational variables *i.e.* rotor speed of 360 rpm, blade length of 180 mm and forward speed of 1.6 km/h. The labour requirement with rotary weeder was reduced to 11.11 man-h/ha when compared to 160 man-h/ha for manual hand weeding. Thus, rotary weeder saved 93% of labour and 75.45% of cost of operation in comparison to manual hand weeding using Kasola in mustard crop.

Keywords: Economical weeding, Mechanical weeding, Mustard, Plant damage, Rotary weeder, Weed management, Weeding efficiency

INTRODUCTION

There are several constraints in agriculture like climate change, insects, pests *etc*. but, weeds are the major reason for declined yield per unit agricultural area in India (Rao and Chauhan 2015). Weeds reduced crop yield by about 65%, depending on the crop, the degree of weed infestation, the plant species, and management measures (Devojee *et al.* 2018). Weeds compete with associated crops for nutrients and other growth factors and if any effective control measure is not performed; they utilize 30 to 40% of soil applied nutrients causing significant crop yield loss (Goel *et al.* 2008) and reduced produce quality. Weed management in crops is one of the labour intensive and expensive operation in crop production. Total actual economic loss of about USD 11 billion was estimated due to weeds alone in 10 major crops of India (Gharde *et al.* 2018). Thus, timely management of weeds is essential to achieve increased agricultural production (Rao and Nagamani 2010). The most common methods for weed control are mechanical, chemical, biological and other methods such as field preparation, crop rotation, growing of intercrops, mulching, solarisation and maintaining optimum plant population (Borbale *et al.* 2021). Herbicide usage is becoming more popular among farmers but problems of environmental contamination, residual toxicity and herbicide resistance development amongst weeds, if not used properly, are major concerns of herbicide use. Manual weeding requires large labour force and accounts for nearly 25% of the total labour requirement (900–1200 man-h/ha) during a cultivation season (Nagesh *et al.* 2014). The problem of labour shortage and high labour charges for agricultural operations is increased with time. The introduction of new agricultural machinery has reduced drudgeries of manual operations with the passage of time and became more popular as a source of power among the farmers (Kunnathadi *et al.* 2016). Mechanical weeding is generally performed by tillage, cutting and pulling weeds. This method of

[1] Farm Machinery and Power Engineering, Dr. Annasaheb shinde College of Agricultural Engineering and Technology, MPKV, Rahuri, Maharashtra 713422, India

[2] Department of Farm Machinery and Power Engineering, College of Agricultural Engineering and Technology, CCS Haryana Agricultural University, Hisar, Haryana125004, India

[3] Northern Region Farm Machinery Training and Testing Institute Tractor Nagar, Ministry of Agriculture and Farmers Welfare, Department of Agriculture, Cooperation and Farmers Welfare, Hisar, Haryana 125001, India

* Corresponding author email: narayan96378@gmail.com

weed control is very effective as it manages the weeds and also keeps the soil surface loose ensuring soil aeration and increased water intake capacity. Mechanical weeding using improved hand tools or power operated machines appear to be most practical and efficient method.

Mustard [*Brassica juncea (*L.*)* Czern.] is one of the most important winter oilseeds crops in India and it accounts for nearly 20-22% of total oilseeds produced in the country (Samar *et al.* 2017). India is the third largest producer of rapeseed-mustard in the world after China and Canada with total world's production area of 19.29% and production of 11.12% (Anonymous 2014, Meena and Sharma 2019). In India, mustard seed is mainly grown in North West parts of India. Haryana, Rajasthan and Uttar Pradesh are the major mustard producing states in the country (Meena 2018). It is well known that weeds interfere with crop plants causing serious impacts either in the competition for water, light and nutrients. Weed competition in mustard is more serious in early stage because crop growth during winter (*Rabi*) season remains slow during first 4 to 6 weeks after sowing. However, during latter stage it grows vigorously and it has suppressing effect on weeds. Among the factors responsible for the low productivity of the mustard weeds are major constraints as they cause yield loss up to 76.3% (Kumar *et al*. 2012) in Indian mustard.

The use of power weeder is the need of the time because they reduce the cost of weeding, maintain timeliness, meet-up scarcity of agricultural labour, and environment friendly as compared to use of weedicide and also pulverize the soil (Kumar *et al.* 2014, 2018). Chemical weed management methods come with several drawbacks, including a negative impact on desired plant growth and the accumulation of chemical residues, which can harm consumers (Borbale *et al.* 2021). The farmer's interest on the use of mechanical weeders has increased due to disadvantages involved in manual and chemical weed control and growing demand for organically produced food. Non-chemical weed control ensures food safety. The precise inter- and intra-row weeders could contribute significantly to safe food production. Though there are various rotary power weeders available for wide row spacing crop 60 cm but, the problem exists with narrow spaced crops 30 cm and ideal row spacing was 45 cm (Shekhawat *et al.* 2012). Hence, a two row self-propelled rotary power weeder was developed for narrow spaced crops to tackle the existing issue of mechanical weed control in narrow spaced crops and to save the environment degradation. This study was conducted with an objective to evaluate the performance of rotary weeder and compare it with manual hand hoe *i.e. Kasola* in farmer's mustard crop field.

MATERIALS AND METHODS

The two rows self-propelled narrow crop rotary weeder was developed by department of Farm Machinery & Power Engineering, COAE&T, CCS HAU, Hisar. It consists of 5 hp diesel engine for transmitting power to rotary units and driving wheels of the weeder. The rotary units consisted of four flanges (two in each unit) and four J types blades having 180- and 195-mm length that are mounted on each flange. Ground clearance is a major factor that affects the plant damage by the weeder during field operation. Hence, keeping in view plant height of crop at the time of weeding the tyre size of 2.75-18 inches with V-shape lugs was selected for the weeder that maintains high ground clearance and provides good traction (**Figure 1**). The technical specification of two row self-propelled narrow crop rotary weeder is depicted in **Table 1**.

Table 1. Specification of two rows self-propelled rotary narrow crop rotary weeder

Particular	Detail
Fuel	Diesel
Engine hp	5
Starting system	Recoil
Cooling system	Air cooled
Type of clutch	Dog clutch
Overall dimensions of machine (L×W×H), mm	1900 × 950 × 1070
Size of tyre, inch	2.75-18
Width of cut each rotary unit, cm	22
Rotary unit wt, kg	52
Overall weight of weeder, kg	178

The performance of two row self-propelled narrow crop rotary weeder and manual hand hoe *i.e.* Kasola were evaluated on farmer's mustard crop field at village Neoli district Hisar, Haryana. The weeding operation was carried out after 40 days of sowing mustard crops at a depth of 5 to 5.5 cm. The weeding operation was carried out at 30,45 and 60 days after sowing (DAS) at different speeds of weeder in sugarcane crop (Mohan et al. 2020). The weeding operation was carried out at 3 to 5 cm (Devojee *et al.* 2019) and 4 to 5 cm (Guru *et al.* 2018) depth of operation. Three factorial randomized block design of experiment was used with two length of blades 180 and 195 mm, three speeds of rotor 330, 360 and 390 rpm and three forward speeds of 1.6, 1.8 and 2 km/h. The performance of a manual-operated single-row

Figure 1. Two rows self-propelled narrow crop rotary weeder

Figure 2. The two rows self-propelled narrow crop rotary weeder during field operation weeding efficiency

weeder used for groundnut crop with a blade length of 200 mm was evaluated. Experiments were conducted in clay soil using prototype rotary blades and a C-shaped blade at rotational speeds of 150, 218, 278 and 348 rpm (Niyamapa and Chertkiattipol 2010). Three replications were maintained for each of the treatment. The weeding efficiency, field efficiency, plant damage and cost of operation were the performance parameters measured for this comparative study. In order to see the significance of variables on dependent parameters the data was analyzed with the help of analysis of variance technique programme given by O.P. Sheoran (www.hau.ac.in) and SPSS version 19.0. Critical differences were also analyzed at 5% level of significance. The results of the performance of weeder on best combination of variables were compared with performance of manual hand hoe *i.e. Kasola*. The field performance parameters studied include:

Weeding efficiency, (%)

Weeding efficiency of weeder was calculated by using equation given below (Goel 2009):

$$\text{Weeding efficiency, (\%)} = \frac{W_1 - W_2}{W_1} \times 100$$

Where,

W_1 = Weed density (no./m^2) before operation

W_2 = Weed density (no./m^2) after operation.

Field efficiency (E_f), (%)

It is the ratio of actual field capacity to theoretical field capacity, usually expressed in percentage. It was calculated as follows,

$$\text{Field efficiency } (E_f), \% = \frac{AFC}{TFC} \times 100$$

Where,

E_f = Field efficiency, %

TFC = Theoretical field capacity, ha/h

AFC = Actual field capacity, ha/h

Crop plant damage, (%)

The percentage of crop plant damage was calculated by counting the number of damaged crop plants after weeding in sample plot and the total number of plants in sample plot before weeding. The following expression was used for calculation (Yadav and Pund 2007):

$$\text{Plant damage, (\%)} = \{1 - \frac{q}{p}\} \times 100$$

Where,

q = Number of crop plants damaged in 25 m row length after weeding, and

p = Total number of crop plants in 25 m row length before weeding.

Economics

Cost of operation, labour requirement and payback period were the economic parameters considered for this study. Cost of operation in rupees per hectare was calculated by considering depreciation, interest, insurance, housing, tax, repair and maintenance, fuel cost and operator wages for the power weeder where as for the manual hand hoe *i.e.* Kasola only the operator wages were taken into consideration. The initial price (total cost of manufacturing) of two rows self-propelled narrow crop rotary weeder was ₹ 63700 and annual use was considered as 500 hours per year for calculation of other economic parameters. The initial price (total manufacturing cost) of developed weeder was ₹ 150000 (Mohan *et al.* 2020).

RESULTS AND DISCUSION

The experiments were conducted for weeding in mustard crop after one month of crop sowing during the *rabi* season of year 2016. The area of experimental plot was one acre with average moisture content of 12.07% (wb) at the time of weeding. Three levels of soil moisture content 7.73, 12.28 and 16.18% was taken at the time of weeding operation in maize crop (Hegazy *et al.* 2014), The type of soil was sandy loam with bulk density of 1.59 g/cm^3. The soil resistance of sandy loam soil was 0.3 kg/cm^2 (Basavaraj *et al.* 2016). The average height of crop at the time of weeding was 22.8 cm and average weed density (number of weeds per square meter) was 97.6. A view of narrow crop rotary power weeder during field operation is shown in **Figure 2**.

The statistical analysis of data on the influence of study variables on weeding efficiency indicated that the weeding efficiency was highly influenced by the blade length, rotor speed and forward speed at 5% level of significance with CD value 0.62, 0.759 and 0.759, respectively. The ANOVA of weeding efficiency is given in **Table 2**. The interactions of the variables were non-significant except for blade length and rotor speed of rotary unit with CD value 1.073.

The blade length, rotor speed and forward speed had significant effect on weeding efficiency of the rotary weeder (**Figure 3**). The maximum weeding efficiency 80.12% was found at rotor speed 360 rpm, forward speed 1.6 km/h and blade length 180 mm. As the blade length decreased from 195 mm to 180 mm, the weeding efficiency increased from 78.34% to 80.12%, because higher blade length of 195 mm got stuck in ground during operation and weeder goes out of row and weeds were intact in these places. The blade length of 195 mm goes deeper in the soil as compared to blade length of 180 mm and creates problem in balancing the two row self-propelled narrow crop rotary weeder. The increased forward speed from 1.6 to 2 km/h, the weeding efficiency decreased due to the difficulty to balance the weeder in between the rows of crop at high forward speed. The increased rotor speed from 360 rpm to 390 rpm creates negative draft and increases the forward speed of weeder that reduces the weeding efficiency as mentioned above. At 390 rpm two row self-propelled narrow crop rotary weeder creates negative draft and also more weeding efficiency, less plant damage found at rotor speed of 360 rpm. Hence, based on the observations made, the rotor speed of 360 rpm, forward speed of 1.6 km/h, blade length of 180 mm and depth of operation was 5 to 5.5 cm was selected for maximum weeding efficiency. The weeding efficiency of power weeder in sugarcane crop is in the range of 98.74 to 91.22, 96.80 to 84.93 and 94.67 to 73.72 at 0.584, 1.35 and 4.153 km/h, respectively (Mohan *et al.* 2020).

Field efficiency

The field efficiency was influenced by the blade length, rotor speed and forward speed at 5 per cent level of significance with CD value 0.112, 0.137 and 0.137, respectively (**Table 3**). The interactions of variables were also significant.

The blade length, rotary speed and forward speed had significant effect on field efficiency

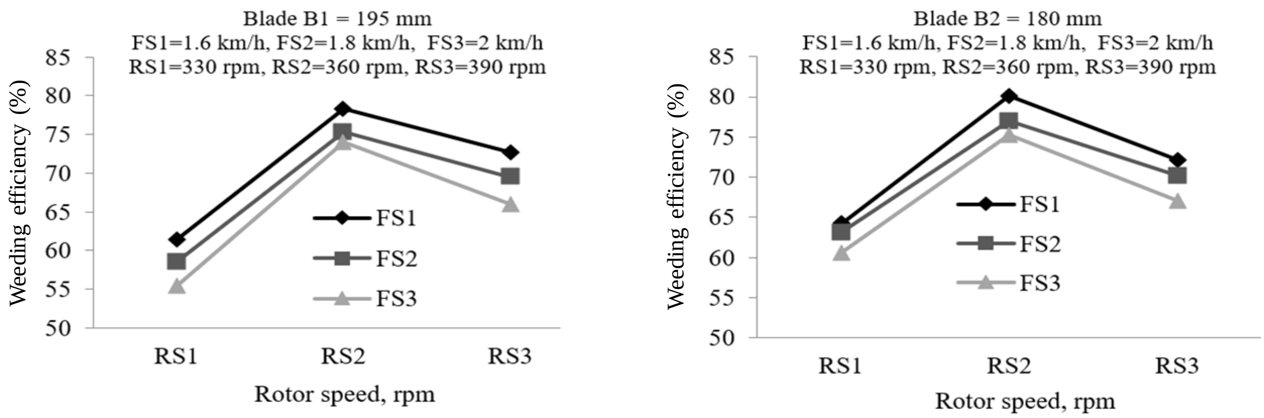

Figure 3. Influence of blade length, rotary speed and forward speed on weeding efficiency of two rows self-propelled narrow crop rotary weeder

Table 2. Effect of study variables on weeding efficiency of two rows self-propelled narrow crop rotary weeder (ANOVA)

Source of variation	DF	Sum of squares	Mean squares	F-calculated	Significance
Replication	2	0.531			
Blade length	1	55.446	55.446	44.196	0.00000
Rotor speed	2	2344.930	1172.465	934.563	0.00000
Blade length x rotor speed	2	33.055	16.528	13.174	0.00006
Forward speed	2	235.147	117.573	93.713	0.00000
Blade length x forward speed	2	3.388	1.694	1.350	0.27273
Rotor speed x forward speed	4	6.505	1.626	1.296	0.29102
Blade length x rotor speed x forward speed	4	3.465	0.866	0.6910	0.60359
Error	34	42.655	1.250		
Total	53	2725.122			

(**Figure 3**). As the rotor speed increased from 330 rpm to 390 rpm the field efficiency increased from 66.69 % to 69.29% as the rotary unit creates negative draft and give a pushing action to rotary weeder. The generated negative draft also reduces the wheel slippage and increases the field efficiency because, generated negative draft gives pushing action to two row self-propelled narrow crop rotary weeder. As weeding efficiency is more important parameter for weeding operation and highest weeding efficiency was obtained at rotor speed of 360 rpm and it was selected for weeding operation. As the blade length decreased from 195 mm to 180 mm, the field efficiency increased from 67.93% to 68.10% as blade length of 195 mm goes deep and gets stuck in ground causing time wastage at those places. The increase in forward speed from1.6 to 2.0 km/h the field efficiency increased from 67.79% to 68.30%, but it was difficult to operate the rotary weeder at high speed in between the crop rows and hence the operating speed of 1.6 km/h was considered optimum for machine field operation.

Crop plant damage

The plant damage was influenced by the blade length, rotor speed and forward speed at 5% level of significance with CD value 1.313, 1.608 and 1.608, respectively (**Table 4**). The crop plant damage varied from 1.19% to 12.93% and 1.20% to 9.96% for blade length of 195 mm and 180 mm respectively. As the blade length decreased from 195 mm to 180 mm, the marginal mean of crop plant damage decreased from 6.13% to 4.13% as control of weeder is difficult for operator with blade length of 195 mm resulting in blade going out of row into the crop which results in crop plant damage. Srinivas *et al*. (2010) reported plant damage for blade length 150 mm (C type blade) and 160 mm (L type blade) was 3.4% and 5.1%, respectively. The crop plant damage of ridge profile power weeder was 2.66% for ridge planted crops (Thorat *et al*. 2014).

As the rotor speed increased from 330 rpm to 390 rpm the marginal mean of plant damage increased from 2.27 % to 8.59% as at high rotary speed rotary weeder creates negative draft and creates problem of weeder control. Similarly, as the forward speed increased from 1.6 to 2.0 km/h the marginal mean of plant damage increased from 3.61% to 4.89% (**Figure 4**). The minimum plant damage (2.90%) occurred at optimized machine variables.

On the basis of field performance of weeder at different levels of study variables, *viz*. blade length, rotor speed and forward speed the maximum weeding efficiency, field efficiency and minimum plant damage were observed at blade length of 180 mm, rotor speed of 360 rpm and forward speed of 1.6 km/h. Hence, weeder performance was evaluated at these levels of study variables and compared with manual hand hoe *i.e*. Kasola. (**Table 5**).

Economical analysis

The estimated economical parameters for the two rows self-propelled rotary narrow crop rotary

Table 3. Effect of study variables on field efficiency of two rows self-propelled narrow crop rotary weeder (ANOVA)

Source of variation	DF	Sum of squares	Mean squares	F-calculated	Significance	LSD (p=0.05)
Replication	2	0.178				
Blade length	1	1.338	1.338	32.802	0.00000	0.112
Rotor speed	2	59.257	29.628	726.407	0.00000	0.137
Blade length x rotor speed	2	0.790	0.395	9.683	0.00047	0.194
Forward speed	2	1.449	0.725	17.764	0.00001	0.137
Blade length x forward speed	2	0.769	0.384	9.425	0.00055	0.194
Rotor speed x forward speed	4	1.205	0.301	7.389	0.00021	0.237
Blade length x rotor speed x forward speed	4	1.637	0.409	10.032	0.00002	0.335
Error	34	1.387	0.041			
Total	53	68.009				

Table 4. Effect of study variables on crop plant damage during the operation of two rows self-propelled narrow crop rotary weeder (ANOVA)

Source of variation	DF	Sum of squares	Mean squares	F-Calculated	Significance
Replication	2	4.049			
Blade length	1	147.246	147.246	6.156	0.00001
Rotor speed	2	504.259	25.129	44.787	0.00000
Blade length x rotor speed	2	14.435	7.217	1.282	0.29054
Forward speed	2	97.786	48.893	8.685	0.00090
Blade length x forward speed	2	0.319	0.159	0.028	0.97212
Rotor speed x forward speed	4	26.120	6.530	1.160	0.54564
Blade length x rotor speed x forward speed	4	7.502	1.875	0.333	0.85371
Error	34	191.404	5.630		
Total	53	993.118			

weeder and manual hand hoe *i.e.* Kasola (**Table 6**), revealed that labour requirement for weeding operation in mustard crop by manual hand hoe was 160 man-h/ha whereas it was only 11.11 man-h/ha with narrow crop rotary power weeder. Speed of operation, field capacity, width of cut, field efficiency, depth of operation, weeding efficiency, and plant damage was 1.6 km/h, 0.09 ha/h, 900 mm, 67.98%, 50 to 55 mm, 80.12% and 2.9% for and two row self -propelled narrow crop rotary weeder and for manual hand hoe (*Kasola)* was 1.0 km/h, 0.05 ha/h, 250 mm, 74.43%, 40 mm, 94.6% and 2.4%, respectively. The speed of operation, width of cut,

Table 5. Comparative performance of two rows self-propelled narrow crop rotary weeder (narrow crop weeder) and manual hand hoe *i.e. Kasola*

Particular	Two row self - propelled narrow crop rotary weeder	Manual hand Hoe (Kasola)
Speed of operation, km/h	1.6	1
Field capacity, ha/h	0.09	0.05
Width of cut, mm	900 (Two row)	250 (Single row)
Field efficiency, %	67.98	74.43
Depth of operation, mm	50 – 55	40
Weeding efficiency, %	80.12	94.6
Plant damage, %	2.9	2.4
Fuel consumption, l/h	1.6	-

depth of operation, field capacity and weeding efficiency was 1.2 km/h, 450 mm, 30 mm, 0.048 ha/h and 92.5%, respectively of developed power weeder in groundnut crops. The crop plant damage was 2.5% with hand operated hoe (Singh 2017). The developed weeder was higher field efficiency 74.43 as compared to cono-weeder 72.89% (Shakya et al. 2016). Thus, the narrow crop rotary power weeder saves 93% labour over manual method of weeding using Kasola. The cost of operation for manual and rotary power weeder was found ₹ 7060 per ha and ₹ 1733/ha, respectively. The rotary weeder saves ₹ 5327/hectare as compared to manual method. The payback period for developed rotary weeder was found to be 1.45 years when annual working hours are assumed as 500 (**Table 6**).

Conclusion

The best performance of the two row narrow crop rotary weeder was observed with blade length of 180 mm, rotor speed of 360 rpm and forward speed of 1.6 km/h. At the best combination of study variables, the weeder gave effective field capacity of 0.09 ha/h, field efficiency of 67.98%, weeding efficiency of 80.12% and plant damage of 2.9%. The rotary weeder saves 75.45% of cost and 93% of labour as compared to manual method of weeding in mustard crop. In order to avoid the drudgery, labour and greater cost of

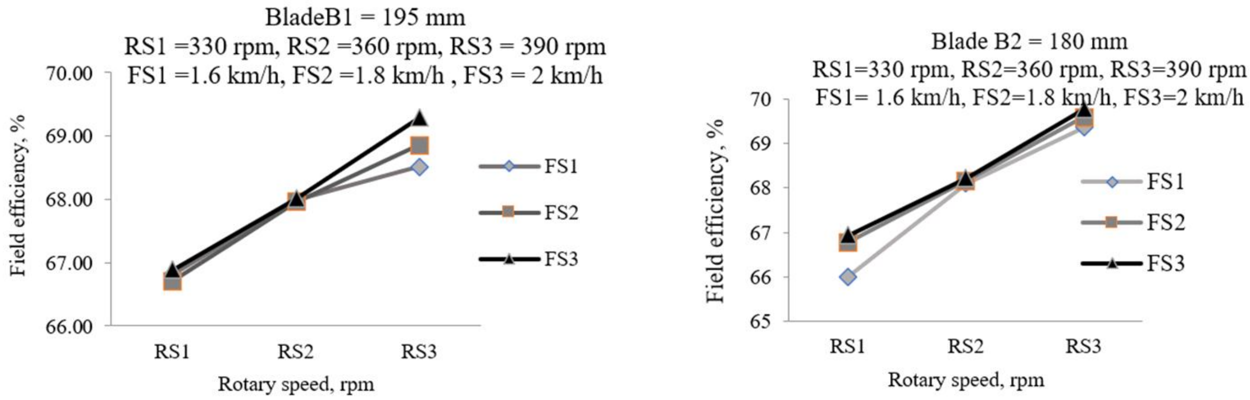

Figure 4. Influence of blade length, rotary speed and forward speed on field efficiency of two rows self-propelled narrow crop rotary weeder

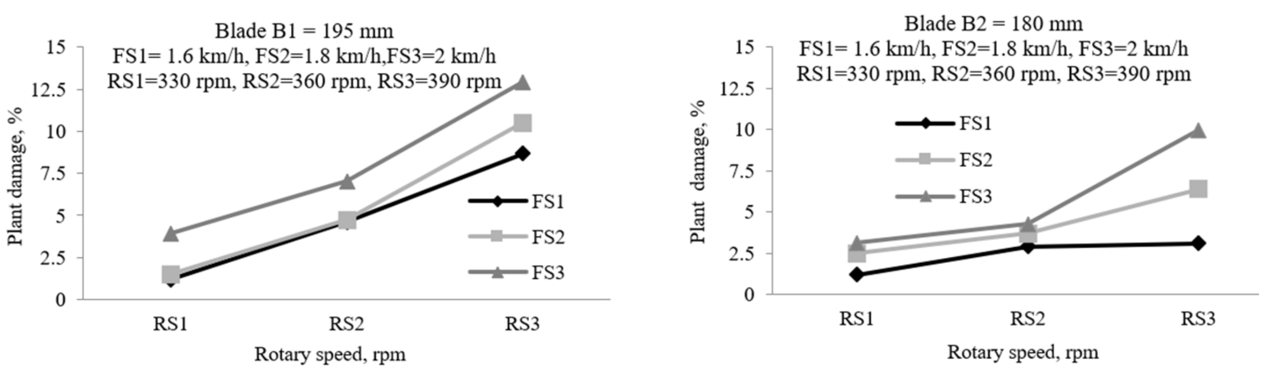

Figure 5. Influence of blade length, rotor speed and forward speed on crop plant damage during the operation of two rows self-propelled narrow crop rotary weeder

Table 6. Comparative economics of the usage of two rows self-propelled narrow crop rotary weeder (narrow crop weeder) weeder and manual hand hoe *i.e.* Kasola

Particular	Rotary power weeder	Manual hand hoe (*Kasola*)
Cost of operation, `/h	156	44.125
Cost of operation, `/ha	1733	7060
Saving in cost of operation over manual, `/ha	5327	-
Saving in cost of operation over manual, %	75.45	-
Payback period, yr	1.45	-
Break Even Point, h/yr	112.44	-
Labour requirement man-h/ha	11.11	160.0
Saving in labour requirement, %	93	-

operation involved in manual weeding, the narrow crop rotary power weeder could be advantageously used for weed management in mustard crop.

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RESEARCH ARTICLE

Efficacy of sequential application of pre- and post-emergence herbicides for weed management in sesame

Neeshu Joshi[1*], Shourabh Joshi[2], J.K. Sharma[1], H.S. Shekhawat[1] and Uma Nath Shukla[3]

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ABSTRACT

A field experiment was conducted during rainy (*Kharif*) seasons of 2019 and 2020 to assess the efficacy of the sequential application of pre- and post-emergence herbicides for managing complex weed flora in line sown sesame (*Sesamum indicum* L.) at Agriculture Research Sub-Station, Sumerpur, Pali. There were nine weed control treatments replicated thrice in a randomized complete block design. Hand weeding twice recorded the highest values of growth parameters and seed yield (1.25 t/ha) which was at par with pre-emergence application (PE) of pendimethalin 750 g/ha followed by (*fb*) quizalofop-p-ethyl 40 g/ha at 20 days after seeding (DAS). The uncontrolled weeds in weedy check caused 50% sesame seed yield reduction. The post-emergence application (PoE) of quizalofop-p-ethyl 40 g/ha at 20 DAS and sequential application of pre-emergence application (PE) of pendimethalin 750 g/ha PE followed by (*fb*) quizalofop-p-ethyl 40 g/ha at 20 DAS recorded the highest weed control efficiency, sesame seed yield, net return and benefit cost ratio and were observed to be superior than the recommended practice of pendimethalin 1000 g/ha PE *fb* hand weeding at 25 DAS.

Keywords: Fenoxaprop-p-ethyl, Quizalofop-p-methyl, Pendimethalin, Sesame, Weed management

INTRODUCTION

Sesame (*Sesamum indicum* L.) is one of the important oilseed crop of India. Globally, India is the largest producer, consumer, and exporter of sesame. India ranks first in the world with respect to area under sesame cultivation with an area of 16.22 lakh hectares, production of 6.57 MT and productivity of 405 kg/ha during 2019-2020. In Rajasthan, sesame was cultivated in 2.70 lakh hectares with a production of 0.78 lakh tonnes and productivity of 289 kg/ha during 2019-20 (Anonymous 2020). Among the several constraints in sesame production, heavy weed infestation is one of the major factors limiting the yield of sesame. Being a slow growing crop during seedling phase, weeds affect the growth of sesame and reduced the yield. The loss of seed yield due to uncontrolled weed growth in sesame has been reported as high as 50 to 70% in sandy loam soils (Dungarwal *et al*. 2003, 2006). Though manual weeding is effective and eco-friendly yet they are tedious, time consuming and costly due to non-availability of labour in time. Thus, herbicides use is preferred as it is effective, quick in action, selective in nature, cost effective and efficient to control weeds during the critical period (Rao and Nagamani 2010), even though the indiscriminate use of chemicals often leads to environmental pollution (Omezzine *et al.* 2011), and development of resistance by weeds against herbicides. Due to involvement of high cost and scarcity of labour for manual weeding, for effective and economic weed control during the critical period, there is a need of evaluation of pre-emergence (PE) and post-emergence (PoE) herbicides in sesame. Hence, an experiment was conducted to evaluate the effect of sequential application of pre- and post-emergence herbicides on weeds, growth, and grain yield of sesame.

MATERIALS AND METHODS

Field studies were conducted during rainy (*Kharif*) season of 2019 and 2020 at Agriculture Research Sub-Station, Sumerpur, Pali, Rajasthan. The soil of experimental field was sandy silty clay loam with P^{H} 7.98, available nitrogen 143.5 kg/ha, available phosphorus 44.2 kg/ha and available potassium 256 kg/ha with low organic carbon content (0.22%). There were nine treatments (**Table 1**). The experiment was laid out in randomized block design

[1] Agriculture Research Sub-Station, Sumerpur, Pali, Rajasthan 306902, India
[2] College of Agriculture, Nagaur, Rajasthan 341001, India
[3] College of Agriculture, Mandor, Jodhpur, Rajasthan 342007, India
* Corresponding author email: neeshu.joshi@gmail.com

with three replications. Sesame variety "*RT-351*" was sown on 08/07/2018 during 2018 and 11/07/2019 during 2019 in row 45 cm apart, using 2.5 kg/ha seed rate with plot size 5m x 4.5 m. Crop was fertilized with 40 kg/ha nitrogen and 25 kg/ha phosphorus and 20 kg/ha potash as basal dose. NPK contents were applied through urea and NPK mixture (12:32:16), respectively. The half dose of nitrogen along with entire dose of phosphorus and potassium were applied as basal at the time of sowing and the remaining half of the dose of nitrogen was top dressed at 30 DAS. For good yield of crop, 250 kg/ha gypsum was also applied at the time of sowing. The crop was irrigated whenever needed. The pre-emergence application (PE) of pendimethalin was done at 2^{nd} day after sowing (DAS) along with irrigation and post-emergence application (PoE) of imazethapyr, quizalofop-p-ethyl, fenoxaprop-p-ethyl herbicides was done at 20 DAS while tembotrione was applied at 10 DAS as early post-emergence application (EPoE). A knap sack sprayer fitted with flat fan nozzle and 500 l/ha of water was used for herbicides spray. Weed density and weed dry weight (biomass) were recorded at 45 and 60 DAS, with the help of 0.5 x 0.5 m quadrat by randomly placing at three places in each plot. Weeds were removed and counted species wise. After drying in hot air oven (60 ± 1^0 C for 24 hours), weed biomass was recorded and reported as per square meter. Weed density and biomass data was subjected to square root "(x + 0.5) transformation before statistical analysis. Weed control efficiency was also calculated as suggested by Maity and Mukherjee (2011). The economics was calculated based on prevailing market rates of agriculture produced and cost of cultivation treatment wise.

RESULTS AND DISCUSSION

Effect on weeds

The major weed flora observed in experimental field was *Cyperus rotundus*, *Cynodon dactylon*, *Amaranthus viridis*, *Dactyloctenium aegyptium*, *Digitaria sanguinalis*, *Phyllanthus niruri*, *Commelina benghalensis* and *Digera arvensis.* All the weed control treatments proved significantly effective in reducing the weed density and biomass as compared to weedy check. Hand weeding twice at 20 and 40 DAS significantly reduced weed density at 45 and 60 DAS compared to rest of the treatments and was found at par with pendimethalin PE followed by (*fb*) quizalofop-ethyl PoE. Weed biomass at 45 DAS was significantly lower with this treatment and 60 DAS it was *on par* with other treatments. Yadav (2004) also reported lowest weed biomass and highest weed control efficiency with pendimethalin 0.5 kg/ha PE *fb* 1 HW at 40 DAS. Among the sequential application of herbicides, the lowest density and biomass of grasses was recorded with pendimethalin 0.75 kg/ha PE *fb* quizalofop-p-ethyl 40 g/ha PoE 20 DAS, which was *on par* with other weed control treatments. However, hand weeding twice at 20 and 40 DAS has recorded significantly lower grassy weed density and biomass than rest of the treatments (**Table 1**). Pendimethalin controlled most of the annual grasses and broad-leaved weed seeds and the later emerged grassy weeds were effectively controlled by quizalofop-p-ethyl or fenoxaprop-p-ethyl conforming the findings of Sivasankar and Subramanyam (2011). The lowest density and biomass of sedges was recorded with fenoxaprop-p-ethyl 70 g/ha PoE and pendimethalin 750 g/ha PE *fb* fenoxaprop-p-ethyl 70 g/ha PoE 20 DAS. Both the treatments were at par with each other. This might be due to effective control of annual sedges by the fenoxaprop-p-ethyl 70 g/ha PoE, which was more effective in suppressing the weed growth compared to pendimethalin 750 g/ha PE. The broad-leaved weeds were effectively controlled by imazethapyr 60g/ha 20 DAS and tembotrione 100 g/ha EPoE at 10 DAS but also caused the crop plants mortality and hence could not be used. Therefore, quizalofop-p-ethyl 40 g/ha and fenoxaprop-p-ethyl 70 g/ha PoE 20 DAS could be used to control annual and perennial grassy weeds. *Argemone Mexicana* was not effectively controlled by pendimethalin 750 g/ha in comparison to rest of the herbicides tested. The lowest total weed biomass with higher weed control efficiency was recorded with hand weeding twice at 20 and 40 DAS due to complete effective removal of all the categories of weeds including *Cyperus iria* which accounted for 25% of the total weed density in the experimental field. The next best treatment that recorded lower weed biomass and higher weed control efficiency was pendimethalin 750 g/ha PE *fb* quizalofop-p-ethyl 40 g/ha PoE at 20 DAS. These results conformed the findings of Vafaei *et al.* (2013) in sesame. Pendimethalin 750 g/ha PE or in combination with post-emergence herbicides quizalofop-p-ethyl 40 g/ha or fenoxaprop-p-ethyl 70 g/ha at 20 DAS was more effective like sole application of quizalofop-p-ethyl PoE or fenoxaprop-p-ethyl PoE in sesame.

Effect on crop

The yield components and seed yield of sesame were significantly influenced by the sequential application of pre- and post-emergence herbicides

(**Table 2**). The highest number of leaves/plant, number of capsules/plant, number of seeds/capsule, test weight and seed yield of sesame were recorded with pendimethalin 750 g/ha PE *fb* quizalofop-p-ethyl 40 g/ha PoE at 20 DAS and it was closely followed by hand weeding twice at 20 and 40 DAS which recorded an yield increase of 93.63% and 85.52%, respectively compared to control. This might be due to decreased competition for growth resources by weeds resulting in better photosynthesis and resultant partitioning in crop manifested to increase all the yield components. These results are in conformity with those of Sootrakar *et al.* (1995). The highest net returns were obtained with pendimethalin 750 g/ha PE *fb* quizalofop-p-ethyl 40 g/ha PoE at 20 DAS and the highest benefit cost ratio was obtained with quizalofop-p-ethyl 40 g/ha PoE at 20DAS. Both these treatments recorded higher net returns and benefit cost ratio than hand weeding twice due to reduced cost of cultivation and increased seed yield. Lowest yield components, seed yield and net returns were recorded with fenoxaprop-p-ethyl 70 g/ha at 20 DAS, among herbicide-based treatments, due to poor weed control. Imazethapyr 60 g/ha PoE at 20 DAS and tembotrione 100 g/ha PoE at 20 DAS caused phytotoxicity rating of 10.0 (in 0-10 scale where, ‘0’ indicates no injury and normal growth and ‘10’ indicates complete destruction of sesame crop plants Nehra and Jagannath (2011) also reported the phytotoxicity effect of imazethapyr on germination and early seedling growth of sunflower and maize.

Table 1. Effect of different treatments on density and biomass of grasses, sedges and broad-leaved weeds (BLW) and weed control efficiency (WCE) in Sesame (pooled data of two years)

Treatment	Weed density (no./m^2)				Weed biomass (g/m^2)				WCE (%)
	Grasses	Sedges	BLW	Total	Grasses	Sedges	BLW	Total	
Head weeding (HW) at 20 and 40 days after sowing (DAS)	6.13 (2.65)	18.80 (4.44)	19.27 (4.50)	44.20 (6.72)	5.39 (2.51)	6.70 (2.77)	14.66 (3.95)	26.78 (5.25)	45.52 (6.81)
Imazethapyr 60 g/ha PoE at 18-20 DAS	3.63 (2.15)	3.24 (2.05)	8.15 (3.02)	15.01 (3.99)	2.74 (1.92)	1.38 (1.54)	6.85 (2.80)	19.96 (3.45)	81.63 (9.01)
Quizalofop 10.8 240 g/ha PoE at 20 DAS	6.03 (2.64)	5.56 (2.56)	21.27 (4.71)	32.86 (5.81)	5.13 (2.46)	2.11 (1.76)	16.76 (4.21)	23.99 (4.99)	59.74 (7.79)
Fenoxaprop-p-ethyl 70 g/ha PoE at 20 DAS	11.67 (3.56)	0.15 (1.07)	25.09 (5.10)	36.91 (6.15)	9.96 (3.31)	0.05 (1.02)	19.19 (4.49)	29.20 (5.50)	54.63 (7.45)
Pendimethalin 0.75 kg/ha PE *fb* HW at 25 DAS	6.24 (2.70)	2.67 (1.91)	39.99 (6.40)	48.89 (7.06)	5.06 (2.46)	1.02 (1.42)	32.66 (5.81)	38.74 (6.30)	39.86 (6.38)
Pendimethalin 0.75 kg /ha (PE) *fb* quizalofop-p-methyl 40 g/ha at 20 DAS	2.43 (1.84)	1.76 (1.65)	30.32 (5.60)	34.51 (5.95)	1.78 (1.66)	0.86 (1.36)	24.94 (5.07)	27.58 (5.34)	57.69 (7.65)
Pendimethalin 0.75 kg /ha (PE) *fb* fenoxaprop-p-ethyl 70 g/ha at 20 DAS	3.75 (2.18)	0.41 (1.18)	38.09 (6.25)	42.25 (6.57)	2.88 (1.96)	0.14 (1.06)	33.15 (5.83)	35.97 (6.08)	47.99 (6.98)
Tembotrione 100 g/ha EPoE at 10 DAS	6.45 (2.73)	17.12 (4.25)	11.27 (3.50)	34.85 (5.98)	5.37 (2.52)	6.22 (2.68)	8.21 (3.03)	19.87 (4.56)	57.35 (7.63)
Control	13.20 (3.76)	25.89 (5.20)	42.39 (6.60)	81.59 (9.08)	11.69 (3.55)	8.48 (3.01)	35.18 (6.00)	55.35 (7.50)	0.00 (1.00)
LSD (p=0.05)	0.36	0.35	0.64	0.49	0.40	0.17	0.60	0.57	0.54

*Figures in parenthesis are the square root transformed (“x+0.5) values; PE = pre-emergence application; PoE = post-emergence application, EPoE = early post-emergence application, *fb* = followed by

Table 2. Effect of different treatments on growth, yield attributing characters of sesame (pooled data of two years)

Treatment	Height at 60 DAS (cm)	Height at harvest (cm)	No. of leaves/ plant	No. of capsules/ plant	No. of grains/ capsule
Head weeding (HW) at 20 and 40 days after sowing (DAS)	124.0	155.1	68.1	35.9	36.7
Imazethapyr 60 g/ha PoE at 18-20 DAS	0 .00	0 .0	0 .0	0 .0	0 .0
Quizalofop 10.8 240 g/ha PoE at 20 DAS	121.2	149.1	58.9	32.5	33.2
Fenoxaprop-p-ethyl 70 g/ha PoE at 20 DAS	117.8	141.2	53.7	26.3	31.3
Pendimethalin 0.75 kg/ha (PE) *fb* HW at 25 DAS	121.1	148.7	54.4	29.2	32.7
Pendimethalin 0.75 kg /ha (PE) *fb* quizalofop-p-methyl 40 g/ha at 20 DAS	127.1	158.2	69.9	36.4	41.3
Pendimethalin 0.75 kg /ha (PE) *fb* fenoxaprop-p-ethyl 70 g/ha at 20 DAS	121.9	152.4	65.9	33.9	35.4
Tembotrione 100 g/ha EPoE at 10 DAS	0	0	0	0	0
Control	113.9	134.1	44.8	24.7	29.7
LSD (p=0.05)	12.5	15.4	11.7	6.7	5.5

Table 3. Effect of different treatments on yield and economics of Sesame

Treatment	Grain yield (t/ha)			Cost of cultivation (x10^3 `/ha)			Gross returns (x10^3 `/ha)			Net returns (x10^3 `/ha)			B:C ratio		
	2019	2020	Pooled	2019	2020	Pooled	2019	2020	Pooled	2019	2020	Pooled	2019	2020	Pooled
Hand weeding (HW) at 20 and 40 days after sowing	1.25	1.24	1.25	21.05	21.05	21.05	81.45	84.86	83.16	60.40	63.81	62.11	2.87	3.03	2.95
Imazethapyr 60 g/ha PoE at 18-20 DAS	0.00	0.00	0.00	12.44	12.44	12.44	0	0	0	-12.44	-12.44	-12.44	-1.00	-1.00	-1.00
Quizalofop 10.8 240 g/ha PoE at 20 DAS	1.23	1.20	1.22	12.43	12.43	12.43	80.28	82.33	81.31	67.85	69.90	68.87	5.46	5.62	5.54
Fenoxaprop-p-ethyl 70 g/ha PoE at 20 DAS	0.92	0.96	0.94	13.03	13.03	13.03	59.99	65.88	62.93	46.96	52.85	49.90	3.60	4.06	3.83
Pendimethalin 0.75 kg/ha (PE) FB HW at 25 DAS	1.13	1.07	1.10	18.50	18.50	18.50	73.09	73.21	73.15	54.58	54.71	54.65	2.95	2.96	2.95
Pendimethalin 0.75 kg /ha (PE) FB quizalofop-p-methyl 40 g/ha at 20 DAS	1.34	1.31	1.32	14.88	14.88	14.88	86.77	89.59	88.18	71.89	74.71	73.30	4.83	5.02	4.93
Pendimethalin 0.75 kg /ha (PE) FB fenoxaprop-p-ethyl 70 g/ha at 20 DAS	1.10	0.96	1.03	15.48	15.48	15.48	71.53	66.01	68.77	56.05	50.54	53.29	3.62	3.26	3.44
Tembotrione 100 g/ha at 10 DAS	0.00	0.00	0.00	15.60	15.60	15.60	0	0	0	-15.60	-15.60	-15.60	-1.00	-1.00	-1.00
Control	0.78	0.68	0.69	11.05	11.05	11.05	45.26	46.96	46.11	34.21	35.91	35.06	3.10	3.25	3.17
LSD (p=0.05)	0.12	0.16	0.09												

Conclusion

The weeds in line sown sesame can be managed with pendimethalin 750 g/ha PE *fb* quizalofop-p-ethyl 40 g/ha PoE at 20 DAS effectively and economically to attain higher sesame productivity.

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RESEARCH ARTICLE

Synergistic integration of crop residue mulch and cultural practices with herbicides for managing weed complex in turmeric in North-Western India

Dharam Bir Yadav*, Lila Bora, Narender Singh, Anil Duhan, Ashok Yadav and S.S. Punia

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ABSTRACT

Turmeric being a wide spaced and long duration crop, weeds pose a serious problem due to its delayed emergence and slow initial growth which provide ideal environment for weeds to grow. This warrants for synergistic integration of residue mulch, cultural practices, and herbicides for effective weed management. Two field experiments were conducted during 2012-13 - 2013-14 and 2014-15 - 2015-16 at CCS Haryana Agricultural University, Regional Research Station, Karnal to evaluate different approaches involving integration of crop residue mulch and cultural practices with herbicides for effective and economical weed management in turmeric. The uncontrolled weeds caused 42-66% turmeric yield loss. Based on four years studies, it may be concluded that pre-emergence (PE) application of metribuzin 700 g/ha or pendimethalin 1000 g/ha or atrazine 750 g/ha integrated with rice straw mulching (10 t/ha) after herbicide application at 3 days after sowing (DAS) and hand weeding at 50 or 75 DAS provided effective control (86-100%) of complex weed flora in turmeric with improved rhizome yield (14.29 to18.60 t/ha), which was comparable to weed free, better economic returns without phyto-toxicity on the crop and detectable herbicidal residues in the turmeric rhizomes and soil at harvest. Integration of 2-hoeing with metribuzin 700 g/ha PE or pendimethalin 1000 g/ha PE were the two other viable options of integrated weed management (IWM) strategy. Among post-emergence (PoE) herbicides, fenoxaprop 67 g/ha 45 DAS, was safe to turmeric while metsulfuron 4 g/ha PoE was toxic. Glyphosate 0.3% PoE at 25 DAS could also be integrated with hoeing twice at 45 and 75 DAS for effective weed management in turmeric. Use of rice straw in IWM strategies in turmeric will also help in reducing herbicide dose, crop residue management without burning, conservation of soil moisture and other natural resources which will helps in long term sustainable and economical production system.

Keywords: Herbicides, Herbicide residues, Integrated weed management, Phyto-toxicity, Straw mulching, Turmeric

INTRODUCTION

Turmeric (*Curcuma longa* L.) is an important herbaceous perennial spice crop in the world and particularly in India. India is the largest producer (about 80% share) and consumer of turmeric in the world. The total area under turmeric is 2.38 lakh ha with a total production of 11.33 lakh tons and average yield of 4.76 t/ha (NHB 2019). In Haryana, it is grown only on 829 ha with production of 10,898 tons and average yield of 13.1 t/ha (DOH-GOH 2019). However, a great scope exists for area expansion particularly under agro-forestry system with poplar in northern districts of Haryana. It also has great significance in north-western Indo-Gangetic Plains particularly in areas near to Shivalik foothills. Turmeric is an important component of Indian kitchen which provides colour and flavour to various dishes. It is also widely used in pickles, curries, confectionaries, as a pigmenting agent in textiles and in Ayurveda for anti-inflammatory diseases (Goel *et al.* 2008).

CCS Haryana Agricultural University, Hisar, Haryana 125004, India

* Corresponding author email: dbyadav@gmail.com

Turmeric is a long duration crop grown during rainy season; hence, a variety of weeds infest the crop and compete for moisture, nutrients and space resulting into sizeable yield reductions (Daulay and Singh 1982; Hossain *et al.* 2008, Kaur *et al.* 2008). Due to wide spaced planting and longer growing period, weeds pose a serious problem in turmeric particularly during initial phase of growth. Delayed emergence, slow initial growth and poor initial canopy development provide ideal environment for weeds to grow and compete with the crop for nutrients, moisture and space causing considerable yield reduction of about 30-75 percent (Krishnamurthi and Ayyaswamy 2000). Uncontrolled weeds have been reported to remove 61, 60 and 74% of total N, P and K utilized by both crop and weeds, respectively (Kaur *et al.* 2008). The yield losses in turmeric caused by weeds are reported to range from

30 to 80% (Krishnamurthi and Ayyaswamy 2000, Hossain *et al.* 2008, Kaur *et al.* 2008, Ratnam *et al.* 2012). Weed free conditions for a long period is desired for better production of rhizomes. Weeds are difficult to control with any single herbicide as diverse weed flora infests the turmeric crop, and use of more than one herbicide particularly at later stages of crop may not be advisable being a spice crop. Many herbicidal options may be explored as pre-emergence (PE) or as post-emergence (PoE) for turmeric (Ratnam *et al.* 2012, Sathiyavani and Prabhakaran 2015), but herbicides alone may not be a viable option for long-term weed management in turmeric.

The turmeric crop is a shade loving plant and requires high moisture in soil for better growth of plants and development of rhizomes. The agronomic practices and mulching could play an important role in reducing weed interference for better yields (Hossain 2005). Crop residue mulching may help as a viable option for maintaining optimum soil moisture for better growth and development in turmeric with added advantage of weed suppression. Hence, the strategies for synergistic integration of crop residue mulch and cultural practices with herbicides are needed to be chalked out for better and economical weed management in turmeric without herbicidal residues in crop produce. A limited information is available on integrated weed management (IWM) by synergistic use of crop residue mulch and cultural practices with herbicides in turmeric crop. Hence, field experiments were conducted to assess the suitability of crop residue mulch and agronomic practices integrated with herbicides for sustainable, viable and economical weed management in turmeric of the region.

MATERIALS AND METHODS

Experiment-1: Field experiment-1 was conducted at CCS Haryana Agricultural University, Regional Research Station, Karnal to evaluate different combination of herbicides along with the cultural practices for control of weeds in turmeric during 2012-13 and 2013-14. The treatments included: pre-emergence application (PE) of metribuzin 700 g/ha and pendimethalin 1000 g/ha at 0-3 days after seeding (DAS), each followed by (*fb*) hoeing twice at 40 and 70 DAS or *fb* fenoxaprop+ metsulfuron 67+4 g/ha at 2-4 leaf stage (LS) or *fb* rice straw mulch 10 t/ha at 3 DAS+ hand weeding (HW) at 50 DAS, and atrazine 750 g/ha PE *fb* fenoxaprop+ metsulfuron 67+4 g/ha at 2-4 leaf stage of weeds (2-4 LS) or *fb* straw mulch 10 t/ha at 3 DAS *fb* HW 50 DAS, along with weed free and weedy checks. The treatments were laid out in randomized block design with three replicates. The plot size was 5.0 m x 2.8 m during 2012-13 and 5.0 m x 4.2 m during 2013-14. Turmeric variety CSTH-9 was planted at a row spacing of 70 cm on 10th July, 2012 and 26th June, 2013. Crop was raised according to package of practices of the State University. The observations on weed density and biomass were recorded at 120 DAS. For weed density, numbers of individual weed species were counted from two randomly placed quadrats (0.5 m x 0.5 m) in each of the plots and converted to per m^2. These weeds were grouped as grassy, broad-leaved weeds and sedges and weed dry weight (biomass) was taken after sun drying and oven drying of samples at 70^0C for 48 hours. Weed control efficiency (WCE) was computed based on weeds biomass by using the following formula used by different workers (Hasanuzzaman *et al.* 2009, Singh *et al.* 2013),

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

Crop growth parameters viz., number of plants/ha, plant height and number of tillers/ plants were recorded at 180 DAS, and crop yield was recorded at harvest. Plant stand was counted on plot basis and converted to per ha. Plant height and number of tillers of five plants were taken from each plot and averaged for recording average plant height and number of tillers per plant, respectively. For crop yield, rhizomes were dug out from the soil and weighed from net plot area (after discarding one row on each side and 1 m on each end) and converted to per hectare. Crop was harvested on 30th April, 2013 and 2014.

Experiment-2: Crop phyto-toxicity was observed in some of the treatments during the experiment-1 and based on it, field experiment-2 was conducted with suitable changes in the treatment combinations during 2014-15 to 2015-16. The treatments included: metribuzin 700 g/ha PE at 0-3 DAS *fb* hoeing twice at 45 and 75 DAS, metribuzin 700 g/ha PE at 0-3 DAS *fb* fenoxaprop 67 g/ha PoE at 45 DAS or metribuzin 700 g/ha PE at 0-3 DAS *fb* rice straw mulching 10 t/ha at 3 DAS *fb* hoeing at 45 DAS, pendimethalin 1000 g/ha PE at 0-3 DAS *fb* hoeing twice at 45 and 75 DAS, pendimethalin 1000 g/ha PE at 0-3 DAS *fb* fenoxaprop 67 g/ha PoE at 45 DAS, pendimethalin 1000 g/ha PE at 0-3 DAS *fb* straw mulching 10 t/ha at 3 DAS *fb* HW at 45 DAS, atrazine 750 g/ha PE at 0-3 DAS *fb* hoeing twice at 45 and 75 DAS, atrazine 1000 g/ha PE at 0-3 DAS *fb* fenoxaprop 67 g/ha PoE at 45 DAS, atrazine 750 g/ha PE at 0-3 DAS *fb* rice straw mulching 10 t/ha at 3 DAS *fb* HW at 45 DAS, oxyfluorfen 300 g/ha PE at 0-3 DAS *fb* hoeing twice at 45 and 75 DAS, oxadiargyl 250 g/ha PE at 0-3 DAS *fb* hoeing twice at 45 and 75 DAS, glyphosate 0.2% (5.0 ml product/L) PoE at 25 DAS *fb* hoeing twice at 45 and 75 DAS, glyphosate 0.3% (7.5 ml product/L) PoE at 25 DAS *fb* hoeing twice at 45 and 75 DAS, along with HW thrice at 25, 45 and 75 DAS, weed free and weedy checks. Glyphosate was applied as PoE spray, as turmeric has tolerance to its lower doses. The experiment was laid out in randomized block design with three replicates. The plot size was 5.0 x 4.2 m, and the same turmeric variety was planted at a row spacing of 70 cm on 25th June, 2014 and 4th July, 2015. Crop was raised according to package of practices of the State University. Herbicides in both the experiments were applied with knapsack sprayer fitted with flat-fan nozzle using spray volume of 500 L/ha.

The observations on weed density and biomass were recorded at 105 DAS in 2014-15 and 75 DAS in 2015-16. As infestation and growth of weeds was more and at an early stage during second year, hence observations were recorded at 75 DAS instead of 105 DAS to avoid intermingling of weeds at advanced stage which makes the weed count difficult. Crop yield was recorded at harvest, and crop was harvested on 19th April, 2015 and 24th March, 2016. The observations on weeds and crop were recorded and weed control efficiency was computed as per methodology explained earlier. Economic parameters like variable cost, net returns over variable cost and benefit-cost ratio were also computed for understanding the economic viability of the treatments.

Residue studies

For residue studies, soils samples and rhizomes of turmeric were collected at harvest from herbicide applied plots during 2014-15 and 2015-16. Residues of herbicides were analyzed using GCMS/MS in Agrochemicals Residues Testing Laboratory, CCS Haryana Agricultural University, Hisar.

Residue analysis: Extraction and clean-up of glyphosate from soil and turmeric rhizome was done by using the method of Hu *et al.* (2008) through derivatization of glyphosate using triflouroacetic anhydride (TFAA) and triflouroethane (TFE). For extraction and clean-up of pendimethalin, metribuzin, atrazine, oxadiargyl and oxyfluorfen, the methodology of (Duhan *et al.* 2018) was used.

GCMS/MS analysis*:* Analysis of different herbicides was carried out using GCMS tandem mass spectrometry (Agilent 7890 A series with 7000 GCMS/MS detector). The details of methodology are elaborated by Kumari *et al.* (2021).

Statistical analysis: Before statistical analysis, the data on weed density were subjected to square root ($\sqrt{x+1}$) transformation to improve the homogeneity of the variance. The data were subjected to the Fisher's method of analysis of variance (ANOVA) (Fisher 1958) and significant treatment effect was judged with the help of 'F' test at the 5% level of significance by adopting the procedure described by Panse and Sukhatme (1985).

RESULTS AND DISCUSSION

Effect on weeds

The weed flora of the field consisted of grasses: *Dactyloctenium aegyptium, Brachiaria reptans, Eragrostis tenella* which were recorded during all the years of the study. In addition to these, other grasses recorded include: *Poa annua* and *Commelina benghalensis* during 2012-13, *Cynodon dactylon* and *Leptochloa chinensis* during 2013-14; and *Digitaria sanguinalis* during 2015-16. Some variation in grassy weed flora occurred during different years due to variation in time of weather, sowing time and growing conditions. Among broad-leaved weeds: *Euphorbia hirta, Phyllanthus niruri* occurred during 2012-2014. *Melilotus indica, Coronopus didymus, Anagallis arvensis* occurred during 2012-13. *Ammannia baccifera* occurred during 2013-14; *Melilotus indica, Coronopus didymus* and *Anagallis arvensis* occurred during 2014-15; *Trianthema monogyna* during 2015-16. Among sedges: *Cyperus rotundus* occurred during all the years. It indicated that along with *kharif* weeds, few *rabi* season broad-leaved weeds also infested the crop due to its long duration.

The treatments with rice straw mulch were found most effective against all type of weeds (**Table 1, 2, 5, 6**). Metribuzin 700 g/ha PE, pendimethalin 1000 g/ha PE or atrazine 750 g/ha PE *fb* straw mulch 10 t/ha at 3 DAS + HW at 50 DAS resulted into lowest density of grassy weeds, broad-leaved weeds and sedges during all the years of the study. Integration of hoeing twice with metribuzin 700 g/ha PE or pendimethalin 1000 g/ha PE was found to be the next best combination in reducing the weed density particularly the grassy weeds and sedges; however, it was inferior to the treatments with rice straw mulch. The tank-mix (TM) application of fenoxaprop 67 g/ha + metsulfuron 4 g/ha at 2-4 LS in sequence each with metribuzin 700 g/ha PE, pendimethalin 1000 g/ha PE or atrazine 750 g/ha PE also significantly reduced the grassy and broad-leaved weeds density and biomass (**Table 1**).

During 2014-15 and 2015-16, sequential application of fenoxaprop 67 g/ha PE with pendimethalin PE or metribuzin PE or atrazine PE was found to be the second-best treatment combination in reducing the density and biomass of grassy weeds indicating effectiveness of fenoxaprop as PoE herbicide against grassy weeds in turmeric (**Table 5, 6**). Those treatments were statistically similar to 2-hoeing treatment combinations each with pendimethalin, metribuzin, atrazine, oxyfluorfen or oxadiargyl (PE) and glyphosate (PoE), and the 3-HW treatment. The treatments having integration of PE herbicides with straw mulching + HW or PE/ PoE herbicides with 2-hoeing were the next best treatment combinations in reducing density and biomass of grassy weeds, and were similar to HW thrice with few exceptions. Among PE herbicides, pendimethalin was found better in reducing density and biomass of grassy weeds followed by metribuzin and atrazine during all the years (**Table 1, 2, 5, 6**).

Metribuzin PE or pendimethalin PE or atrazine PE *fb* straw mulch *fb* HW provided the lowest density and biomass of broad-leaved weeds and sedges during all the years, which was similar to weed free check and superior to all other weed management treatments (**Table 1, 2, 5, 6**). The PE herbicide combinations with 2-hoeing were the next best treatment combination in reducing BLW population and biomass and were similar to HW thrice. Among PE herbicidal treatment combinations, treatments with fenoxaprop (PoE) resulted in maximum density of BLW. Integration of hoeing twice with oxyfluorfen 300 g/ha PE in 2014-15 or glyphosate 0.3% (PoE) in 2015-16 was also found effective in reducing BLW population similar to HW thrice. Glyphosate 0.3% also provided control of BLW and sedges.

Integration of hoeing twice with PE herbicides including oxyfluorfen PE were found to be the next best treatment combinations in reducing sedges population and biomass in 2014-15, and were similar to HW thrice but such effects were not repeated in 2015-16 (**Table 5, 6**). Fenoxaprop was non-effective against sedges during all the years. The treatments with straw mulch could effectively reduce the sedges population among all the weed management treatments over the years (**Table 1, 2, 5, 6)**.

Maximum weed control efficiency (86.1-100.0%) was recorded under metribuzin, pendimethalin or atrazine PE + rice straw mulch 10 t/ ha *fb* one HW during all the years (**Table 2, 6).**

Table 1. Effect of different treatments on density of grassy weeds at 120 DAS in turmeric, 2012-13 and 2013-14

Treatment	Dose (g/ha)	Time (DAS)	Density of weeds (no./m^2): Grassy weeds 2012-13	Grassy weeds 2013-14	Broad-leaved weeds 2012-13	Broad-leaved weeds 2013-14	Sedges 2012-13	Sedges 2013-14
Metribuzin *fb* hoeing *fb* hoeing	700/-/-	0-3/40/70	6.48(41.3)	1.00(0.0)	8.68(74.7)	5.45(28.7)	5.62(30.7)	4.79(23.3)
Metribuzin *fb* fenoxaprop+ metsulfuron	700/67+4	0-3/2-4 LS	4.58(20.0)	2.43(5.3)	8.25(67.3)	4.37(18.7)	7.54(56.0)	6.98(48.0)
Metribuzin *fb* straw mulching + HW	700/10T/-	0-3/50	2.56(6.0)	1.00(0.0)	4.58(20.7)	1.00(0.0)	2.52(6.0)	1.00(0.0)
Pendimethalin *fb hoeing fb* hoeing	1000/-/-	0-3/40/70	6.34(39.3)	1.00(0.0)	7.73(59.3)	5.96(34.7)	6.02(35.3)	5.45(29.3)
Pendimethalin *fb* fenoxaprop+ metsulfuron	1000/67+4	0-3/2-4 LS	4.79(22.0)	2.34(4.7)	8.72(75.3)	4.86(22.7)	7.68(58.7)	7.19(52.0)
Pendimethalin *fb* straw mulching + HW	1000/10T/-	0-3/50	3.83(14.0)	1.00(0.0)	5.25(27.3)	1.00(0.0)	1.67(2.7)	1.00(0.0)
Atrazine *fb* fenoxaprop+ metsulfuron	750/67+4	0-3/2-4 LS	5.17(26.0)	3.21(9.3)	7.53(56.0)	4.56(20.0)	7.27(52.0)	6.56(42.0)
Atrazine *fb* straw mulching + HW	750/10T/-	0-3/50	2.83(7.3)	1.00(0.0)	4.32(18.0)	1.00(0.0)	2.85(7.3)	1.00(0.0)
Weed free			1.00(0.0)	1.00(0.0)	1.00(0.0)	1.00(0.0)	1.00(0.0)	1.00(0.0)
Weedy check			8.54(72.0)	9.43(88.7)	1.00(0.0)	5.80(32.7)	1.00(0.0)	5.48(29.3)
LSD (p=0.05)			0.92	0.80	1.30	0.72	1.19	1.38

*Original figures in parentheses were subjected to square root transformation $(\sqrt{x+1})$ before statistical analysis; Abbreviations: HW=hand weeding, *fb*= followed by, DAS=days after sowing, LS=leaf stage, T=tons/ha

Table 2. Effect of different weed control treatments on weed biomass at 120 DAS in turmeric, 2012-13 and 2013-14

Treatment	Dose (g/ha)	Time (DAS)	Weed biomass (g/m^2): Grass weeds 2012-13	Grass weeds 2013-14	BLW 2012-13	BLW 2013-14	Sedges 2012-13	Sedges 2013-14	Total weeds 2012-13	Total weeds 2013-14	Weed control efficiency (%) 2012-13	Weed control efficiency (%) 2013-14
Metribuzin *fb* hoeing *fb* hoeing	700/-/-	0-3/40/70	23.9	0.0	13.2	3.9	3.3	2.9	40.4	6.8	79.2	92.5
Metribuzin *fb* fenoxaprop+ metsulfuron	700/67+4	0-3/2-4LS	43.8	8.6	30.9	2.1	6.8	10.4	81.5	21.1	58.1	76.6
Metribuzin *fb* straw mulching + HW	700/10T/-	0-3/50	7.2	0.0	4.2	0.0	1.4	0.0	12.8	0.0	93.4	100
Pendimethalin *fb* hoeing *fb* hoeing	1000/-/-	0-3/40/70	24.3	0.0	13.9	4.3	3.7	2.7	41.9	7.0	78.5	92.2
Pendimethalin *fb* fenoxaprop+ metsulfuron	1000/67+4	0-3/2-4LS	43.8	11.3	37.3	2.1	7.0	9.5	88.1	22.9	54.7	74.6
Pendimethalin *fb* straw mulching + HW	1000/10T/-	0-3/50	10.9	0.0	5.0	0.0	0.5	0.0	16.4	0.0	91.6	100
Atrazine *fb* fenoxaprop+ metsulfuron	750/67+4	0-3/2-4LS	48.1	14.6	38.3	2.3	7.0	8.6	93.4	25.5	52.0	71.7
Atrazine *fb* straw mulching + HW	750/10T/-	0-3/50	10.3	0.0	4.1	0.0	1.7	0.0	16.1	0.0	91.7	100
Weed free			0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100	100
Weedy check			194.5	81.8	0.0	4.6	0.0	3.8	194.5	90.2	0.0	0.0
LSD (p=0.05)			10.4	11.8	8.6	1.2	1.8	2.2	16.3	12.5		

Abbreviations: HW=hand weeding, BLW=broad-leaved weeds, *fb*= followed by, DAS=days after sowing, LS=leaf stage, T=tons/ha

Channappagoudar *et al.* (2013) also reported better weed control efficiency with pendimethalin 1.5 kg/ha in turmeric. Integration of hoeing twice with PE herbicides was found to be the next best combination which resulted in 68.3 to 92.5% WCE. Integration of hoeing twice with oxyfluorfen PE or oxadiargyl PE (67.4-69.9%) or glyphosate 0.3% PoE (65.2-87.0%) during 2014-15 and 2015-16 also resulted in satisfactory WCE. The fenoxaprop treatments provided WCE (80.7-84.7%) almost similar to HW thrice (82.4%) during 2015-16 but similar or lower WCE (62.7-68.6%) than 3-HW (72.9%) during 2014-15.

Suppressing effect of straw mulch on weeds is due to physical obstruction to germinating weed seedlings and barrier to light penetration towards soil surface, resulting in fewer emergence of weeds. Gill *et al.* (2000) found that the herbicidal treatments alone did not provide season-long weed control in turmeric, but the integration of metribuzin PE, atrazine PE or diuron PE with one hand weeding at 55 DAS achieved effective control of weeds. Manhas *et al.* (2011) has also reported that increase in the paddy straw mulch levels from no mulch to 6.25 t/ha and then to 9.38 t/ha significantly decreased weeds in turmeric. Kaur *et al.* (2008) reported that pendimethalin PE, metribuzin PE or atrazine PE integrated with straw mulch 9 t/ha gave satisfactory weed management in turmeric in Punjab. Similarly, integration of hoeing, hand weeding or straw mulch 10 t/ha with metribuzin PE, pendimethalin PE or atrazine PE were found effective in controlling weeds in turmeric by Barla *et al.* (2015). Ratnam *et al.* (2012) reported the weed control efficacy of integration of oxyfluorfen 0.25 kg/ha PE *fb* quizalofop-ethyl 0.05 kg/ha PoE and hand weeding twice at 60 and 90 DAS.

Effect on crop

During 2012-13 and 2013-14, metribuzin 700 g/ha PE, pendimethalin 1000 g/ha PE or atrazine 750 g/ha PE with straw mulch 10 t/ha at 3 DAS and one HW, resulted in maximum number of surviving plants at 180 DAS, which were similar to metribuzin or pendimethalin with 2-hoeing and weed free check (**Table 3**). These treatments resulted in higher plant stand than weedy check, but the differences were not always significant. Lowest number of surviving

Table 3. Effect of different weed control treatments on yield attributes (at 180 DAS) and yield of turmeric, 2012-13 and 2013-14

Treatment	Dose (g/ha)	Time (DAS)	No. of plants (‘000/ha) 2012-13	No. of plants (‘000/ha) 2013-14	Plant height (cm) 2012-13	Plant height (cm) 2013-14	No. of tillers/plant 2012-13	No. of tillers/plant 2013-14	Yield (t/ha) 2012-13	Yield (t/ha) 2013-14
Metribuzin *fb* hoeing *fb* hoeing	700/-/-	0-3/40/70	43.1	41.7	98.0	103.1	5.53	4.07	10.01	10.30
Metribuzin *fb* fenoxaprop+ metsulfuron	700/67+4	0-3/2-4 LS	24.7	35.1	22.4	55.1	1.87	3.67	2.40	5.96
Metribuzin *fb* straw mulching + HW	700/10T/-	0-3/50	42.1	45.9	97.5	124.8	6.33	5.33	14.29	15.24
Pendimethalin *fb* hoeing *fb* Hoeing	1000/-/-	0-3/40/70	42.8	40.8	97.2	102.1	5.27	4.07	11.81	12.44
Pendimethalin *fb* fenoxaprop+ metsulfuron	1000/67+4	0-3/2-4 LS	25.2	33.8	20.9	49.0	1.47	3.40	1.60	6.49
Pendimethalin *fb* straw mulching + HW	1000/10T/-	0-3/50	46.2	44.1	98.2	111.3	6.47	4.80	15.05	17.16
Atrazine *fb* fenoxaprop+ metsulfuron	750/67+4	0-3/2-4 LS	21.2	34.7	22.9	53.7	1.73	3.60	1.88	5.83
Atrazine *fb* straw mulching + HW	750/10T/-	0-3/50	45.7	44.3	96.8	118.9	6.20	5.07	14.99	16.97
Weed free			45.2	41.6	94.3	106.9	5.60	4.53	13.51	13.55
Weedy check			36.4	39.3	87.9	105.7	3.80	3.80	4.58	7.50
LSD (p=0.05)			6.9	4.2	5.3	14.6	0.96	0.75	1.57	0.76

Abbreviations: HW=hand weeding, *fb*= followed by, DAS= days after sowing, LS=leaf stage, T=tons/ha

Table 4. Phyto-toxicity of different herbicidal treatments on turmeric crop at different intervals, 2012-13 and 2013-14

Treatment	Dose (g/ha)	Time (DAS)	Phyto-toxicity (%) 2012-13 30 DAS	2012-13 60 DAS	2012-13 90 DAS	2012-13 12 DAS	2013-14 30 DAS	2013-14 60 DAS	2013-14 90 DAS	2013-14 12 DAS
Metribuzin *fb* hoeing *fb* hoeing	700/-/-	0-3/40/70	10.0	4.0	0.0	0.0	0.0	0.0	3.3	3.3
Metribuzin *fb* fenoxaprop+ metsulfuron	700/67+4	0-3/2-4 LS	10.0	28.3	78.3	90.0	0.0	48.3	50.0	35.0
Metribuzin *fb* straw mulching + HW	700/10T/-	0-3/50	10.0	1.3	0.0	0.0	0.0	0.0	0	0.0
Pendimethalin *fb* hoeing *fb* Hoeing	1000/-/-	0-3/40/70	0.0	0.0	0.0	0.0	0.0	0.0	0	0.0
Pendimethalin *fb* fenoxaprop+ metsulfuron	1000/67+4	0-3/2-4 LS	0.0	33.3	86.7	90.0	0.0	61.7	55.0	43.3
Pendimethalin *fb* straw mulching + HW	1000/10T/-	0-3/50	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Atrazine *fb* fenoxaprop+ metsulfuron	750/67+4	0-3/2-4 LS	2.0	31.7	83.3	90.0	0.0	40.0	50.3	53.3
Atrazine *fb* straw mulching + HW	750/10T/-	0-3/50	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Weed free			0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Weedy check			0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0

Abbreviations: HW=hand weeding, *fb* =followed by, DAS=days after sowing, LS=leaf stage, T=tons/ha plants was recorded under the fenoxaprop + metsulfuron (TM) treatment, due to the phyto-toxicity of the herbicide combination on turmeric. Plant height under all the weed management treatments, except fenoxaprop + metsulfuron, were similar to each other and weed free check during 2012-13. During 2013-14, plant height was maximum under PE herbicides + straw mulch + HW treatments, which was followed by PE herbicides + 2-hoeing treatments. Plant height under herbicide + straw mulch + HW treatments and weed free check was higher than weedy check during both the years; however, during 2013-14, plant height under weed free and weedy checks was similar. Falling of dried weeds after maturity in weedy check resulted in high soil moisture conditions due to its mulching effect, which might have mitigated the negative effect of weeds on plant height.

Among weed management treatments, metribuzin or pendimethalin PE or atrazine PE + straw mulch + HW resulted in maximum number of tillers, which was followed by metribuzin PE or pendimethalin PE + hoeing twice during 2012-13 and 2013-14 (**Table 3**). All weed management treatments, other than treatments having fenoxaprop + metsulfuron, resulted in tillering statistically similar

Table 5. Effect of different weed control treatments on density of weeds at 105/ 75 DAS* in turmeric, 2014-15 and 2015-16

Treatment	Dose (g/ha)	Time (DAS)	Weed density (no./m²)					
			Grass weeds		Broad-leaved weeds		Sedges	
			2014-15	2015-16	2014-15	2015-16	2014-15	2015-16
Metribuzin *fb* hoeing *fb* hoeing	700/-/-	0-3/45/75	4.85(24.0)	3.31(10.0)	6.61(44.0)	5.54(30.0)	5.18(26.0)	15.96(254.0)
Metribuzin *fb* fenoxaprop	700/67/-	0-3/45	3.82(14.7)	2.37(4.7)	7.40(58.7)	7.49(55.3)	6.83(46.0)	15.28(233.3)
Metribuzin *fb* straw mulching *fb* HW	700/10T/-	0-3/3/75	1.00(0.0)	3.69(12.7)	1.00(0.0)	2.79(7.3)	1.00(0.0)	5.31(29.3)
Pendimethalin *fb* hoeing *fb* hoeing	1000/-/-	0-3/45/75	3.95(16.7)	1.66(2.0)	6.49(42.0)	5.62(30.7)	5.12(25.3)	14.64(214.0)
Pendimethalin *fb* fenoxaprop	1000/67	0-3/45	4.43(18.7)	1.00(0.0)	7.90(62.0)	7.50(56.0)	6.71(45.3)	15.80(250.0)
Pendimethalin *fb* straw mulching *fb* HW	1000/10T/-	0-3/3/75	1.00(0.0)	2.37(4.7)	1.00(0.0)	2.63(6.0)	1.00(0.0)	5.97(35.3)
Atrazine *fb* hoeing *fb* hoeing	750/-/-	0-3/45/75	4.57(20.0)	3.69(12.7)	5.69(32.0)	5.36(28.0)	5.17(26.0)	11.43(130.0)
Atrazine *fb* fenoxaprop	750/67	0-3/45	5.12(25.3)	3.21(9.3)	7.36(53.3)	6.91(47.3)	6.79(45.3)	11.85(140.7)
Atrazine *fb* straw mulching *fb* HW	750/10T/-	0-3/3/75	1.00(0.0)	4.43(18.7)	1.00(0.0)	2.95(8.0)	1.00(0.0)	5.47(29.3)
Oxyfluorfen *fb* hoeing *fb* hoeing	300/-/-	0-3/45/75	4.39(18.7)	3.59(12.0)	6.98(48.0)	8.08(64.7)	5.83(33.3)	15.60(243.3)
Oxadiargyl *fb* hoeing *fb* hoeing	250/-/-	0-3/45/75	4.49(19.3)	3.32(10.0)	8.18(66.0)	9.39(87.3)	6.66(43.3)	14.71(216.7)
Glyphosate *fb* hoeing *fb* hoeing	0.2%/-/-	25/45/75	3.88(14.7)	3.49(11.3)	8.79(76.7)	9.71(93.3)	3.60(12.0)	8.47(71.3)
Glyphosate *fb* hoeing *fb* hoeing	0.3%/-/-	25/45/75	2.97(8.0)	1.90(2.7)	9.33(86.0)	6.98(48.0)	2.85(7.3)	7.21(52.0)
Hand weeding thrice	-/-/-	25/45/75	3.90(14.7)	3.40(10.7)	6.99(48.7)	6.34(39.3)	4.91(23.3)	9.49(89.3)
Weed free			1.00(0.0)	1.00(0.0)	1.00(0.0)	1.00(0.0)	1.00(0.0)	1.00(0.0)
Weedy check			6.71(44.7)	7.63(57.3)	9.45(88.7)	11.15(123.3)	6.80(45.3)	17.38(301.3)
LSD (p=0.05)			1.19	0.47	1.62	1.03	0.96	1.52

Abbreviations: HW=hand weeding, *fb*= followed by, DAS=days after sowing, T=tons/ha; *At 105 DAS in 2014-15 and 75 DAS in 2015-16; **Original figures in parentheses were subjected to square root transformation $(\sqrt{x+1})$ before statistical analysis

Table 6. Effect of different weed control treatments on weed biomass and weed control efficiency (WCE) at 105/75 DAS* in turmeric, 2014-15 and 2015-16

Treatment	Dose (g/ha)	Time (DAS)	Weed biomass (g/m²)								WCE (%)	
			Grassy weeds		Broad-leaved weeds		Sedges		Total weeds			
			2014-15	2015-16	2014-15	2015-16	2014-15	2015-16	2014-15	2015-16	2014-15	2015-16
Metribuzin *fb* hoeing *fb* hoeing	700/-/-	0-3/45/75	33.1	14.3	6.3	6.3	6.4	30.3	45.8	50.9	68.3	85.1
Metribuzin *fb* fenoxaprop	700/67/-	0-3/45	28.9	1.9	8.3	13.9	8.1	44.6	45.3	60.4	68.6	82.4
Metribuzin *fb* straw mulching *fb* HW	700/10T/-	0-3/3/75	0.0	36.4	0.0	4.4	0.0	0.3	0.0	41.1	100.0	88.0
Pendimethalin *fb* hoeing *fb* hoeing	1000/-/-	0-3/45/75	21.5	12.7	5.7	9.8	5.5	38.1	32.7	60.6	77.3	82.3
Pendimethalin *fb* fenoxaprop	1000/67	0-3/45	34.1	0.0	10.0	16.5	8.1	49.5	52.2	66.0	63.8	80.7
Pendimethalin *fb* Straw mulching *fb* HW	1000/10T/-	0-3/3/75	0.0	23.5	0.0	4.0	0.0	2.4	0.0	29.9	100.0	91.3
Atrazine *fb* hoeing *fb* hoeing	750/-/-	0-3/45/75	29.8	20.3	5.2	7.9	4.6	21.0	39.6	49.2	72.6	85.6
Atrazine *fb* fenoxaprop	750/67	0-3/45	36.8	8.2	8.2	11.6	8.8	32.7	53.8	52.5	62.7	84.7
Atrazine *fb* straw mulching *fb* HW	750/10T/-	0-3/3/75	0.0	42.1	0.0	4.8	0.0	0.8	0.0	47.7	100.0	86.1
Oxyfluorfen *fb* hoeing *fb* hoeing	300/-/-	0-3/45/75	30.9	46.8	5.9	20.7	6.7	44.1	43.5	111.6	69.9	67.4
Oxadiargyl *fb* hoeing *fb* hoeing	250/-/-	0-3/45/75	28.7	39.6	7.0	28.9	10.1	36.9	45.8	105.4	68.3	69.2
Glyphosate *fb* hoeing *fb* hoeing	0.2%/-/-	25/45/75	32.5	13.8	12.2	35.0	5.5	15.2	50.2	64.0	65.2	81.3
Glyphosate *fb* hoeing *fb* hoeing	0.3%/-/-	25/45/75	19.6	5.9	12.2	25.6	3.5	12.9	35.3	44.4	75.5	87.0
Hand weeding thrice	-/-/-	25/45/75	27.4	22.5	6.1	18.9	5.6	19.0	39.1	60.4	72.9	82.4
Weed free			0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	100.0
Weedy check			120.5	194.8	12.7	60.5	11.1	87.3	144.3	342.6	0.0	0.0
LSD (p=0.05)			20.1	9.5	2.6	9.8	2.0	17.6	20.8	22.7		

Abbreviations: HW: hand weeding, *fb:* followed by, DAS: days after sowing, T: tons/ha; *At 105 DAS in 2014-15 and 75 DAS in 2015-16 to weed free with few exceptions. Lowest number of tillers was recorded under fenoxaprop + metsulfuron treatments which was even lower than the weedy checks (3.80/plant), owing to its phyto-toxicity on turmeric.

PE herbicides + mulching + HW produced highest rhizome yield of turmeric which was similar or even higher than weed free check during all the years (**Table 3, 7**) confirming observations of Manhas *et al*. (2011). The second-best treatment combination was realized to be metribuzin PE or pendimethalin PE *fb* hoeing twice during 2012-13 and 2013-14 (**Table 3**). Integration of hoeing twice with PE of metribuzin, pendimethalin, atrazine, oxyfluorfen or glyphosate 0.3% PoE produced rhizome yields similar to HW thrice in 2014-15 and 2015-16 except metribuzin + hoeing twice being better than HW thrice and similar to weed free check during 2014-15 (**Table 7**). The treatments of PE herbicides + fenoxaprop PoE also produced rhizome yield similar to weed free check/ HW thrice in 2014-15, but these were inferior to weed free check/ HW thrice in 2015-16 except pendimethalin *fb* fenoxaprop being at par with HW thrice. Oxadiargyl PE or glyphosate 0.2% (PoE) + hoeing twice produced lower yield than weed free/HW thrice during both the years. Performance of oxyfluorfen treatment was not consistent, as it produced rhizome yield like HW thrice in 2014-15 but like weedy check in 2015-16. HW thrice produced grain yield like weed free checks during 2014-15, but lower in 2015-16. Lowest rhizome yields were recorded under the treatments having fenoxaprop + metsulfuron (**Table 3**), due to its phyto-toxicity on the crop. There was 42-66% loss in rhizome yield of turmeric under due to weeds during all the years (**Table 3, 7**).

Phyto-toxicity

The treatments with fenoxaprop+ metsulfuron showed phyto-toxicity on the crop at all the stages of observation (90% in 2012-13 and 35-53% in 2013-14 at 120 DAS) (**Table 4**). The differential behavior might be attributed to early planting of crop in second year. There was minor phyto-toxicity at initial stage (10% at 30 DAS) with metribuzin 700 g/ha PE during 2012-13, which recovered with time. Other treatments did not show any phyto-toxic effects on the crop.

There was no phyto-toxicity of any of the herbicidal treatments on turmeric during 2014-2015 and 2015-2016, indicating possibilities of their safe use in turmeric. No phyto-toxicity of fenoxaprop in 2014-15 and 2015-16 but fenoxaprop+ metsulfuron showed phytotoxicity in earlier years (**Table 3**) indicating that fenoxaprop was safe to the turmeric crop but not the metsulfuron.

Economics

The integration of PE herbicides with mulching + HW resulted in highest net returns and benefit-cost ratio among all the treatments during both the years (**Table 7**) as reported by Kaur *et al*. (2008). PE herbicides + fenoxaprop PoE treatments were the next best treatments in respect of net returns and B-C ratio during 2014-15. While during 2015-16, hoeing twice integrated with metribuzin/ atrazine were

Table 7. Effect of different weed control treatments on productivity and economics of turmeric, 2014-15 and 2015-16

Treatment	Dose (g/ha)	Time (DAS)	Yield (t/ha)		Variable cost (₹/ha)		Net returns (₹/ha)		B:C ratio	
			2014-15	2015-16	2014-15	2015-16	2014-15	2015-16	2014-15	2015-16
Metribuzin *fb* hoeing *fb* hoeing	700/-/-	0-3/45/75	14.25	15.51	65,887	66,358	76,605	88,709	2.16	2.34
Metribuzin *fb* fenoxaprop	700/67/-	0-3/45	16.01	12.69	54,758	55,228	105,309	71,628	2.92	2.30
Metribuzin *fb* straw mulching *fb* HW	700/10T/-	0-3/3/75	18.30	17.50	61,185	61,655	121,803	113,306	2.99	2.84
Pendimethalin *fb* hoeing *fb* hoeing	1000/-/-	0-3/45/75	14.42	13.95	65,704	66,175	78,454	73,358	2.19	2.11
Pendimethalin *fb* fenoxaprop	1000/67	0-3/45	15.86	13.08	54,575	55,045	104,011	75,785	2.91	2.38
Pendimethalin *fb* straw mulching *fb* HW	1000/10T/-	0-3/3/75	18.60	16.93	61,002	61,472	124,994	107,874	3.05	2.75
Atrazine *fb* hoeing *fb* hoeing	750/-/-	0-3/45/75	14.05	14.63	65,051	65,522	75,414	80,732	2.16	2.23
Atrazine *fb* fenoxaprop	750/67	0-3/45	15.44	12.10	53,922	54,392	100,473	66,561	2.86	2.22
Atrazine *fb* straw mulching *fb* HW	750/10T/-	0-3/3/75	17.94	16.62	60,349	60,819	119,001	105,390	2.97	2.73
Oxyfluorfen *fb* hoeing *fb* hoeing	300/-/-	0-3/45/75	14.14	7.68	65,156	65,626	76,201	11,205	2.17	1.17
Oxadiargyl *fb* hoeing *fb* hoeing	250/-/-	0-3/45/75	12.62	10.48	65,417	65,887	60,798	38,955	1.93	1.59
Glyphosate *fb* hoeing *fb* hoeing	0.2%/-/-	25/45/75	13.22	11.78	65,417	65,887	66,788	51,892	2.02	1.79
Glyphosate *fb* hoeing *fb* hoeing	0.3%/-/-	25/45/75	16.09	13.31	66,070	66,540	94,807	66,540	2.43	2.00
Hand weeding thrice	-/-/-	25/45/75	15.53	13.24	69,754	70,224	85,512	62,202	2.23	1.89
Weed free			15.17	15.18	69,754	70,224	81,900	81,539	2.17	2.16
Weedy check			6.73	8.79	50,944	51,414	16,367	36,463	1.32	1.71
LSD (p=0.05)			1.51	0.46						

Abbreviations: HW: hand weeding, *fb:* followed by, DAS: days after sowing, T: tons/ha superior to metribuzin/ atrazine + fenoxaprop treatments as reported by Barla *et al.* (2015). Glyphosate 0.3% + hoeing twice was also found promising in respect of net returns and B-C ratio.

Residue studies

None of the soil and turmeric rhizome samples collected at harvest were found to contain residues of any of the applied herbicides above detection limit of 0.01 µg/ml (in case of glyphosate and oxadiargyl) and 0.001 µg/ml (in case of pendimethalin, atrazine, metribuzin and oxyfluorfen). This indicated about the safe application of these herbicides for weed management in turmeric.

The present four years study revealed that the weeds pose a profoundly serious problem in turmeric causing yield losses to the extent of 42-66%. Pre-emergence application of metribuzin 700 g/ha, pendimethalin 1000 g/ha or atrazine 750 g/ha integrated with 10 t/ha rice straw mulching after three days of herbicide application and one hand weeding at 50/75 DAS proved effective to control complex weed flora in turmeric with improved rhizome yields and better economic returns. The integration of hand hoeing twice at 45 and 75 DAS with metribuzin 700 g/ha PE, pendimethalin 1000 g/ha PE or atrazine 750 g/ha PE were also found to be the next best IWM options, if straw for mulching is available. Use of rice straw in IWM strategies in turmeric will also help sustain and economize such production systems by curtailing undesired herbicide load, better crop residue management (avoiding burning) and conserving soil moisture and other natural resources. There were no detectable residues of any of the tested herbicides in the soil and turmeric rhizomes at harvest, indicating their safety for weed management in turmeric.

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RESEARCH ARTICLE

Effect of planting geometry and potato seed tuber size on weeds and potato tuber yield

Vivek Kumar[1]* and C.S. Aulakh[2]

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ABSTRACT

A field experiment was conducted during winter *(Rabi)* seasons of 2014-15 and 2015-16 at Punjab Agricultural University, Ludhiana, India to study the effect of potato planting geometry (50 × 15 cm, 65 × 11.5 cm, 70 × 10.7 cm and 75 × 10 cm) and seed tuber size (25-35 mm, 35-45 mm, 45-55 mm) on weed density and biomass, and tuber yield of potato. The potato canopy cover was higher and the weed density and biomass were lower with closer planting geometry of 50 × 15 cm followed by 65 × 11.5 cm. The growth attributes (number of stems/plant and leaf area index), tuber number and tuber yield were not significantly influenced by varying planting geometry. Potato seed tuber size exerted a significant effect on weed infestation resulting in significantly lower weed density and biomass with large sized seed tubers followed by medium sized seed tubers as compared to small sized seed tubers. Growth attributes, tuber number and tuber yield of potato were also significantly higher with large sized seed tubers followed by medium sized tubers compared to small sized tubers. Thus, the potato planting geometry of 50 × 15 cm for manual planting by small and marginal farmers and 65 × 15 cm for mechanized potato production along with medium sized seed tubers are the viable options for effective weed management and optimal potato tuber yield.

Keywords: Planting geometry, Potato, Seed tuber size, Tuber yield, Weed management

INTRODUCTION

Potato (*Solanum tuberosum* L.) is one of the most important commercial vegetable crops widely grown in India and abroad. India is the second largest potato producer in the world with an area of 2.17 million ha and production of 50.2 million tons (FAOSTAT 2021). Among the several constraints in potato cultivation, weeds are the major ones which often pose a serious problem in its production (Yadav *et al.* 2021). Even though potato plants have quick spreading and robust growing nature yet, it is considered as a weak competitor of weeds. Weed management is a challenge for potato production program because of scarcity of labor for hand weeding and limited options for registered herbicides (Bhullar *et al.* 2015). Besides, wider row spacing in potato also favors heavy infestation of variety of weed species by providing favorable conditions for an early start of weeds well before the crop emergence. To achieve high tuber yield, weeds must be controlled at a proper stage, otherwise they reduce tuber yield by 34.4 to 86.0% (Monteiro *et al.* 2011 and Yadav *et al.* 2014), depending on weed growth and competitiveness. Potato producers usually apply early post-emergence herbicides followed by earthing up with tractor-drawn implements to suppress late emerging weeds. Weeds should be controlled in initial phases of crop growth by increasing crop competition through adoption of best crop production practices and making microenvironment conducive to potato crop. In this regard, planting geometry can play a vital role as growth and development of weeds can be suppressed by narrowing planting geometry (Mahajan *et al.* 2016). Closely spaced crop provides good smothering potential on growth and development of weeds due to less availability of space for growth and development, thereby competing for nutrients and moisture better than the weeds. Similarly, a crop's ability to suppress weeds can also be enhanced if crop achieves early vigorous growth. Potato seed tuber size can also play an important role in initial faster crop growth as large sized tubers have more availability of nutrients (stored food) to the plant which help in early emergence and establishment and thus, vigorous and faster growth of potato plants and having crop architecture and microenvironment that smothers weeds. The weeds emerging out under better crop

Punjab Agricultural University, Ludhiana, Punjab 141004, India

[1] KVK, Sri Muktsar Sahib, PAU, Ludhiana (Punjab)

[2] School of Organic Farming, PAU, Ludhiana (Punjab)

* Corresponding author email: vivek33@pau.edu

canopy are generally frail and do not have severe negative effect on tuber productivity. Thus, the present study was undertaken to quantify the influence of potato planting geometry and seed tuber size on weed infestation and productivity of potato crop.

MATERIALS AND METHODS

A field experiment was carried out during winter (*Rabi*) seasons of 2014-15 and 2015-16 at Punjab Agricultural University, Ludhiana, India representing the Indo-Gangetic alluvial plains. The soil (0-15 cm) was loamy sand with neutral pH (7.20), normal electrical conductivity (0.24 mmhos/cm), medium organic carbon (0.60%), low available N (260 kg/ha), and high available P (42.1 kg/ha) and K (400 kg/ha). The experiment was conducted in split plot design with three replications. The main plots consisted of four planting geometries: 50 × 15 cm, 65 × 11.5 cm, 70 × 10.7 cm and 75 × 10 cm, and sub plots three seed sizes (based on diameter): small (25-35 mm), medium (35-45 mm) and large (45-55 mm). Plant population was uniform in all the planting geometries. The sowing of potato cultivar '*Kufri Pukhraj*' was done on 17 October during 2014-15 and 19 October during 2015-16. The seed rate for small, medium and large seed tuber grades was 3.3, 6.0 and 9.3 tons/ha, respectively. The first irrigation was given immediately after sowing to ensure better germination. While irrigating the field, over flooding of the ridges was avoided to prevent subsequent hardening of the soil surface which interferes with emergence, growth, and development of tubers. The crop received 5 and 6 irrigations during first and second year, respectively. Application of paraquat 0.30 g/ha was done at 5% emergence of the potato crop after 10 days of sowing (DAS). Earthing up was done manually at 30 DAS to enhance proper tuberization and weed control. Haulm cutting was done in the first week of January and the crop was harvested in end January. Weed density (grasses, broad-leaved weeds and sedges) was recorded before herbicide application (10 DAS), before earthing up (30 DAS) and after earthing up (45 DAS) while total weed biomass was recorded before earthing up (30 DAS) and after earthing up (45 DAS). Leaf area index (LAI), number of stems/plant and canopy cover (%) were recorded at 30 and 45 DAS. Haulm yields were recorded at haulm cutting stage while the tuber yields and tuber number were recorded at harvesting. The pooled data were subjected to statistical analysis using OPSTAT software (http://14.139.232.166/opstat) developed by CCS Haryana Agricultural University, Hisar (Haryana), India.

RESULTS AND DISCUSSION

Weed flora

The weed flora consisted of *Poa annua* L., *Phalaris minor* Retz., *Cyperus rotundus* L., *Rumex dentatus* L., *Chenopodium album* L., *Malva parviflora* L., *Medicago denticulata* Willd., *Anagallis arvensis* L. and *Coronopus didymus* L.. Similar weed flora in potato was reported by Bhullar *et al.* (2015).

Effect of planting geometry on weeds

The total and species wise density of grasses, sedges, broad-leaved weeds were significantly influenced by planting geometry (**Table 1**). The lowest weed density at 10, 30 and 45 DAS was observed with closer planting geometry (50 × 15 cm) and it was significantly lower than wider planting geometries of 65 × 11.5 cm, 70 × 10.7 cm and 75 × 10 cm. Among the wider planting geometries (65 × 11.5 cm, 70 × 10.7 cm and 75 × 10 cm), the planting geometry 65 × 11.5 cm recorded significantly lower individual as well as total weed density, and the planting geometry 75 × 10 cm recorded the highest weed density at all the growth stages. Similar trend was observed for weed biomass at 30 and 45 DAS. Lower weed density at initial phase of crop (10 DAS) with closer plant geometries of 50 × 15 cm and 65 × 11.5 cm was due to narrow inter-row spacing in these planting geometries as most of the weeds emerged in the furrows but not on the ridges. At the later stages of crop growth i.e. 30 and 45 DAS, the lower weed density and biomass in planting geometries of 50 × 15 cm and 65 × 11.5 cm was mainly due to the higher canopy cover of the crop (**Table 2**) which might have enhanced smothering potential and thus, the competitive ability of the crop. The benefits of reducing row spacing has also been reported earlier in relation to early canopy closure that increases the capability of crops to compete with weeds for sunlight, nutrients and water (Laurie *et al.* 2015) and lowering weed density and biomass (Hussain *et al.* 2016, Kalaichelvi 2008).

Effect of planting geometry on crop growth and tuber yield

The number of stems per plant and LAI at 30 and 45 DAS, tuber yield, tuber number and haulm yield were not affected significantly with planting geometry (**Table 1** and **2**) and that might be due to uniform plant population (13.3 plants/m^2) in all the planting geometries. Further, the number of stems per plant apart from being a varietal character also depends upon seed tuber size and their physiological status, hence, it was not influenced as the cultivar and seed size were uniform in all the planting geometries. Earlier studies have also reported non-significant effect of planting geometries on number of stems per plant (Akassa *et al*. 2014, Dagne 2015 and Kumar *et al*. 2012) and tuber yield (Singh *et al*. 1995, Kumar *et al*. 2001, Kumar 2012 and Kumar *et al.* 2021). However, canopy cover was significantly influenced by planting geometries (**Table 2**), the significantly highest being in closer planting geometry (50 × 15 cm). Among the wider planting geometries (65 × 11.5 cm, 70 × 10.7 cm and 75 × 10 cm), 65 × 11.5 cm recorded significantly higher canopy cover than 75 × 10 cm. Laurie *et al.* (2015) also observed that canopy cover for the narrow planting geometry was faster than that of wider planting geometry.

Effect of seed tuber size on weeds

The seed tuber size had non-significant effect on weed density and weed biomass at 10 DAS (**Table 1**). However, at 30 and 45 DAS, the weed density was significantly influenced by seed tuber size. The significantly lowest weed density was observed with large sized seed tubers than medium and small sized tubers. The medium sized tubers had also significantly lower weed population than small sized tubers. The similar results were observed for total weed biomass at 30 and 45 DAS. The effect of seed tuber size on weed infestation might be due to higher number of stems per plant, LAI and canopy cover (**Table 2**) with medium and large seed tubers. The higher availability of nutrients (stored food) to the plants in large tubers results early emergence and establishment, and thus, more growth and development of plants. This faster canopy closure and vigorous growth helped the crop to be more competitive as compared to the associated weeds.

Effect of potato seed tuber size on crop growth and tuber yield

Potato seed tuber size had a significant influence on number of stems per plant, canopy cover and LAI at 30 and 45 DAS (**Table 2**). All these parameters were significantly higher with large sized seed tubers as compared to medium and small sized seed tubers, the medium sized seed tubers further being better than small sized seed tubers. The higher number of stems per plant with large and medium sized seed tubers might be due to higher number of eyes/tuber which consequently produced higher number of stems per plant (Kumar *et al.* 2015). The higher LAI and canopy cover with large seed tubers might be due to the more availability of nutrients (stored food) to the plant resulting in early emergence and establishment and thus, more growth and development of plants. Nasir and Akassa (2018), Ebrahim *et al.* (2018) and Kumar *et al.* (2021) also reported higher number of stems per plant and LAI with large sized seed tubers.

The significantly highest number of potato tubers was obtained with large sized potato seed tubers than all the other grades of seed tubers (**Table 2**). The medium sized seed tubers had also significantly higher number of tubers than small sized seed tubers. The higher number of tubers per unit area with large and medium sized seed tubers might be due to higher number of eyes on large sized seed tubers which consequently produced higher number of stems per plant and ultimately the higher number of tubers per plant (Kumar *et al.* 2015). Nasir and Akassa (2018), Ebrahim *et al.* (2018) and Kumar *et al.* (2021) also reported higher number of stems and tubers per plant with large sized seed tubers. The highest tuber and haulm yield (42.9 and 17.9 t/ha,

Table 1. Potato planting geometry and seed size effects on weed density and biomass in potato

Treatment	Weed density (no./m^2)												Weed biomass (g/m^2)	
	Before herbicide application (10 DAS)				Before earthing-up (30 DAS)				After earthing-up (45 DAS)				Before earthing-up (30 DAS)	After earthing-up (45 DAS)
	BLW	Grasses	Sedges	Total	BLW	Grasses	Sedges	Total	BLW	Grasses	Sedges	Total		
Planting geometry (cm × cm)														
50 × 15	43.4	61.9	10.6	115.9	37.3	9.8	5.1	52.2	4.6	3.3	2.1	10.0	5.4	2.1
65 × 11.5	71.2	118.2	17.0	206.4	50.8	18.2	6.9	75.9	6.0	5.6	3.1	14.7	12.4	4.9
70 × 10.7	81.0	128.9	19.7	229.6	54.5	22.4	8.2b	85.2	6.9	6.4	4.3	17.7	14.2	6.5
75 × 10	88.2	140.4	23.0	251.7	58.3	26.9	9.6	94.8	8.2	6.8	4.9	19.9	16.0	7.9
LSD (p=0.05)	7.9	11.2	2.3	15.7	6.0	3.7	1.7	6.9	1.5	0.8	0.8	1.8	2.7	1.1
Potato seed size (mm)														
25-35	69.5	111.3	17.5	198.3	58.5	24.5	9.8	92.8	9.1	6.8	4.6	20.4	15.5	6.4
35-45	72.3	111.7	17.8	201.8	50.7	18.8	7.5	77.0	6.3	5.5	3.5	15.3	11.9	5.3
45-55	71.2	114.1	17.3	202.6	41.5	14.7	5.1	61.3	3.9	4.3	2.8	11.0	8.7	4.3
LSD (p=0.05)	NS	NS	NS	NS	4.6	2.4	1.3	6.1	1.3	1.0	0.8	1.4	1.1	0.4

Pooled data over 2 years; DAS = days after sowing; BLW= broad-leaved weeds

Table 2. Planting geometry and potato seed size effects on growth parameters and tuber yield of potato

Treatment	No. of stems/plant		Canopy cover (%)		LAI		Tuber number ('000/ ha)	Tuber yield (t/ha)			Haulm yield (t/ha)		
	Before earthing-up (30 DAS)	After earthing-up (45 DAS)	Before earthing-up (30 DAS)	After earthing-up (45 DAS)	Before earthing-up (30 DAS)	After earthing -up (45 DAS)		2014 -15	2015-16	Pooled	2014 -15	2015 -16	pooled
Planting geometry (cm × cm)													
50 × 15	3.14	3.33	60.6	94.6	2.09	2.76	940.2	41.3	42.3	41.8	16.6	16.3	16.5
65 × 11.5	3.31	3.67	53.8	87.8	2.04	2.64	918.4	41.6	41.7	41.7	16.1	16.4	16.3
70 × 10.7	3.69	3.78	51.2	83.9	1.99	2.70	940.4	42.1	41.9	42.0	16.4	16.1	16.3
75 × 10	3.42	3.50	48.3	80.8	2.01	2.56	899.7	41.2	40.5	40.8	17.0	16.2	16.6
LSD (p=0.05)	NS	NS	4.97	5.13	NS	NS	NS	NS	NS	NS	NS	NS	NS
Seed size (mm)													
25-35	2.63	2.79	46.4	83.2	1.68	2.27	836.1	39.3	39.1	39.2	14.9	14.6	14.7
35-45	3.46	3.67	52.5	86.7	2.15	2.78	953.9	42.4	42.8	42.6	16.7	16.5	16.6
45-55	4.08	4.25	61.6	90.4	2.26	2.95	984.0	42.9	42.9	42.9	18.1	17.7	17.9
LSD (p=0.05)	0.43	0.35	2.63	2.12	0.14	0.16	23.6	1.5	1.3	0.9	2.0	1.9	1.3

Pooled data over 2 years; DAS = days after sowing; LAI = leaf area index

Table 3. Correlation among potato growth attributes, weed density and biomass, and potato tuber yield

Treatment	LAI		Stems (no./plant)		Canopy cover (%)		Weed density (no./m^2)			Weed biomass (g/m^2)	
	30 DAS	45 DAS	30 DAS	45 DAS	30 DAS	45 DAS	10 DAS	30 DAS	45 DAS	30 DAS	45 DAS
LAI (45 DAS)	0.946**										
Stem no./plant (30 DAS)	0.823**	0.880**									
Stem no./plant (45 DAS)	0.799**	0.851**	0.946**								
Canopy cover (%) (30 DAS)	0.748**	0.818**	0.588*	0.631*							
Canopy cover (%) (45 DAS)	0.563^{NS}	0.639*	0.284^{NS}	0.293^{NS}	0.882**						
Weed density (no./m^2) (10 DAS)	-0.100^{NS}	-0.156^{NS}	0.276^{NS}	0.219^{NS}	-0.557^{NS}	-0.815**					
Weed density (no./m^2) (30 DAS)	-0.652*	-0.739**	-0.418^{NS}	-0.437^{NS}	-0.935**	-0.978**	0.733**				
Weed density (no./m^2) (45 DAS)	-0.727*	-0.814*	-0.525^{NS}	-0.530^{NS}	-0.954**	-0.956**	0.635**	0.981**			
Weed biomass (g/m^2) (30 DAS)	-0.590*	-0.688*	-0.339^{NS}	-0.348^{NS}	-0.922**	-0.970**	0.790**	0.977**	0.960**		
Weed biomass (g/m^2) (45 DAS)	-0.464^{NS}	-0.531^{NS}	-0.137^{NS}	-0.178^{NS}	-0.826**	-0.984**	0.891**	0.946**	0.902**	0.945**	
Potato tuber yield (t/ha)	0.922**	0.960**	0.841**	0.870**	0.731**	0.531^{NS}	-0.083^{NS}	-0.630*	-0.718*	-0.578*	-0.444^{NS}

*Significant at p= 0.05 level; **Significant at p = 0.01 level; NS = non-significant; LAI = leaf area index; DAS = days after seeding

respectively) were obatined with the large seed tubers and it was statistically at par with the medium seed tubers (42.6 and 16.6 t/ha, respectively) but significantly higher than that with small tubers. The medium seed tubers also recorded significantly higher tuber and haulm yield than small seed tubers. Increase in tuber and haulm yield with medium and large seed tubers might be due to increase in number of tubers and stems per plant. Ebrahim *et al.* (2018) also reported higher total tuber yield with medium to large sizes.

Correlation among growth attributes, weed infestation and tuber yield

LAI at 30 and 45 DAS was significantly and positively correlated with number of stems per plant and canopy cover except LAI at 30 DAS which exhibited a positive but non-significant correlation with canopy cover at 45 DAS (**Table 3**). LAI at 30 and 45 DAS had significant negative correlation with weed density at 30 and 45 DAS and with weed biomass at 30 DAS; whereas it had negative but non-significant correlation with weed biomass at 45 DAS. The number of stems per plant at 30 and 45 DAS had a significant and positive correlation with canopy cover at 30 DAS, however, it had positive but non-significant correlation with canopy cover at 45 DAS. Canopy cover at both the stages exhibited a significant negative correlation with weed density and weed biomass. Weed density at 30 and 45 DAS had a highly significant and positive correlation with each other and with weed biomass at both the stages. Similarly, weed density at 10 DAS had also significant and positive correlation with weed density and biomass at 30 and 45 DAS. Potato tuber yield showed a significant positive correlation with potato LAI and number of stems per plant at 30 and 45 DAS and with canopy cover at 30 DAS. However, potato tuber yield showed a significant negative correlation with weed density at 30 and 45 DAS and weed biomass at 30 DAS.

Conclusion

The closer planting geometry in combination with medium potato seed size tubers can be used for better weed management and higher potato tuber yields. Thus, the potato planting geometry of 50 × 15 cm for manual planting by small farmers and 65 × 15 cm for mechanized potato production along with medium sized potato seed tubers (35-45mm) may be used as a viable component of integrated weed management for higher potato productivity.

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RESEARCH ARTICLE

Effect of irrigation levels and weed management practices on weeds, water productivity and yield of cauliflower

Anil Kumar, Sidharth Baghla, Navneet Kaur*, Tigangam P. Gangmei, S.S. Rana and Sandeep Manuja

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ABSTRACT

Water shortage and weed infestation are major constraints in vegetable production. Micro-irrigation integrated with weed management practices is one way to maximize the yield and water productivity in crops. A field trial was conducted during *Rabi* seasons of 2018-19, 2019-20 and 2020-21 at the Water Management Farm of CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur to study the effect of irrigation levels and weed management practices on weeds, crop and water productivity in cauliflower. The experiment was laid out in split plot design with three irrigation levels (0.9 PE, 0.7 PE and 0.5 PE) in main plots and four weed management practices (black polythene mulch, pre-plant incorporation (PPI) of pendimethalin 1.5 kg/ha followed by (*fb*) hand weeding, pendimethalin 1.5 kg/ha PPI *fb* straw mulching and weedy check) in sub plots. The treatments were replicated thrice. The irrigation given to crop at 0.9 PE level proved to be better in terms of yield and net returns in cauliflower. Black polythene mulch resulted in efficient weed control and improving crop developmental parameters and yield attributes. There was progressive increase in weed density and biomass with increase in irrigation level, with least in lower irrigation level of 0.5PE. It is concluded that higher crop productivity and returns in cauliflower can be obtained by using black polythene mulch and irrigation applied at 0.9PE level. However, under limited water availability, the best alternative will be applying irrigation at 0.7 PE level and using black polythene mulch.

Keywords: Cauliflower, Irrigation levels, Mulching, Water productivity, Weed management

INTRODUCTION

Cauliflower (*Brassica oleracea* L. var. *botrytis*), one of the most important vegetable crop in world, belongs to family Brassicaceae. In India, it covers an area of 473 thousand hectares with production and productivity of 9225 thousand tonnes and 19.5 t/ha, respectively (Anonymous 2020-21). It is usually grown for its white edible curd, which is used in number of preparations like vegetable, curry, pickle, and soup. Cauliflower is highly nutritive containing protein, minerals (potassium, calcium, and sodium), fibre, fat, carbohydrates and vitamins. The crop grows well in range of 15-21°C and prefers soil rich in organic matter with pH range of 5.5-6.5 (Savita *et al*. 2014). It is medium rooted crop and requires enough moisture in root zone.

Cauliflower being a sensitive crop, requires frequent irrigation to keep the crop vigorous. Both irrigation and weed management are important agronomic practices for successful production of crop (Sen *et al.* 2018, Kumari and Devi 2020). The management of these factors not only improves the efficiency of the system, but also reduces cost and environmental problems. Water table is depleting day by day at an alarming rate. This is due to traditional irrigation methods of flooding, which results in reducing water use efficiency and overexploitation of groundwater (Sandhu *et al.* 2019). The demand for water is expected to rise in future because of increasing world population, increase in irrigated area and climate change. The only key to mitigate the water shortage in agriculture is to increase agricultural water productivity. Micro-irrigation has emerged as one of the best alternatives to conventional irrigation which applies water directly in the root zone of plants, improves water productivity under low water retention soils, saves more than 60% water and increases the yield by 30-40% over traditional methods (Magar and Nandgude 2005). Drip irrigation was proved beneficial in fruit and vegetable crops to attain high economic return. Along with irrigation method, scheduling of irrigation based on consumptive use of crop can also be helpful in improving water use efficiency.

Weeds are important cause of reduced cauliflower productivity (Qasem 2007). Frequent irrigations are required in cauliflower due to high evapotranspiration demand, which support weed growth and reduces crop yield. Weeds remove the

Department of Agronomy, CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur, (176062) H.P. India.

* Corresponding author email: kaurn281295@gmail.com

available nutrients in large quantity from soil and reduce crop growth, reduce the yield, and impair the quality of produce. Thus, weed management needs special attention. Weeds are controlled effectively by hand weeding traditionally. But shortage and high cost of labour makes weed control more challenging making farmers to opt for use of herbicides, which poses threat to environment and natural resources. Use of organic mulches for weed management was experimented (Agarwal *et al.* 2022), but their high volume and transportation cost make their use limited. The use of polyethylene mulch is an effective mean for controlling weed population (Sen *et al.* 2018). Moreover, it is more efficient as compared to organic mulches (Sathiyamurthy *et al.* 2017).

In many parts of North-western Himalayas, water and weed management are the major constraints faced in cultivation of cauliflower due to reasons like erratic rain and high evaporative demand. However, research efforts on integration of micro-irrigation with proper weed management practices to improve water and cauliflower and productivity are limited. Hence, this study was carried out to evaluate and identify optimal irrigation levels and weed management treatments to effectively manage weeds and attain economically optimal water productivity, net returns, and yield of cauliflower.

MATERIALS AND METHODS

The study was conducted in *Rabi* season 2018-19, 2019-20 and 2020-21 at the Water Management Research Farm of Department of Soil Science, CSK Himachal Pradesh Krishi Vishvavidyalaya, Palampur. It is located at 32° 06 ´ 39.1´´ N latitude and 76° 32´ 10.5´´ E longitude and at an elevation of 1290 m above mean sea level. The location represents the sub temperate mid-hill zone of Himachal Pradesh. Analysis of physical and chemical properties of soil of the experimental site was done before execution of the experiment. The soil of experimental area was silty clay loam in texture with 17.5% sand, 50.0% silt and 32.5% clay and slightly acidic (pH=5.3) in nature. It was medium in available N (273.48 kg/ha), high in phosphorus (33.08kg/ha) and low in available K (121.44 kg/ha).

Cauliflower variety used in the experiment was *Palam Uphaar*. The recommended package of practices for planting, nutrients and disease pest and other management were followed, whereas the weed and irrigation treatments were applied as per experimental treatments. There were twelve treatment combinations comprising of three irrigation levels in main plots (irrigation at 0.9 PE, 0.7 PE and 0.5 PE and four weed management treatments in sub plots (black polythene mulch; pre-plant incorporation (PPI) of pendimethalin 1.5 kg/ha followed by (*fb*) 1 hand weeding at 40-45 days after transplanting (DAT); pendimethalin 1.5 kg/ha PPI *fb* straw mulching and weedy check) in split-plot design with three replications.

Irrigation scheduling

The irrigation schedule as per different irrigation levels tested was developed using the daily climatic data of the meteorological observatory of Department of Agronomy (CSKHPKV Palampur). The Pan Evaporation method was used to determine reference evapotranspiration (ETO). To relate pan evaporation to ETO, USWB class A open pan data on evaporation and empirically derived pan coefficient was used. The following formula was used to calculate crop evapotranspiration:

ETO= Kpan X Epan {Kpan=pan coefficient Epan= evaporation (mm/day)}

ETC= ETo X Kc {ETc= crop evapotranspiration (mm/day) KC= crop coefficient}

The net depth of water applied for each irrigation as per level was worked out using the equation:

Dn=ETo X KC X % Wetted area

The gross depth of water to be applied was computed using the equation

Dg=Dn/EU (Dg = gross depth of irrigation (mm/day) D n = Net depth of water (mm/day) EU = Average emission uniformity (fraction)

The volume of water to be applied per treatment plot was worked out using the equation

V= Dg X A (A= Area of bed m^2)

The time of operation (TO) of the drip irrigation system for each plot was calculated as follow:

TO= V/Q Where (TO= time of operation V= Volume of water applied litre day^{-1} Q= water applied per bed lph)

Q= q X n (q= average emitter discharge lph, N = number of emitters in the bed)

The irrigation was scheduled at an interval of 3 days. The average discharge per emitter was 2 lph and the numbers of emitters were 36.

Weed management practices

The herbicide pendimethalin was applied as pre-plant incorporation 24 hours before transplanting. After cleaning the plots, the plastic mulch (black polythene sheet: 25 micron) was laid before 7 days of transplanting and holes were made at desired spacing for transplanting. In straw mulch treatment, 5 t/ha mulching material from farm wastes was used and applied after herbicide application.

Observations

In each plot, data on weed density and biomass was recorded at monthly intervals from 50 cm × 50 cm quadrat placed randomly at two places in each of the plot. The data obtained was converted to number and grams per square meter, respectively by multiplying the average count and dry weight of the weeds with factor 4.

At the time of curd maturity, only fully grown leaves per plant were recorded, while the small leaves in the inner whorl were not counted to obtain number of leaves per plant. The length of the stalk was noted by measuring the length from the ground level to the position of the first leaf with the help of measuring scale. Days taken to curd initiation was recorded by counting the number of days from the date of transplanting to the day when 50% initiation of curds was achieved. Days taken to marketable curd maturity was recorded by counting the number of days from the date of transplanting to the day when 50% of curds attained a marketable size and at this stage; the younger inner leaves covering the curd just began to separate. The diameter of the curd (cm) was measured with the help of a thread followed by scale. Gross weight (g/plant) was recorded at the time of marketable maturity which included the weight of the curd along with leaves and stalk. After harvesting, fresh weight of curd (g) was recorded. Marketable curd (%) was calculated as the ratio of marketable curd to the number of curds and multiplied by 100. The pooled marketable curd yield obtained from each plot was converted into kg/ha. Water productivity (kg/m^3) was calculated by dividing the yield (kg/ha) obtained by total water use (m^3/ha).

The data generated from field was subjected to statistical analysis using the technique of analysis of variance for split-plot design for the interpretation of results. The treatment differences were compared at 5 per cent level of significance (p=0.05).

RESULTS AND DISCUSSION

Weed density

The pooled data of three years on effect of irrigation levels and weed management treatments on weed density in cauliflower (**Table 1**) indicated that at all stages (30, 60 and 90 DAT) significantly higher weed density with 0.9 PE irrigation level was observed as compared to other levels. At 30 DAT, when irrigation level was reduced to 0.7 PE and 0.5 PE, weed density was reduced with both levels at par with each other. Whereas, at 60 and 90 DAT, significantly lower weed density was recorded in 0.5 PE irrigation level over other two levels, which could be attributed to the weed seed bank to germinate and grow vigorously when there was enough moisture in soil as reported by Kishore *et al.* (2018).

Weed density at all observed stages revealed that use of black polythene mulch resulted in significantly lower weed density when compared to other treatments. The highest weed density was found in weedy check treatment at all the stages. Amongst the other treatments, pendimethalin 1.5 kg/ha PPI *fb* straw mulching resulted in lower weed density at 30 and 90 DAT as compared to pendimethalin 1.5 kg/ha PPI *fb* hand weeding. Both the treatments were at par with each other at 60 DAT due to reduction in germination of weed seeds with mulching as reported by Ferdous *et al.* (2017) with plastic mulching in cauliflower.

Weed biomass

It was found that weed dry matter decreased with decrease in irrigation level. At 30 DAT, significantly higher weed dry matter was noted in 0.9 PE irrigation level which was statistically at par with 0.7 PE (**Table 1**). Whereas, at 60 and 90 DAT, 0.9 PE resulted in significantly higher weed biomass over other levels. In all the stages of crop, weed dry matter was lowest with 0.5 PE irrigation level.

Effect of weed management was similar as reflected in weed count. Use of black polythene mulch resulted in significantly lower weed biomass. While the highest weed biomass was recorded in weedy check at all stages. The results agree with Suresh *et al.* (2014) who reported the beneficial effect of black polythene mulch on weed suppression in cauliflower.

Effect on cauliflower

Significantly higher number of leaves, higher stalk length, higher curd diameter, individual curd weight, marketable curd and gross weight per plant were recorded at 0.9 PE as compared to 0.7 and 0.5 PE (**Table 2** and **3**). Whereas, lowest number was seen in 0.5 PE as observed by Bozkurt *et al.* (2011), Yu *et al.* (2006), Abdelkhalik *et al.* (2019) pertaining to number of leaves, stalk length, yield attributes, respectively. Lesser number of days were taken in curd initiation and marketable curd maturity at 0.9 PE level (**Table 2**). Sohail *et al.* (2018) and Salman *et al.* (2018) reported similar results in cauliflower.

In case of weed management practices, significantly higher number of leaves, stalk length, lesser number of days taken for curd initiation and to marketable curd maturity were observed with black polythene mulch which was statistically at par with pendimethalin 1.5 kg/ha followed by straw mulching and pendimethalin 1.5 kg/ha followed by hand weeding (**Table 2**). Significantly higher curd diameter (11.71 cm), gross weight per plant (680.22 g), individual curd weight (516 g) and marketable curd (88%) were also noted with black polythene mulch when compared to other treatments (**Table 3**). Weedy check resulted in lowest yield attributes. These results are in line with those reported by Sen *et al.* (2018), Qasem (2009), Kumar *et al.* (2019) pertaining to leaves, stalk length, days to curd initiation, days to marketable curd maturity, yield attributes, respectively.

Cauliflower yield

The increase in irrigation level from 0.5 PE to 0.7 PE and 0.9 PE significantly increased the marketable yield of cauliflower (**Table 3**). The percent increase at 0.7 PE and 0.9 PE over 0.5 PE was 72.2 and 88.8, respectively. The highest yield recorded was with 0.9 PE (12801 kg/ha). Micro irrigation at 0.9 PE provides sufficient moisture in crop root zone and increase the availability of nutrients resulting in increased yield of crop as reported by Bozkurt *et al.* (2011).

Significantly higher cauliflower yield was obtained under black polythene mulch (14464 kg/ha) which was followed by weed management practice of pendimethalin 1.5 kg/ha PPI *fb* straw mulching (11808 kg/ha). The use of black polythene mulch and pendimethalin 1.5 kg/ha *fb* straw mulch as weed management practice increased the curd yield by 191 and 132%, respectively over weedy check. This could be attributed to optimum moisture and temperature conditions maintained by mulching that suppressed the weed density and improved crop yield as reported by Ahmed *et al.* (2020).

Table 1. Effect of irrigation levels and weed management treatments on weed density and biomass (pooled data of 3 years)

Treatment	Weed density(no./m^2)			Weed biomass (g/m^2)		
	30 DAT	60 DAT	90 DAT	30 DAT	60 DAT	90 DAT
Irrigation level						
0.9PE	(42)5.90	(41)5.81	(58)6.93	(26)4.56	(25)4.83	(49)6.34
0.7PE	(32)5.07	(34)5.26	(40)5.77	(22)4.37	(22)4.42	(43)6.00
0.5PE	(25)4.47	(26)4.62	(34)5.17	(17)3.76	(15)3.71	(36)5.38
LSD (p=0.05%)	0.72	0.44	0.40	0.47	0.34	0.31
Weed management						
Black polythene mulch	(1)1.25	(4)2.00	(3)1.88	(0)0.92	(5)2.30	(4)2.04
Pendimethalin 1.5 kg/ha PPI *fb* 1 HW at 40-45 DAT	(36)5.95	(25)4.47	(47)6.79	(22)4.69	(14)3.78	(43)6.54
Pendimethalin at 1.5 kg/ha PPI *fb* straw mulching	(26)5.12	(23)4.82	(29)5.40	(25)5.02	(26)5.10	(27)5.21
Weedy check	(68)8.27	(84)9.24	(96)9.76	(40)6.29	(37)6.11	(97)9.85
LSD (p=0.05%)	0.37	0.55	0.51	0.50	0.40	0.48

Data subjected to $\sqrt{x+0.5}$ transformation and figures in parentheses are original values; PPI: pre-plant incorporation; HW: hand weeding; DAT: days after transplanting

Table 2. Effect of irrigation levels and weed management treatments on developmental stages of cauliflower (pooled data of 3 years)

Treatment	No. of leaves at maturity	Stalk length (cm)	Days to curd initiation	Days to marketable curd maturity
Irrigation level				
0.9PE	22	7.20	75	87
0.7PE	20	4.71	76	87
0.5PE	15	4.06	79	93
LSD (p=0.05)	1.79	0.25	1.15	1.92
Weed management				
Black polythene mulch	20	5.44	75	87
Pendimethalin 1.5 kg/ha PPI fb 1 HW at 40-45 DAT	19	3.91	77	91
Pendimethalin at 1.5 kg/ha PPI fb straw mulching	20	5.10	75	87
Weedy check	17	3.76	79	91
LSD (p=0.05)	1.53	0.55	1.72	3.08

Interaction effect of irrigation levels and weed management practices on yield

Significantly higher curd yield was obtained when black polythene mulch was used as weed management practice with an irrigation level of 0.9 PE over all other combinations (**Table 4**). Black polythene mulch resulted in better moisture utilization and suppressed weed growth, thus increasing crop yield.

Net returns

The net returns increased by 34 and 38% with irrigation application level of 0.7 PE and 0.9 PE, respectively over 0.5PE (**Table 3**). Higher net returns in these treatments could be due to higher yield obtained because of optimum moisture in root zone.

Among weed management practices, pendimethalin 1.5 kg/ha with straw mulching gave significantly higher net returns (80625 ₹/ha) which was at par with pendimethalin *fb* hand weeding (80336 ₹/ha) and black polythene mulch (75974 ₹/ha). This might be due to higher cost of black polythene mulch. The results are in close conformity with those reported by Vazquez *et al.* (2010).

Interaction effect of irrigation levels and weed management practices on net returns

At 0.9 PE irrigation level, black polythene mulch gave significantly higher net returns over other weed management practices (**Table 4**) due to less weed competition and optimum soil, air, water ratio in these treatments which is also supported by Salim *et al.* (2008).

Significantly higher net returns were obtained with black polythene mulch at 0.7 PE level, which was at par with both, pendimethalin followed by straw mulching and pendimethalin followed by hand weeding. Whereas, at 0.5 PE, pendimethalin followed by straw mulching proved to be better which was at par with pendimethalin followed by hand weeding.

Water productivity

The highest water productivity of 2.59 kg curd yield /m^3 water used was obtained when crop was given irrigation of 0.7PE level (**Table 3**). It was further observed that the increase in irrigation level from 0.5PE to 0.7PE significantly increased the water productivity. Further increase in irrigation level to 0.9PE significantly decreased the water productivity as compared to the productivity obtained with 0.7 PE irrigation although it was higher than the water productivity from 0.5PE level. Highest water productivity at a level lower than highest irrigation may be attributed to optimum level for maximum incremental yield. Similar results were reported by Harris *et al.* (2014) in cabbage.

Water productivity was significantly higher when black polyethylene mulch (2.98 kg/m^3) was used to suppress weeds which was followed by pendimethalin 1.5 kg/ha with straw mulching. The findings are in agreement with Kumari *et al.* (2020).

Interaction effect of irrigation levels and weed management practices on water productivity

Significantly higher water productivity was obtained when black polythene mulch was used and crop was given irrigation at 0.7 PE level when compared to all other combinations of irrigation levels and weed management practices (**Table 4**). This could be attributed to reduced evaporation and increased water harvesting and yield in this treatment resulting in higher water productivity.

It was concluded that significantly higher marketable cauliflower curd yield and net returns can be obtained with irrigation application at 0.9PE level

Table 3. Effect of irrigation levels and weed management practices on yield attributes in cauliflower (pooled data of three years)

Treatment	Curd diameter (cm)	Gross weight per plant(g)	Individual curd weight(g)	Marketable curd (%)	Marketable yield (kg/ha)	Net returns Rs/ha	Water productivity (kg/m^3)
Irrigation level							
0.9PE	11.30	608.67	453	77	12801	88128	2.31
0.7PE	10.76	600	432	75	12191	78979	2.59
0.5PE	8.50	471.33	343	64	7077	2256	1.82
LSD (p=0.05)	0.44	32.16	16.62	0.82	439	6599	0.07
Weed management							
Black polythene mulch	11.71	680.22	516	88	14464	75974	2.98
Pendimethalin 1.5 kg/ha PPI *fb* 1 HW at 40-45 DAT	10.06	598.56	388	72	11522	80336	2.39
Pendimethalin at 1.5 kg/ha PPI *fb* straw mulching	10.91	637.11	444	83	11808	80625	2.52
Weedy check	8.08	324.11	288	46	4965	-11117	1.07
LSD (p=0.05)	0.45	24.42	24.86	2.29	224	5836	0.04

Table 4. Interaction effect of irrigation level and weed management practices on yield, net returns and water productivity (pooled data of three years)

Weed management treatments	Yield (kg/ha)			
	Irrigation level			
	0.9PE	0.7PE	0.5PE	Mean
Black polythene mulch	17654	16717	9022	14464
Pendimethalin 1.5 kg/ha PPI *fb* 1 HW at 40-45 DAT	13883	13263	7421	11522
Pendimethalin at 1.5 kg/ha PPI *fb* straw mulching	13952	13679	7793	11808
Weedy check	5717	5107	4071	4965
Mean	12801	12191	7077	
LSD (p=0.05)	Irrigation level= 439		I×W=389	
	Weed management practice = 224		I×W*=550	
	Net returns (x10^3 `/ha)			
Weed management/irrigation	0.9PE	0.7PE	0.5PE	Mean
Black polythene mulch	123.82	109.77	-5.66	75.97
Pendimethalin 1.5 kg/ha PPI *fb* 1 HW at 40-45 DAT	115.75	106.45	18.82	80.34
Pendimethalin at 1.5 kg/ha PPI *fb* straw mulching	112.78	108.69	20.41	80.62
Weedy check	0.17	-8.99	-24.53	-11.12
Mean	88.3	78.98	2.26	
LSD (p=0.05)	Irrigation level= 6.60		I×W=5.84	
	Weed management practice = 3.37		I×W*=8.26	
	Water productivity(kg/m^3)			
Weed management/irrigation	0.9PE	0.7PE	0.5PE	Mean
Black polythene mulch	3.13	3.51	2.29	2.98
Pendimethalin 1.5 kg/ha PPI *fb* 1 HW at 40-45 DAT	2.48	2.80	1.91	2.39
Pendimethalin at 1.5 kg/ha PPI *fb* straw mulching	2.58	2.96	2.01	2.52
Weedy check	1.04	1.10	1.06	1.07
Mean	2.31	2.59	1.82	
LSD (p=0.05)	Irrigation level= 0.074		I×W=0.077	
	Weed management practice = 0.044		I×W*=0.104	

and using black polythene mulch to manage weeds. Among the tested weed management treatments, pendimethalin with straw mulching proved to be more economical as compared to polythene mulch. The highest water productivity was obtained with irrigation level of 0.7PE and black polythene mulch and hence drip irrigation at level of 0.7 PE along with use of black polythene mulch can be adopted for limited water available condition.

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RESEARCH ARTICLE

Occurrence and distribution of *Alternanthera bettzickiana* (Regel) Voss., an invasive weed in the uplands of Kerala

Teresa Alex[1]* and Meera V. Menon[2]

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ABSTRACT

A survey was conducted in the uplands (or garden lands) along roadsides, uncultivated areas and in wastelands in seven agro-ecological units (AEUs) representing the central zone of Kerala during 2020 and 2021 to assess the occurrence and invasiveness of *Alternanthera bettzickiana* (Regel) Voss. The weed exhibited highest summed dominance ratio and importance value index in all but one of the AEUs. Diversity indices like Shannon-Wiener index, Simpson's diversity index and Evenness index were lower for a particular region (AEU 9), showing the dominance of this weed species there. The density of *A. bettzickiana* was positively correlated with nitrogen content, and dry matter production was influenced by both organic carbon and nitrogen content of the soil. The study concluded that *A. bettzickiana* is gaining the status of problematic weed in the central parts of Kerala, dominating mostly in uncultivated areas with occational occurrence observed in cropped lands also. Hence, efforts to prevent its spread need to be taken up by concerned authorities.

Keywords: *Alternanthera bettzickiana,* Distribution, Dominance, Invasive weed, Survey

INTRODUCTION

Biological invasion by plants, insects and mammals is a global concern due to the environmental, ecological and economic issues caused by them and is considered as the second worst threat to biological diversity after habitat fragmentation. Among these, invasive plants are a major threat to global agricultural production. An invasive plant species is deliberately or unintentionally introduced into an area outside its natural habitat, which alters the native biological diversity. Such plants expand into the native plant communities and quickly broaden their spatial distribution (Richardson *et al.* 2000). They possess various biological and physiological characteristics that favor their invasiveness, including the capability to produce large number of minute light weight seeds which aid in rapid dispersal, higher competitive ability, lack of seed dormancy, absence of natural enemies, release of allelopathic chemicals and greater physiological adaptability to new environments (Shah *et al.* 2020).

Alternanthera bettzickiana (Regel) Voss. is a spreading perennial herb, which is acquiring the status of an invasive weed in many parts of the world. It belongs to the family Amaranthaceae and is commonly known as calico plant. It has its origin in tropical America and now successfully inhabited various parts of Asia. In India, it is found throughout the plains, degraded deciduous forests and wastelands in the southern and north-eastern states, especially in Kerala, Karnataka, Tamil Nadu and Assam (Rao *et al.* 2019). Rapid spreading behavior of this weed often causes alteration of species structure of plant communities in the invaded areas (Thangamani *et al.* 2019). *A. bettzickiana* is now appearing as a major weed in vegetable, fruits and tuber growing areas, and also in unutilized lands in Kerala. Since it has started gaining attention only recently, systematic studies on the extent of its wide occurrence in Kerala have not been attempted. Hence a survey was conducted to study the occurrence and the extent of distribution of *A. bettzickiana* in the central zone of Kerala.

MATERIALS AND METHODS

A survey was conducted in the central zone of Kerala which includes Agro- Ecological Units (AEUs) 5, 6, 9, 10, 11, 15 and 22 covering Malappuram, Palakkad, Thrissur and Ernakulam districts (**Figure 1**). The survey was conducted from October to December in 2020 and 2021 in the uplands or garden lands where water stagnation did not occur. The wetlands, where rice is cultivated, were not included in the survey. Quadrats of size 0.5 x 0.5 m were placed randomly in uncultivated lands

[1] College of Agriculture, Kerala Agricultural University, Thrissur, Kerala 680656, India
[2] Cashew Research Station, Kerala Agricultural University, Thrissur, Kerala 680656, India
* Corresponding author email: teresaalex93@gmail.com

including road sides and wastelands of each location of the surveyed areas. Cropped lands were observed for the incidence of the weed but no data regarding density and dominance of weed were recorded. Locations for survey within AEUs were randomly selected and a total of 20 quadrats were sampled at each AEU. Within each quadrat, the number of *A. bettzickiana* and other weed species were recorded separately and various measures indicating weed abundance like density, relative density, frequency, relative frequency, relative abundance, summed dominance ratio and importance value index were worked out for each species as per the standard methods proposed by Misra (1968), Odum (1971) and Raju (1977). Weed survey data of both the years was pooled for each locality. Plants of *A. bettzickiana* and soil samples were collected from each location. The data presented here pertains to uncultivated areas of surveyed AEUs. General climatic parameters like mean annual temperature, annual rainfall and soil type are depicted in **Table 1** and surveyed locations are depicted in **Figure 1.**

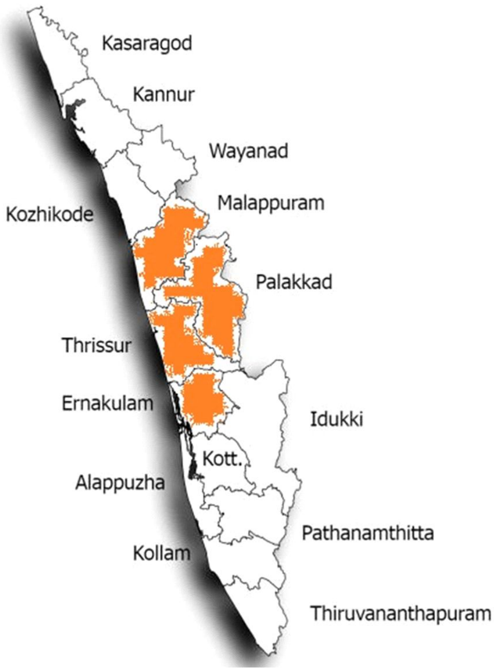

Figure1. Representation of surveyed locations

Table 1. Climatic parameters and soil types of surveyed AEUs

Agro-ecological unit	Mean annual temperature (°C)	Rainfall (mm)	Soil type
AEU 5	27.6	3,049	Sandy loam
AEU 6	27.8	2,902	Gravelly clay
AEU 9	26.5	2,827	Laterite soil
AEU 10	27.6	2,795	Gravelly clay
AEU 11	27.9	3,006	Gravelly clay
AEU 15	26.2	3,460	Acidic clay soil
AEU 22	27.6	1,196	Non gravelly loams

(KAU 2020)

Community diversity indices of the surveyed areas like species richness (R: total number of species in a given area), Shannon-Wiener diversity index (H'), Simpson's diversity index (C), Simpson's dominance index (C') and Evenness index (J) were worked out using following equations

$$\text{Shannon's diversity index } H' = -\sum_{i=1}^{K} Pi\ lnPi$$

$$\text{Simpson's diversity index } (C) = \sum_{i=1}^{K} Pi^{\,2}$$

$$\text{Simpson's dominance index } (C') = 1 - \sum_{i=1}^{K} Pi^{2}$$

$$\text{Evenness index} = \mathrm{H}'/\log \mathrm{R}$$

Where, Pi is the proportion of number of individuals of species 'i' to the total number of individuals of all species in the quadrat (K)

Chemical characteristics of the soil samples (pH, EC, available nitrogen, phosphorus and potassium) collected from surveyed locations were analyzed using standard procedures. A correlation analysis between densities of *A. bettzickiana* and soil characters was performed.

RESULTS AND DISCUSSION

Phytosociological indices indicated that *A. bettzickiana* was a dominant weed in all the surveyed areas except in AEU 5 which is a part of Ernakulam district. A total of 15 weed species were observed in uncultivated lands of AEU 5 and 9, 21 in AEU 6 and 10, 23 in AEU 11 and 17 each in AEU 15 and 22. In majority of these areas *A. bettzickiana* recorded highest density, frequency, relative density, relative frequency, importance value index and summed dominance ratio. Broad-leaved weeds *Synedrella nodiflora*, *Ageratum conyzoides*, *Cleome burmanii* and *Mitracarpus hirtus*, grasses like *Cynodon dactylon* and *Dactyloctenium aegyptium*, and the sedge *Cyperus rotundus* were also found to be dominant.

Lowest density of *A. bettzickiana* was recorded in AEU 5 (2.6 plants/ m^2) which covered parts of Ernakulam district and highest (5.1 plants/ m^2) was recorded in AEU 9 and 10 (**Table 2**) in the districts of Ernakulam and Palakkad. Various factors like season of the year, climate, soil texture and structure, soil chemical characters *etc*. influence the density of a weed species in an area (Bukun and Guler 2005). Difference in density of *A. bettzickiana* at various locations observed in this survey may be due to the variation of soil in organic carbon content and soil nutrient status (**Table 7**).

Table 2. Density and frequency of weed species observed in surveyed locations

Weed species	Density (no./m^2) AEU							Frequency (%) AEU						
	5	6	9	10	11	15	22	5	6	9	10	11	15	22
Aerva lanata	-	-	0.2	-	0.4	-	0.5	-	-	10.0	-	15.0	-	15.0
Ageratum conyzoides	1.3	-	1.2	1.6	-	2.2	1.3	47.5	-	47.5	45.0	-	57.5	37.5
Alternanthera bettzickiana	2.6	4.4	5.1	5.1	4.5	5.0	4.5	62.5	82.5	82.5	75.0	80.0	80.0	80.0
Alternanthera brasiliana	-	0.5	-	-	-	-	-	-	15.0	-	-	-	-	-
Axonopus compressus	-	-	-	0.4	0.8	-	-	-	-	-	15.0	30.0	-	-
Bidens pilosa	-	-	0.7	-	-	1.6	-	-	-	25.0	-	-	50.0	-
Biophytum sensitivum	1.3	0.7	-	-	0.7	-	0.9	35.0	20.0	-	-	20.0	-	27.5
Borreria hispida	-	-	-	-	-	2.1	-	-	-	-	-	-	40	-
Brachiaria distachya	-	-	0.9	-	-	-	-	-	-	30.0	-	-	-	-
Cardiospermum helicacabum	-	2.0	-	-	0.7	-	-	-	65.0	-	-	20.0	-	-
Centrosema pubescens	-	0.4	-	0.4	0.3	-	0.5	-	15.0	-	15.0	10.0	-	30.0
Chromolaena odorata	-	-	-	-	0.2	0.3	0.7	-	-	-	-	10.0	20.0	25.0
Cleome burmannii	-	0.8	0.5	1.3	1.2	0.8	-	-	32.5	22.5	45.0	37.5	35.0	-
Colocasia esculenta	0.7	-	-	-	-	-	-	40.0	-	-	-	-	-	-
Commelina sp.	-	-	-	0.5	0.8	0.6	1.2	-	-	-	15	25.0	22.5	40.0
Cyclea peltata	-	-	-	0.2	-	-	-	-	-	-	-	15.0	-	-
Cynodon dactylon	2.4	2.2	1.3	2.6	1.9	3.8	1.6	52.5	47.5	42.5	50.0	50.0	75.0	42.5
Cyperus iria	-	1.4	-	-	-	-	-	-	35.0	-	-	-	-	-
Cyperus rotundas	1.9	1.5	1.1	1.4	1.7	2.1	1.3	55.0	42.5	37.5	50.0	42.5	62.5	40.0
Dactyloctenium aegyptium	2.6	-	2.0	1.9	0.8	1.1	1.5	55.0	-	50.0	47.5	17.5	40.0	42.5
Digitaria sanguinalis	1.4	1.0	-	1.2	-	-	1.0	42.5	25	-	30.0	-	-	30.0
Eragrostis tenella	-	-	-	-	1.1	-	-	-	-	-	-	20.0	-	-
Euphorbia hirta	-	-	-	-	0.3	0.5	-	-	-	-	-	15.0	20.0	-
Hemidesmus indicus	0.8	-	-	0.8	-	-	-	52.5	-	-	25.0	-	-	-
Ischaemum indicum	-	0.5	-	1.3	0.7	-	0.9	-	15	-	30.0	15.0	-	27.5
Leucas aspera	-	0.5	-	-	-	-	-	-	15	-	-	-	-	-
Ludwigia parviflora	-	1.9	0.4	-	-	-	-	-	35.0	10.0	-	-	-	-
Melochia corchorifolia	-	-	-	0.5	-	-	-	-	-	-	25.0	-	-	-
Merremia vitifolia	-	-	-	-	-	-	0.3	-	-	-	-	-	-	15.0
Mikania micrantha	1.4	-	-	-	0.6	0.7	-	55.0	-	-	-	20.0	37.5	-
Mimosa invisa	-	0.6	-	-	-	0.5	-	-	20.0	-	-	-	25.0	-
Mimosa pudica	1.3	0.8	-	-	-	0.7	0.3	55.0	32.5	-	-	-	35.0	15.0
Mitracarpus hirtus	-	2.1	0.9	1.0	-	2.5	-	-	35.0	17.5	40.0	-	40.0	-
Mollugo verticillata	-	-	-	1.0	-	-	-	-	-	-	30.0	-	-	-
Paspalum distichum	-	0.5	-	-	0.7	-	-	-	15.0	-	-	20.0	-	-
Phyllanthus niruri	-	0.7	1.0	-	-	-	-	-	20.0	30.0	-	-	-	-
Pouzolzia zeylanica	-	-	-	-	2.2	-	-	-	-	-	-	50.0	-	-
Scoparia dulcis	1.0	-	-	0.9	0.8	-	-	45.0	-	-	32.5	15.0	-	-
Sida acuta	-	-	-	-	0.5	-	-	-	-	-	-	30.0	-	-
Sida rhombifolia	0.8	0.4	-	0.3	-	0.2	-	50.0	20.0	-	-	-	-	15.0
Sphagneticola trilobata	-	1.8	1.3	-	1.0	1.9	-	-	40.0	30.0	20.0	22.5	50.0	-
Synedrella nodiflora	3.4	3.7	2.9	3.2	3.1	3.4	2.3	67.5	70.0	72.5	62.5	65.0	67.5	60.0
Vernonia cineria	1.1	-	0.3	-	0.4	-	0.6	45.0	-	12.5	-	20.0	-	22.5

The frequency of *A. bettzickiana* ranged from 62.5% to 82.5% which indicated the wide distribution of the weed in the surveyed areas. *A. bettzickiana* was observed at a frequency of 50% in the pineapple plantations of Kerala spreading over the central districts of the state (Girija and Menon 2019). The highest frequency of 82.5% was found in AEU 6 which includes parts of Malappuram and Thrissur districts and AEU 9 in the district of Ernakulam and lowest value was in AEU 5 where *Synedrella nodiflora* was found to be the most frequently distributed species (67.5%) (**Table 2**).

The numerical strength of a species in a given community is indicated by relative density. Relative frequency points out the ecological importance of various species in a plant community and it is regarded as the degree of dispersion of a given species in relation to all the individuals occurring in an area (Travlos *et al.* 2018). Relative density and relative frequency of *A. bettzickiana* in surveyed areas ranged from 12.3% to 29.3% and 9.6% to 17.7% respectively, which was higher than other weed species of the observed communities. Girija and Menon (2019) reported 27% relative frequency for *A. bettzickiana* in the pineapple cultivating tracts of Kerala. Relative abundance was also found to be highest for *A. bettzickiana* in all the surveyed agro-ecological units except in AEU 5 where *Synedrella nodiflora* and *Cynodon dactylon* exhibited greater values (**Table 3**).

Importance value index (IVI) judges the overall significance of a species in a community since it is calculated using the relative abundance, relative frequency and relative density of an individual. The

Table 3. Relative density, Relative frequency and relative abundance of weed species observed in surveyed locations

Weed species	Relative density (%) AEU							Relative frequency (%) AEU							Relative abundance (%) AEU						
	5	6	9	10	11	15	22	5	6	9	10	11	15	22	5	6	9	10	11	15	22
Aerva lanata			1.3		1.6		2.5			2.1		2.4		2.7			5.0		3.1		6.3
Ageratum conyzoides	5.9	-	6.9	5.9	-	8.4	6.7	7.3	-	10.2	7.0	-	8.6	6.8	6.7	-	5.9	6.0	-	7.8	6.9
Alternanthera bettzickiana	12.3	17.7	29.3	19.5	17.8	19.1	23.4	9.6	13.0	17.7	11.8	12.5	12.1	14.5	10.6	9.1	14.5	11.1	7.2	12.3	11.2
Alternanthera brasiliana	-	1.8	-	-	-	-	-	-	2.3	-	-	-	-	-	-	4.2	-	-	-	-	-
Axonopus compressus	-	-	-	1.6	3.0	-	-	-	-	-	2.1	4.6	-	-	-	-	-	4.0	2.9	-	-
Bidens pilosa	-	-	3.8	-	-	7.1	-	-	-	-	-	-	8.1	-	-	-	-	-	-	7.0	-
Biophytum sensitivum	7.1	2.4	-	-	2.9	-	4.5	5.6	3.1	5.5	-	3.1	-	5.0	9.5	4.1	6.3	-	4.7	-	6.2
Borreria hispida	-	-	-	-	-	7.1	-	-	-	-	-	-	5.6	-	-	-	-	-	-	9.5	-
Brachiaria distachya	-	-	5.7	-	-	-	-	-	6.3	-	-	-	-	-	-	-	7.5	-	-	-	-
Cardiospermum helicacabum	-	7.1	-	-	2.6	-	-	-	9.9	-	-	3.1	-	-	-	3.8	-	-	4.2	-	-
Centrosema pubescens	-	1.5	-	1.4	1.0	-	2.8	-	2.3	-	2.1	1.5	-	5.5	-	3.4	-	3.5	3.2	-	3.6
Chromolaena odorata	-	-	-	-	0.8	1.3	-	-	-	-	-	1.5	3.3	-	-	-	-	-	2.6	3.3	-
Cleome burmannii	-	-	2.9	4.8	4.9	3.2	3.5	-	-	4.8	7.4	5.9	5.4	4.6	-	-	5.6	4.6	4.3	4.6	5.1
Colocasia esculenta	4.0	-	-	-	-	-	-	6.4	-	-	-	-	-	-	4.7	-	-	-	-	-	-
Commelina sp.	-	-	-	1.8	3.1	2.4	6.1	-	-	-	2.1	3.9	3.4	7.3	-	-	-	4.5	4.1	5.1	6.2
Cyclea peltata	-	-	-	0.8	-	-	-	-	-	-	2.1	-	-	-	-	-	-	2.0	-	-	-
Cynodon dactylon	11.8	9.3	7.2	10.3	7.6	14.7	8.0	8.0	7.6	9.2	7.1	7.8	11.3	7.7	12.0	7.7	6.9	7.6	4.9	10.1	7.6
Cyperus iria	-	4.9	-	-	6.9	-	-	-	5.3	-	-	6.6	-	-	-	4.9	-	-	5.3	-	-
Cyperus rotundas	-	6.2	6.6	5.5	3.1	8.1	6.9	-	6.8	8.1	7.1	2.8	9.4	7.3	-	6.1	7.0	4.0	5.8	6.8	6.6
Dactyloctenium aegyptium	12.2	-	12.7	7.2	-	3.7	8.0	8.4	-	10.4	7.3	-	5.6	7.7	11.9	-	10.0	6.2	-	5.0	7.4
Digitaria sanguinalis	6.7	3.6	-	4.5	-	-	5.0	6.5	3.8	-	4.7	-	-	5.5	8.3	5.0	-	6.4	-	-	6.4
Eragrostis tenella	-	-	-	-	4.2	-	-	-	-	-	-	3.0	-	-	-	-	-	-	6.7	-	-
Euphorbia hirta	-	-	-	-	1.2	2.1	-	-	-	-	-	2.3	3.1	-	-	-	-	-	2.6	6.0	-
Hemidesmus indicus	3.7	-	-	3.0	-	-	-	8.2	-	-	3.8	-	-	-	3.8	-	-	5.0	-	-	-
Ischaemum indicum	-	1.8	-	5.1	2.8	-	4.7	-	2.3	-	4.3	2.3	-	5.0	-	4.2	-	6.2	6.2	-	6.7
Leucas aspera	-	1.6	-	-	-	-	-	-	2.3	-	-	-	-	-	-	3.8	-	-	-	-	-
Ludwigia parviflora	-	6.7	1.8	-	-	-	-	-	5.3	2.2	-	-	-	-	-	6.7	7.6	-	-	-	-
Melochia corchorifolia	-	-	-	1.8	-	-	-	-	-	-	3.6	-	-	-	-	-	-	2.7	-	-	-
Merremia vitifolia	-	-	-	-	-	-	1.4	-	-	-	-	-	-	2.8	-	-	-	-	-	-	3.2
Mikania micrantha	6.6	-	-	-	2.2	2.6	-	8.4	-	-	-	3.2	5.7	-	6.8	-	-	-	3.5	3.6	-
Mimosa invisa	-	2.2	-	-	-	1.9	-	-	3.2	-	-	-	3.7	-	-	4.5	-	-	-	4.0	-
Mimosa pudica	6.2	3.4	-	3.9	-	2.9	1.7	8.5	5.2		5.7		5.4	2.7	6.0	4.4		3.5		4.1	4.4
Mitracarpus hirtus	-	7.7	5.0	6.4	-	8.5	-	-	5.3	3.8	5.3	-	5.6	-	-	7.6	11.7	8.5	-	11.3	-
Mollugo verticillata	-	-	-	3.9	-	-	-	-	-	-	4.7	-	-	-	-	-	-	5.7	-	-	-
Paspalum distichum	-	1.8	-	-	2.8	-	-	-	2.3	-	-	3.1	-	-	-	4.2	-	-	4.5	-	-
Phyllanthus niruri	-	2.6	5.4	3.5	-		-	-	3.1	6.5	5.0	-	-	-	-	4.4	7.3	4.4	-	-	-
Pouzolzia zeylanica	-	-	-	-	8.6	-	-	-	-	-	-	7.8	-	-	-	-	-	-	5.6	-	-
Scoparia dulcis	4.2	-	-	2.7	3.0	-	-	6.7	-	-	4.3	2.3	-	-	5.5	-	-	4.1	6.4	-	-
Sida acuta	-	-	-	-	1.8	-	-	-	-	-	-	4.5	-	-		-	-	-	1.9	-	-
Sida rhombifolia	3.8	1.5	-	1.2	-	-	1.0	7.7	3.1	-	2.9			2.7	4.0	2.5	-	2.2		-	2.8
Sphagneticola trilobata	-	7.2	6.5	-	3.9	7.2	-	-	6.3	6.7	-	3.5	7.5	-	-	7.4	9.1	-	5.5	7.5	-
Synedrella nodiflora	16.1	14.9	16.6	12.3	12.4	13.3	11.8	10.3	11.0	15.6	9.7	10.2	10.2	10.9	12.7	9.2	9.3	8.3	6.2	10.1	7.6
Vernonia cinerea	6.3	-	1.4	-	1.6	-	-	7.2	-	2.7	-	3.0	-	-	6.5	-	4.4	-	2.6	-	-

contribution of a weed species to the weed population of an area is represented by summed dominance ratio (SDR) (Bhager *et al.* 1999). Higher IVI (32.5 - 61.5) and SDR (10.8% - 20.5%) of *A. bettzickiana* (**Table 4**) in the surveyed areas indicated its dominance over other species. No prominent variation in the density, dominance and occurrence of *A. bettzickiana* and weed flora composition was observed across the years of survey.

Higher values of Shannon-Wiener diversity index (H'), Evenness index (J) and Simpson's diversity index (C) and lower value of Simpson's dominance index (C') indicates more diverse community with even distribution of various species. Dominance of a single species in a community causes reduction in the value of H', C and J and escalation of C' (Nkoa *et al.* 2015). Lower values of H' (2.01), C (0.85) and J (0.81) and higher value of C' (0.14) recorded in AEU 9 including portions of Ernakulam district indicated the domination of a single weed species, primarily *A. bettzickiana*, when compared to other surveyed areas. AEU 5, which had lowest density and frequency of *A. bettzickiana,* recorded highest evenness index (0.95), indicating more uniform distribution of various species in the observed community (**Table 5**). AEU 11 comprising parts of the Malappuram district, which possessed highest species richness of 23, recorded highest Simpson's diversity index and lowest dominance index.

Spatial variation in the infestation of a weed species depends upon the physical, chemical and biological properties of soil, along with climate and topography. Edaphic factors are more influential in explaining the dominance, relative abundance and growth of a weed species in an area (Lousada *et al.*

Table 4. Summed dominance ratio (SDR) and importance value index (IVI) of weed species observed in surveyed locations

Weed species	IVI AEU							SDR (%) AEU						
	5	6	9	10	11	15	22	5	6	9	10	11	15	22
Aerva lanata	-	-	8.4	-	9.6	-	11.6	-	-	2.8	-	2.4	-	3.9
Ageratum conyzoides	19.9	-	23.1	18.8	-	23.7	20.5	6.6	-	7.7	6.3	-	8.3	6.8
Alternanthera bettzickiana	32.5	39.8	61.5	42.4	29.9	36.8	49.1	10.8	13.3	20.5	14.1	12.5	14.5	16.4
Alternanthera brasiliana	-	8.3	-	-	-	-	-	-	2.8	-	-	-	-	-
Axonopus compressus	-	-	-	7.7	-	-	-	-	-	-	2.6	-	-	-
Bidens pilosa	-	-	15.6	-	-	14.6	-	-	-	5.2	-	-	4.7	-
Biophytum sensitivum	22.2	9.5	-	-	8.0	-	15.7	7.4	3.2	-	-	3.5	-	5.2
Borreria hispida	-	-	-	-	-	15.2	-	-	-	-	-	-	5.1	-
Brachiaria distachya	-	-	19.5	-	-	-	-	-	-	6.5	-	-	-	-
Cardiospermum helicacabum	-	20.8	-	-	12.4	-	-	-	6.9	-	-	3.6	-	-
Centrosema pubescens	-	7.1	-	7.0	4.7	-	11.8	-	2.4	-	2.3	1.9	-	3.9
Chromolaena odorata	-	-	-	-	4.1	6.6	-	-	-	-	-	1.6	2.6	-
Cleome burmannii		12.5	19.5	16.7	-	14.1	-	-	4.2	6.5	5.6	-	4.4	-
Colocasia esculenta	15.0	-	-	-	-	-	-	5.0	-	-	-	-	-	-
Commelina sp.	-	-	-	-	14.8	14.5	19.5	-	-	-	-	5.0	3.6	6.5
Cyclea peltata	-	-	-	8.4	-	-	-	-	-	-	2.8	-	-	-
Cynodon dactylon	31.8	24.6	23.3	4.9	11.1	30.9	23.3	10.6	8.2	7.8	1.6	3.7	12.0	7.8
Cyperus iria	-	15.1	-	-	-	-	-	-	5.0	-	-	-	-	-
Cyperus rotundas	24.6	19.1	21.6	16.6	20.5	21.6	20.8	8.2	6.4	7.2	5.5	6.8	8.1	6.9
Dactyloctenium aegyptium	32.5	-	33.2	20.7	18.2	10.6	23.1	10.8	-	11.1	6.9	6.3	4.8	7.7
Digitaria sanguinalis	21.5	12.5	-	15.6	-	-	16.9	7.2	4.2	-	5.2	-	-	5.6
Eragrostis tenella	-	-	-	-	13.3	-	-	-	-	-	-	3.9	-	-
Euphorbia hirta	-	-	-	-	9.7	16.6	-	-	-	-	-	4.6	3.8	-
Hemidesmus indicus	15.7	-	-	11.9	-	-	-	5.2	-	-	4.0	-	-	-
Ischaemum indicum	-	8.3	-	15.6	4.8	-	16.4	-	2.8	-	5.2	2.0	-	5.5
Leucas aspera	-	7.7	-	-	-	-	-	-	2.6	-	-	-	-	-
Ludwigia parviflora	-	18.8	11.7	-	-	-	-	-	6.3	3.9	-	-	-	-
Melochia corchorifolia	-	-	-	8.1	-	-	-	-	-	-	2.7	-	-	-
Merremia vitifolia	-	-	-	-	-	-	7.4	-	-	-	-	-	-	2.5
Mikania micrantha	21.7	-	-	-	11.0	11.9	-	7.2	-	-	-	2.9	4.0	-
Mimosa invisa	-	9.9	-	-	-	11.8	-	-	3.3	-	-	-	3.2	-
Mimosa pudica	20.7	12.9		13.1		13.1	8.8	6.9	4.3	-	4.4	-	4.1	2.9
Mitracarpus hirtus	-	20.6	20.5	20.2	-	17.0	-	-	6.9	6.8	6.7	-	8.5	-
Mollugo verticillata	-	-	-	14.3	-	-	-	-	-	-	4.8	-	-	-
Paspalum distichum	-	8.3	-	-	12	-	-	-	2.8	-	-	4	-	-
Phyllanthus niruri	-	10.0	19.2	12.9	-	-	-	-	3.3	6.4	4.3	-	-	-
Pouzolzia zeylanica	-	-	-	-	21.3	-	-	-	-	-	-	7.3	-	-
Scoparia dulcis	16.3	-	-	11.2	8.6	-	-	5.4	-	-	3.7	3.9	-	-
Sida acuta	-	-	-	-	6.4	-	-	-	-	-	-	2.7	-	-
Sida rhombifolia	15.6	7.0		6.3	-	-	6.5	5.2	2.3	-	2.1	-	-	2.2
Sphagneticola trilobata	-	20.9	22.3	-	12.9	22.4	-	-	7.0	7.4	-	4.3	7.4	-
Synedrella nodiflora	39.0	35.0	41.5	30.3	27.4	30.4	30.4	13.0	11.7	13.8	10.1	9.6	11.2	10.1
Vernonia cinerea	20.0	-	8.5	-	5.6	-	12.0	6.7	-	2.8	-	2.4	-	4.0

Table 5. Diversity indices of surveyed locations

Diversity indices	Agro ecological units (AEU)						
	5	6	9	10	11	15	22
Shannon-Wiener diversity index (H’)	2.24	2.62	2.05	2.71	2.61	2.39	2.56
Simpson’s diversity index (C)	0.91	0.92	0.85	0.92	0.92	0.90	0.87
Simpson’s dominance index (C’)	0.09	0.08	0.15	0.08	0.08	0.10	0.13
Evenness index (J)	0.95	0.86	0.81	0.90	0.86	0.89	0.90

Table 6. Characteristics of *A. bettzickiana* in the surveyed Agro ecological units (AEU)

AEUs	Shoot length (cm)	Leaf length (cm)	Leaf width (cm)	No. of flowers	No. of seeds/plant	Biomass (g/plant)
AEU 5	79.0	6.4	1.8	98.4	590.0	22.8
AEU 6	93.7	5.5	2.3	83.5	555.0	26.5
AEU 9	111.1	7.2	3.2	104	624.0	41.3
AEU 10	102.2	6.3	3.3	110	606.0	38.0
AEU 11	62.8	4.0	1.8	66.3	442.8	27.6
AEU 15	94.5	5.2	2.1	92.0	552.0	35.0
AEU 22	88.2	5.1	1.9	86.3	541.5	29.4

Table 7. Soil chemical properties in the surveyed AEUs

AEUs	pH	EC (dS/m)	Organic carbon (%)	Available N (kg/ha)	Available P (kg/ha)	Available K (kg/ha)
AEU 5	5.68	0.11	0.60	135.0	48.2	115.2
AEU 6	5.81	0.21	0.89	170.5	54.1	178.6
AEU 9	5.64	0.24	1.29	313.2	89.5	167.0
AEU 10	5.75	0.18	1.60	326.5	39.1	225.5
AEU 11	6.01	0.16	0.76	203.4	30.3	262.0
AEU 15	5.86	0.25	0.98	273.0	76.7	194.0
AEU 22	5.77	0.17	0.68	195.0	26.0	158.5

2013). Morphological features of the weed showed slight variation with respect to locations surveyed (**Table 6**), indicating that there was only a single ecotype of the weed. Density of *A. bettzickiana* was correlated positively with all the studied soil properties, while only nitrogen content of the soil exhibited significant correlation (**Table 8**). Sandy loam soil type and relatively low organic C, available N and K contents could be related to the lowest density and frequency of *A. bettzickiana* in AEU 5 (**Table 7**). Weed biomass had significant positive correlation with organic carbon and nitrogen content of the soil. Plants belonging to Amaranthaceae family are efficient accumulators of nitrogen. Leaf nitrogen content of *A. bettzickiana* ranged from 1.6 to 2% while it was reported to be 2.4% in *Alternanthera philoxeroides* (Boyd 1968) and 2.8% in *Alternanthera tenella* (Patil and Kore 2015). This could be one of the possible reason for dense and dominant growth of the weed in nitrogen rich soils.

Table 8. Spearman's correlation coefficient for chemical properties of the soil in relation to density and biomass of *A. bettzickiana*

Soil parameters	Density of *A. bettzickiana*	Biomass g/plant
pH	0.198	-0.285
EC	0.753	0.579
Organic carbon	0.684	0.854*
Available nitrogen	0.818*	0.974*
Available phosphorus	0.276	0.551
Available potassium	0.608	0.271

Phytosociological and density indices obtained from the survey clearly indicated that *A. bettzickiana* had become a problematic dominating weed in the non-cultivated areas and waste lands in the central zone of Kerala with its abundant growth in soils with high organic carbon and nitrogen content. Its incidence has been noticed in various cropped areas also during the survey, pointing to its chance of becoming a major weed in crops, particularly vegetable, tuber and fruit crops, in future. *A. bettzickiana* thus becomes a serious weed threat in the upland cultivated areas of the state and warrants for the development and implementation of a comprehensive management strategy.

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RESEARCH NOTE

Nitrogen and weed management effects on weeds and yield of barley in Kandahar, Afghanistan

Karamatullah Fazil[1], T.K. Das[2]*, C.P. Nath[3], R. Nazir[1] and M. Samim[1]

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ABSTRACT

Growth and yield of barley (*Hordeum vulgare* L.) are highly influenced by nutrients and weed management. Nitrogen (N) is the most crucial nutrient to which barley crop responds readily. Efficient management of N and weeds can provide higher yield, better quality, and higher income to the farmers. Therefore, a field experiment was conducted in a split-plot design with three replications during winter season of 2019-20 in the Afghanistan National Agricultural Sciences and Technology University (ANASTU), Kandahar, Afghanistan to evaluate the effect of weed and N management on weeds growth and barley productivity. There were three weed management options in main plots, such as weedy check, herbicide use alone [post-emergence application (PoE) of clodinafop-propargyl 60 g/ha + metsulfuron-methyl 4 g/ha (tank-mix) at 30 days after sowing (DAS)], and integrated weed management (IWM) involving stale seed bed 15 days before sowing + wheat crop residue (2.5 t/ha) retention + clodinafop-propargyl + metsulfuron-methyl (tank-mix) PoE with half of the recommended dose at 30 DAS]. Four N levels (~0, 40, 80 and 120 kg N/ha, *i.e.*, N_0, N_{40}, N_{80} and N_{120}) were included as sub-plot treatments. The IWM led to significantly lower density and biomass of weeds at 40 and 70 DAS and significantly increased weed control efficiency (WCE) and weed control index (WCI). Clodinafop-propargyl (60 g/ha) + metsulfuron-methyl (4 g/ha) (tank-mix) PoE also resulted in significantly lower density and biomass of weeds and higher WCE and WCI than weedy check at all stages. IWM being at par with clodinafop-propargyl + metsulfuron-methyl (tank-mix) PoE led to higher growth (crop height, dry weight, leaf area index and growth rate) and yield of barley. On the contrary, the effect of nitrogen levels was not significant on the weed density and biomass reduction. N_{120} and N_{80} were comparable with respect to growth, yield attributes and yield of barley. Thus, IWM with 80 kg N/ha may be recommended for better weed management and higher barley yield and income in Kandahar, Afghanistan.

Keywords: Barley, Clodinafop-propargyl, Integrated weed management, Metsulfuron-methyl, Nitrogen

Barley is an important grain cereal and ranks fourth after wheat, rice and maize in both yield and area of cereal crops grown worldwide. It is grown widely in Afghanistan as forage and grain crop and used for consumption of humans, animals, and birds. Its productivity in Afghanistan is about 1.39 t/ha, which is much lower than the world average of 3.13 t/ha (FAOSTAT 2017). Weed competition and poor weed management are the major reasons for lower productivity of barley in Afghanistan, along with other factors like shortage of rainfall under rainfed condition, nutrients, and other inputs. Weeds are considered as one of the most serious biotic stresses and weed competition during critical period (15-30 DAS) of crop growth can reduce yield significantly. Thus, weed control is a key factor for obtaining high yield and income (Kaur *et al*. 2018). Hand weeding is cumbersome and costlier, therefore, using selective herbicides, IWM can be a best alternative and economical option.

Nitrogen (N) is the most essential nutrient for barley and its efficient management can provide higher yield, better quality, and higher income to the farmers. Weed control and N fertilizer applications have been studied widely in the world separately for its role and improving crop yield and quality. However, studies with respect to weed and N management together in a location-specific soil and climate condition on barley in Afghanistan are scanty. Thus, the present study was conducted to assess the effects of weed management and N doses on weeds growth and barley growth and yield.

The field experiment was conducted during winter season of 2019-20 at the Afghanistan National Agricultural Sciences and Technology University (ANASTU), Kandahar, Afghanistan. Climate is semi-

[1] Afghanistan National Agricultural Sciences and Technology University (ANASTU), Kandahar, Afghanistan

[2] ICAR-Indian Agricultural Research Institute, New Delhi - 110 012, India

[3] ICAR-Indian Institute of Pulses Research, Kanpur - 208 024, U.P., India

* Corresponding author email: tkdas64@gmail.com

arid to sub-tropical with extreme cold and hot situations. Maximum and minimum temperature were 31°C and -10°C, and maximum and minimum relative humidity were 77.1% and 32.6%, respectively during crop growing season in 2019-20. Total rainfall received during crop growing season was 276.9 mm. Soil was sandy loam with pH 7.13, electrical conductivity 2.29 dS/m, organic carbon 0.3%, available N 125.4 kg/ha, available P 7.9 kg/ha and available K 159 kg/ha. The experiment was laid out in a split plot design with three replications. The main plot treatments were: three weed management options such as weedy check, herbicide use alone [post-emergence application (PoE) of clodinafop-propargyl 60 g/ha + metsulfuron-methyl 4 g/ha (tank-mix) at 30 days after sowing (DAS)], and integrated weed management (IWM) involving stale seed bed 15 days before sowing + wheat crop residue (2.5 t/ha) retention + clodinafop-propargyl + metsulfuron-methyl (tank-mix) PoE with half of the recommended dose at 30 DAS]. Four N levels (~0, 40, 80 and 120 kg N/ha, i.e., N_0, N_{40}, N_{80} and N_{120}) were adopted as sub-plot treatments. For stale seed bed, irrigation followed by ploughing was done 15 days before sowing to allow weed emergence, and then ploughed to eradicate emerged weeds. Barley 'variety Darulaman 013' was sown using 100 kg seed/ha. Herbicides were applied using a knapsack sprayer fitted with flat fan nozzle at 30 DAS with respective doses as per the treatments. Nitrogen was applied in three equal splits: 1/3rd of N and full dose of P and K through urea, TSP, and potassium sulfate, respectively were applied as basal. Rest N was applied at CRI (first irrigation) and flowering stages. Species-wise weeds were collected at 40 and 70 DAS from all plots using a quadrat of 0.5 m × 0.5 m and categorized into narrow-leaved, broad-leaved, and total weeds. Weeds were dried for estimating species-wise and total weed dry weight (biomass). Weed data [population (density) and biomass] were statistically transformed (Das 1999). Weed control efficiency (WCE) based on weed density, weed control index (WCI) based on weed biomass and weed index (WI) were determined as per Das (2008). Barley plant height, dry matter accumulation, leaf area index, crop growth rate (CGR), grain yield and harvest index were recorded using standard procedures (Rana *et al.* 2014).

Effect on weeds

Major broad-leaved weeds that predominated the experimental field were *Carthamus lanatus* L. (Saffron thistle), *Lactuca serriola* L. (Prickly lettuce or milk thistle) and *Convolvulus arvensis* L. (Field bindweed). Major narrow-leaved weeds were *Cynodon dactylon* (L.) Pers. (Bermuda grass), *Bromus hordeaceus* L. (Barley brome or soft brome) and *Phalaris minor* Retz. (Littleseed canarygrass). Broad-leaved weeds were more dominant than grassy weeds. The occurrence and distribution of similar weeds flora has been reported by Ziar *et al.* (2017). Both IWM and herbicide use alone resulted in significantly lower weed density and biomass and higher weed control efficiency and weed control index than weedy check **(Table 1)**. But IWM resulted in highest reduction of density and biomass of narrow-leaved, broad-leaved and total weeds. It also had significantly higher WCE and WCI at all stages of growth. Several authors (Baghel *et al.* 2020, Das and Das 2018, Kaur *et al.* 2020; Punia *et al.* 2016, Rasmussen and Rasmussen 2000) have reported similar results. Among the nitrogen levels, lower weed density and biomass were recorded in N_0 treatment due to lack of N, which has role in promoting weed germination and growth. Thus, the density and biomass of weeds were less where nitrogen was not applied. Similar phenomenon was reported by Blackshaw *et al.* (2003) and Ma³ecka and Blecharczyk (2008). Lower density and biomass of weeds were obtained in IWM under no-fertilization. Maximum weed control efficiency and weed control index were found in N_{80} treatment among the N management treatments at all stages of growth **(Table 1)**.

Effect on barley crop growth and yield

Among weed management treatments, IWM resulted in tallest barley plants, which were significantly taller than the other treatments at all dates except 70 DAS **(Table 2)**. This treatment led to significantly higher dry matter accumulation and leaf area index than herbicide use alone and weedy check treatments at all stages of growth. Better management of all three categories of weeds led to higher crop growth and canopy formation, which ultimately promoted higher vigour of barley crop in this treatment as reported by O'Donovan *et al.* (2001), Kumar *et al.* (2012) and Holm *et al.* (2006). In this treatment, crop residue retention could prevent weed germination, conserve moisture, and regulate soil temperature, which might have selectively favored barley crop and boosted up its growth. Crop residue on decomposition also might have supplied essential nutrients to soil resulting in greater plant height and higher values of growth parameters of barley. Higher the N level greater was the barley plant height, dry weight, leaf area index and crop growth rate (CGR). The values of these growth variables were highest at

N_{120} treatment closely followed by N_{80} **(Table 2)**. After sowing of barley on 27 November 2019, a very cold weather having weekly mean minimum temperature of -10°C prevailed, which affected crop growth heavily. Also, there was heavy rainfall for about a month. Therefore, crop growth was much lower than normal having shorter plants and stunted growth at initial/early stage. Again, crop assumed growth with normalcy of weather (Légère and Samson 2004; Ma³ecka and Blecharczyk 2008). Interaction between weed control and N level was significant for barley dry weight and CGR at 40 and 70 DAS but for plant height at 70 DAS **(Table 2)**. Greater plant height was associated with IWM combined with N_{80} (~80 kg N/ha). Similarly, dry weight was higher in IWM x N_{120} closely followed by IWM x N_{80} at 40 DAS, but in IWM x N_{80} closely followed by IWM x N_{120} at 70 DAS. Possible reason could be that retention of crop residue, low weed pressure, and application of N might have been optimum for barley crop demand.

The IWM resulted in higher grain yield and harvest index **(Table 3)** among the weed management options, conforming Baghel *et al.* (2020), Nath *et al.* (2017), Puniya *et al.* (2016), and Das and Yaduraju (2012). Again, in accordance with growth, barley grain yield was highest in N_{120} followed by N_{80}, but both the N levels were comparable and gave significantly higher grain yield than others. The effects of N itself and its doses played roles. Higher the dose of N, higher was the yield as reported earlier (Kohistani and Choudhary 2019, Ram and Buttar 2012, Meena and Mann 2010). Weed index (percent

Table 1. Total weed density and biomass and weed control efficiency (WCE), weed control index (WCI) and weed index (WI) as affected by treatments in barley

Treatment	Total weed density (no./m^2)		Total weed biomass (g/m^2)		Weed control efficiency (%)		Weed control index (%)		Weed index (%)
	40 DAS	70 DAS	40 DAS	70 DAS	40 DAS	70 DAS	40 DAS	70 DAS	
Weed management									
Weedy check	53.7	141.3	0.40	3.21	0.0	0.0	0.0	0.0	24.1
Herbicide use alone	18.7	23. 7	0.15	0.34	60.7	78.6	58.6	88.1	6.6
IWM	9.3	8.3	0.10	0.29	81.9	90.9	72.6	87.8	0.0
LSD (p=0.05)	8.3	77.7	0.08	1.37	7.96	9.02	14.8	9.0	10.4
Nitrogen doses									
N_0	21.8	42.2	0.23	0.89	40.0	53.1	44.3	56.1	41.1
N_{40}	25.3	55.1	0.19	1.09	43.9	53.7	34.2	57.1	18.5
N_{80}	36.0	58.2	0.29	1.40	54.8	60.9	52.2	60.0	-6.7
N_{120}	25.8	75.5	0.16	1.74	51.6	58.3	44.3	61.4	-11.9
LSD (p=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	19.8
Interaction									
LSD (p=0.05)	NS*	NS*	NS*	NS*	NS*	NS*	NS*	NS*	NS*

* Non-significant; # Significant

Table 2. Barley plant height, dry matter accumulation, leaf area index and crop growth rate (CGR) at different stages of growth as affected by treatments

Treatment	Barley plant height (cm)		Dry matter accumulation (g/m^2)		Leaf area index		CGR (g/m^2 (land area)/day)	
	40 DAS	70 DAS	40 DAS	70 DAS	40 DAS	70 DAS	0-40 DAS	40-70 DAS
Weed management								
Weedy check	8.5	12.7	9.2	58.7	0.13	1.28	0.23	1.65
Herbicide use alone	8.9	13.1	9.9	60.1	0.13	1.29	0.25	1.67
IWM	10.8	14.1	13.9	88.9	0.16	1.41	0.35	2.50
LSD (p=0.05)	1.67	0.93	1.09	4.31	NS	0.08	0.027	0.138
Nitrogen doses								
N_0	8.1	11.6	8.3	50.8	0.12	1.14	0.21	1.42
N_{40}	9.2	13.3	9.9	67.2	0.13	1.24	0.25	1.91
N_{80}	10.1	14.2	12.2	79.4	0.16	1.45	0.31	2.24
N_{120}	10.2	14.5	13.6	79.5	0.15	1.49	0.34	2.20
LSD (p=0.05)	0.56	0.40	0.67	1.31	0.013	0.06	0.03	0.051
Interaction								
LSD (p=0.05)	NS*	S#	S#	S#	NS*	NS*	S#	S#

* Non-significant; # Significant

Table 3. Barley yield, harvest index and nutrient status after harvest as affected by treatments

Treatment	Grain yield (t/ha)	Harvest index (%)	Nutrient status in soil (kg/ha)		
			Available N	Available P	Available K
Weed management					
Weedy check	2.5	40.2	131.7	8.8	168.1
Herbicide use alone	3.1	38.5	139.0	9.4	145.1
IWM	3.5	39.8	160.3	9.0	232.7
LSD (p=0.05)	0.36	NS	6.7	0.08	9.5
Nitrogen doses					
N_0	1.9	44.3	87.8	9.0	203.3
N_{40}	2.7	37.1	126.8	6.5	176.8
N_{80}	3.6	39.5	195.2	10.9	180.6
N_{120}	3.7	37.1	204.8	10.0	167.2
LSD (p=0.05)	0.14	3.69	5.8	0.6	2.1
Interaction					
LSD (p=0.05)	NS*	NS*	S#	S#	S#

* Non-significant; # Significant

grain yield loss) was minimum in IWM, where a set of weed control methods applied (**Table 1**). N_{120} and N_{80} resulted in higher grain yield. The negative WI showed weed management superiority to even the best weed management option. Soil available N after harvest **(Table 3)** was higher in IWM and N_{120} treatments, closely followed by N_{80}. In IWM, crop residue on gradual decomposition supplied nutrients to soil and increased N level, whereas in N_{120} level, the N dose was responsible. Soil available P was higher in herbicide used alone and N_{80} treatment, whereas soil available K was higher in IWM and N_0 treatments. Through better weed control, N, P and K removal by weeds were prevented and N, P, and K were reserved in soil and increased their content in soil. Crop residue retention also played a role. The K and N have synergistic effects and application of one of them increases requirement of other by crop. So, in N_0 treatment, N was not applied, and the absorption of K was lower by crop, which increased its status in soil.

Higher cost of cultivation was incurred due to IWM (36530 AFN/ha) and N_{120} (34120 AFN/ha) treatments **(Table 4)**. The cost of cultivation of these treatments were higher because of more use of resources/inputs/practices (crop residue, stale seed bed, herbicides, and more amount of urea). Simultaneously, net returns and net benefit: cost were also significantly higher in these treatments. Already mentioned that higher barley yield was obtained in these treatments, which increased gross returns, net returns and net benefit: cost.

This study indicates that IWM led to better weed suppression and higher growth and yield of barley. Both 80 and 120 kg N/ha gave similar weed control and growth and yield of barley and were superior to other N doses. Applying 80 kg N/ha to barley would lead to a considerable saving of N (~40 kg/ha) without compromising yield. Therefore, IWM combined with application of 80 kg N/ha is economically and environmentally superior and may be recommended.

Table 4. Cost of cultivation, gross and net returns (AFN/ha) and net benefit: cost of barley across the treatments

Treatment	Economics			
	Cost of cultivation ($\times 10^3$ AFN/ha)	Gross returns ($\times 10^3$ AFN/ ha)	Net returns ($\times 10^3$ AFN/ha)	Net B:C
Weed management				
Weedy check	26.03	79.02	50.56	1.8
Herbicide use alone	26.79	98.98	70.51	2.5
IWM	36.53	104.66	76.20	2.7
LSD (p=0.05)	-	12.57	12.57	0.44
Nitrogen doses				
N_0	24.85	59.57	31.10	1.1
N_{40}	28.41	86.84	58.37	2.1
N_{80}	31.27	111.43	82.96	2.9
N_{120}	34.12	119.04	90.58	3.2
LSD (p=0.05)	-	3.16	3.16	0.12
Interaction				
LSD (p=0.05)	-	NS*	NS*	NS*

* Non-significant; # Significant

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RESEARCH NOTE

Effect of different pre- and post-emergence herbicides for weed management in chickpea

Anamika Nepali, Arvind Verma, J.K. Singh*, Deepa Verma and Pooja

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ABSTRACT

A field experiment was conducted during the winter (*Rabi*) season 2017-18 at Instructional Agronomy Farm of Rajasthan College of Agriculture, MPUAT, Udaipur. The experiment consisted of twelve weed management treatments which were replicated thrice in Randomize Block Design. Chickpea (cv. *Pratap Chana-1*) was used as a test crop. The hand weeding twice 30 and 60 days after seeding (DAS) followed by pre-emergence application (PE) of pendimethalin 1000 g/ha or pendimethalin 750 g/ha have significantly reduced total weed density and biomass and attained the highest chickpea seed yield. The net return and B:C ratio was significantly higher with pendimethalin 1000 g/ha PE and pendimethalin 750 g/ha PE due to lesser cost of herbicides usage compared to hand weeding.

Keywords: Chickpea, Economics, Herbicides, Pendimethalin, Weed management

India is the largest producer as well as a consumer of pulses. In India, the area under chickpea was 10.17 million hectares with a production of 11.35 million tons and average productivity 1116 kg per hectare, during 2019-20. Rajasthan ranks first in area, followed by Maharashtra, Madhya Pradesh and Uttar Pradesh. In Rajasthan, chickpea is one of the major crop grown with 2.46 million ha of area, 2.66 million tons of production and 1080 kg/ha productivity (GOI 2020). Unchecked weeds were reported to cause considerable reduction in chickpea seed yield up to 63% (Kaur and Kumar 2016). Manual weeding which is commonly used by farmers is constrained by limited availability and high prices of farm workers resulting in difficulty to the manually control weeds during critical periods of crop growth. Thus, the use of herbicides may be desirable for the control of weeds particularly at early stages as herbicides will control the emerging weeds for a substantial period of time (Rathod *et al*. 2017). However, herbicides use in chickpea by farmers is limited and a few farmers integrate pre-emergence herbicides use with manual weeding once or twice. This study was carried out to assess the effect of different pre- and post-emergence herbicides on weeds, crop yield and economics of chickpea.

Maharana Pratap University of Agriculture and Technology, Udaipur, Rajsthan-313 001, India

* Institute of Agricultural Sciences, Banaras Hindu University, Varanasi, Uttar Pradesh 221005, India

* Corresponding author email: jksinghbhu3@gmail.com

The field experiment was carried out during winter (*Rabi*) season of 2017-18 at Instructional Farm of Agronomy, Rajasthan College of Agriculture, Udaipur, Rajasthan. The experiment consisting of 12 weed management treatments *viz*., pre-emergence application (PE) of pendimethalin 750 g/ha, pendimethalin 1000 g/ha PE, metribuzin 150 and 200 g/ha PE, post-emergence application (PoE) of imazethapyr 50 and 75 g/ha at 20 days after seeding (DAS), quizalofop - ethyl 40 and 50 g/ha PoE at 20 DAS, imazethapyr + imazamox ready mix (RM) 15+15 g/ha PoE at 20 DAS, imazethapyr + imazamox (RM) 20+20 g/ ha PoE at 20 DAS, hand weeding twice at 30 and 60 DAS and weedy check. A randomized block design with three replications was used. The required amounts of herbicides were applied using 500 liters/ha of water with a knap-sack sprayer fitted with a flat-fan nozzle. The soil of the experimental site was clay loam in texture, slightly alkaline in reaction. The pH of soil was 8.1. Available N, P and K content in the soil was 249.2, 21.6 and 378.7 kg/ha, respectively. Chickpea '*Pratap Channa-1*' was grown with a seed rate of 80 kg/ha at 30 cm x 25 cm plant geometry. The crop was provided with 20 kg N and 40 kg P/ha as basal dose. The crop received total rainfall of 4.20 mm during the cropping season and the maximum and minimum temperatures were ranged between 23.47 to 31.71^{o}C and 5.21 to 13.03^{o}C, respectively. At sampling time of 30, 60 DAS and at harvest, a quadrat of 0.25 m^2 was placed at four places in each plot marked with wooden pegs and observations like weed density, weed biomass were recorded and weed control efficiency percentage was calculated using standard procedures. Yield attributes were estimated at harvest and yield was calculated and expressed in kg/ha. Weed density and biomass were square root transformed by using formula ($\sqrt{x+0.5}$) before analysis. While ANOVA indicated significance in treatment effects it was adjudged by calculating critical difference at 5 per cent level of significance, wherever, the results were found significantly by 'F' test.

Effect on weeds

In the experimental field of chickpea, the predominant broad-leaved weeds were, *Chenopodium album* (22.7%), *Chenopodium murale* (19.2%), *Convolvulus arvensis* (13.0%), *Melilotus indica* (13.3%) and *Malva parviflora* (17.7%) and the narrow-leaved and sedges were *Phalaris minor* Retz. (7.8%) and *Cyperus rotundus* (6.3%) **(Table 1)**. All the weed control treatments resulted significantly lesser density of grasses, broad-leaved weeds as well as total weeds compared to weedy check at 60 DAS **(Table 1)**. Significantly lesser grassy weed density was noticed with quizalofop-ethyl 50 g/ha PoE at 20 DAS and it was at par with quizalofop-ethyl 40 g/ha PoE at 20 DAS and pendimethalin 1000 g/ha PE. These were followed by pendimethalin 750 g/ha PE. The lowest number of broad-leaved weeds was observed with pendimethalin 1000 g/ha PE **(Table 1)** and in which at par with pendimethalin 750 g/ha PE at 60 DAS. The minimum density of total weeds was also recorded with pendimethalin 1000 g/ha PE. Singh *et al.* (2017) found that the pre-emergence application of pendimethalin 0.75 kg/ha was most effective in reducing weed density and biomass in chickpea.

At 60 DAS greater reduction of grassy weeds was with quizalofop-ethyl 50 g/ha PoE at 20 DAS which was statistically at par with quizalofop-ethyl 40 g/ha PoE at 20 DAS, pendimethalin 1000 g/ha PE and pendimethalin 750 g/ha PE as compared to the weedy check. Significant reduction in broad-leaved weeds biomass was observed with pendimethalin 1000 g/ha PE which was statistically at par with pendimethalin 750 g/ha PE. Pendimethalin 1000 g/ha PE also recorded highest (90.04%) reduction in total weed biomass and was statistically at par with pendimethalin 750 g/ha **(Table 1)**. The highest weed control efficiency was recorded with hand weeding twice at 30 and 60 DAS. The highest weed control efficiency of grassy weeds was achieved by quizalofop-ethyl 50 g/ha applied at 20 DAS PoE followed by quizalofop-ethyl 40 g/ha PoE at 20 DAS, pendimethalin 1000 g/ha PE and pendimethalin 750 g/ha PE. Patel *et al.* (2017) reported that quizalofop-ethyl 40 g/ha PoE at 20 DAS + HW at 40 DAS was most effective in controlling weeds in chickpea.

The highest weed control efficiency was observed with pendimethalin 1000 g/ha PE, followed by pendimethalin 750 g/ha and imazethapyr 75 g/ha PoE at 20 DAS. **(Table 1)**. The increased weed control efficiency with integration of pendimethalin 1 kg/ha PE with two inter-cultivations twice at 30 and 45 DAS was reported by Chavada *et al.* (2017).

The minimum uptake of N, P and K by weeds was observed with hand weeding twice at 30 and 60 DAS which was statistically at par with pendimethalin 1000 g/ha PE and pendimethalin 750 kg/ha PE **(Table 3)**. Chavada *et al.* (2017) observed that hand weeding at 30 and 45 DAS recorded significantly higher nutrient uptake of N (72.79 kg/ha), P (13.99 kg/ha) and K (20.23 kg/ha) by chickpea

Table 1. Effect of weed control treatments on weed density, weed biomass and weed control efficiency at 60 DAS in chickpea

Treatment	Weed density* (no./m^2)			Weed biomass (g/m^2)			Weed control efficiency (%)		
	Grassy weeds	Broad-leaved weeds	Total weeds	Grassy weeds	Broad-leaved weeds	Total weeds	Grassy weeds	Broad-leaved weeds	Total weeds
Pendimethalin 750 g/ha PE	2.81	3.92	4.78	3.14	3.97	5.01	87.71	87.94	87.90
Pendimethalin 1000 g/ha PE	2.41	3.68	4.40	3.04	3.60	4.65	88.67	90.13	90.04
Metribuzin 150 g/ha PE	4.66	5.62	7.27	7.39	8.73	11.41	30.16	39.92	36.16
Metribuzin 200 g/ha PE	4.47	6.31	7.70	6.04	7.30	13.50	53.34	58.20	56.39
Imazethapyr 50 g/ha PoE at 20 DAS	3.93	4.64	6.04	3.96	5.65	6.86	80.05	75.22	77.17
Imazethapyr 75 g/ha PoE at 20 DAS	3.73	4.88	6.10	3.81	5.07	6.30	81.83	80.02	80.67
Quizalofop-ethyl 40 g/ha PoE at 20 DAS	2.41	7.40	7.76	2.88	11.00	11.40	89.72	4.61	36.51
Quizalofop-ethyl 50 g/ha PoE at 20 DAS	2.17	7.36	7.64	2.72	10.93	11.24	91.00	5.84	38.51
Imazethapyr + imazamox 15 + 15 g/ha PoE at 20DAS	5.13	5.81	7.71	6.76	8.35	10.72	41.42	45.23	43.84
Imazethapyr + imazamox 20 + 20 g/ ha PoE at 20 DAS	5.02	6.03	7.82	6.64	7.85	10.26	43.07	51.46	48.27
Hand weeding twice at 30 and 60 DAS	0.71	0.71	0.71	0.71	0.71	0.71	100.00	100.00	100.00
Weedy check	5.86	7.41	9.42	8.83	11.26	14.30	0.00	0.00	0.00
LSD (p=0.05)	0.41	0.34	0.32	2.54	3.28	3.47			

* $\sqrt{x+0.5}$ transformed values and data in parentheses are original values, PE: pre-emergence, PoE: post-emergence

and significantly lower uptake of N (3.87 kg/ha), P (0.39 kg/ha) and K (1.68 kg/ha) by weeds.

Effect on chickpea

The highest chickpea plant height was observed with pendimethalin 1000 g/ha PE followed by pendimethalin 750 g/ha PE, imazethapyr 75 g/ha and imazethapyr 50 g/ha PoE at 20 DAS, metribuzin 150 g/ha PE and imazethapyr + imazamox (RM) 20+20 g/ ha PoE at 20 DAS **(Table 2)**. The plant dry matter was higher with hand weeding twice and was on par with pendimethalin 1000 g/ha PE, pendimethalin 750 g/ha PE and imazethapyr 75 g/ha PoE. Pendimethalin 1000 g/ha PE has recorded significantly higher pods/ plant and the weight of seeds/plant followed by its lower dose of 750 g/ha PE than the rest of the herbicidal treatments **(Table 2)**. The seeds/pod and 100-seed weight were not influenced by the weed management treatments. The minimum seed yield was recorded in weedy check **(Table 3)**. Amongst the treatments, significantly higher chickpea seed yield was obtained with hand weeding twice at 30 and 60 DAS which was statistically at par with pendimethalin 1000 g/ha PE followed by pendimethalin 750 g/ha PE and imazethapyr 75 g/ha PoE at 20 DAS. The greater biological yield was with hand weeding twice at 30 and 60 DAS followed by pendimethalin 1000 g/ha PE, pendimethalin 750 g/ha PE, imazethapyr 75 g/ha at 20 DAS, imazethapyr 50 g/ha at 20 DAS and metribuzin 150 g/ha. The maximum seed yield of chickpeas with manual hand weeding twice at 30 and 50 DAS was reported earlier (Kaur and Kumar, 2016). Dubey *et al.* (2018) reported highest chickpeas seed yield and test weight with tank mix application of pendimethalin 1000 g (PE) *fb* imazethapyr 75 g + quizalofop 60 g/ha as PoE. The highest net return was realized with pendimethalin 1000 g/ha PE (**Table 3)** which was higher than the rest of the treatments, except with pendimethalin 750 g/ha PE, hand weeding twice at 30

Table 2. Effect of weed control treatments on growth and yields attributes of chickpea during rabi 2017-18

Treatment	Plant population (lakh/ha)	Plant height (cm)	No. of branches/ plants	Plant dry matter accumulation (g/plant)	No. of Pods/ plant	No. of Seeds/ pod	Weight of seeds (g/plant)	100-seed weight (g)
Pendimethalin 750 g/ha PE	2.87	46.2	4.0	29.53	40.1	1.4	14.9	23.54
Pendimethalin 1000 g/ha PE	2.89	46.6	4.1	30.03	40.8	1.4	15.4	23.56
Metribuzin 150 g/ha PE	2.80	44.5	3.9	26.22	38.4	1.3	13.3	23.21
Metribuzin 200 g/ha PE	2.76	42.9	3.7	25.81	36.4	1.2	11.6	22.64
Imazethapyr 50 g/ha PoE at 20 DAS	2.85	45.2	3.9	26.32	39.1	1.4	14.5	23.45
Imazethapyr 75 g/ha PoE at 20 DAS	2.84	45.9	4.0	28.65	39.8	1.3	14.0	23.53
Quizalofop-ethyl 40 g/ha PoE at 20 DAS	2.78	41.7	3.6	17.06	34.8	1.2	10.5	22.36
Quizalofop-ethyl 50 g/ha PoE at 20 DAS	2.78	42.2	3.7	25.63	35.8	1.2	11.1	22.43
Imazethapyr + imazamox 15+15 g/ha PoE at 20 DAS	2.78	44.1	3.8	26.07	37.5	1.3	12.6	22.87
Imazethapyr + imazamox 20+20 g/ha PoE at 20 DAS	2.76	43.9	3.8	25.92	36.8	1.2	12.0	22.81
Hand weeding twice at 30 and 60 DAS	2.91	47.4	4.2	31.49	41.8	1.5	16.2	23.67
Weedy check	2.77	41.4	3.6	15.28	31.3	1.1	8.13	20.37
LSD (p=0.05)	NS	3.73	NS	2.88	3.9	NS	3.37	NS

* PE: pre-emergence application, PoE: post-emergence application, DAS: Days after seeding

Table 3. Effect of weed control treatments on yield and economics of chickpea and nutrients uptake by weeds and crop at harvest

Treatment	Seed yield (t/ha)	Haulm yield (t/ha)	Biological yield (t/ha)	Harvest index (%)	Net return ($x10^3$₹/ha)	B:C	Nutrient uptake by crop (kg/ha)			Nutrient uptake by weed (kg/ha)		
							N	P	K	N	P	K
Pendimethalin 750 g/ha PE	1.69	3.88	5.57	30.32	64.83	2.84	89.7	15.1	75.8	5.63	0.88	5.67
Pendimethalin 1000 g/ha PE	1.72	3.96	5.68	30.31	65.89	2.80	92.3	16.4	78.4	4.27	0.60	4.37
Metribuzin 150 g/ha PE	1.59	3.70	5.30	30.10	61.08	2.81	81.9	13.7	68.3	34.91	7.33	34.75
Metribuzin 200 g/ha PE	1.50	3.37	4.87	30.95	56.07	2.56	73.2	10.8	58.9	25.20	6.05	24.72
Imazethapyr 50 g/ha PoE at 20 DAS	1.64	3.80	5.44	30.18	62.99	2.83	86.5	14.6	72.9	8.55	1.54	8.57
Imazethapyr 75 g/ha PoE at 20 DAS	1.61	3.75	5.36	30.02	60.90	2.68	84.0	13.0	70.2	7.62	1.42	7.64
Quizalofop-ethyl 40 g/ha PoE at 20 DAS	1.48	3.13	4.61	32.32	53.44	2.32	67.8	10.7	53.6	38.92	9.08	36.39
Quizalofop-ethyl 50 g/ha PoE at 20 DAS	1.50	3.26	4.77	31.59	54.17	2.32	71.1	11.6	56.2	36.40	8.69	34.99
Imazethapyr + imazamox 15 + 15 g/ha PoE at 20 DAS	1.57	3.46	5.03	31.22	59.18	2.70	78.1	12.1	62.8	31.59	7.18	31.16
Imazethapyr + imazamox 20 + 20 g/ha PoE at 20 DAS	1.55	3.43	4.98	31.20	58.09	2.63	76.2	11.8	61.0	30.09	6.91	29.18
Hand weeding twice at 30 and 60 DAS	1.75	4.07	5.81	30.17	63.75	2.35	95.3	17.5	82.0	2.36	0.45	3.54
Weedy check	0.77	1.11	1.87	47.24	17.23	0.83	31.3	4.1	20.5	68.47	16.71	65.10
LSD (P=0.05)	0.12	0.60	0.55	NS	5.41	0.11	9.5	2.1	12.71	3.58	0.80	3.49

Market price of chickpea seed ₹ 45.0 and halum ₹ 2.5/kg * PE: pre-emergence, PoE: post-emergence, DAS: Days after seeding and 60 DAS, imazethapyr 50 g/ha PoE at 20 DAS, imazethapyr 75 g/ha PoE at 20 DAS and metribuzin 150 g/ha PE. The highest B:C ratio was recorded with pendimethalin 750 g/ha PE. The B:C ratio with imazethapyr 50 g/ha PoE at 20 DAS, metribuzin 150 g/ha PE and pendimethalin 1000 g/ha PE was at par with each other. Maximum net returns and B:C ratio with pendimethalin 1.00 kg/ha in chickpea was reported earlier by Kour *et al.* (2015). All the weed control treatments recorded significant increases in N, P and K uptake by the crop compared to weedy check **(Table 3)**. The highest uptake of N, P and K were recorded with hand weeding twice at 30 and 60 DAS and was statistically at par with pendimethalin 1000 g/ha PE.

Conclusion

The pre-emergence application of pendimethalin 1000 g/ha was found effective and most remunerative weed management treatment in chickpea under rainfed condition of Udaipur region of Rajasthan.

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RESEARCH NOTE

Effect of herbicides on complex weed flora and yield of summer greengram

Pramod Kumar, V.J. Patel*, D.D. Chaudhari and B.D. Patel

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ABSTRACT

To study the effect of a few herbicides on weed dynamics and yield of summer greengram (*Vigna radiata* L.), a field experiment was conducted on loamy sand soil during summer season of 2020. *Digitaria sanguinalis, Cynodon dactylon, Eleusine indica* and *Dactyloctenium aegyptium* among monocot and *Digera arvensis, Portulaca oleracea, Trianthema monogyna* and *Phyllanthus niruri*, the dicot weeds were dominant in experimental field. The pre-emergence application (PE) of either pendimethalin 750 g/ha or pendimethalin + imazethapyr (pre-mix) 750 g/ha or oxyfluorfen 117.5 g/ha PE or inter-cultivation twice and hand weeding twice at 20 and 40 days after seeding (DAS) significantly reduced the density and biomass of monocot and dicot weeds in summer greengram. These treatments recorded higher greengram growth, yield attributes, *viz.* plant height plant dry biomass, nodule dry weight, number of pods/plant, seed yield and benefit cost ratio (B:C).

Keywords: Greengram, Herbicide, Oxyfluorfen, Pendimethalin + imazethapyr, Weed management

Greengram [*Vigna radiata* (L.) R. Wilczek] is a leguminous crop considered to be the hardiest of all pulse crops and has the capacity to fix atmospheric nitrogen through symbiotic nitrogen fixation. The infestation of annual and perennial weeds in summer greengram, especially at early stages of crop growth, pose considerable competition for nutrient, water, light and space with crop plants and causing hindrance in achieving desired yield. The potential yield loss in greengram due to weeds has been estimated to range between 10-45% (Rao and Chauhan 2015). Thus, weed management is the key factor for enhancing the productivity of greengram. Moreover, besides low yield of crop, weeds increase production cost, harbor insect-pest and diseases, decreasing quality of farm produce. Currently, herbicide usage for weed management is becoming popular among the farmers due to unavailability of labour in time and also due to higher labour wages. Hence, the effect of a few herbicides on weeds and greengram was studies in this experiment to identify suitable herbicides for managing weeds in summer greengram.

This field study was carried out on loamy sand soil during summer season of 2020 at Agronomy farm of B. A. College of Agriculture, Anand Agricultural University, Anand, Gujarat. The total rainfall receiving during the crop period was 78.2 mm. The mean weekly maximum temperature ranged between 34.7 °C to 42.5 °C and minimum temperature ranged from 20.1 °C to 28.0 °C during the crop season. The soil of experimental field was low in organic carbon (0.34%), medium in available phosphorus (38.21 kg/ha), high in available potash (282.7 kg/ha) and slightly alkaline in reaction (pH 7.97). Ten treatments were tested including: pre-emergence application (PE) of pendimethalin 750 g/ha, oxyfluorfen 117.5 g/ha and pendimethalin + imazethapyr (pre-mix) 750 g/ha, post-emergence application (PoE) of imazethapyr 70 g/ha, imazethapyr + imazamox (pre-mix) 70 g/ha, fluazifop-p-butyl + fomesafen (pre-mix) 250 g/ha, propaquizafop + imazethapyr (pre-mix) 125 g/ha, sodium acifluorfen + clodinafop-propargyl (pre-mix) 245 g/ha and inter-cultivation (IC) followed by (*fb*) hand weeding (HW) at 20 and 40 days after seeding (DAS) and weedy check. A randomized block design with four replications was used. Pre- and post-emergence herbicides were applied one day and 28 days after sowing, respectively with knapsack sprayer fitted with flat fan nozzle by using 500 litre of water/ha as per treatment. Sowing of the greengram variety 'GAM 5' was done on 20th March 2020 using a seed rate of 20 kg/ha keeping the row spacing of 30 cm. Recommended dose of fertilizer (NPK 20-40-00 kg/ha) was applied common to all the treatments as a basal dose in the form of urea and single super phosphate. Seven irrigations were given to the crop. Weed samples were collected by arbitrarily placing a quadrat of size 0.25 m^2 in each plot at 25, 60 DAS and at harvest and the data was converted into m^2. For

B.A. College of Agriculture, Anand Agricultural University, Anand, Gujarat 388110, India

* Corresponding author email: avjpatel28@aau.in

uniformity, data related to weed parameters were subjected to square root transformation $(\sqrt{x+1})$. Other growth and yield attributing observation, *viz.* plant height at 30, 60 DAS and at harvest, nodule dry weight (mg/plant) at 39 DAS, plant dry matter (g/plant) at 39 DAS, seed and haulm yield were recorded from net plot area using standard procedures.

Weed flora

Digitaria sanguinalis, Cynodon dactylon, Eleusine indica and *Dactyloctenium aegyptium* as monocot and *Digera arvensis, Portulaca oleracea, Trianthema monogyna* and *Phyllanthus niruri* as dicot were the dominant weeds observed in the experimental field of summer greengram.

Effect on weeds

Complete control of monocot and dicot weeds was recorded with IC *fb* HW at 20 and 40 DAS (**Table 1**). Complete control of monocot weeds at 25 DAS was achieved with pendimethalin 750 g/ha PE and pendimethalin + imazethapyr (pre-mix) 750 g/ha PE. At 50 DAS, pendimethalin 750 g/ha PE, pendimethalin + imazethapyr (pre-mix) 750 g/ha PE and oxyfluorfen 117.5 g/ha PE remained at par with each other and recorded significantly lower biomass of monocot and dicot weeds except dicot weeds with oxyfluorfen 117.5 g/ha. At harvest, significantly lowest density of total weeds was achieved under IC *fb* HW and was at par with pendimethalin 750 g/ha PE with respect to total weeds biomass due to broad spectrum control of weeds with pendimethalin + imazethapyr PE and pendimethalin PE. Further, IC *fb* HW was found more effective in managing the monocot and dicot weeds as initially emerged weeds were controlled by inter-culturing and hand weeding carried out at 20 DAS and weeds emerged later were efficiently managed by additional inter-culturing and hand weeding carried out at 40 DAS. Effective management of weeds through cultural practices was also reported by Panda *et al.* (2021).

Effect on crop

The weed management practices did not exert any significant influence on plant population recorded at 20 DAS whereas, plant height was significantly influenced at 30, 60 DAS and at harvest (**Table 2**). The higher plant height was recorded at 30 DAS under weedy check treatment while at 60 DAS and at harvest higher plant height was observed under pendimethalin 750 g/ha PE. The results are in agreement findings of Patel *et al.* (2016). IC *fb* HW at 20 and 40 DAS registered significantly higher plant dry biomass and nodule dry weight and it was at par with pendimethalin 750 g/ha PE, pendimethalin + imazethapyr (pre-mix) 750 g/ha PE, oxyfluorfen 117.5 g/ha PE, propaquizafop + imazethapyr (pre-mix) 125 g/ha PoE and sodium acifluorfen + clodinafop-propargyl (pre-mix) 245 g/ha PoE with

Table 1. Effect of treatments on density and biomass of monocot and dicot weeds in summer greengram

Treatment	Density (no./ m^2)						Biomass (g/m^2)					
	Monocot			Dicot			Monocot			Dicot		
	25 DAS	50 DAS	At harvest	25 DAS	50 DAS	At harvest	25 DAS	50 DAS	At harvest	25 DAS	50 DAS	At harvest
Pendimethalin 750 g/ha PE	1.00^{b} (0)	2.77^{e} (7)	4.33^{de} (18)	1.62^{cd} (2)	2.43^{e} (5)	2.77^{e} (7)	1.00^{b} (0.00)	3.27^{e} (10.01)	7.07^{f} (49.11)	1.95^{g} (3.72)	2.87^{e} (7.40)	3.98^{d} (15.63)
Oxyfluorfen 117.5 g/ha PE	1.31^{b} (1)	4.15^{d} (17)	4.77^{cde} (22)	2.81^{b} (7)	2.62^{de} (6)	3.15^{de} (9)	1.22^{b} (0.62)	4.74^{d} (21.81)	8.77^{e} (75.9)	3.17^{f} (9.17)	3.33^{e} (10.17)	6.87^{bc} (46.15)
Pendimethalin + imazethapyr EC (pre-mix) 750 g/ha PE	1.00^{b} (0)	2.62^{e} (6)	4.56^{cde} (20)	2.12^{bc} (4)	2.62^{de} (6)	3.30^{cde} (10)	1.00^{b} (0.00)	3.33^{e} (10.26)	7.35^{ef} (53.19)	2.56^{fg} (6.54)	3.09^{e} (8.76)	5.77^{c} (32.30)
Imazethapyr 70 g/ha PoE	9.46^{a} (89)	6.23^{b} (38)	5.08^{bcd} (25)	4.97^{a} (24)	3.86^{b} (14)	4.22^{b} (17)	8.31^{a} (68.46)	7.73^{b} (58.99)	14.24^{ab} (203.85)	6.52^{cd} (42.15)	5.29^{cd} (27.19)	8.47^{b} (71.18)
Imazethapyr + imazamox (pre-mix) 70 g/ha PoE	8.98^{a} (80)	5.09^{cd} (25)	5.38^{abc} (28)	4.64^{a} (21)	3.30^{bc} (10)	3.86^{bcd} (14)	7.64^{a} (57.49)	6.45^{c} (40.73)	11.92^{cd} (143.34)	5.80^{de} (33.17)	6.95^{b} (47.93)	7.27^{bc} (52.93)
Fluazifop-p-butyl + fomesafen (pre-mix) 250 g/ha PoE	8.90^{a} (79)	5.90^{bc} (36)	5.99^{ab} (35)	5.19^{a} (26)	3.58^{bc} (12)	3.98^{bc} (15)	7.52^{a} (55.90)	7.20^{bc} (51.51)	13.79^{b} (191.01)	7.24^{bc} (51.35)	5.07^{d} (25.20)	7.01^{bc} (48.57)
Propaquizafop + imazethapyr (pre-mix) 125 g/ha PoE	9.20^{a} (84)	5.29^{bc} (27)	4.79^{cde} (22)	4.77^{a} (22)	3.11^{cd} (9)	3.61^{bcd} (12)	7.57^{a} (56.45)	6.28^{c} (38.62)	11.03^{d} (121.10)	5.45^{e} (28.88)	5.76^{cd} (32.34)	7.07^{bc} (50.42)
Sodium-acifluorfen + clodinafop-propargyl (pre-mix) 245 g/ha PoE	9.04^{a} (81)	5.28^{bc} (27)	4.98^{cd} (24)	5.18^{a} (26)	3.43^{bc} (11)	4.35^{b} (18)	7.62^{a} (57.09)	6.52^{c} (41.83)	13.31^{bc} (176.29)	7.83^{b} (61.00)	6.25^{bc} (38.87)	8.54^{b} (72.92)
IC *fb* HW at 20 and 40 DAS	1.00^{b} (0)	1.00^{f} (0)	3.86^{e} (14)	1.00^{d} (0)	1.00^{f} (0)	1.62^{f} (2)	1.00^{b} (0)	1.00^{f} (0.00)	6.25^{f} (38.12)	1.00^{h} (0)	1.00^{f} (0.00)	3.40^{d} (16.35)
Weedy check	9.42^{a} (88)	10.19^{a} (104)	6.37^{a} (41)	5.19^{a} (26)	6.21^{a} (38)	6.69^{a} (44)	7.84^{a} (60.95)	14.03^{a} (196.25)	15.51^{a} (239.69)	9.30^{a} (85.50)	11.67^{a} (135.34)	14.86^{a} (219.81)
LSD (p=0.05)	Sig.	Sig.	Sig.	Sig.	Sig.	Sig.	Sig.	Sig.	Sig.	Sig.	Sig.	Sig.

Figure in parentheses are original values and subjected to square root transformation $(\sqrt{x+1})$ before statistical analysis. PE: Pre-emergence; PoE: Post-emergence; DAS: Days after seeding; *fb*: Followed by; IC: Inter-culturing; HW: Hand weeding

Table 2. Effect of treatments on growth, yield attributes and yield of summer greengram

Treatment	Plant population (per meter row length) at 20 DAS	Plant height (cm)			Plant dry biomass (g/plant) at 39 DAS	Nodule dry weight (mg/plant) at 39 DAS	No. of pods/ plant	Seed index (g) (100 seed wt.)	Seed yield (kg/ha)	B:C
		30 DAS	60 DAS	At harvest						
Pendimethalin 750 g/ha PE	10.23	15.45^{ab}	43.78^{a}	47.28^{a}	31.06^{ab}	40.37^{a}	30.05^{a}	4.61	1401^{a}	3.29
Oxyfluorfen 117.5 g/ha PE	10.18	15.03^{abc}	42.20^{a}	45.25^{ab}	29.61^{abc}	38.32^{a}	29.60^{a}	4.60	1337^{a}	3.40
Pendimethalin + imazethapyr (pre-mix) 750 g/ha PE	10.20	15.08^{abc}	43.68^{a}	45.93^{ab}	30.57^{abc}	38.82^{a}	29.95^{a}	4.61	1377^{a}	3.30
Imazethapyr 70 g/ha PoE	10.08	14.78^{abc}	40.23^{ab}	42.28^{bc}	27.13^{c}	36.38^{ab}	15.85^{c}	4.41	769^{c}	1.91
Imazethapyr + imazamox (pre-mix) 70 g/ha PoE	10.10	12.75^{c}	40.53^{ab}	43.50^{ab}	27.25^{bc}	36.89^{ab}	20.63^{b}	4.54	1043^{b}	2.50
Fluazifop-p-butyl + fomesafen (pre-mix) 250 g/ha PoE	10.10	14.58^{abc}	40.25^{ab}	43.43^{ab}	27.04^{c}	36.57^{ab}	16.75^{c}	4.54	882^{bc}	2.11
Propaquizafop + imazethapyr (pre-mix) 125 g/ha PoE	10.18	14.03^{abc}	40.58^{ab}	44.03^{ab}	29.52^{abc}	38.35^{a}	29.35^{a}	4.59	1291^{a}	3.13
Sodium acifluorfen + clodinafop-propargyl (pre-mix) 245 g/ha PoE	10.08	13.05^{bc}	40.55^{ab}	43.73^{ab}	29.01^{abc}	36.78^{ab}	20.35^{b}	4.57	1003^{b}	2.39
IC *fb* HW at 20 and 40 DAS	10.30	14.80^{abc}	41.15^{a}	44.98^{ab}	32.75^{a}	40.58^{a}	30.75^{a}	4.63	1408^{a}	2.88
Weedy check	10.05	16.38^{a}	36.70^{b}	38.55^{c}	27.11^{c}	33.60^{b}	8.95^{d}	4.51	344^{d}	0.92
LSD (p=0.05)	NS	Sig.	Sig.	Sig.	Sig.	Sig.	Sig.	NS	Sig.	-

PE: Pre-emergence; PoE: Post-emergence; DAS: Days after seeding; *fb:* Followed by; IC: Inter-culturing; HW: Hand weeding

respect to plant dry biomass. While in case of nodule dry weight all the weed control treatments remained at par with each other except weedy check. All the yield attributing and yields *viz.*, number of pods/plant and seed yield were significantly higher under IC *fb* HW at 20 and 40 DAS which remained at par with pendimethalin 750 g/ha PE, pendimethalin + imazethapyr (pre-mix) 750 g/ha PE, oxyfluorfen 117.5 g/ha PE and propaquizafop + imazethapyr (pre-mix) 125 g/ha PoE). The results are in accordance with the findings of Subbulakshmi (2021) and Ramesh and Rathika (2020). The higher seed yield was due to effective control of weeds which reduced the crop weed competition at the critical growth stages of greengram and provided almost weed free environment that facilitated better growth, development and increase in yield. Similarly, effectiveness of imazethapyr + pendimethalin 800 g/ha on increasing seed yield was also observed by Singh *et al.* (2017) and Kumar *et al.* (2019) while in case of cultural practices Patel *et al.* (2016).

Economics

The economic analysis revealed maximum benefit cost ratio achieved with oxyfluorfen 117.5 g/ha PE (3.40) which was closely followed by pendimethalin + imazethapyr (pre-mix) 750 g/ha PE (3.30) and pendimethalin 750 g/ha (3.29) PE. Gupta *et al.* (2019) also recorded higher B:C with pendimethalin + imazethapyr (RM) 750 g/ha PE in greengram.

Based on the results it was concluded that effective and economical weed management in summer greengram can be achieved by application of either pendimethalin 750 g/ha PE or pendimethalin + imazethapyr (pre-mix) 750 g/ha PE or oxyfluorfen 117.5 g/ha PE or inter-cultivation and hand weeding at 20 and 40 days after seeding (DAS).

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RESEARCH NOTE

Herbicidal combinations for managing weeds and improving crop productivity in summer blackgram

Vishal Singh[1], Naushad Khan[2], Utkarsh Singh[1] and Raghvendra Singh[1]

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ABSTRACT

An experiment was conducted at the Students Instructional Farm, Department of Agronomy, Chandra Shekhar Azad University of Agriculture and Technology, Kanpur, India during summer season of 2018 to find out the most effective pre- and post-emergent herbicide combination for effective management of weeds in blackgram. Experiments consisted of ten treatments. The lowest weed density and biomass, weed index and highest weed control efficiency and blackgram yield as well as B:C ratio was observed with pre-emergence application (PE) of pendimethalin 1000 g/ha followed by post-emergence application (PoE) of imazethapyr 50 g/ha which was effective and economical in managing weeds in blackgram.

Keywords: Blackgram, Imazethapyr, Pendimethalin, Weed management, Weed control efficiency

Blackgram is the fourth most important crop after chickpea, pigeon pea and green gram in India. Weeds pose a serious problem and compete for nutrients, water and light, which could have otherwise boosted up crop productivity. Blackgram is not good competitor against weeds in the earlier stages of its growth and weed management plan is required to ensure proper crop growth and productivity (Singh and Singh 2020). Farmers use of herbicides in pulses is less as hand weeding or inter-cultivation are normally practiced Bhandari *et al.* (2004) reported that application of imazethapyr at 25 g/ha had no adverse effects on rain-fed blackgram and resulted in statistically comparable seed yield to that of hand weeding twice at 20 and 40 days after sowing (DAS). Hence, weed management with herbicides is an option to manage weeds and thereby increasing the productivity of blackgram. As the broad-spectrum weeds management with single herbicides may not be effective, herbicide combinations may be more beneficial (Nandan *et al.* 2011). Thus, the present experiment was conducted to test the performance of a few post-emergence herbicides in combination with pre-emergence herbicides for weed management during critical period of crop weed competition in blackgram during summer season.

[1] Acharya Narendra Deva University of Agriculture and Technology, Ayodhya, Uttar Pradesh 224229, India

[2] Chandra Shekhar Azad University of Agriculture and Technology, Kanpur, Uttar Pradesh 208002, India

* Corresponding author email: smillingbudha1@gmail.com

Field experiment was conducted during summer season of 2018 at Students' Instructional Farm, Department of Agronomy, Chandra Shekhar Azad University of Agriculture and Technology, Kanpur, Uttar Pradesh, India. The soil of experimental field was alkaline in reaction (8.2 pH), low in available nitrogen (176.74 kg/ha) and medium in organic carbon (0.56%), available phosphorus (19.30 kg /ha) and potassium (217.80 kg/ha). The experiments consisted of 10 treatments: pre-emergence application (PE) of pendimethalin 1000 g/ha, post-emergence application (PoE) of imazethapyr 50 g/ha at 20 DAS, quizalofop 50 g/ha PoE at 25 DAS, pendimethalin 1000 g/ha PE followed by (*fb*) imazethapyr 50 g/ha PoE at 20 DAS, pendimethalin 1000 g/ha PE *fb* quizalofop 50 g/ha PoE at 25 DAS, pendimethalin 1000 g /ha PE *fb* one hand weeding at 20 DAS, imazethapyr 50 g/ha at 20 DAS *fb* quizalofop 50 g/ha at 25 DAS, hand weeding twice at 20 and 40 DAS, weed free and weedy check. A randomized block design with three replications was used. Blackgram variety *Shekher-2* was sown on 10th March, 2018 keeping 30 cm distance apart with a depth of 5-7 cm by using the local plough. The recommended dose of fertilizers (20 kg N + 60 kg P + 40 kg K/ha) was applied to crop at the time of sowing through di-ammonium phosphate (DAP), urea and muriate of potash (MOP). Pre-emergence application of herbicides was done on next day of sowing while post-emergence application of herbicides was done at 20 DAS and 25 DAS or 3-4 leaf stage of weeds as per treatment with the help of manually operated Knapsack sprayer fitted using flat fan nozzle using

500 litres of water/ha. Observations on individual weed density were recorded from three spot selected randomly from each plot at 45 DAS with the help of 0.5 x 0.5 m size quadrat. Weeds occurring in the quadrat were counted species wise and total number of weeds/m^2 was calculated by multiplying by 4.

Dry weight of weeds (biomass) was recorded at 45 DAS. After counting, weeds were cut close to the ground surface and sun dried for two days. After that the samples were dried in hot air oven at 70 ± 1 ^{0}C for 48 hours till attain constant weight and then dry weight of weed was recorded in g/m^2.

The data on weed density and biomass were put to square root transformation ($\sqrt{x+0.5}$) to normalize their distribution as per the procedure suggested by Gomez and Gomez (1984). The weed index was computed using formula of Gill and Kumar (1969). The Benefit: Cost Ratio (B:C) is the ratio of gross realisation to total cultivation cost calculated using the formula below.

$$\text{B:C} = \frac{\text{Gross realisation (Re/ha)}}{\text{Total cost of cultivation (Re/ha)}}$$

Effect on weeds

The major weeds in the experimental site were, broad-leaved weeds: *Trianthema monogyna* (horse purslane) and *Commelina benghalensis* (tropical spiderwort), *Eclipta alba* (false daisy) and *Parthenium hysterophorus* (congress grass); grassy weeds: *Digitaria sanguinalis* and *Cynodon dactylon* (bermuda grass) and the sedge *Cyperus rotundus* (purple nut sedge). Weedy check recorded the highest weed density and biomass (**Table 1)** whereas, the lowest being observed under weed free. Hand weeding twice at 20 and 40 DAS proved most effective to reduce the weeds weed density and biomass. However, application of pendimethalin 1000 g/ha PE + one hand weeding at 20 DAS recorded the lowest density of all weeds at 45 DAS except *Digitaria sanguinalis* followed by pendimethalin 1000 g/ha PE + imazethapyr 50 g/ha PoE. Lower weed biomass was recorded with pendimethalin 1000 g/ha PE+ one hand weeding at 20 DAS as reported by Kumar and Tewari (2004) and pendimethalin 1000 g/ha PE + imazethapyr 50 g/ha PoE . Kumar and Tewari (2004) reported the very good control of *Trianthema monogyna* by pendimethalin.

Among herbicide-based treatments, pendimethalin 1000 g/ha PE + one hand weeding at 20 DAS gave maximum (52.89%) weed control efficiency followed by pendimethalin 1000 g/ha PE + imazethapyr 50 g/ha PoE which is 51.24%. Raju *et al.* (2017) observed higher WCE with application of pendimethalin 750 g /ha *fb* imazethapyr 75 g/ha. The maximum WCE was recorded with two hand weeding at 20 and 40 DAS and weed free.

The treatments having high WCE recorded lower value of weed index. The lowest weed index was observed under pendimethalin 1000 g/ha PE+ imazethapyr 50 g/ha PoE (3.92%) followed by pendimethalin 1000 g/ha PE + one hand weeding at 20 DAS (4.84%). Similar observation was also noted by Patel *et al.* (2015) in blackgram. The efficient control of weeds in combined application of pre- and post-emergent herbicides resulted in higher yield and lower weed index.

Table 1. Effect of weed control treatments on density and biomass of different weed species at 45 DAS in blackgram

Treatment	Weed density (no./m^2)							Total weed biomass (g/m^2)
	Trianthema monogyna	*Digitaria sanguinalis*	*Eclipta alba*	*Cyperus rotundus*	*Cynodon dactylon*	*Parthenium hysterophorus*	Total weed density	
Pendimethalin 1000 g/ha PE	2.35 (8.05)	2.75 (7.10)	3.05 (8.85)	10.66 (113.19)	3.53 (11.99)	3.64 (12.81)	13.09 (171)	9.84 (96.40)
Imazethapyr 50 g/ha at 20 DAS	2.73 (6.99)	2.57 (6.13)	2.70 (6.80)	10.79 (116.12)	3.54 (12.09)	3.60 (12.46)	12.97 (167.92)	9.30 (86.05)
Quizalofop 50 g/ha at 25 DAS	3.48 (11.63)	3.77 (10.89)	3.56 (12.20)	10.51 (110.01)	3.27 (10.21)	3.92 (14.92)	13.53 (182.64)	10.05 (100.61)
Pendimethalin 1000 g/ha PE + Imazethapyr 50 g/ha at 20 DAS	2.21 (4.40)	1.73 (2.51)	2.14 (4.11)	10.24 (104.41)	3.06 (8.91)	3.02 (8.63)	11.76 (138.01)	8.24 (67.47)
Pendimethalin 1000 g/ha PE + qquizalofop 50 g/ha at 25 DAS	2.64 (6.52)	2.55 (6.04)	2.60 (6.31)	10.11 (101.83)	2.98 (8.41)	3.10 (9.12)	12.04 (144.66)	8.90 (78.85)
Pendimethalin 1000 g/ha PE + one hand weeding at 20 DAS	2.18 (4.26)	2.10 (3.39)	2.07 (3.79)	8.64 (74.25)	2.90 (7.92)	2.77 (7.22)	10.29 (105.46)	7.96 (62.93)
Imazethapyr 50 g/ha at 20 DAS + quizalofop 50 g/ha at 25 DAS	2.44 (5.50)	2.49 (5.71)	2.57 (6.13)	10.05 (100.54)	2.86 (7.72)	3 (8.52)	11.76 (138.6)	8.38 (69.81)
Hand weeding twice (20 and 40 DAS)	2.00 (3.53)	1.76 (2.60)	1.95 (3.32)	7.63 (57.78)	2.57 (6.11)	2.18 (4.28)	9.03 (81.15)	7.48 (55.83)
Weed free	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.00
Weedy check	3.66 (12.93)	3.96 (15.21)	3.90 (15.21)	12.44 (154.46)	4.34 (18.39)	4.45 (19.37)	16.01 (255.83)	16.90 (285.24)
LSD (p=0.05)	0.210	0.257	0.350	0.396	0.833	0.261	1.014	0.773

Table 2. Effect of herbicides on weed control efficiency (WCE), weed control and yield of summer blackgram

Treatment	WCE (%) at 45 DAS	Weed Index (%)	Grain yield (kg/ha)	Straw yield (kg/ha)	Harvest index (%)
Pendimethalin 1000 g/ha PE	41.77	25.11	820	2910	21.19
Imazethapyr 50 g/ha at 20 DAS	44.97	23.10	842	2932	22.31
Quizalofop 50 g/ha at 25 DAS	40.53	28.12	787	2853	21.62
Pendimethalin 1000 g/ha PE + imazethapyr 50 g/ha at 20 DAS	51.24	3.92	1052	3468	23.27
Pendimethalin 1000 g/ha PE + quizalofop 50 g/ha at 25 DAS	47.33	10.68	978	3312	22.79
Pendimethalin1000 g/ha PE + one hand weeding at 20 DAS	52.89	4.84	1042	3436	23.26
Imazethapyr 50g/ha at 20 DAS + quizalofop 50 g/ha at 25 DAS	50.41	5.47	1035	3405	23.30
Hand weeding twice (20 and 40 DAS)	55.73	3.01	1062	3552	23.01
Weed free	100	0.0	1095	3645	23.10
Weedy check	0	37.44	685	2640	20.60
LSD (p=0.05)			101	160	_

Table 3. Effect of weed management treatments on economics of summer blackgram

Treatment	Cost of cultivation (x10^3 `/ha)	Gross return (x10^3 `/ha)	Net return (x10^3 `/ha)	B:C ratio
Pendimethalin 1000 g/ha PE	30.50	61.74	31.24	2.02
Imazethapyr 50 g/ha at 20 DAS	30.62	63.06	32.44	2.05
Quizalofop 50 g/ha at 25 DAS	30.91	59.62	28.71	1.92
Pendimethalin 1000 g/ha PE + imazethapyr 50 g/ha at 20 DAS	31.76	77.62	45.86	2.44
Pendimethalin 1000 g/ha PE + quizalofop 50 g/ha at 25 DAS	32.10	72.68	40.59	2.26
Pendimethalin1000 g/ha PE + one hand weeding at 20 DAS	34.25	76.88	42.64	2.24
Imazethapyr 50g/ha at 20 DAS + quizalofop 50 g/ha at 25 DAS	32.22	76.32	44.10	2.30
Hand weeding twice (20 and 40 DAS)	36.56	78.66	42.10	2.15
Weed free	40.56	81.00	37.13	1.99
Weedy check	29.31	50.59	18.31	1.72

Effect on blackgram

The highest blackgram seed yield (1052 kg/ha) was recorded with the pendimethalin 1000 g/ha PE *fb* imazethapyr 50 g/ha PoE with an increase in the seed yield of 34.8% over the weed check followed by pendimethalin 1000 g /ha PE *fb* one hand weeding at 20 DAS. The weed free treatment noted the highest increase in yield of seed by 37.4% over the weedy check. Crop yield was inversely associated with the density of weeds. The weedy check caused 37.40% reduction in seed yield, when compared to weed free. Harisha *et al*. (2021) also recorded higher seed yield with lower weed index under twice hand weeding treatment. Biological yield was found to be significantly higher with the application of pendimethalin 1000 g/ha PE+ imazethapyr 50 g/ha PoE with highest harvest index. The cost of weed management practices has influenced the total cost of cultivation in blackgram. The highest benefit-cost ratio (2.44), gross return as well as net return was realised with pendimethalin 1000 g/ha PE+ imazethapyr 50 g/ha PoE.

It was concluded that pendimethalin 1000 g/ha PE *fb* imazethapyr 50 g/ha PoE and pendimethalin 1000 g/ha PE *fb* one hand weeding at 20 DAS could be the best possible alternative options for effective and economic weed management in blackgram.

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RESEARCH NOTE

Integrated weed management effect on yield and economics of cowpea

C.P. Amaya* and P. Gayathri Karthikeyan

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ABSTRACT

A field experiment was conducted at instructional farm II of College of Agriculture, Padannakkad, Kerala, India during the *Rabi* 2020 to evaluate the efficacy and identify economic weed management treatment for managing weeds in cowpea [*Vigna unguiculata* (L.) Walp.]. The weed parameters were significantly influenced by the weed management practices. The weed density and biomass and higher weed control efficiency during different periods of crop growth were consistently lower with pre-emergence application (PE) of pendimethalin 0.75 kg/ha + mulching 7t/ha which indicated that pre-emergence herbicide application could effectively manage the weeds emerging early in the season and the later emerged weeds could be successfully controlled by mulching. It was as effective as two hand weeding done 15 and 30 days after seeding (DAS). The effective management of weeds by it resulted in higher yield and B:C ratio.

Keywords: Cowpea, Hand weeding, Imazethapyr, Mulching, Pendimethalin

Pulses are the major source of protein in Indian diet, containing significant amount of fibres, vitamins and minerals. India is the largest producer, consumer and importer of pulses in the world with a production of 23.15 mt from an area of 28.34 Mha with a projected production demand of 35 mt by 2030 (GoI 2018). Weed infestation is one of the major factors that is limiting the productivity of pulses. In Kerala, cowpea [*Vigna unguiculata* (L.) Walp.] is the major pulse crop grown. Farmers, especially in Kasaragod district, are constrained to adopt manual method of weed management for pulses owing to the non-availability and high cost of labour engaged in hand weeding. Cowpea is sensitive to weed infestation especially in the initial 5 to 8 weeks during which uncontrolled weeds cause the cowpea yield loss upto 60% depending on the location, season and weed population (Yadav *et al.* 2017). Hand weeding at 20-35 DAS, pre-emergence application of pendimethalin (PE) 1 to 1.5 kg/ha (Yadav *et al.* 2017) and green leaf mulching by Sapkota *et al*. (2015) were found effective to manage weeds in pulses. Integration of different weed management techniques would result in better management of weeds compared to any single management method (Rao and Nagamani, 2010, Pooniya *et al.* 2014). Hence, this study was carried out to the efficacy and economics of integrated weed management (IWM) treatment to manage weeds in cowpea and improve cowpea productivity.

A field study was conducted at Instructional farm II of College of Agriculture, Padannakkad, Kerala Agricultural university located at 12º14’45’’N latitude and 75º 8’6’’E longitude at an elevation of 9 m above mean sea level from December 2020 to March 2021. The soil was red sandy loam in texture with (low in available N, high in available P and medium in available K). The field experiment was laid out in Randomized Block Design (RBD) with eleven treatments and three replications. The treatments combination were: pre-emergence application (PE) of pendimethalin 0.75 kg/ha at 0-3 days after seeding (DAS); pendimethalin 0.75 kg/ha PE at 0-3 DAS + hand weeding at 20-25 DAS; pendimethalin 0.75 kg/ha PE 0-3 DAS + mulching 7t/ha; post-emergence application (PoE) of imazethapyr 75 g/ha at 20 DAS; imazethapyr 75 g/ha PoE at 20 DAS + hand weeding at 35 DAS; imazethapyr 75 g/ha PoE at 20 DAS + mulching 7t/ha; mulching 7t/ha + hand weeding at 20 DAS; hand weeding twice at 15 and 30 DAS; mulching alone 7t/ha; weedy check (control); weed free. Short duration cowpea variety *PGCP 6* sown at a spacing of 30 x 25 cm with a seed rate of 60 kg/ha. Pendimethalin was applied immediately after sowing while imazethapyr was applied at 20 DAS after the establishment of the crop. Herbicides were applied using knapsack sprayer

Department of Agronomy, College of Agriculture, Padannakkad, Kasaragod, Kerala 671314, India

* Corresponding author email: amayacp97@gmail.com

using 500 L of water per hectare. Fertilizers were applied uniformly in all the plots as recommended in the KAU package of practices. Observations on weed parameters were recorded at 15, 30, 45 and 60 DAS by placing quadrat randomly in each of the experimental plot. The weed samples were collected for estimating density, dry weight (biomass), weed index and weed control efficiency of weeds, using standard methodology. Biometric observations were recorded at both flowering and harvesting stage. Yield attributes were recorded at the harvesting stage. These data were analysed statistically using the software WASP 2.0 by ICARGOA.

Effect on weeds

The weed flora observed in the experimental plots were identified and classified based on their ontogeny and morphology (**Table 1**). There were 53 weed species found in the experimental field out of which 34 were broad-leaved weeds, 18 grasses and one sedge (*Kyllinga monocephala*) was observed in the experimental site.

Effect on weed density and biomass

Weed density of an area depends on the weed seed bank, tillage, type of weed seeds present *etc*. (Grundy and Jones 2002). Variation in weed density at different time period was observed (**Table 2**) due to the varying time of application of the different weed management practices, alone or in combination. The weedy check recorded a steady increase in weed density which may be attributed to the absorption of water and nutrients efficiently with minimum competition from the crop.

At 15 DAS, weed density and biomass was minimum where pendimethalin 0.75 kg/ha PE + mulching 7 t/ha which was at par with pendimethalin 0.75 kg/ha at PE and pendimethalin 0.75 kg/ha PE + hand weeding at 20 DAS. Similar observations were made by Yadav *et al.* (2017).

At 30 DAS, significantly lowest value for weed density and biomass was recorded with pendimethalin 0.75 kg/ha PE *fb* hand weeding at 20-25 DAS due to combined efficacy of pendimethalin that managed initial flush of weeds and hand weeding which managed late emerged flushes (20 DAS) that resulted in minimized weed density. This was comparable with mulching *fb* hand weeding at 20 DAS; pendimethalin 0.75 kg/ha PE + mulching 7 t/ha. At 45 DAS, imazethapyr 75 g/ha PoE at 20 DAS + hand weeding at 35 DAS recorded lowest weed density and biomass and was on par with that of pendimethalin 0.75 kg/ha PE + mulching 7 t/ha which indicated that pre-emergence herbicide application could effectively manage the weeds emerging early in the season and the later emerged weeds could be successfully controlled by mulching which was equivalent to two hand weeding done 15 and 30 DAS. At 60 DAS, significantly lowest weed density was recorded with hand weeding twice 15 and 30 DAS which was on par with pendimethalin 0.75 kg/ha PE + mulching 7 t/ha.

Pendimethalin PE alone could not control the weeds efficiently at later stages of the crop growth, in spite of causing delay in weed emergence as indicated by the weed density at 15 DAS. There was significant reduction in weed density when pendimethalin was combined with mulching or hand weeding. The weeds emerged later were suppressed by mulching. Hand weeding, mulching and other intercultural operations and their combination with pre- and post-emergent herbicide application at different period of crop duration has resulted in lower weed density and biomass which can also be attributed to the better utilization of resources by cowpea due to effective weed management by those treatments (Kumar 2008).

Table 1. Weed biodiversity associated with the cowpea

	Annuals	Perennials
Grasses	*Dactyloctenium aegyptium, Panicum maximum, Panicum repens, Brachiaria reptans, Digitaria sanguinalis, Ischaemum rugosum, Eragrostis pilosa, Cenchrus carthamus, Leptochloa chinensis, Poa annua* and *Eleusine indica*	*Cynodon dactylon, Axonopus compressus, Desmostachya bipinnata, Dichanthium annulatum, Stenotaphrum secundatum, Agropyron repens* and *Sorghum halepense*
Sedges	*Kyllinga monocephala*	
Broad-leaved weeds	*Commelina benghalensis, Commelina diffusa, Amaranthus viridis, Ageratum conyzoides, Euphorbia hirta, Scoparia dulcis, Achyranthes Aspera, Chenopodium album, Cleome viscosa, Cleome burmannii, Eclipta alba, Ipomoea pes-tigridis, Vernonia cinerea, Phyllanthus niruri, Setaria verticillata, Leucas aspera, Aerva lanata, Alternanthera sessilis, Ludwigia parviflora, Trianthema portulacastrum* and *Emilia sonchifolia*	*Convolvulus arvensis, Oxalis corniculata, Boerhavia diffusa, Tridax procumbens, Sida acuta, Sida rhombifolia, Desmodium triflorum, Hemidesmus indicus, Mimosa pudica, Alternanthera sessilis, Arachis pintoi, Hyptis suaveolens, Physalis minima, Urena lobata* and *Rhynchosia minima*

Weed free maintained throughout the cropping period recorded the lowest weed biomass and highest WCE (100%) throughout the period of study (**Table 3**). At 15 DAS, the WCE recorded with pendimethalin 0.75 kg/ha PE + mulching; pendimethalin 0.75 kg/ha PE + hand weeding at 20-25 DAS and pendimethalin 0.75 kg/ha PE were on par with weed free. At 30 DAS, pendimethalin 0.75 kg/ha PE + hand weeding at 20-25 DAS has recorded significantly highest WCE among all the treatments except weed free, mulching 7t/ha + hand weeding at 20 DAS and pendimethalin 0.75 kg/ha PE + mulching 7t/ha. At 45 DAS, WCE was significantly higher in hand weeding twice at 15 and 30 DAS which was superior to all other treatments except weed free and on par with imazethapyr 75 g/ha PoE *fb* hand weeding at 35 DAS, mulching 7t/ha *fb* hand weeding at 20 DAS and pendimethalin 0.75 kg/ha PE *fb* hand weeding at 20-25 DAS. At harvesting stage (60 DAS), the treatment mulching 7 t/ha *fb* hand weeding at 20 DAS recorded highest value for WCE which was superior to all other treatments except weed free, pendimethalin 0.75 kg/ha PE *fb* mulching 7t/ha, and imazethapyr 75 g/ha PoE *fb* hand weeding at 35 DAS which were on par with each other. Similar observation made by Mathew *et al.* (1995) and Singh and Sekhon (2013).

The weed index values (**Table 3**) were significantly lowest with mulching *fb* hand weeding at 20 DAS except that with weed free check, pendimethalin 0.75 kg/ha PE + mulching 7t/ha. The effect of seed yield and weeds biomass might be the reason behind low WI (Kumar 2008, Idapuganti *et al.* 2005).

Effect on cowpea

The different IWM combinations were effective in suppressing weed growth for about 40 days which resulted in significant enhancement in pod yield which would otherwise have resulted in about 80% yield loss as observed in the weedy check which recorded the lowest value for pod yield. On comparing the effect of weed density and biomass on the cowpea yield it can be inferred that lower weed density and biomass could effectively reduce the competition between crop and weed for resources which has resulted in increased the cowpea yield. Highest seed yield was recorded in weed free, mulching along with pendimethalin PE and mulching along with hand weeding at 20 DAS (**Table 3**). Mulching reduced the weed growth and competition of weeds against crop from sowing to harvesting by providing the environment conductive to crop growth

Table 2. Weed density and biomass in cowpea at successive crop growth stages

Treatment	Weed density (no./m^2)				Weed dry biomass (kg/ha)			
	15 DAS	30 DAS	45 DAS	60 DAS (at harvest)	15 DAS	30 DAS	45 DAS	60 DAS (at harvest)
Pendimethalin 0.75 kg/ha PE	14.7 (3.9)	29.0(5.4)	62.7(7.9)	150.0(12.2)	76.7(2.1)	356.2(4.3)	629.0(5.5)	2109.0(10.6)
Pendimethalin 0.75 kg/ha PE *fb* HW	16.3(4.1)	4.0(2.1)	36.7(6.0)	95.7(9.8)	71.0(2.0)	6.3(0.9)	120.4(2.5)	329.(4.2)
Pendimethalin 0.75 kg/ha PE + mulching	7.0(2.5)	8.7(3.4)	15.3(4.5)	61.3(7.8)	23.9(1.3)	33.4(1.6)	142.1(2.8)	362.2(4.3)
Imazethapyr 75 g/ha PoE	136.0(11.7)	44.3(6.7)	97.7(9.9)	156.7(12.5)	400.4(4.5)	454.5(4.9)	626.5(5.6)	1976.3(10.0)
Imazethapyr 75 g/ha PoE *fb* HW	140.0(11.8)	45.0(6.7)	11.7(3.5)	82.7(9.1)	428.2(4.7)	444.5(5.2)	26.6(1.4)	432.5(4.9)
Imazethapyr 75 g/ha PoE + mulching	22.3(4.7)	29.3(5.4)	38.0(6.2)	78.3(8.8)	180.9(3.1)	223.5(3.7)	222.3(3.5)	738.6(6.1)
Mulching + hand weeding	26.7(5.2)	5.0(2.3)	23.0(4.8)	70.0(8.3)	174.3(3.0)	13.5(1.1)	26.7(1.3)	435.7(4.7)
Hand weeding twice	127.3(11.3)	13.7(3.7)	17.3(4.2)	52.0(7.2)	311.2(4.0)	101.8(2.2)	26.3(1.3)	490.3(5.0)
Mulching alone	25.7(5.1)	45.0(6.7)	80.0(8.9)	138.3(11.8)	214.0(3.3)	382.4(4.4)	936.7(7.0)	2154.4(10.3)
Weedy check	142.3(11.9)	280.7(16.8)	351.3(18.7)	443.3(21.1)	1832.8(9.6)	4158.5(14.1)	4164.3(14.4)	6915.5(18.4)
Weed free	0.0(0.7)	0.0(0.7)	0.0(0.7)	0.0(0.7)	0.0(0.7)	0.0(0.7)	0.0(0.7)	0.0(0.7)
LSD (p=0.05)	0.72	0.75	1.11	1.28	0.52	0.68	0.67	0.81

*Transformed values are given in parentheses; PE: Pre-emergence; PoE: Post-emergence; HW: Hand weeding

Table 3. Weed control efficiency, seed yield and weed index as influenced by the different weed control treatments in cowpea

Treatment	Weed control efficiency (%)				Seed yield (kg/ha)	Weed index (%)
	15 DAS	30 DAS	45 DAS	60 DAS		
Pendimethalin 0.75 kg/ha PE	95.87(9.81)	91.41(9.58)	84.79(9.23)	69.48(8.36)	1028.52(32.07)	59.75(7.76)
Pendimethalin 0.75 kg/ha PE *fb* HW	96.06(9.82)	99.85(10.01)	97.14(9.88)	94.60(9.75)	1219.63(34.91)	52.25(7.26)
Pendimethalin 0.75 kg/ha PE + mulching	98.70(9.96)	99.20(9.98)	96.58(9.85)	94.77(9.76)	2366.14(48.64)	6.19(2.57)
Imazethapyr 75 g/ha PoE	77.86(8.84)	89.07(9.46)	84.91(9.24)	71.41(8.48)	1170.43(34.21)	54.20(7.39)
Imazethapyr 75 g/ha PoE *fb* HW	76.42(8.76)	89.31(9.47)	99.36(9.99)	93.73(9.70)	1200.24(34.64)	53.03(7.31)
Imazethapyr 75 g/ha PoE + mulching	90.12(9.52)	94.63(9.75)	94.67(9.75)	89.32(9.47)	1261.00(35.51)	50.66(7.15)
Mulching + hand weeding	90.49(9.53)	99.67(10.00)	99.35(9.99)	96.64(9.85)	2336.50(48.33)	4.63(2.20)
Hand weeding twice	83.06(9.14)	97.55(9.90)	99.37(9.99)	92.90 (9.66)	1120.26(33.47)	56.46(7.52)
Mulching alone	88.26(9.42)	90.78(9.55)	77.29(8.81)	68.82(8.32)	851.40(29.17)	66.68(8.19)
Weedy check	0.00(0.70)	0.00(0.70)	0.00(0.707)	0.000(0.707)	181.94(13.48)	92.88(9.66)
Weed free	100.00(10.02)	100.00 (10.02)	100.00(10.02)	100.00(10.02)	2697.16(51.93)	0.000(0.707)
LSD (p=0.05)	0.25	0.07	0.15	0.12	0.47	0.32

*Transformed values are given in parentheses; PE: Pre-emergence; PoE: Post-emergence; HW: Hand weeding

Table 4. Economics of weed control treatments in cowpea

Treatment	Economics			
	Cost of cultivation (x10³ `/ha)	Gross income (x10³ `/ha)	Net income (x10³ `/ha)	BCR
Pendimethalin 0.75 kg/ha PE	79.05	87.42	8.37	1.10
Pendimethalin 0.75 kg/ha PE *fb* HW	80.57	103.67	23.10	1.28
Pendimethalin 0.75 kg/ha PE + mulching	82.09	201.12	119.03	2.45
Imazethapyr 75 g/ha PoE	78.31	99.49	21.18	1.27
Imazethapyr 75 g/ha PoE *fb* HW	80.90	102.02	21.12	1.26
Imazethapyr 75 g/ha PoE + mulching	82.42	107.18	24.77	1.30
Mulching + hand weeding	81.00	198.60	11.76	2.45
Hand weeding twice	81.76	95.22	13.46	1.16
Mulching alone	80.24	72.37	-7.87	0.90
Weedy check	77.96	15.46	-62.49	0.20
Weed free	94.68	229.26	134.58	2.42
LSD (0.01)		4.03	1.00	0.05

resulting in higher cowpea yield. Efficient weed control measures help in the growth and development of crop plants by enhancing photosynthetic process thereby decreasing the crop weed competition leading to improved cowpea seed yield (Freitas *et al.* 2009, Mekonnen *et al.* 2017).

Economics

Highest gross returns and net returns were obtained with weed-free, pendimethalin PW with mulching; and mulching + hand weeding (**Table 4**). Highest value for B: C ratio was recorded with mulching + hand weeding at 20 DAS and pendimethalin 0.75 kg/ha PE + mulching 7t/ha which was on par with weed free due to higher gross income with lower cost of cultivation as observed by Sasikala *et al.* (2004). Integration of weed management methods has leads to efficient control of weeds instead of the use of any single method (Yadav *et al.* 2017).

Application of herbicides along with mulching and provision of mulching followed by hand weeding at most critical stage and maintenance of weed free condition is better and most economical method of weed management in cowpea. Integration of different weed management practices that manage weeds both in the initial stages along with the new weed flushes in the later stages have resulted in better weed management during the critical period of crop weed competition. Pendimethalin PE along with mulching and mulching along with hand weeding could effectively keep the field weed free in the critical period of crop weed competition and this was reflected in the yield and yield attributes. Hence, these proven integrated weed management methods can be recommended for higher yield and profit in cowpea.

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RESEARCH NOTE

Effect of herbicide mixtures on weeds and yield of summer groundnut

T.G. Lakshmidevi, V.J. Patel*, B.D. Patel and D.D. Chaudhari

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ABSTRACT

Field experiment was carried during summer 2020 at Agronomy farm, B. A. College of Agriculture, Anand Agricultural University, Anand, Gujarat on loamy sand soil to study the effect of herbicide mixtures on weeds and yield of summer groundnut (*Arachis hypogaea* L.). The experiment was conducted in randomized block design with twelve treatments, replicated four times. Weed density decreased significantly with pre-emergence application (PE) of pendimethalin + oxyfluorfen (tank mix) 900 + 120 g/ha and intercultivation (IC) followed by (*fb*) hand weeding (HW) at 20 and 50 days after seeding (DAS), as compared to other treatments, which resulted in significant increase in growth and yield attributes *viz.*, periodical plant height (cm), plant dry biomass (g/plant), nodule dry weight (mg/plant), number of pods/ plant, pod yield (kg/ha), haulm yield (kg/ha), seed index (g), harvest index (%) and shelling percentage (%). Maximum net returns (Rs. 125485/ha) and B:C (4.94) was achieved with pendimethalin + oxyfluorfen 900 + 120 g/ha PE which was closely followed by IC *fb* HW at 20 and 50 DAS and early post-emergence application of fluazifop-p-butyl (11.1%) + fomesafen (11.1%) SL (pre-mix) 250 g/ha.

Keywords: Groundnut, Fluazifop-p-butyl + fomesafen, Herbicide, Pendimethalin + oxyfluorfen, Weed management

The major constraint limiting production of groundnut is inadequate weed management (Naim *et al.* 2010). In groundnut, less crop canopy during the first 6 weeks of growth favours strong competition with weeds causing significant reduction in yield (Shanwad *et al.* 2011). The extent of yield losses due to weeds range from 47% during the summer season to 62% during the *Kharif* season. In irrigated summer groundnut, average yield loss due to weed infestation was 89% (Giri *et al.* 1998). The heavy infestation of weeds during critical stage of crop necessaites theremoval of weeds either manually or chemically for attaining improved groundnut yield (Vora *et al.* 2019, Kundu *et al.* 2021).

The field experiment was conducted at the Agronomy Farm, B.A. College of Agriculture, Anand Agricultural University, Anand during summer season of the year 2020. The soil of the experimental field was loamy sand in texture having low in organic carbon, medium in available phosphorus and high in available potassium with 7.97 pH. The experiment was laid out in randomized block design with twelve treatments comparised of: pre-emergence application (PE) of pendimethalin (30%) EC + oxyfluorfen (23.5%) EC (tank mix) 900 + 120 g/ha, pendimethalin (30%) + imazethapyr (2%) EC (pre-mix) 900 + 60 g/ha PE, imazethapyr (35%) + imazamox (35%) WG (pre-mix) 70 g/ha PE, early post-emergence application (EPoE) of imazethapyr (35%) + imazamox (35%) WG (pre-mix) 70 g/ha, fluazifop-p-butyl (11.1%) w/w+ fomesafen (11.1%) w/w SL (pre-mix) 250 g/ha EPoE, post-emergence application (PoE) of fluazifop-p-butyl (11.1%) w/w + fomesafen (11.1%) w/w SL (pre-mix) 250 g/ha, propaquizafop (2.5%) + imazethapyr (3.75%) w/w ME (pre-mix) 125 g/ha EPoE, propaquizafop (2.5%) + imazethapyr (3.75%) w/w ME (pre-mix) 125 g/ha PoE, sodium acifluorfen (16.5%) + clodinafop-propargyl (8%) EC (pre-mix) 245 g/ha EPoE, sodium acifluorfen (16.5%) + clodinafop-propargyl (8%) EC (pre-mix) 245 g/ha PoE, intercultivation (IC) followed by (*fb*) hand weeding (HW) at 20 and 50 days after seeding (DAS) and weedy check replicated four times. Groundnut cv. GG 34 was sown on 30th January, 2020 keeping spacing of 30 cm between row by using seed rate of 120 kg/ha. The crop was harvested on 16th June, 2020. Herbicides were applied by using battery operated knapsack sprayer fitted with flat-fan nozzle by mixing in 500 litre of water/ha as per treatments. The crop was fertilized with recommended rate of fertilizer with 25 kg N and 50 kg P_2O_5/ha in the form of urea and single super phosphate, respectively as a basal dose. The rest of the recommended package of practices were adopted to raise the crop. Density and dry weight (biomass) of weeds were recorded from randomly selected four spots by using 0.25 m^2 iron quadrat from net plot through destructive sampling at 30, 60 DAS and at harvest. Other growth and yield

B.A. College of Agriculture, Anand Agricultural University, Anand, Gujarat 388 110, India

* Corresponding author email: avjpatel28@aau.in

attributing observation was also recorded from net plot area. Data on various observations during the experiment period was statistically analysed as per the standard procedure developed by Cochran and Cox (1957).

Effect on weeds

Among all the weed species observed in the experimental field, *Eleusine indica*, *Dactyloctenium aegyptium* and *Eragrostis major*, the monocots and *Digera arvensis* L., *Boerhaavia diffusa*, *Chenopodium album* and *Chenopodium murale*, the dicots were dominant and rest of the weed species were considered as other weeds.

Pendimethalin + oxyfluorfen (tank mix) 900 + 120 g/ha PE, pendimethalin + imazethapyr (pre-mix) 900 + 60 g/ha PE, fluazifop-p-butyl + fomesafen (pre-mix) 250 g/ha EPoE, propaquizafop + imazethapyr (pre-mix) 125 g/ha EPoE, sodium-acifluorfen + clodinafop-propargyl (pre-mix) 245 g/ha EPoE and IC *fb* HW at 20 and 50 DAS provided effective control and minimised the monocot and dicot weed density and biomass at 30 and 60 DAS. At 60 DAS, pendimethalin + oxyfluorfen (tank mix) 900 + 120 g/ha PE and IC *fb* HW at 20 and 50 DAS provided complete control of monocot and dicot weeds. Oxyfluorfen and pendimethalin mixture was very effective when applied prior to and at the time of weed seed germination against grasses and broad-leaved weeds, providing broad spectrum control of weed in grounnut.

The monocot and dicot weed density and biomass at harvest was significantly lower under IC *fb* HW at 20 and 50 DAS but it was at par with pendimethalin + oxyfluorfen EC (tank mix) 900 + 120 g/ha PE, fluazifop-p-butyl + fomesafen (pre-mix) 250 g/ha EPoE, pendimethalin + imazethapyr (pre-mix) 900 + 60 g/ha PE. Punia *et al.* (2017) observed the lowest weed density with imazethapyr + pendimethalin (ready mix) at 1000 g/ha in greengram.

Effect of crop

The growth attributes like plant height (cm) at 60 DAS and at harvest, plant dry biomass plant (g/ plant) and dry weight of nodules (mg/plant) were significantly affected by different weed management practices. Significantly higher plant height (45.29 cm) and plant dry biomass (14.22 g/plant)at harvest and nodule dry weight (65.75 g/plant) was recorded under IC *fb* HW at 20 and 50 DAS andit was statistically similar with pendimethalin + oxyfluorfen (tank mix) 900 + 120 g/ha PE at 45, 60 DAS and at harvest as reported by Patel *et al.* (2020). Similarly, Choudhary *et al.* (2017) also observed effective nodules/plant and dry weight under weed free treatment in groundnut.

Among the yield attributing characters, higher number of pods/plant (23.08), seed index (62.80 g), harvest index (41.46%), shelling percentage (66.31%) and pod yield (3058 kg/ha) wererecorded

Table 1. Density and biomass of monocot and dicot weeds as influenced by different treatments

Treatment	Weed density (no./ m^2)						Weed biomass(g/m^2)						WCE (%) at harvest
	Monocot			Dicot			Monocot			Dicot			
	30 DAS	60 DAS	At harvest	30 DAS	60 DAS	At harvest	30 DAS	60 DAS	At harvest	30 DAS	60 DAS	At harvest	
Pendimethalin + oxyfluorfen (tank mix) 900 + 120 g/ha PE	1.00^{e}	1.00^{f}	2.62^{f}	1.00^{f}	1.00^{e}	2.62^{fg}	1.00^{e}	1.00^{d}	4.74^{e}	1.00^{f}	1.00^{d}	6.20^{d}	90.52
	(0.0)	(0.0)	(6.0)	(0.0)	(0.0)	(6.0)	(0.0)	(0.0)	(21.9)	(0.0)	(0.0)	(38.5)	
Pendimethalin + imazethapyr (pre-mix) 900+60 g/ha PE	1.00^{e}	2.12^{de}	2.65^{ef}	2.12^{e}	5.46^{cd}	3.15^{ef}	1.00^{e}	1.76^{d}	4.85^{e}	1.34^{e}	3.67^{c}	6.96^{d}	88.02
	(0.0)	(4.0)	(7.0)	(4.0)	(29.0)	(9.0)	(0.0)	(2.3)	(27.92)	(0.8)	(12.6)	(48.4)	
Imazethapyr + imazamox (pre-mix) 70 g/ha PE	2.24^{d}	3.30^{c}	4.11^{d}	3.73^{d}	6.61^{abc}	4.11^{cd}	1.309^{d}	3.29^{c}	11.88^{cd}	1.92^{d}	6.99^{b}	12.87^{bc}	52.10
	(4.0)	(10.0)	(16.0)	(13.0)	(43.0)	(16.0)	(0.7)	(9.9)	(140.52)	(2.7)	(48.4)	(164.8)	
Imazethapyr + imazamox (pre-mix) 70 g/ha EPoE	2.62^{cd}	3.80^{c}	4.55^{cd}	3.86^{d}	6.68^{abc}	4.46^{c}	1.43^{cd}	3.34^{c}	14.05^{bc}	1.98^{d}	7.17^{b}	13.10^{bc}	42.31
	(6.0)	(14.0)	(20.0)	(14.0)	(48.0)	(19.0)	(1.1)	(10.2)	(196.80)	(2.9)	(50.9)	(170.9)	
Fluazifop-p-butyl + fomesafen (pre-mix) 250 g/ha EPoE	1.00^{e}	1.81^{ef}	2.62^{f}	1.00^{f}	1.00^{e}	2.96^{efg}	1.00^{e}	1.62^{d}	5.20^{e}	1.00^{f}	1.00^{d}	7.17^{d}	87.62
	(0.0)	(3.0)	(6.0)	(0.0)	(0.0)	(8.0)	(0.0)	(2.0)	(26.35)	(0.0)	(0.0)	(52.6)	
Fluazifop-p-butyl + fomesafen (pre-mix) 250 g/ha PoE	2.81^{c}	5.07^{b}	5.37^{bc}	4.11^{cd}	7.34^{ab}	5.47^{b}	1.49^{c}	4.71^{b}	14.95^{b}	2.07^{cd}	7.38^{b}	13.61^{bc}	35.73
	(7.0)	(25.0)	(28.0)	(16.0)	(53.0)	(29.0)	(1.2)	(21.2)	(222.87)	(3.3)	(54.3)	(186.8)	
Propaquizafop + imazethapyr (pre-mix) 125 g/ha EPoE	1.00^{e}	3.11^{cd}	3.68^{de}	2.43^{e}	5.88^{bcd}	3.84^{cd}	1.00^{e}	3.02^{c}	10.30^{d}	1.60^{e}	6.68^{b}	11.01^{c}	63.52
	(0.0)	(9.0)	(13.0)	(5.0)	(34.0)	(14.0)	(0.0)	(8.2)	(107.57)	(1.6)	(44.2)	(125.0)	
Propaquizafop + imazethapyr (pre-mix) 125 g/ha PoE	2.81^{c}	5.28^{ab}	5.81^{ab}	5.28^{ab}	7.37^{a}	6.15^{a}	1.50^{c}	4.96^{b}	15.77^{ad}	2.57^{ab}	7.49^{b}	14.10^{ab}	25.05
	(7.0)	(27.0)	(33.0)	(27.0)	(54.0)	(37.0)	(1.2)	(23.8)	(252.67)	(5.6)	(56.3)	(225.1)	
Sodium acifluorfen + clodinafop-propargyl (pre-mix) 245 g/ha EPoE	1.00^{e}	1.78^{ef}	2.82^{ef}	2.81^{e}	4.63^{d}	3.45^{de}	1.00^{e}	1.90^{d}	14.47^{bc}	1.45^{e}	6.47^{b}	10.92^{c}	47.86
	(0.0)	(4.0)	(8.0)	(7.0)	(22.0)	(11.0)	(0.0)	(5.1)	(210.48)	(1.1)	(41.0)	(121.9)	
Sodium acifluorfen + clodinafop-propargyl (pre-mix) 245 g/ha PoE	3.30^{b}	5.36^{ab}	5.99^{ab}	4.68^{bc}	7.56^{a}	6.38^{a}	1.66^{b}	5.29^{ab}	16.72^{ab}	2.33^{bc}	8.90^{a}	15.15^{ab}	19.89
	(10.0)	(28.0)	(35.0)	(22.0)	(57.0)	(40.0)	(1.8)	(27.0)	(280.73)	(4.6)	(79.7)	(229.9)	
IC *fb* HW at 20 and 50 DAS	1.00^{e}	1.00^{f}	2.43^{f}	1.00^{f}	1.00^{e}	2.43^{g}	1.00^{e}	1.00^{d}	7.09^{e}	1.00^{f}	1.00^{d}	6.30^{d}	86.15
	(0.0)	(0.00)	(5.0)	(0.0)	(0.0)	(5.0)	(0.0)	(0.0)	(49.39)	(0.0)	(0.0)	(38.9)	
Weedy check	3.99^{a}	6.31^{a}	6.85^{a}	5.91^{a}	8.02^{a}	6.77^{a}	2.74^{a}	6.20^{a}	18.53^{a}	2.85^{a}	10.13^{a}	16.87^{a}	-
	(15.0)	(39.0)	(46.0)	(34.0)	(64.0)	(45.0)	(6.5)	(37.4)	(348.59)	(7.1)	(101.8)	(288.8)	
LSD (p=0.05)	Sig.	Sig.	Sig.	Sig.	Sig.	Sig.	Sig.	Sig.	Sig.	Sig.	Sig.	Sig.	-

*PE: pre-emergence pplication, EPoE: early post-emergence pplication, PoE: post-emergence pplication, IC: intercultivation, *fb:* followed by, HW: hand weeding

Table 2. Growth, yield attributes and yield of summer groundnutas influenced by different treatments

Treatment	Plant height (cm)			Plant dry biomass (g/plant)			Nodule dry weight (mg/plant) At 45 DAS	No. of pods/plant	Seed index (g) (100 seed wt.)	Pod yield (kg/ha)	Net return (`/ha)	B:C
	30 DAS	60 DAS	At harvest	45 DAS	60 DAS	At harvest						
Pendimethalin + oxyfluorfen (tank mix) 900 + 120 g/ha PE	8.55	16.85^{c}	39.95^{bcd}	13.24^{ab}	16.33^{ab}	71.26^{b}	63.33^{ab}	22.93^{a}	62.07^{ab}	2979^{ab}	125485	4.94
Pendimethalin + imazethapyr (pre-mix) 900+60 g/ha PE	8.63	16.71^{c}	39.23^{cd}	11.46^{bcde}	14.79^{bcd}	67.43^{bc}	62.03^{abc}	21.58^{ab}	61.05^{ab}	2822^{abc}	116440	4.53
Imazethapyr + imazamox (pre-mix) 70 g/ha PE	8.55	16.30^{c}	39.36^{cd}	10.60^{def}	13.87^{cde}	61.26^{cde}	57.85^{bcd}	19.95^{b}	57.14^{bcd}	2513^{cde}	100971	4.12
Imazethapyr + imazamox (pre-mix) 70 g/ha EPoE	8.73	17.08^{c}	41.24^{abcd}	10.35^{def}	13.06^{def}	57.07^{def}	55.85^{cd}	17.40^{c}	54.36^{cde}	2397de	94723	3.92
Fluazifop-p-butyl + fomesafen (pre-mix) 250 g/ha EPoE	8.30	16.60^{c}	39.52^{cd}	12.77^{abc}	15.06^{b}	70.44^{b}	62.23^{abc}	21.93^{ab}	60.69^{ab}	2854^{abc}	119545	4.79
Fluazifop-p-butyl + fomesafen (pre-mix) 250 g/ha PoE	8.35	19.12^{b}	42.36^{abcd}	9.90^{def}	12.61^{ef}	56.82^{ef}	54.88^{d}	17.40^{c}	54.00^{cde}	2169^{e}	83477	3.65
Propaquizafop + imazethapyr (pre-mix) 125 g/ha EPoE	8.55	16.55^{c}	39.40^{cd}	10.91^{cdef}	14.31^{cde}	62.05^{cde}	59.87^{abcd}	20.23^{b}	58.39^{abc}	2538^{cde}	102356	4.19
Propaquizafop + imazethapyr (pre-mix) 125 g/ha PoE	8.70	19.91^{b}	42.88^{abc}	9.56^{efg}	12.77^{ef}	55.01^{f}	54.84^{d}	12.53^{d}	52.35^{de}	1673^{f}	56742	2.77
Sodium acifluorfen + clodinafop-propargyl (pre-mix) 245 g/ha EPoE	8.70	17.15^{c}	38.20^{d}	11.58^{bcd}	14.49^{bcde}	63.39^{cd}	60.65^{abcd}	20.75^{b}	59.21^{abc}	2602^{bcd}	105179	4.23
Sodium acifluorfen + clodinafop-propargyl (pre-mix) 245 g/ha PoE	8.80	20.40^{b}	43.83^{ab}	9.44^{fg}	10.96^{f}	51.82^{f}	54.65^{d}	11.38^{d}	52.09^{de}	1704^{f}	57765	2.77
IC *fb* HW at 20 and 50 DAS	8.75	16.65^{c}	40.74^{bcd}	14.22^{a}	17.87^{a}	75.92^{a}	65.75^{a}	23.08^{a}	62.80^{a}	3058^{a}	124634	4.38
Weedy check	8.80	21.50^{a}	45.29^{a}	8.03^{g}	9.11^{g}	42.12^{g}	54.30^{d}	8.53^{e}	50.65^{e}	991^{g}	23976	1.81
LSD (p=0.05)	NS	Sig.	Sig.	Sig.	Sig.	Sig.	Sig.	Sig.	Sig.	Sig.	-	-

*PE: pre-emergence pplication, EPoE: early post-emergence pplication, PoE: post-emergence pplication, IC: intercultivation, *fb:* followed by, HW: hand weeding

underIC *fb* HW at 20 and 50 DAS which was closely followed by pendimethalin + oxyfluorfen (tank mix) 900 + 120 g/ha PE and fluazifop-p-butyl + fomesafen (pre-mix) 250 g/ha EPoE. Higher pod yield might be due to lessergrowth of weeds as evident from the weed density and biomass. Mehriya *et al*. (2021) also obtained higher pod yield under hand weeding at 20 and 40 DAS.

The economic analysis revealed that maximum net returns (₹125485/ha) and B:C (4.94) was achieved with pendimethalin + oxyfluorfen (tank mix) 900 + 120 g/ha PE followed by fluazifop-p-butyl + fomesafen (pre-mix) 250 g/ha EPoE and IC *fb* HW at 20 and 50 DAS with B:C of 4.79 and 4.38, respectively.

It can be concluded that interculturing and hand weeding at 20 and 50 DAS effectively control the weeds, but it is the laborious, time consuming and costlier method of weed control. Hence, under paucity of labour, pendimethalin + oxyfluorfen (tank mix) 900 + 120 g/ha PE could be used for effective weed management and obtaining higher pod yield of summer groundnut with net return and benefit cost ratio.

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RESEARCH NOTE

Effect of herbicides on weed dynamics and productivity of soybean

K.K. Binjha, S. Barla* and R.R. Upasani

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ABSTRACT

A field experiment was conducted at Birsa Agricultural University, Ranchi, Jharkhand, during rainy *(Kharif)* season of 2019 to study the efficacy of herbicides on weed dynamics and productivity of soybean. The treatments comprised of: post-emergence application (PoE) of imazethapyr 75g/ha at 20 days after sowing (DAS), imazethapyr + imazamox 75 g/ha PoE 20 DAS, quizalofop-ethyl 50 g/ha PoE 20 DAS, sodium-acifluorfen + clodinafop-propargyl 125 g/ha PoE, imazethapyr + pendimethalin 1.0 kg/ha PoE, hand weeding twice at 20 and 40 DAS, weed free (hand weeding thrice at 20, 40 and 60 DAS), and weedy check. A randomized block design with three replications was used. Quizalofop-ethyl 50 g/ha PoE recorded maximum yield attributes, *viz.* number of pods /plant (48), number of seeds/pod (2.73), 100 seeds weight (12.46) and yield of soybean (2.15 t/ha) owing to reduced weed biomass and higher weed control efficiency (73.33%) during initial crop growth stage and realized maximum net return (₹ 57221/ha) and B:C ratio (2.34).

Keywords: Productivity, Soybean, Quizalofop-ethyl, Weed control efficiency

Soybean [*Glycine max* (L.) Merril] is one of the important oilseed crops with its immense potential for food, oil, fuel and numerous industrial products (Gandhi 2009). Soybean is rich in high quality protein (40-42%) and other nutrients like calcium and iron. The area, production and productivity of soybean in world, is 121.5 m ha, 334.89 m t, and 2.76 t/ha, respectively (DES 2018). Soybean crop area is 10.56 m ha in India with a productivity of 1.08 m t. In Jharkhand soybean is grown as rainfed crop in upland and medium land situations with low productivity of 1.26 t/ha (Soybean NFSM). There is tremendous scope of soybean cultivation in Jharkhand. Among different production factors limiting soybean productivity, weeds are considered to be the major as the yield reduction due to uncontrolled weed is about 84 % (Kachroo *et al.* 2003). It, being a rainy season crop, heavily infested with grasses, broad-leaved and sedges weeds which compete for light, food, water and space against the soybean crop, and ultimately reduce the crop yield. Hence, for effective weed control in soybean crop, application of appropriate herbicides or other control measures is needed.

A field experiment was conducted at Birsa Agricultural University, Ranchi during rainy *(Kharif)* season of 2019 on sandy loam soil, moderately acidic in nature (pH 5.4), having EC 0.17/dSm, low organic carbon (4.2 g/kg) and available nitrogen (160 kg/ha), medium phosphorus (19 kg/ha) and potassium (146 kg/ha). The experiment was laid out in randomized block design with 8 treatments replicated thrice. The treatments consisted of eight different weed management treatments, *viz.* post-emergence application (PoE) of imazethapyr 75 g /ha at 20 DAS, imazethapyr + imazamox ready mix (RM) 75 g/ha PoE, quizalofop-ethyl 50 g/ha PoE, sodium-acifluorfen + clodinafop-propargyl (RM) 125 g/ha PoE, imazethapyr + pendimethalin (RM) 1.0 kg/ha PoE, hand weeding twice at 20 and 40 days after seeding (DAS), weed free (hand weeding thrice at 20, 40 and 60 DAS) and weedy check. Herbicides were applied on 20 DAS using 500 liters of water/ha with flat fan nozzle fitted knapsack sprayer. The observations on weeds were recorded at 30, 45 and 60 DAS. Weeds were counted using a quadrat of 0.25 square meter (0.5 x 0.5 m), and data obtained were expressed as density (no./m^2). The percent composition of weed flora was estimated from weedy check plot. Data on weeds were subjected to square root transformation ($\sqrt{x+0.5}$) before its statistical analysis.

Effect on weeds

The dominant weeds, associated with soybean crop in the experimental field, comprised of all category of weeds, *viz.* broad-leaved weeds like

Department of Agronomy, Birsa Agricultural University, Ranchi-834006, Jharkhand, India

* Corresponding author email: sheela.barla.123@gmail.com

Stellaria media, Commelina benghalensis and *Phyllanthus niruri*, among grassy weeds *Dactyloctenium aegyptium, Echinochloa colona, Eleusine indica* and *Digitaria sanguinalis* and the sedge *Cyperus rotundas*.

Quizalofop-ethyl 50 g/ha PoE suppressed grassy weeds to the extent of 60.24 per cent at 30 DAS and 100 per cent at 45 and 60 DAS compared to weedy check (**Table 1**). Mean biomass of grassy and broad-leaved weeds increased from 30 DAS to 45 DAS by 91.54 and 74.63 per cent, respectively. Later at 60 DAS it decreased due to different herbicide treatments. The total mean weed biomass decreased 7.88 per cent from 30 to 60 DAS. Quizalofop-ethyl is quickly absorbed by the weeds; hence rain, even one hour after spray does not affect its effectiveness. Kushwah *et al.* (2006) also proved that quizalofop -p-ethyl 15 g/ha PoE was very effective against *Commelina benghalensis* and *Echinochloa colona*.

Hand weeding twice recorded maximum weed control efficiency *i.e.* 97.46, 93.96 and 96.40% at 30, 45 and 60 DAS (**Table 2**). Among herbicides, maximum weed control efficiency was recorded by quizalofop-ethyl 50 g/ha PoE *i.e.* 73.33, 69.10 and 69.37% at 30, 45 and 60 DAS, respectively, as it curbed the growth of the grassy weeds effectively and resulted in the lowest weed biomass which may be the main reason for higher weed control efficiency.

Table 1. Weed biomass as influenced by weed control treatments

Treatment	Weed biomass (g/m^2)										
	30 DAS				45 DAS				60 DAS		
	NL	BLW	S	Total	NL	BLW	S	Total	NL	BLW	Total
Imazethapyr 75 g/ha PoE	9.83 (98.19)	7.96 (63.88)	2.59 (6.45)	12.09 (168.52)	10.98 (120.32)	8.43 (76.64)	3.02 (8.64)	14.29 (205.60)	8.35 (71.36)	9.57 (91.25)	12.74 (162.61)
Imazethapyr + imazamox 75 g/ha PoE	10.16 (103.52)	8.54 (72.8)	3.34 (10.99)	13.68 (187.31)	12.98 (168.64)	7.51 (59.68)	3.07 (9.55)	15.35 (237.87)	11.52 (135.68)	4.27 (18.27)	12.28 (153.95)
Quizalofop-ethyl 50 g /ha PoE	0.71 (0)	9.64 (92.69)	3.96 (15.41)	10.41 (108.11)	0.71 (0)	14.13 (199.79)	0.71 (0)	14.13 (199.79)	0.71 (0)	10.62 (112.80)	10.62 (112.80)
Sodium-acifluorfen + clodinafop 125 g/ha PoE	7.44 (55.09)	6.54 (46.4)	6.33 (39.57)	11.80 (141.07)	9.55 (95.47)	11.30 (132.27)	6.09 (36.88)	16.05 (264.61)	7.61 (57.52)	5.08 (28.96)	9.27 (86.48)
Imazethapyr + pendimethalin 1.0 kg /ha PoE	7.88 (62.61)	8.44 (71.2)	4.25 (17.71)	12.29 (151.52)	15.49 (239.89)	11.02 (121.81)	2.17 (7.11)	19.22 (368.81)	9.38 (89.36)	9.30 (89.97)	13.38 (179.33)
Hand weeding twice at 20 and 40 DAS	1.56 (1.97)	1.85 (3.07)	2.15 (4.75)	3.17 (9.79)	3.01 (9.39)	4.44 (19.25)	3.18 (9.71)	6.23 (38.35)	1.18 (1.33)	3.55 (12.4)	3.7 (13.73)
Weed free	0.71 (0)	0.71 (0)	0.71 (0)	0.71 (0)	0.71 (0)	0.71 (0)	0.71 (0)	0.71 (0)	0.71 (0)	0.71 (0)	0.94 (0)
Weedy check	13.67 (187)	12.59 (159)	7.81 (17.92)	20.14 (406.67)	18.24 (339.99)	16.72 (279.52)	5.29 (27.84)	25.41 (647.35)	14.30 (205.76)	12.88 (165.87)	19.24 (371.63)
LSD(p=0.05)	1.67	2.12	1.04	1.97	2.99	2.52	1.03	2.39	2.30	2.10	1.77

Figures in parentheses are original values subjected to square root ($\sqrt{x+0.5}$) transformation; NL = narrow-leaved weeds, BL = broad-leaved weeds, S= sedges; PoE = post-emergence application

Table 2. Weed Index (WI), weed control efficiency (WCE), yield components, Yield and harvest index (HI) of soybean as influenced by weed control treatments

Treatment	WI (%)	WCE (%) 30 DAS	WCE (%) 45 DAS	WCE (%) 60 DAS	No. of pods/ plant	No. of seeds/ pod	100 seeds weight (g)	Seed yield (t/ha)	Straw yield (t/ha)	HI (%)
Imazethapyr 75 g/ha PoE	26.02	58.30	67.66	55.82	41	2.00	11.76	1.93	3.91	32.82
Imazethapyr + imazamox 75 g/ha PoE	23.09	53.54	62.93	58.86	44	2.13	11.02	2.00	3.58	35.85
Quizalofop-ethyl 50 g/ha PoE	16.73	73.33	69.11	69.37	48	2.73	12.46	2.15	3.70	36.76
Sodium-acifluorfen + clodinafop 125 g/ha PoE	30.72	63.71	58.28	76.69	42	1.97	9.77	1.80	3.32	35.23
Imazethapyr + pendimethalin 1.0 kg/ha PoE	32.76	61.52	42.26	51.38	42	2.33	11.62	1.73	3.26	34.38
Hand weeding twice at 20 and 40 DAS	6.54	97.46	93.96	96.40	41	2.2	11.36	2.44	3.50	41.03
Weed free	0.00	100.00	100.00	99.40	52	2.47	10.97	2.60	3.55	42.34
Weedy check	57.44	0.00	0.00	0.00	24	1.53	9.78	1.11	1.85	37.47
LSD(p=0.05)	18.01	12.40	13.25	9.53	9.40	0.38	1.39	0.47	0.66	7.08

Table 3. Economics of soybean as influenced by weed control treatments

Treatment	Cost of cultivation (₹/ha)	Gross return (₹/ha)	Net return (₹/ha)	B:C ratio
Imazethapyr 75 g/ha PoE	23201	73632	50431	2.17
Imazethapyr + imazamox 75 g/ha PoE	24821	75853	51032	2.06
Quizalofop-ethyl 50 g /ha PoE	24416	81637	57221	2.34
Sodium-acifluorfen + clodinafop 125 g/ha PoE	24007	68439	44432	1.85
Imazethapyr + pendimethalin 1.0 kg /ha PoE	24946	65981	41035	1.64
Hand weeding twice at 20 and 40 DAS	37736	92119	54383	1.44
Weed free	44111	98373	54262	1.23
Weedy check	22436	42186	19750	0.88
LSD(p=0.05)		17741.28	17741.28	0.72

Effect on soybean yield attributes and yield

Quizalofop-ethyl 50 g/ha PoE was as effective as weed free and recorded significantly higher pods per plant (48), seeds per pod (2.73) and 100 seed weight (12.46 g) which was 78.43, 27.40, 50 percent higher compared to those in weedy check (**Table 2**). Similar results were reported by Benke *et al.* (2011).

Among different herbicides quizalofop-ethyl 50 g/ha PoE proved to be best treatment in producing significantly higher seed (2.15 t/ha) and straw yield (3.70 t/ha) followed by imazethapyr + imazamox 75 g/ha at 20 DAS compared to weedy check (**Table 2**). This treatment also recorded minimum weed index (16.73%).

Economics

Quizalofop-ethyl 50 g/ha PoE, recorded higher gross return (₹ 81637/ha), net return (₹ 57221/ha) and B:C ratio (2.34) compared to weedy check (₹ 42186/ha, ₹ 19750/ha and 0.88) (**Table 3**). Samant *et al*. (2014) and Pratap *et al*. (2019) also observed maximum economical yield and effective control of grassy weeds with quizalofop-ethyl in groundnut and soybean.

Thus, it can be summarized that quizalofop-ethyl 50 g/ha PoE was effective in reducing weed biomass resulting higher weed control efficiency (73.33%) during initial crop growth stage, produced maximum soybean yield (2.15 t/ha) and attained maximum net return ₹ 57221/ha and B:C ratio 2.34.

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RESEARCH NOTE

Herbicidal impact on density of *Cuscuta campestris Yunck.* emerged in berseem fodder crop

Varsha Gupta*, Deep Singh Sasode, Ekta Joshi, Y.K. Singh, Rahul Ojha and Kavita Bhadu

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ABSTRACT

A field experiment was conducted at the research farm of RVSKVV Gwalior during *Rabi* 2018-19 and 2019-20 to assess the efficacy of different pre- and post- emergence herbicides to manage *Cuscuta campestris Yunck.* in berseem. *C. campestris,* well known as a dodder, is a serious problem in berseem. Eight treatments consisting of pre-emergence application (PE) of pendimethalin 1000 g/ha, early post-emergence application (EPoE) at 10 days after sowing (DAS) of pendimethalin 1000 g/ha, oxyfluorfen 250 g/ha PE, post-emergence application (PoE) of imazethapyr 40 g/ha after first cut at 60 DAS, imazethapyr 40 g/ha PoE after last cut at 120 DAS, imazethapyr 40 g/ha PoE after first cut + 40 g/ha after last cut, *Cuscuta* free and control plot (no herbicide application) were laid out in RBD with three replications. Imazethapyr 40 g/ha PoE after first cut at 60 DAS was found to be very effective in controlling the *C. campestris* resulting 43% and 16% higher fodder and seed yield, respectively with 43.6% higher profitability. The next best was imazethapyr 40 g/ha PoE after first cut + 40 g/ha after last cut. Pendimethalin PE and oxyfluorfen PE caused phytotoxicity to berseem due to the higher dose of both herbicides and reduced the fodder and seed yield drastically.

Key words: Berseem, *Cuscuta campestris*, Fodder crop, Imazethapyr, Oxyfluorfen, Pendimethalin

Berseem (*Trifolium alexandrinum* L.) is one of the most important *Rabi* season leguminous fodder crop in India and is widely cultivated because of multi cut test regeneration, high fodder yield and nutritional value. After Egypt and Pakistan, India is having the highest area under berseem cultivation (Muhammad *et al*. 2014). In India, it is grown in approximately 2 Mha area (Pandey and Roy 2011) with a productivity of 60-110 t/ha (Anon 2012a). It is widely cultivated because of multi cut test regeneration, high fodder yield and nutritional value. Berseem fodder has 20% crude protein, 62% total digestible nutrients with 65% digestibility (Anon 2012b) and feeding of green fodder stimulates and enhances the milk production in dairy animals. The infestation of weeds reduces green fodder (23-28%) and seed yield (38-44%) (Wasnik *et al*. 2017). Among the weeds infesting berseem, *Cuscuta campestris Yunck.* (Cuscuta) is a serious problem in berseem.

The frequent irrigation, suitable temperature and better nutrient availability during the forage production provides conducive environment for growth of *Cuscuta* which appears simultaneously with crop plants and competes with the crop for essential nutrients, light, moisture and space thus causing substantial reduction in green forage yield. Besides this, seed quality is also impaired due to mixing of weed seeds. Cuscuta, well known as a dodder and locally called as *Amar bail*, has hard-coated seed that can remain dormant in the soil for more than 20 years. It is an annual stem holoparasitic weed. It grows only by penetrating tissues of host plants to obtain water and nutrients. *Cuscuta* density of 2 plants/m^2 caused 15-16% reduction in yield of fodder crop (Mishra 2012). *Cuscuta* can be controlled by using *Cuscuta* free crop seeds, harrowing in crop rows before it parasitizes the host (Mishra 2009). This study was conducted to assess the efficacy of different pre- and post- emergence herbicides to manage *C. campestris* in berseem.

A field experiment was conducted at the research farm of Rajmata Vijayaraje Scindia Krishi Vishwa Vidhyalaya, Gwalior of 412 m altitude from sea level, 23^{0}10'N latitude, 79^{0}54'E longitude during *Rabi* 2018-19 and 2019-20 seasons. The soil of the experimental field was sandy clay loam in texture with organic carbon of 0.3% having pH 7.8, low in available nitrogen (237 kg/ha), medium in available phosphorus (19.7 kg/ha) and potash (277 kg/ha). Eight treatments consisting of pre-emergence application (PE) of pendimethalin 1000 g/ha, early

Rajmata Vijayaraje Scindia Krishi Viswa Vidhyalaya, Gwalior, Madhya Pradesh 474002, India

* Corresponding author email: drvarshagupta11@gmail.com

post-emergence application (EPoE) at 10 days after sowing (DAS) of pendimethalin 1000 g/ha, oxyfluorfen 250 g/ha PE, post-emergence application (PoE) of imazethapyr 40 g/ha after first cut at 60 DAS, imazethapyr 40 g/ha PoE after last cut at 120 DAS, imazethapyr 40 g/ha PoE after first cut + 40 g/ ha after last cut, *Cuscuta* free and weedy check (no herbicide application) were laid out in RBD with three replications.The *Cuscuta* infested seed was purchased from the local market and sown in rows 20 cm apart in first week of November during both the years with a seed rate 25 kg/ha. Before sowing seeds were soaked for half an hour and treated with *Rhizobium meliloti* culture which helps in nitrogen fixation after the establishment of the seedlings. Basal dose of N:P:K 20:80:20 kg/ha through urea, SSP and muriate of potash, respectively was applied in the field. Herbicides were applied with a knapsack sprayer fitted with flat fan nozzle at a spray volume of 500 l/ha. Number of *Cuscuta campestris* emerged/m^2 was recorded at 30, 60 90 and 120 DAS.The first cutting of fodder was done at 60 DAS and subsequent two cuttings were done in 30 days intervals when the crop attained the height of around 45 cm from the ground. The cuttings were done at about 5-7 cm height for better quick growth. The total fodder yield includes the weight of *Cuscuta* vines as it was very difficult to remove from the host plants. The crop was left for seed production after the third cut and given light irrigations until flowering and seed setting. It was harvested in the last week of May during both the years.

Effect on *Cuscuta*

Imazethapyr 40 g/ha PoE after first cut and 40 g/ ha after last cut in berseem have effectively reduced the density of *Cuscuta* and caused 68% and 80% reduction in the density of *Cuscuta* at 90 and 120 DAS, respectively. Imazethapyr 40 g/ha PoE after first cut caused *Cuscuta* density reduction of 65% and 73% over weedy check at 90 and 120 DAS, respectively (**Table 1**). Pendimethalin 1000 g/ha PE and oxyfluorfen 250 g/ha PE caused reduction in *Cuscuta* density of 83% and 73%, respectively at 30 DAS. At 60 and 90 DAS, the impact of both herbicides was decreased and reduction in *Cuscuta* density of 57-40% and 73-51%, respectively was noticed.

Effect on crop

Maximum fodder yield (65.82 t/ha) and seed yield (357 kg/ha) was recorded with imazethapyr 40 g/ha PoE after first cut of berseem and was proved significantly superior over rest of the treatments. Imazethapyr 40 g/ha PoE after first cut and 40 g/ha PoE after last cut in berseem were next best treatments (**Table 2**). The oxyfluorfen 250 g/ha PE and pendimethalin 1000 g/ha PE were phytotoxic to the crop as they caused 78 and 77% injury,

Table 1 Effect of different weed management practices on density of *Cuscuta* emerged, in berseem during 2018-19, 2019-20 and pooled

Treatment	Emerged *Cuscuta* density (no./m^2)											
	30 DAS			60 DAS			90 DAS			120 DAS		
	2018-19	2019-20	Pooled	2018-19	2019-20	Pooled	2018-19	2019-20	Pooled	2018-19	2019-20	Pooled
Pendimethalin 1000 g/ha PE	1.02 (0.54)	1.17 (0.86)	1.09 (0.70)	1.66 (2.27)	1.76 (2.67)	1.71 (2.47)	1.70 (2.38)	1.22 (0.99)	1.46 (1.69)	1.71 (2.43)	1.23 (1.02)	1.47 (1.73)
Pendimethalin 1000 g/ha EPoE at 10 DAS	1.05 (0.61)	1.07 (0.64)	1.06 (0.63)	1.56 (1.94)	2.29 (5.70)	2.02 (3.82)	1.61 (2.09)	1.16 (0.85)	1.39 (1.47)	1.59 (2.10)	1.21 (0.95)	1.40 (1.53)
Oxyfluorfen 250 g/ha PE	1.26 (1.09)	1.31 (1.23)	1.29 (1.16)	1.43 (1.53)	1.41 (1.50)	1.42 (1.52)	1.48 (1.69)	1.24 (1.04)	1.36 (1.37)	1.47 (1.65)	1.29 (1.17)	1.38 (1.41)
Imazethapyr 40 g/ha PoE after first cut	1.32 (1.23)	2.53 (5.97)	1.92 (3.60)	1.14 (0.81)	1.63 (2.17)	1.39 (1.49)	1.15 (0.81)	1.23 (1.01)	1.19 (0.91)	1.17 (0.88)	1.23 (1.01)	1.20 (0.94)
Imazethapyr 40 g/ha PoE after last cut	1.33 (1.27)	2.49 (5.70)	1.91 (3.48)	2.02 (3.60)	2.24 (4.53	2.13 (4.07)	2.03 (3.63)	1.58 (2.00)	1.80 (2.82)	1.22 (1.00)	1.59 (2.04)	1.41 (1.52)
Imazethapyr 40 g/ha PoE after first cut *fb* imazethapyr 40 g/ha PoE after last cut	1.35 (1.32)	2.48 (5.70)	1.91 (3.51)	1.26 (1.08)	1.87 (3.00)	1.56 (2.04)	1.25 (1.06)	1.18 (0.90)	1.22 (0.98)	1.11 (0.73)	1.20 (0.95)	1.15 (0.84)
Cuscuta free	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)	0.71 (0.00)
Weedy check	1.35 (1.32)	2.81 (7.40)	2.08 (4.36)	2.10 (3.93)	2.82 (7.50)	2.46 (5.72)	2.02 (3.58)	1.59 (2.03)	1.80 (2.81)	2.13 (4.03)	1.65 (2.23)	1.89 (3.13)
LSD (p=0.05)	0.062	0.287	0.205	0.158	0.280	0.224	0.072	0.149	0.115	0.203	0.075	0.150

Original data were subjected to square root $\sqrt{x+0.5}$ transformation and presented in parentheses, PE = pre-emergence application, EPoE = early post-emergence application, PoE = post-emergence application, *fb* = followed by, DAS = days after seeding

Table 2. Effect of different weed management practices on crop phytotoxicity, yield and economics in berseem during 2018-19, 2019-20 and pooled

Treatment	Visual phytotoxicity (%) before first cut	Total fodder yield in three cuts (t/ha)			Seed yield (kg/ha)			Net returns (`/ha)			B:C ratio		
		2018-19	2019-20	Pooled	2018-19	2019-20	Pooled	2018-19	2019-20	Pooled	2018-19	2019-20	Pooled
Pendimethalin 1000 g/ha PE	77.17	14.47	11.34	12.91	61	76	68	-14483	-6774	-10628	0.68	0.82	0.75
Pendimethalin 1000 g/ha EPoE at 10 DAS	23.67	53.65	55.47	54.56	273	371	322	76052	112631	94341	2.68	4.02	3.35
Oxyfluorfen 250 g/ha PE	78.00	11.76	7.06	9.41	64	47	56	-18433	-18571	-18502	0.60	0.51	0.55
Imazethapyr 40 g/ha PoE after first cut	4.33	59.84	71.80	65.82	233	480	357	79234	157075	118154	2.74	5.23	3.99
Imazethapyr 40 g/ha PoE after last cut	0.00	59.18	69.03	64.10	212	462	337	73206	147326	110266	2.55	4.75	3.65
Imazethapyr 40 g/ha PoE after first cut *fb* imazethapyr 40 g/ha PoE after last cut	2.67	61.01	67.37	64.19	248	451	349	82943	144437	113690	2.81	4.83	3.82
Cuscuta free	0.00	65.04	79.13	72.09	236	516	376	83852	168470	126161	2.71	4.92	3.81
Weedy check	0.00	42.19	50.08	46.13	147	468	308	41212	123265	82238	1.93	4.41	3.17
LSD (p=0.05)	5.449	4.737	7.077	5.934	31.1	45.4	38.4	7574.6	18350.3	13834	0.164	0.513	0.375

*PE = pre-emergence application, EPoE = early post-emergence application, PoE = post-emergence application, *fb* = followed by, DAS = days after seeding

respectively before first cut which could not be recovered upto third cut (120 DAS). Similar results were reported in Hisar (Priyanka *et al.* 2018).

Economics

The highest fodder yield of 72.09 t/ha and seed yield of 376 kg/ha resulted in higher net monetary returns and B:C ratio (₹ 126161/ha and 3.81, respectively) under *Cuscuta* free plots. Among herbicides-based treatments, the maximum monetary returns (₹ 118154/ha) and B:C ratio (3.99) was recorded with imazethapyr 40 g/ha PoE after first cut. Due to higher dose of pre-emergence herbicides, pendimethalin 1000 g/ha and oxyfluorfen 250 g/ha led to negative net returns and B:C ratio (0.75 and 0.55, respectively), which was 76% and 82% lesser over weedy check.

It was concluded that imazethapyr 40 g/ha PoE after first cut was most efficient in controlling the *Cuscuta* and provided 43% and 16% higher fodder and seed yield, respectively with 43.6% higher profitability compared to weedy check. The next effective treatment was imazethapyr 40 g/ha PoE after first cut + 40 g/ha PoE after last cut.

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RESEARCH NOTE

Effect of increased temperature and soil moisture levels on *Cyperus rotundus* L.

Ajit Kumar Mandal*[1], Ga. Dheebakaran[2], Mahamaya Banik[3] and C. Chinnusamy[4]

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ABSTRACT

Indian agriculture would suffer from elevated temperature and drought during the second part of this century, due to climate change. Weeds respond quickly to stress and adapt to the environment faster than crops. In this context, an experiment was carried out in growth chamber during 2015-16 with an objective to evaluate the effect of increase in air temperature and variations in soil moisture on *Cyperus rotundus* L. (purple nutsedge). A complete randomized design with 10 treatments and three replications was used for this pot culture experiment. The *C. rotundus* plants were grown for three generations. The treatments comprised of three temperature levels, viz. daily ambient (control), ambient +2°C and ambient +4°C increase over the ambient and two soil moisture levels, *viz.* soil moisture provision at 100 per cent of evaporation (M_{100}) and 60 per cent of evaporation (M_{60}). The combination of treatment were imposed at all stages of growth. *C. rotundus* had high acclimatization capacity and better growth under elevated temperature up to +4°C and under sufficient moisture due to its C_4 pathway, which helped the weed to utilize the moisture and temperature more efficiently even during stress and record higher growth. It is concluded that, at projected future temperature (up to +4°C), *C. rotundus* may become more problematic, particularly during the rainy season.

Keywords: Climate change, *Cyperus rotundus L.*, Elevated temperature, Soil moisture, Purple nutsedge

Intergovernmental Panel on Climate Change (IPCC 2013) report indicated that, climate scenarios predict an increase of annual mean temperatures by 1.5 – 4°C by the end of 21st century. If these forecasts are realized, crops and cropping systems would likely experience significant changes, and it is so for the associated weeds. Because of climate change, plants may be subjected to high temperatures and low soil moisture during the growing season (Knapp *et al*. 2008). Recent studies had strongly suggested that geographic range transformations (spread and distribution) for agricultural weeds would be a highly probable outcome from global climate change (Fuhrer 2003, Naidu 2015). Globally, there is a growing list of recent changes in species distributions, abundances and life cycles that are likely to be due to climate change (Naidu *et al*. 2014). Climate change will impose several challenges for managing weeds.

Sedge weeds are distributed in all parts of the world, especially in damp, wet, dry, and marshy region of the tropical, temperate, and sub-tropical regions of the globe. *Cyperus rotundus* L. (purple nutsedge) is described as an aggressive competitor because of its fast growth, dense, rhizomatous habit, prolific reproduction, C_4 photosynthetic pathway and allelopathic properties. *C. rotundus* is the most problematic world's worst weed present in 92 countries in 52 crops (Holm *et al*. 1977). It is a perennial weed, mainly propagated by vegetative means and also by seeds.

Weeds have more adaptability to stress conditions than crops. Hence, it is important to understand the adoptability of weeds under future projected climate, particularly to elevated temperature and moisture stress. With this back ground, the present study was conducted to assess effect of increased temperature and soil moisture stress on *C. rotundus* during three generations.

A growth-chamber experiment was carried out at Agro Climate Research Centre, Tamil Nadu Agricultural University, Coimbatore, during

[1] Department of Agrometeorology, Dr. Kalam Agricultural College, Arrabari, Kishanganj-855107, (BAU-Sabour) Bihar, India

[2] Agro Climate Research Centre, Tamil Nadu Agricultural University, Coimbatore 641003, Tamil Nadu, India

[3] Department of Plant Breeding and Genetics, Dr. Rajendra Prasad Central Agricultural University, Pusa 848125, Bihar, India

[4] Department of Agronomy, Tamil Nadu Agricultural University, Coimbatore 641003, Tamil Nadu, India

* Corresponding author email: ajitmeteorology@gmail.com

December 2015 – May 2016. Chamber 1 was setup to maintaining 4^0C higher than the ambient temperature (+4^oC) and the Chamber 2 was for 2^0C higher than the ambient temperature (+2^oC). A logger continuously recorded the weather at three minutes interval in both inside and outside of growth chamber.

The latitude, longitude and altitude of the experiment location are 11^0N, 77^0E and 426.7m above MSL, respectively and Coimbatore comes under the Western agro climate zone of Tamil Nadu**.** Coimbatore is climatically categorized as Semi-Arid Tropic (SAT) climate with an average annual rainfall of 696 mm distributed in 47 rainy days. The long period average annual mean maximum and minimum temperatures are 31.7 and 21.3^0C, respectively. The normal annual mean relative humidity is 85 and 49 per cent during morning and evening, respectively. The average mean bright sunshine is seven hour per day and solar radiation is 311 cal/cm^2/day

The study was conducted with 10 treatments and three replications in Completely Randomized Design (CRD). Each treatment was a combination of one temperature and one soil moisture level. The temperature levels were varied as ambient (control), ambient + two degree (+2^oC), ambient +four degree (+4^oC) increase over the ambient temperature. The soil moisture levels were, supply of soil moisture provision at 100 per cent (M_{100}) and 60 per cent of evaporation (M_{60}) occurred previous day. The treatment combinations were: ambient +2^0C + M_{100} (+2^oC + M_{100}) for all the three generation, +2^0C + M_{100} for 1st and 2nd generations, +4^0C + M_{100} for 3rd generation, +2^0C + M_{100} for 1st generation and +4^0C + M_{100} for 2nd and 3rd generation, ambient +4^0C + M_{100} for all the three generation (+4^oC + M_{100}), ambient + M_{100} (0^oC + M_{100}) for all the three generation, ambient +2^0C + M_{60} (+2^oC + M_{60}) for all the three generation, +2^0C + M_{60} for 1st and 2nd generations, +4^0C + M_{60} for 3rd generation, +2^0C + M_{60} for 1st generation and +4^0C + M_{60} for 2nd and 3rd generation, ambient +4^0C + M_{60} (+4^oC + M_{60})for all the three generation and ambient + M_{60} (0^oC + M_{60}) for all the three generation.

Trial was conducted for three generations of weed and the temperature and moisture levels were varied generation to generation, as per treatment. The tubers used in first trial was considered as first generation, further their progeny tubers used in the second trial were considered as second generation. Finally the harvested tubers from second generation were used for further experiment; which named as third generation. Each of the generation period was 45 Days.

Irrigation with good water was done to the pots based on pan evaporation reading as per the treatment schedule. The loss of water through evaporation was calculated every day and equal water was poured in the pots for 100 percent moisture level. In 60 percent moisture stress treatment, the quantity of water equal to 60 percent of open pan evaporation was poured. The water poured was calculated as detailed in **Table 1**.

Observations were recorded for plant height (cm), number of leaves (number/plant), leaf area (cm^2), number of flowers, number of tubers and total dry matter production (g) of *Cyperus rotundus* at 45 days after planting (DAP). The data was analyzed using AGRESS statistical software and F test was performed.

Effect on *C. rotundus* growth parameters

The plant height at 45 Day after planting (DAP) was ranged from 26.6 to 37.6, 17.4 to 31.6 and 12.2 to 30.3 cm during 1st, 2nd and 3rd generations, respectively (**Table 2**). In general, there was a decreasing trend in plant height from 1st generation to 3rd generation. The height of *C. rotundus* was significantly higher in T_4 (+4^0C with M_{100}) followed by T_9 (+4^0C with M_{60}) during all three generations as compared to all other treatments. The plant height was significantly lower in control (T_5, +0^0C with M_{100}), followed by T_{10} (+0^0C with M_{60}).

The average number of leaves per plant at 45 DAP were ranged from 10.1 to 13.8, 9.7 to 12 and 8.3 to 12.7 during 1st, 2nd and 3rd generations, respectively. It was observed that the number of leaves per plant was significantly higher in the treatment number T_4 (+4^0C with M_{100}) followed by T_9 (+4^0C with M_{60}), like that of plant height. Initially, there was significantly lower number of leaves per plant were observed in the treatment number T_6 and

Table 1. Water poured in the pots for irrigation requirement calculation

Diameter of pot	:	25cm	Radius of pot	:	12.5cm = 0.125m
Area of pot	:	22/7 x0.125 x 0.125 sq m = 0.049 sq m			
1mm of water in 1square meter =1 litre			1cubic meter = 1000 litre		
Hence, for 1mm in 0.049sq m = 49ml					
If pan evaporation reading is 5 then water required for 100 % level pots =5 x 49ml =245ml and for 60 % = 147 ml					

T_7 (+2^{0}C with M_{60}) during the 1st generation. During the 2nd and 3rd generations, lower number of leaves per plant were observed in T_5 which was on par with T_6, T_7 and T_{10}. In both the moisture level (M_{100} and M_{60}), the treatments that received elevated temperature of +4^{0}C produced a greater number of leaves per plant than +2^{0}C and ambient conditions.

The mean leaf area per plant at 45 Day after planting was ranged from 25.9 to 70.3 cm^2, 20.9 to 60.3 cm^2 and 10.9 to 58.3 cm^2 during 1st, 2nd and 3rd generations, respectively. As that of plant height, the leaf area was also shown decreasing trend from 1st generation to 3rd generation. It was observed that, the leaf area per plant was significantly higher in the treatment number T_4 (+4^{0}C with M_{100}) followed by T_9 (+4^{0}C with M_{160}). The leaf area per plant was significantly lower in control (T_5, +0^{0}C with M_{100}), followed by T_{10} (+0^{0}C with M_{60}) in all three generation.

The results of different treatments on growth parameters of *C. rotundus* were positively influenced by elevated temperature and negatively by soil moisture stress. The elevated temperature of +4^{0}C and 100 per cent moisture produced significantly more height, leaves and leaf area than all other treatments. Ghannoum *et al*. (2000) and Sage and Kubien (2003) reported that the C_4 species respond positively to elevated higher temperature. Thus, *C. rotundus* better performed better under elevated temperature with enough soil moisture. The physiological plasticity of weeds and their greater intraspecific genetic variation compared with most crops could provide weeds with a competitive advantage in a changing environment. Controlling weeds is likely to be more difficult and expensive under climate change (Naidu 2015). *C. rotundus* growth would be more during rainy season and severely restricted during summer due to soil moisture variation. Also, the availability of a resource changes within the environment, it is more likely that weeds will show a greater variations in growth and reproductive response (Trumble 2013). Hence, the *C. rotundus* grew better under elevated temperature (Mandal *et al*. 2017a and b).

The mean value of total dry matter produced per plant at 45 DAP were ranged from 0.456 to 1.104 g/ plant, 0.368 to 0.908 g/plant and 0.212 to 0.937 g/ plant during 1st, 2nd and 3rd generations, respectively (**Table 3**). In general, the total and partitioned dry matter production by the *C. rotundus* was significantly higher in T_4 (+4^{0}C with M_{100}) during all the generation. The dry matter production was recorded significantly lower in T_{10} (+0^{0}C with M_{60}) during 1st generation then 2nd generation onwards T_5 (+0^{0}C with M_{100}) recorded significantly lower dry matter production than all other treatments.

At 45 DAP, the mean value of *C. rotundus* tubers per plant were ranged from 3.7 to 5.5, 3.7 to 6.6 and 2.8 to 5.7 during 1st, 2nd and 3rd generations, respectively (**Table 3**). In general, there was lesser number of tuber production during 3rd generation. Among the temperature levels, +4^{0}C elevated temperature treatments produced significantly more number of tubers than ambient and +2^{0}C temperatures treatments. The elevated temperature of +4^{0}C and 100 per cent moisture (T_4) resulted in significantly higher tubers than all ambient and +2^{0}C treatments either with or without moisture stress.

In general, the moisture stressed treatments (T_6 to T_{10}) had produced more flower than the non-stressed plants (**Table 3**). Among the temperature treatments, the elevated temperature of +4^{o}C produced more flowers than the ambient and +2^{o}C treatments. The ambient temperature treatments produced very small number of flowers compared to

Table 2. Effect of elevated temperature and soil moisture levels on plant height, number of leaves and leaf area of *Cyperus rotundus* at 45 days after planting during three generations

Treatment				Plant height (cm)			No. of leaves			leaf area (cm^2)		
No.	I Gen	II Gen	III Gen	I Gen	II Gen	III Gen	I Gen	II Gen	III Gen	I Gen	II Gen	III Gen
T_1	+2^{o}C + M_{100}	+2^{o}C + M_{100}	+2^{o}C + M_{100}	33.7	27.1	20.6	10.8	12.0	10.3	52.7	41.3	36.4
T_2	+2^{o}C + M_{100}	+2^{o}C + M_{100}	+4^{o}C + M_{100}	33.0	26.1	23.9	11.0	11.5	11.3	51.7	41.5	43.3
T_3	+2^{o}C + M_{100}	+4^{o}C + M_{100}	+4^{o}C + M_{100}	32.5	27.2	26.9	11.4	11.6	11.7	53.6	47.4	55.1
T_4	+4^{o}C + M_{100}	+4^{o}C + M_{100}	+4^{o}C + M_{100}	37.6	31.6	30.3	13.8	11.9	12.7	70.3	60.3	58.3
T_5	0^{o}C + M_{100}	0^{o}C + M_{100}	0^{o}C + M_{100}	28.2	21.6	12.2	11.2	9.7	8.3	28.4	20.9	10.9
T_6	+2^{o}C + M_{60}	+2^{o}C + M_{60}	+2^{o}C + M_{60}	31.8	25.4	19.9	10.1	10.3	8.7	36.9	36.6	21.1
T_7	+2^{o}C + M_{60}	+2^{o}C + M_{60}	+4^{o}C + M_{60}	31.1	26.7	24.3	10.2	10.0	10.0	38.0	35.6	34.7
T_8	+2^{o}C + M_{60}	+4^{o}C + M_{60}	+4^{o}C + M_{60}	31.4	26.8	26.1	11.2	11.3	10.7	38.0	40.1	40.8
T_9	+4^{o}C + M_{60}	+4^{o}C + M_{60}	+4^{o}C + M_{60}	35.9	27.4	28.0	12.2	11.6	11.3	55.4	44.0	47.8
T_{10}	0^{o}C + M_{60}	0^{o}C + M_{60}	0^{o}C + M_{60}	26.6	17.4	15.3	10.9	10.6	9.7	25.9	24.1	18.2
	Mean			32.2	25.7	22.8	11.3	11.0	10.5	45.1	39.2	36.7
	LSD (p=0.05)			23.1	2.5	2.6	1.1	1.1	1.2	4.5	3.8	2.1

Table 3. Effect of elevated temperature and soil moisture levels on number of flowers, number of tubers and total dry matter production of *Cyperus rotundus* at 45 DAP during three generations

Treatment				No. of flowers			No. of tubers			Total Dry Matter production (g/plant)		
No.	I Gen	II Gen	III Gen	I Gen	II Gen	III Gen	I Gen	II Gen	III Gen	I Gen	II Gen	III Gen
T_1	+2°C + M_{100}	+2°C + M_{100}	+2°C + M_{100}	0.0	0.0	1.0	5.3	6.3	2.8	0.849	0.648	0.587
T_2	+2°C + M_{100}	+2°C + M_{100}	+4°C + M_{100}	0.0	0.0	1.0	5.3	6.2	3.8	0.840	0.650	0.700
T_3	+2°C + M_{100}	+4°C + M_{100}	+4°C + M_{100}	0.0	0.0	1.3	5.0	6.5	5.4	0.853	0.718	0.858
T_4	+4°C + M_{100}	+4°C + M_{100}	+4°C + M_{100}	0.0	0.0	1.7	5.5	6.6	5.7	1.104	0.908	0.937
T_5	0°C + M_{100}	0°C + M_{100}	0°C + M_{100}	0.7	0.7	0.3	3.7	3.7	2.9	0.503	0.368	0.212
T_6	+2°C + M_{60}	+2°C + M_{60}	+2°C + M_{60}	0.0	0.0	1.3	4.5	5.4	2.9	0.646	0.584	0.398
T_7	+2°C + M_{60}	+2°C + M_{60}	+4°C + M_{60}	0.0	0.0	1.3	4.7	4.9	4.4	0.644	0.571	0.583
T_8	+2°C + M_{60}	+4°C + M_{60}	+4°C + M_{60}	0.0	0.0	1.7	4.7	5.5	4.7	0.629	0.605	0.650
T_9	+4°C + M_{60}	+4°C + M_{60}	+4°C + M_{60}	0.0	0.0	2.3	5.3	6.3	5.4	0.865	0.657	0.751
T_{10}	0°C + M_{60}	0°C + M_{60}	0°C + M_{60}	0.0	0.7	0.7	3.8	4.2	3.9	0.456	0.369	0.313
	Mean			0.1	0.1	1.3	4.8	5.6	4.2	0.739	0.608	0.599
	LSD (p=0.05)						0.6	0.6	0.5	0.117	0.090	0.075

elevated temperature treatments. The *C. rotundus* had the advantage of being C_4 plant in tuber production under elevated temperature.

Conclusion

C. rotundus had high acclimatization capacity and produced more growth under elevated temperature up to +4°C, with sufficient moisture. It is concluded that in the future under elevated temperature accompanied by adequate rain/moisture, *C. rotundus* might become a greater problematic weed and necessary management techniques that are effective under changing climatic conditions need to be evolved and implemented.

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RESEARCH NOTE

Stimulatory effect of sesame on the germination and seedling growth of *Melochia corchorifolia* L.

Dhanu Unnikrishnan[1], Sheeja K. Raj*[1], P. Shalini Pillai[1], M. Ameena[1], D. Jacob[2] and Atul Jayapal[3]

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ABSTRACT

Severe infestation of *Melochia corchorifolia* L. (Chocolate weed) in sesame (*Sesamum indicum* L.) fields of Onattukara tract of Kerala, India evoked to conduct studies on the allelopathic effect of sesame plant parts leachate and blended extract on the germination and seedling growth of *M. corchorifolia*. Results revealed that, the tested concentrations of sesame leachate and blended extract had stimulatory effect on germination and growth of this weed. Further, sesame leachate had higher stimulatory effect than blended extract on germination and seedling growth of *M. corchorifolia*. The highest concentration of sesame leachate (1:2.5 w/v) recorded the greatest stimulatory effect. The stimulatory effect of sesame leachate on the germination and growth of *M. corchorifolia* might be the reason for the severe infestation of *Melochia corchorifolia* in sesame fields.

Keywords: Allelopathy, Chocolate weed, Germination, *Melochia corchorifolia,* Seedling vigour, Sesame, Weed ecology

Sesame (*Sesamum indicum* L.) is the oldest indigenous oilseed crop cultivated in the tropical regions of India, for its edible seeds. A higher oil content (46-64%) and dietary energy (6355 kcal/kg) makes it a very common food ingredient all over the world (Kaul *et al*. 2020). Sesame is a popular oilseed crop of Kerala from ancient times, especially as a summer crop in the rice fallows of Onattukara tract, which is the major sesame growing tract of Kerala extended over an area of 2800 ha in three major taluks, *viz*. Karunagapally, Karthikapally and Mavelikkara of Kollam and Alappuzha districts of Kerala, India. Rice-rice-sesame is the major cropping sequence of Onattukara. Currently, the farmers of Onattukara are facing a major threat from *Melochia corchorifolia* L. (Chocolate weed), a member of Malvaceae family. *M. corchorifolia* has been spreading fast in the sesame fields causing havoc to the farmers. The seeds of this weed resemble sesame and germinate along with sesame, gaining competitive advantage over the crop causing severe yield reduction.

Allelopathy is defined as any direct or indirect influence of one plant on the other plants through the release of chemicals (Subtain *et al*. 2014). Allelopathic effects are selective in nature, concentration dependent and can either stimulate or inhibit the growth and development of companion plants (Cheema *et al*. 2004). Application of allelopathic water extracts of sorghum at lower concentrations enhanced the germination and growth attributes of wheat (Anwar *et al*. 2003). Sesame is a potential allelopathic crop containing allelochemicals like saponins, flavonoids, tannins, phenols, alkaloids, *etc*. (Fasola and Ogunsola 2014).

The infestation of *M. corchorifolia* weed was found relatively less in lowland paddy and other upland crops. These differences in occurrence of *M. corchorifolia* evoked the interest in possible allelopathic effect of sesame on the germination and growth of *M. corchorifolia*. In this context, the present study was conducted with an objective to investigate the allelopathic effect of sesame on the germination and growth attributes of *M. corchorifolia*.

Sesame plants used for the experiment were raised during March to June (2021) in the ûeld of Onattukara Regional Agricultural Research Station (ORARS), Kayamkulam, Kerala, India. The field was located at 8.93° N and 76.39° E at 3.05 m MSL. Fresh sesame plant samples at active growth stage (30 DAS) were collected carefully from the field without damaging the roots. The roots were cleaned in clean water to remove the dirt and soil adhered to the roots. Allelopathic study was conducted with blended

[1] Department of Agronomy, College of Agriculture, Vellayani, Kerala Agricultural University, Thiruvananthapuram, Kerala 695522, India

[2] OFR Centre, Onattukara Regional Agricultural Research Station, KAU, Kayamkulam, Kerala 686582, India

[3] Onattukara Regional Agricultural Research Station, KAU, Kayamkulam, Kerala 690502, India

* Corresponding author email: sheeja.raj@kau.in

extract and leachate of sesame.

Preparation of blended extract: Plants were chopped into small pieces of 2 cm length using a fodder cutter. The plant material was ground with distilled water in a blender. The ground material was weighed (100 g each) and mixed with 250 mL, 500 mL, 1000 mL and 2000 mL distilled water to make blended extract solutions of four different concentrations of 1:2.5, 1: 5, 1: 10, 1: 20 (w/v) respectively. The blended extract was shaken for 24 h at room temperature on an orbital shaker (Orbital shaker S01, Stuart Scientific Co. Ltd) at 100 RPM and the resultant mixture was filtered through four layers of cheesecloth. The blended extracts prepared were stored in sealed plastic bottles and kept in refrigerator at 4°C until further use.

Preparation of leachate: Plants were chopped into small pieces of 2 cm length using a fodder cutter. The leachate was prepared by soaking the weighed plant (100 g each) material for 48 h in 250 mL, 500 mL, 1000 mL and 2000 mL distilled water to make leachates of 4 different concentrations of 1:2.5, 1: 5, 1: 10, 1: 20 (w/v) respectively. The leachates thus collected were filtered and used for treating *M. corchorifolia* seed samples.

Germination bioassay: *M. corchorifolia* seeds were collected from matured plants. Seeds were allowed to dry for 2 weeks at 25°C, sieved to remove extraneous matter and stored in air tight plastic containers. Mechanically scarified seeds were used for the experiment. Scarification was done on the day of the experiment. Mechanical scarification was done by spreading the seeds on a wooden board and rubbing with emery cloth, by moving the cloth 10 cm up and down three times (Mobli *et al.* 2020). Emery cloth of the firm John Oakey and Mohan with grit range 16-220 was used to scarify the seeds.

Twenty-five matured *M. corchorifolia* seeds were placed in petri dish (9 cm diameter) containing a layer of filter paper. Separate experiments were conducted for blended extract and leachate. The experiments were conducted in completely randomized design with four treatments comprising different concentrations, *viz.* 1:2.5, 1: 5, 1: 10, 1: 20 (w/v) and a control, replicated four times. The filter papers placed in petri dish were moistened with 5 mL of different concentrations of blended extract/ leachate. Control treatments were moistened using distilled water. The germinated seeds were counted at 24 h intervals for seven days. Seeds with 2 mm emerged radicle were considered as germinated. Experiments were conducted simultaneously and experiments were repeated for conformation. On 8th day, seedlings were collected without damaging the root system. Seedling fresh, root and shoot length were measured and average was worked out. The samples were dried in hot air oven at 65 ± 5°C to constant weight. The seedling dry weight was expressed in g/plant. Based on the above observations, seedling emergence percentage, speed of germination (Bartlett 1973), seedling vigour index I and II (Abdul-baki and Anderson 1973) were worked out.

1) $\text{Germination percentage} = \frac{\text{Total number of seeds emerged}}{\text{Total number of seeds}} \text{x } 100$

2) Speed of germination (SG) = $n_1/d_1 + n_2/d_2 + \ldots\ldots\ldots + n_x/d_x$.

Where, n_1 is the number of seeds germinated on 1st day, n_2 is the number of seeds germinated on 2nd day……….n_x is the number of seeds germinated on xth day, d_1 is the 1st day , d_2 the 2nd day and d_x the xth day.

3) Seedling vigor index I (SVI I) = Seedling length (cm) × Germination percentage

4) Seedling vigor index II (SVI II) = Seedling dry weight (g) × Germination percentage

Analysis of variance technique for CRD (Cochran and Cox 1965) was used for the statistical analysis of the experimental data and the significance was tested using F test. Wherever the F values were found significant, critical difference was calculated at five per cent probability level.

Effect of sesame on germination of *M. corchorifolia*

Leachate of sesame was observed to have stimulatory effect on the germination of *M. corchorifolia* seeds. But blended extract of sesame did not have any significant effect (**Table 1**). A germination percentage of 49.33% was observed with leachate of 1: 2.5 (w/v) concentration and was on par with the concentration of 1:5 (w/v). Control recorded the lowest germination percentage (41.33%). Speed of germination was also influenced by sesame leachates of different concentrations (**Table 1**). Higher values of 4.65 and 4.55 were observed by leachates of concentration 1: 2.5 (w/v) and 1: 5 (w/v), respectively and the control treatment recorded the lowest value (4.033). Leachates also had a positive effect on the seedling vigour index I and II (**Figure 1**). The highest value for seedling vigour index I was exhibited by 1: 2.5 (w/v) concentration and was at par with 1: 5 (w/v) concentration. Seedling vigour index II was found to be significantly higher (5.58) for leachate of 1: 2.5 (w/v) concentration. Control treatment recorded the lowest value for both seedling vigour index I and II. Blended extract did not have any significant effect.

Stimulatory effect *M. corchorifolia* might be due to the selective permeability of seed coat of *M. corchorifolia* to the allelochemicals present in the sesame leachate. Wang *et al*. (2010) observed that leachates of wheat stubbles at higher concentration (100% and 50%) enhanced the seed germination and seedling fresh weight and radicle length of cucumber seedlings due to the presence of allelochemicals present in the leachates which stimulated á- amylase activity. Root exudation, leaching from the above ground plant parts, volatilization and decomposition of plant parts are the ways by which allelochemicals are released in to the rhizosphere of the plant. Stimulatory effect of sesame leachate on the germination and seedling growth of *M. corchorifolia* might be the reason for severe infestation of *M. corchorifolia* in sesame fields of *Onattukara* tract.

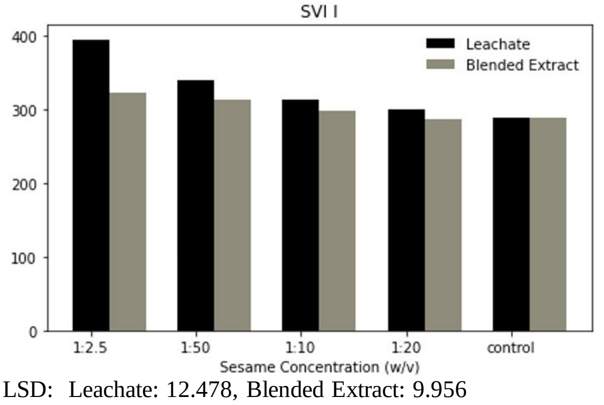
Effect of sesame on growth attributes of *M. corchorifolia*

The results on the bioassay studies revealed that the sesame leachate and blended extract had significant stimulatory effect on the growth attributes of *M. corchorifolia* seedlings. However, the response was found to be concentration dependent and higher concentration resulted in higher values for the growth attributes. Sesame leachate at the highest concentration (1: 2.5 w/v) recorded the highest seedling fresh weight (0.137 g) and was on par with leachate of concentration 1:5 (w/v) which recorded a seedling fresh weight of 0.132 g. The lowest concentration recorded the lowest seedling fresh weight (0.120 g) and remained comparable with the control. Seedling fresh weight of *M. corchorifolia*, recorded with higher concentration of sesame leachate (1:2.5 w/v) was 14.16 per cent greater than control.

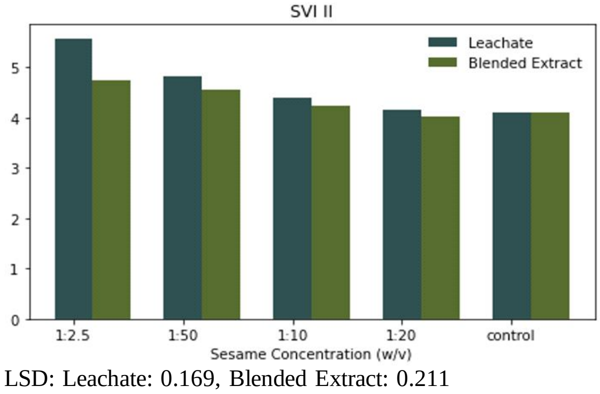
Blended extract of sesame also showed a positive effect on the seedling fresh weight of *M. corchorifolia* (**Table 1**). However, the effect was not as pronounced as in the case of leachate. Higher concentration (1: 2.5 w/v) recorded higher seedling fresh weight of 0.127 g and was on par with 1: 5 and 1:10 w/v concentrations. Control recorded the lowest seedling fresh weight (0.120 g). Higher concentration of blended extract (1:2.5 w/v) showed 5.8 per cent increase in seedling fresh weight of the weed compared to control.

Seedling dry weight of *M. corchorifolia* also followed the same trend as that of seedling fresh weight. As the concentration of leachate decreases, a decline in seedling dry weight was observed (**Table 1**). The highest concentration of sesame leachate (1: 2.5w/v) resulted in the highest dry weight and it was on par with 1.5 w/v concentration. The lowest dry weight was recorded by the control. An increase of 13.4 per cent in seedling dry weight was observed in the highest concentration (1:2.5 w/v) as compared to control. Similarly, the highest concentration of blended extract of sesame (1: 2.5 w/v) resulted in the highest seedling dry weight which was at par with 1: 5 and 1:10 (w/v) concentrations. The lowest concentration (1:20 w/v) and the control recorded the lowest dry weight.

Seedling shoot length of *M. corchorifolia* was also significantly influenced by sesame leachate and blended extract (**Table 1**). As in the case of seedling weight, a higher shoot length of 5.17 cm was observed in 1:2.5 (w/v) concentration (the highest concentration) and it was at par with 1: 5 (w/v) concentration. Shoot length was found to decrease with the decrease in concentrations and the control recorded the lowest shoot length. The increase in seedling shoot length observed at higher concentration of sesame leachate (1.25 w/v) was 10.7 per cent over control. Blended extract of higher concentrations (1:2.5 and 1:5 (w/v)) also resulted in higher seedling shoot length. Increase in seedling shoot length at higher concentration (1.2.5 w/v) was to the tune of 5.8% over control.



LSD: Leachate: 12.478, Blended Extract: 9.956



LSD: Leachate: 0.169, Blended Extract: 0.211

Figure 1. Effect of sesame whole plant leachate and blended extract on seedling vigour index I (SVI I) and seedling vigour index II (SVI II) of M. *corchorifolia*

Table 1. Effect of sesame whole plant leachate and blended extract on germination and seedling growth of *M. corchorifolia* seedlings

Sesame whole plant leachate and blended extract concentration (w/v)	Germination (%)		Speed of germination		Seedling fresh weight (g)		Seedling dry weight (g)		Shoot length (cm)		Root length (cm)	
	Leachate	Blended extract	Leachate	Blended extract	Leachate	Blended extract	Leachate	Blended extract	Leachate	Blended extract	Leachate	Blended extract
1: 2.5	49.33	45.33	4.65	4.43	0.137	0.127	0.110	0.104	5.17	4.93	2.63	2.47
1: 5	45.33	44.00	4.55	4.25	0.132	0.125	0.106	0.103	4.97	4.80	2.53	2.43
1 : 10	44.00	42.67	4.14	4.08	0.122	0.124	0.100	0.098	4.73	4.67	2.40	2.37
1: 20	42.67	41.33	3.99	3.90	0.120	0.120	0.098	0.097	4.70	4.67	2.35	2.30
Control	41.33	41.33	4.00	4.00	0.120	0.120	0.097	0.097	4.67	4.66	2.33	2.30
LSD (p= 0.05)	5.035	NS	0.404	NS	0.007	0.005	0.005	0.005	0.312	0.190	0.126	NS

Sesame leachate alone had significant effect on the root length of *M. corchorifolia* (**Table 1**). Leachate at higher concentrations [1:2.5 (w/v) and 1:5 (w/v)] recorded higher root length of 2.63 cm and 2.53 cm, respectively compared to lower doses. The control recorded the lowest value of 2.33 cm.

Both the leachate and blended extract of sesame had stimulatory effect on the growth attributes of *Melochia corchorifolia* which might be due to the growth promoting effect of allelochemicals present in the sesame leachate and blended extract. Zhu *et al.* (2005) reported that allelopathic effects of plants depend on their types and concentrations. The enhancement in shoot length and seedling fresh and dry weight of maize with fresh shoot aqueous extract of *Tithonia diversifolia* due to the accumulation of some allelochemicals in large amounts (Oyerinde *et al.* 2009); stimulated shoot and root growth of *Lactuca sativa* and *Cassia mimosoides* with leaf extracts of *Euphorbia serpens* (Dana and Domingo 2006) and *Phytolacca americana* (Kim *et al.* 2005) respectively were reported earlier.

Sesame leachate and blended extract had stimulatory effect on the seedling growth of *M. corchorifolia.* which could be inferred that, leachates from the decomposed residues of sesame and leachates might have stimulatory effect on germination and growth of *M. corchorifolia*. This could be the plausible reason for the heavy infestation of *M. corchorifolia* in sesame fields. Hence, to reduce the infestation of *M. corchorifolia*, it is suggested that alternative crops should be raised for three to four years for reducing the weed seed bank of *M. corchorifolia*.

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