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Research notes

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RESEARCH ARTICLE

Sequential application of herbicides for weed management in direct-seeded basmati rice

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ABSTRACT

Due to the water issue and labour shortage during cultivation of rice in India, there is an urgent need to shift towards the alternatives of puddled transplanted rice. Therefore, direct-seeded rice (DSR) is emerging as a productive technique in place of puddle transplanted rice to tackle this situation. The primary biological obstacles to its success, however, are weeds. Therefore, a study has been conducted comprising of 10 treatments with three replications in direct-seeded rice cv. '*Basmati 370'* during the *Kharif* (rainy) seasons of 2018 and 2019 at Research Farm of AICRP-Weed Management, Chatha, SKUAST-Jammu in a randomized block design. At 60 DAS, significantly lowest density as well as biomass of grassy weeds were recorded in oxyfluorfen 175 g/ha as pre-emergence (PE) *fb* fenoxaprop-p-ethyl + 2,4-D-EE (60+500 g/ha) at 25 days after sowing (DAS). However, significantly lowest *Cyperus* species density and biomass was noticed in pendimethalin 1000 g/ha as PE *fb* bispyribac-sodium 25 g/ha at 25 days after sowing. More than 80% weed control efficiency was observed in oxyfluorfen 175 g/ha as pre-emergence (PE) *fb* fenoxaprop-p-ethyl + 2,4-D-EE (60+500 g/ha), pendimethalin 1000 g/ha as PE *fb* bispyribac-sodium 25 g/ha and pretilachlor 600 g/ha *fb* penoxsulam + cyhalofop-butyl 150 g/ha. In addition to this, the results revealed that significantly higher grain and straw yield of rice with highest net returns and benefit cost ratio were observed in pendimethalin 1000 g/ha as PE *fb* bispyribac-sodium 25 g/ha at 25 DAS. The findings of this study will help farmers who are cultivating direct-seeded rice to make decisions on the application of herbicides based on the weed flora existing in the field.

Keywords: Basmati rice**,** Direct-seeded rice, Herbicide, Weed control efficiency, Weed management

INTRODUCTION

With 25% of the world's rice production, India is the one of the top producers in the world. With a projected rise in output, India is expected to produce more than 130 million metric tonnes of rice in the year 2023. Jammu and Kashmir, Himachal Pradesh, Punjab, Haryana, Delhi, Uttarakhand, and Western Uttar Pradesh are the Indian states famous for Basmati rice (NCML 2019). To meet the global rice demand, it is estimated that about 114 million tons of additional milled rice need to be produced by 2035, which is equivalent to an overall increase of 26% in the next 25 years (Kumar and Ladha 2011).

Three main techniques are used to grow rice, *viz*. transplanting, dry-seeding and wet-seeding. Traditional transplanted rice is now quickly being replaced by direct-seeding in locations with good drainage and irrigation systems (Balasubramanian and Hill 2000). Direct-seeded rice (DSR) has a lot of advantages, but it also needs careful management. Direct-seeded rice plants are more vulnerable to weed competition in the early phases of growth where weed control is more difficult. Also, dry tillage and aerobic soil conditions favours the germination and growth of weeds, which can result in losses of 50 to 90 per cent in grain output (Chauhan and Johnson 2011, Chauhan and Open 2012, Chauhan *et al.* 2011, Prasad 2011). Because there are fewer weed control alternatives in DSR than in transplanted rice, research has revealed that grain yield losses are larger in DSR than on transplanted rice (Baltazar and De Datta 1992, Chauhan and Johnson 2010). The presence of standing water that limits light to weed seeds buried in the soil and the absence of weed seedlings are the two reasons giving transplanted rice a upper hand over the DSR (Baltazar and De Datta 1992, Chauhan 2012 and Chauhan and Johnson 2010). Hence, adequate weed management is crucial for successful DSR production. Herbicides, mechanical cultivation and cultural techniques can all be used in conjunction to manage weeds and reduce weed competition to maintain a healthy and successful rice crop. It is crucial to properly evaluate the individual weed stress in each field and select the best weed control strategies for that environment. The availability of systematic herbicide is crucial to change weed

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composition environment in DSR systems. To give farmers more options for weed management in DSR, it is vital to assess various pre and post herbicides. Therefore, the present investigation was carried out with the objective to study the effect of pre- and post-emergence herbicidal weed management on weed flora dynamics and productivity of basmati rice.

MATERIALS AND METHODS

The present field experiment was conducted during the *Kharif* (rainy season of 2018 and 2019 at Research Farm of AICRP-Weed Management, Chatha, SKUAST-Jammu in a randomized block design with three replications having ten treatments namely pendimethalin1000 g/ha as PE, pretilachlor 600 g/ha as PE, oxyfluorfen 175 g/ha as PE, bispyribac-sodium 25 g/ha at 25 DAS, penoxsulam + cyhalofop-butyl 150 g/ha at 25 DAS, fenoxaprop-p-ethyl + 2,4-D -EE (60+500 g/ha) at 25 DAS, pendimethalin1000 g/ha *fb* bispyribac-sodium 25 g/ha at 25 DAS, pretilachlor 600 g/ha *fb* penoxsulam + cyhalofop-butyl 150 g/ha at 25 DAS, oxyfluorfen 175 g/ha *fb* fenoxaprop-p-ethyl + 2,4-D -EE (60+500 g/ha) at 25 DAS and control (weed check).

The experimental site was situated at 32.6529° N latitude and 74.8071° E longitude at an elevation of 332 meters above mean sea level. The average annual rainfall in the experimental area was 1115 mm, of which 70-75% is from June to September, and the remaining 25-30% though small number of showers from the western disturbances in January to March in winter. The region has a subtropical climate with hot, dry summers followed by a hot and humid monsoon season. The soil of the experimental field was sandy clay loam in texture, slightly alkaline in reaction, low in organic carbon and available nitrogen but medium in phosphorus and potassium. The rice variety '*Basmati 370*' was sown on 16th June 2018 and 15th June 2019 and harvested on 28th October 2018 and 5th November 2019, respectively. The gross plot size was 6.0 x 4.4 m. In direct-seeded rice, pre-emergence herbicide pendimethalin 1.0 kg/ha, pretilachlor 600 g/ha and oxyfluorfen 175 g/ha were applied on same day of sowing and all the post-emergence herbicides were applied at 25 days after sowing using 500 L water/ha. All the herbicides were applied by using a Knapsack sprayer fitted with flat fan nozzle. The recommended doses of 30 kg N + 20 kg P + 10 kg K/ha were uniformly applied. Full dose of P and K, and half N were applied as basal at the time of sowing, whereas rest of the N was given in two equal splits as top dressing at mid tillering stage and panicle initiation stage. Besides the rainfall, field was kept under moist conditions by applying irrigation as and when hair line cracks appeared throughout the crop growth. Data on weed density and biomass of weeds were recorded at 30 days after sowing and 60 days after sowing of crop using 1 x 1 m quadrate and was subjected to square root transformation by adding 1.0 to original values prior to statistical analysis. Data on yield and yield attributes were recorded at the time of crop harvest.

RESULTS AND DISCUSSION

Effect of different weed management treatments on weeds

The experimental field was dominated by *Echinochloa* spp. and *Digitaria sanguinalis* amongst grassy weeds; *caesulia axillaris* and *Physalis minima* amongst broad-leaved weeds and *Cyperus* spp. *(difformis* and *iria)*. Beside these major weeds, *Commelina benghalensis, Cucumis* spp., *Euphorbia* spp. and *Dactyloctenium aegyptium* were recorded as other weeds.

Different pre-emergence herbicides treatments showed significant effect on total weed density at 30 DAS in direct-seeded rice (**Table 1**). Among pre-emergence herbicides, oxyfluorfen 175 g/ha recorded significantly lowest total weed density as compared to pendimethalin 1000 g/ha and pretilachlor 600 g/ha during both the years. At 60 DAS, different weed management treatments had significant effect on the grassy weeds, broad-leaved weeds, *Cyperus* spp. *(difformis* and *iria)* and another weed. Under the grassy weeds, results revealed that oxyfluorfen 175 g/ha *fb* fenoxaprop-p-ethyl + 2,4-D -EE (60+500 g/ha) at 25 DAS exhibited lowest density of *Echinochloa* spp. which was noticed to be statistically at par with pendimethalin 1000 g/ha *fb* bispyribac-sodium 25 g/ha at 25 DAS and significantly lower than other treatments. Similarly, oxyfluorfen 175 g/ha *fb* fenoxaprop-p-ethyl + 2,4-D -EE (60+500 g/ha) at 25 DAS resulting in the significantly lowest weed density of *Digitaria sanguinalis* than other treatments (**Table 2**). It was also observed that fenoxaprop-p-ethyl applied treatments exhibited higher control of *Digitaria sanguinalis* than other herbicides. Blouin *et al.* (2010) also reported that fenoxaprop-p-ethyl provides excellent control of major grasses such as *L. chinensis, D. aegyptium, D. sanguinalis* and *E. colona* that are predominant in DSR.

In the case of broad-leaved weeds, oxyfluorfen 175 g/ha *fb* fenoxaprop-p-ethyl + 2,4-D -EE (60+500 g/ha) at 25 DAS exhibited the lowest weed density for both *C. axillaris* and *P. minima* which was statistically at par with pendimethalin 1000 g/ha *fb* bispyribac-sodium 25 g/ha at 25 DAS in case of *C. axillaris*. Similar trend was observed in case of other weed species that oxyfluorfen 175 g/ha *fb* fenoxaprop-p-ethyl + 2,4-D -EE (60+500 g/ha) at 25 DAS exhibiting the lowest weed density than other treatments.

For the *Cyperus* species *(difformis* and *iria)*, the lowest weed density was noticed to be under the pendimethalin 1000 g/ha *fb* bispyribac-sodium 25 g/ha at 25 DAS herbicidal treatment which was found to be statistically at par with pretilachlor 600 g/ha *fb* penoxsulam + cyhalofop-butyl 150 g/ha at 25 DAS during both the years and significantly lower than other treatments. Similarly, the lowest total weed density was noticed with pendimethalin 1000 g/ha *fb* bispyribac-sodium 25 g/ha at 25 DAS which was statistically at par with oxyfluorfen 175 g/ha *fb* fenoxaprop-p-ethyl + 2,4-D -EE (60+500 g/ha) at 25 DAS herbicidal treatment. Similar results were reported by Walia *et al.* (2008) where bispyribac-sodium effectively controlled all common predominant weeds, including all *Cyperus* spp. and *Echinochloa* spp. The lowest total weed biomass was noticed with oxyfluorfen 175 g/ha *fb* fenoxaprop-p-ethyl + 2,4-D -EE (60+500 g/ha) at 25 DAS which was statistically at par with pendimethalin 1000 g/ha *fb* bispyribac-sodium 25 g/ha at 25 DAS herbicidal treatment (**Table 3**). The sequential application of pre- and post-emergent herbicides showed significantly better weed control efficiency than alone

Table 1. Effect of weed management treatments on weed density (no./m^2) at 30 DAS in direct-seeded basmati rice (*Kharif* 2018 and 2019)

Treatment	Total weed density (no./m^2)	
	2018	2019
Pendimethalin1000 g/ha as PE	7.23 (51.33)	6.90 (46.67)
Pretilachlor 600 g/ha as PE	8.06 (64.00)	7.70 (58.33)
Oxyfluorfen 175 g/ha as PE	6.16 (37.00)	6.11 (36.33)
Bispyribac-sodium 25 g/ha at 25 DAS	10.72 (114.00)	10.41 (107.33)
Penoxsulam + cyhalofop-butyl 150 g/ha at 25 DAS	10.80 (115.67)	10.34 (106.00)
Fenoxaprop-p-ethyl + 2-4-D -EE (60+500 g/ha) at 25 DAS	10.74 (114.33)	10.42 (107.67)
Pendimethalin1000 g/ha *fb* bispyribac-sodium 25 g/ha at 25 DAS	7.18 (50.67)	6.83 (45.67)
Pretilachlor 600 g/ha *fb* penoxsulam + cyhalofop-butyl 150 g/ha at 25 DAS	8.10 (64.67)	7.79 (59.67)
Oxyfluorfen 175 g/ha *fb* fenoxaprop-p-ethyl + 2-4-D -EE (60+500 g/ha) at 25 DAS	6.38 (39.67)	6.22 (37.67)
Control	10.89 (117.67)	10.38 (106.67)
LSD (p=0.05)	0.38	0.41

Data was subjected to square root transformation ($\sqrt{x+1}$). Original values are in parentheses

Table 2. Effect of weed management treatments on weed density (no./m^2) at 60 DAS in direct-seeded basmati rice

Treatment	Grassy weeds				Broad-leaved weeds				*Cyperus* spp.		Other		Total	
	Echinochloa sp.		*D. sanguinalis*		*C. axillaris*		*P. minima*							
	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019
Pendimethalin1000 g/ha as PE	3.55 (11.67)	3.61 (12.00)	2.44 (5.00)	2.31 (4.33)	2.24 (4.00)	2.31 (4.33)	2.51 (5.33)	2.45 (5.00)	5.83 (33.00)	5.74 (32.00)	3.05 (8.33)	2.89 (7.33)	8.26 (67.33)	8.12 (65.00)
Pretilachlor 600 g/ha as PE	4.04 (15.33)	4.12 (16.00)	2.77 (6.67)	2.58 (5.67)	2.58 (5.67)	2.45 (5.00)	2.71 (6.33)	2.45 (5.00)	6.38 (39.67)	6.24 (38.00)	3.27 (9.67)	3.06 (8.33)	9.18 (83.33)	8.89 (78.00)
Oxyfluorfen 175 g/ha as PE	3.27 (9.67)	3.06 (8.33)	2.16 (3.67)	2.31 (4.33)	1.82 (2.33)	2.00 (3.00)	2.00 (3.00)	2.08 (3.33)	5.42 (28.33)	5.26 (26.67)	2.58 (5.67)	2.38 (4.67)	7.33 (52.67)	7.16 (50.33)
Bispyribac-sodium 25 g/ha at 25 DAS	3.00 (8.00)	2.83 (7.00)	2.82 (7.00)	2.38 (4.67)	1.91 (2.67)	2.00 (3.00)	1.63 (1.67)	1.73 (2.00)	4.10 (16.00)	3.74 (13.00)	2.89 (7.33)	2.71 (6.33)	6.60 (42.67)	6.08 (36.00)
Penoxsulam + cyhalofop-butyl 150 g/ha at 25 DAS	3.96 (14.67)	3.42 (10.67)	2.16 (3.67)	1.83 (2.33)	1.73 (2.00)	1.91 (2.67)	1.73 (2.00)	1.73 (2.00)	4.03 (15.33)	3.79 (13.33)	2.82 (7.00)	2.65 (6.00)	6.76 (44.67)	6.16 (37.00)
Fenoxaprop-p-ethyl + 2-4-D -EE (60+500 g/ha) at 25 DAS	2.82 (7.00)	2.65 (6.00)	1.73 (2.00)	1.63 (1.67)	1.91 (2.67)	2.08 (3.33)	1.52 (1.33)	1.73 (2.00)	5.15 (25.67)	4.97 (23.67)	2.38 (4.67)	2.16 (3.67)	6.65 (43.33)	6.43 (40.33)
Pendimethalin1000 g/ha *fb* bispyribac-sodium 25 g/ha at 25 DAS	1.63 (1.67)	1.53 (1.33)	2.00 (3.00)	1.73 (2.00)	1.52 (1.33)	1.63 (1.67)	1.41 (1.00)	1.53 (1.33)	2.82 (7.00)	2.65 (6.00)	1.91 (2.67)	1.73 (2.00)	4.20 (16.67)	3.92 (14.33)
Pretilachlor 600 g/ha *fb* penoxsulam + cyhalofop-butyl 150 g/ha at 25 DAS	1.99 (3.00)	1.83 (2.33)	2.16 (3.67)	1.83 (2.33)	1.73 (2.00)	1.83 (2.33)	1.82 (2.33)	1.63 (1.67)	3.21 (9.33)	2.94 (7.67)	2.23 (4.00)	2.00 (3.00)	5.03 (24.33)	4.51 (19.33)
Oxyfluorfen 175 g/ha *fb* fenoxaprop-p-ethyl + 2-4-D -EE (60+500 g/ha) at 25 DAS	1.41 (1.00)	1.41 (1.00)	1.41 (1.00)	1.53 (1.33)	1.52 (1.33)	1.53 (1.33)	1.00 (0.00)	1.15 (0.33)	3.78 (13.33)	3.37 (10.33)	1.52 (1.33)	1.63 (1.67)	4.35 (18.00)	4.12 (16.00)
Control	5.44 (28.7)	5.69 (31.3)	3.83 (13.7)	4.00 (15.0)	2.99 (8.0)	3.11 (8.67)	3.31 (10.0)	3.74 (13.0)	7.96 (62.3)	8.27 (67.3)	3.21 (9.3)	3.51 (11.33)	11.53 (132.0)	12.15 (146.7)
LSD (p=0.05)	0.30	0.28	0.23	0.24	0.27	0.25	0.18	0.22	0.46	0.44	0.25	0.33	0.40	0.35

Data was subjected to square root transformation ($\sqrt{x+1}$). Original values are in parentheses application of either pre-emergence or post-emergence herbicides. The use of herbicide combinations, whether applied simultaneously tank-mixed or sequentially, improved weed control as compared to a single herbicide application (Mahajan and Timsina 2011and Mahajan *et al.* 2013).

Effect of different weed management treatments on yield

Among the weed management practices, all the weed management treatments recorded significantly higher grain and straw yield of rice compared to weedy check (**Table 4**). Pendimethalin 1000 g/ha as PE *fb* bispyribac-sodium 25 g/ha at 25 DAS resulted in highest grain yield (2.67 t/ha for 2018 and 2.57 t/ha for 2019) and straw yield (5.52 t/ha for 2018 and 5.48 t/ha for 2019) which was also found to be statistically at par with pretilachlor 600 g/ha as PE *fb* penoxsulam + cyhalofop-butyl 150 g/ha at 25 DAS for both grain yield (2.45 t/ha for 2018 and 2.39 t/ha for 2019) and straw yield (4.91 t/ha for 2018 and 4.86 t/ha for 2019). The increased availability of nutrients, water, light, and space for crop in these treatments due to successful weed control may be the cause of the improved crop development. According to Walia *et al.* (2008), pendimethalin 0.75 kg/ha as pre-emergence *fb* bispyribac-sodium 25 g/ha as post-emergence caused enhanced weed control to result in a 372% increase in rice grain yield in comparison to weedy check. They also observed that controlling of weeds in DSR is challenging by using single herbicide. Walia *et al.* (2012) reported that pendimethalin 0.75 kg/ha applied as pre-emergence combined with bispyribac-sodium 25 g/ha or azimsulfuron 20 g/ha as post-emergence resulted in yields that were 61.7 and 42.1% greater than pendimethalin 0.75 kg/ha applied alone. Similar results were reported by Walia *et al.* (2012) who demonstrated an increase in grain and straw yield with pre-emergence application of pendimethalin 0.75 kg/ha followed by bispyribac-sodium 25 g/ha. The oxyfluorfen 175 g/ha *fb* fenoxaprop-p-ethyl + 2,4-D -EE (60+500 g/ha) at 25 DAS resulted about 90% weed control efficiency but grain and straw yields were significantly lower than pretilachlor 600 g/ha as PE *fb* penoxsulam + cyhalofop-butyl 150 g/ha and pendimethalin 1000 g/ha as PE *fb* bispyribac-sodium 25 g/ha. This was due to phytotoxicity in germination of rice caused by per-emergence application of oxyfluorfen 175 g/ha.

Effect of different weed management treatments on economics

The cost of cultivation differed for different herbicidal treatments with oxyfluorfen 175 g/ha *fb* fenoxaprop-p-ethyl + 2,4-D -EE (60+500 g/ha) at 25 DAS resulting in the highest cost of cultivation (₹ 30284/ha for 2018 and ₹ 31584/ha for 2019). Pendimethalin 1000 g/ha *fb* bispyribac-sodium 25 g/ha at 25 DAS resulted in numerically higher gross returns (₹ 111874/ha for 2018 and ₹ 107909/ha for 2019), net return (₹ 82267/ha for 2018 and ₹ 77002/ha for 2019), and benefit cost ratio (2.78 for 2018 and 3.49 for 2019) followed by pretilachlor 600 g/ha

Table 3. Effect of weed management treatments on weed biomass (g/m^2) in basmati rice

Treatment	Weed biomass (g/m^2) at 60 DAT								WCE	
	Grassy		BLWs		Sedges		Total			
	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019
Pendimethalin1000 g/ha as PE	4.89 (22.96)	4.84 (22.44)	3.76 (13.16)	3.62 (12.14)	4.35 (17.93)	4.22 (16.85)	7.42 (54.05)	7.24 (51.43)	52.98	57.01
Pretilachlor 600 g/ha as PE	5.51 (29.35)	5.41 (28.29)	4.26 (17.21)	4.14 (16.11)	4.68 (20.99)	4.63 (20.39)	8.27 (67.54)	8.11 (64.79)	41.24	45.84
Oxyfluorfen 175 g/ha as PE	4.36 (18.02)	4.25 (17.05)	2.97 (7.84)	2.87 (7.22)	3.99 (14.94)	3.88 (14.07)	6.46 (40.80)	6.27 (38.34)	64.51	67.94
Bispyribac-sodium 25 g/ha at 25 DAS	4.20 (16.65)	4.12 (16.01)	2.69 (6.27)	2.65 (6.03)	3.01 (8.18)	2.98 (7.89)	5.66 (31.10)	5.56 (29.92)	72.94	74.98
Penoxsulam + cyhalofop-butyl 150 g/ha at 25 DAS	4.81 (22.15)	4.69 (21.01)	2.55 (5.49)	2.47 (5.08)	3.04 (8.25)	2.96 (7.77)	6.07 (35.89)	5.91 (33.87)	68.78	71.68
Fenoxaprop-p-ethyl + 2-4-D -EE (60+500 g/ha) at 25 DAS	3.47 (11.09)	3.41 (10.65)	2.59 (5.78)	2.52 (5.34)	3.66 (12.43)	3.55 (11.58)	5.50 (29.30)	5.35 (27.57)	74.51	76.95
Pendimethalin1000 g/ha *fb* bispyribac-sodium 25 g/ha at 25 DAS	2.61 (5.82)	2.65 (6.01)	2.02 (3.12)	1.94 (2.75)	2.16 (3.71)	2.15 (3.63)	3.69 (12.65)	3.66 (12.40)	89.00	89.64
Pretilachlor 600 g/ha *fb* penoxsulam + cyhalofop-butyl 150 g/ha at 25 DAS	3.07 (8.47)	3.04 (8.25)	2.64 (5.98)	2.39 (4.72)	2.45 (5.00)	2.40 (4.76)	4.51 (19.45)	4.33 (17.72)	83.08	85.18
Oxyfluorfen 175 g/ha *fb* fenoxaprop-p-ethyl + 2-4-D -EE (60+500 g/ha) at 25 DAS	1.90 (2.61)	1.86 (2.46)	1.74 (2.07)	1.74 (2.02)	2.81 (6.92)	2.79 (6.76)	3.55 (11.61)	3.50 (11.24)	89.90	90.60
Control	7.67 (57.94)	7.79 (59.65)	5.10 (25.13)	5.26 (26.69)	5.73 (31.87)	5.85 (33.27)	10.76 (114.95)	10.98 (119.62)	0.00	0.00
LSD (p=0.05)	0.39	0.36	0.41	0.38	0.38	0.36	0.50	0.44	-	-

Data was subjected to square root transformation ($\sqrt{x+1}$). Original values are in parentheses

Table 4. Effect of weed management treatments on yield attributes and yield of direct-seeded basmati rice

Treatment	Grain yield (kg/ha)		Straw yield (kg/ha)		Gross returns (x10^3 ₹/ha)		Cost of cultivation (x10^3 ₹/ha)		Net returns (x10^3 ₹/ha)		B: C ratio	
	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019	2018	2019
Pendimethalin1000 g/ha as PE	1.94	1.85	3.84	3.78	80.75	77.31	26.96	28.26	53.79	49.06	2.00	2.74
Pretilachlor 600 g/ha as PE	1.65	1.55	3.32	3.28	68.94	64.97	26.13	27.43	42.80	37.53	1.64	2.37
Oxyfluorfen 175 g/ha as PE	1.58	1.48	3.12	3.05	65.85	62.12	27.12	28.42	38.72	33.70	1.43	2.19
Bispyribac-sodium 25 g/ha at 25 DAS	2.12	2.03	4.31	4.27	88.51	85.26	27.31	28.61	61.20	56.65	2.24	2.98
Penoxsulam + cyhalofop-butyl 150 g/ha at 25 DAS	1.63	1.58	3.23	3.18	68.15	66.02	27.81	29.11	40.34	36.91	1.45	2.27
Fenoxaprop-p-ethyl + 2-4-D -EE (60+500 g/ha) at 25 DAS	1.80	1.76	3.53	3.49	75.07	73.31	27.82	29.12	47.26	44.20	1.70	2.52
Pendimethalin1000 g/ha *fb* bispyribac-sodium 25 g/ha at 25 DAS	2.67	2.57	5.52	5.48	111.87	107.91	29.61	30.91	82.27	77.00	2.78	3.49
Pretilachlor 600 g/ha *fb* penoxsulam + cyhalofop-butyl 150 g/ha at 25 DAS	2.45	2.39	4.91	4.86	102.38	99.99	29.28	30.58	73.09	69.41	2.50	3.27
Oxyfluorfen 175 g/ha *fb* fenoxaprop-p-ethyl + 2-4-D -EE (60+500 g/ha) at 25 DAS	2.07	2.00	3.85	3.79	86.01	83.18	30.28	31.58	55.73	51.59	1.84	2.63
Control	1.11	1.05	2.09	2.04	46.04	43.89	24.66	25.96	21.38	17.93	0.87	1.69
LSD (p=0.05)	0.31	0.29	0.69	0.68	-	-	-	-	-	-	-	-

fb penoxsulam + cyhalofop-butyl 150 g/ha at 25 DAS (**Table 4**). Singh *et al.* (2016) reported that in terms of the benefit cost ratio, the sequential application of pendimethalin as PE *fb* bispyribac-sodium + azimsulfuron as PoE was more cost-effective than the non-treated weed free treatment. Khaliq *et al.* (2012) also reported previously that post application of bispyribac-sodium increased rice grain yield and economic returns.

It was concluded that pendimethalin 1000 g/ha as PE *fb* bispyribac-sodium 25 g/ha or pretilachlor 600 g/ha *fb* penoxsulam + cyhalofop-butyl 150 g/ha found economical suitable for direct-seeded rice with more than 80% weed control efficiency.

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RESEARCH ARTICLE

Pendimethalin plus pyrazosulfuron for pre-emergence control of complex weed flora in dry-seeded rice

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ABSTRACT

Heavy weed infestation is one of the major constraints in dry-seeded rice. In North-West India, farmers use pendimethalin for pre-emergence control of grasses and small-seeded broad-leaf weeds, while bispyribac is used for post-emergence control of grasses. Continuous use of these herbicides has resulted in weed shift from annual grasses to broad-leaf weeds and sedges, and from annual weeds to perennial weeds particularly *Cyperus rotundus*. Field studies were carried out for successive three years (during 2016-18) in *Kharif* (rainy) season to evaluate pendimethalin plus pyrazosulfuron (pre-mix) at variable doses for pre-emergence control of grasses, sedges and broad-leaf weeds in dry-seeded rice. The uncontrolled growth of grasses, sedges and broad-leaf weeds in dry-seeded rice for whole crop season resulted in 68.7% reduction in crop yield. Pre-emergence application of pendimethalin plus pyrazosulfuron 1150 g/ha effectively reduced weed density and biomass of *Digitaria sanguinalis, Dactyloctenium aegyptium, Echinochloa colona, Cyperus rotundus, C. iria, Phyllanthus niruri, Alternanthera philoxeroides, Mollugo nudicaulis* and *Digera arvensis* with weed control efficiency of 85.3% up to 40 DAS. Though grain yield was maximum in weed free, pre-emergence use of pendimethalin plus pyrazosulfuron 1150 g/ha resulted in the highest returns. Therefore, it was concluded that pendimethalin plus pyrazosulfuron 1150 g/ha as pre-emergence herbicide provided economical control of grasses, broad-leaf weeds and sedges in dry-seeded rice during early crop-weed competition period.

Keywords: Broad-leaf weeds, direct-seeded rice, grasses, sedges, weed control efficiency

INTRODUCTION

Conventionally, rice (*Oryza sativa* L.) is transplanted in puddled fields by transplanting nursery seedlings in Indo-Gangetic plains of Indian sub-continent, which requires huge labour and a large amount of water. However, due to water scarcity and rising labour wages, questions of sustainability of rice production system arises (Chauhan *et al.* 2012). Aerobic rice systems are among the most promising approaches for saving water and reduce water application by 44% relative to conventionally transplanted systems by reducing percolation, seepages and evaporative losses, while maintaining yield at an acceptable level. Dry direct-seeded rice (DSR) is one of the technologies that significantly reduce labour and water requirements (Chauhan 2012). Therefore, farmers in some areas are shifting from traditional transplanted rice to mechanized DSR in response to the rising production costs and shortages of labour and water.

Direct-seeded rice is subjected to much higher weed pressure than rice sown under conventional puddled transplanting method due to alternate wetting and drying conditions (Balasubramanian and Hill 2002). Heavy weed infestation is one of the major constraints in DSR, and there is a risk of crop yield loss to the tune of 5-100% (Rao *et al.* 2007). The main reasons for high weed pressure in DSR are the absence of a weed-suppressive effect of standing water at the time of crop emergence and the absence of a seedling size advantage to suppress newly emerged weed seedlings (Chauhan and Johnson 2010, Rao *et al.* 2007). The total biomass attained by weeds was 86-94% higher in aerobic rice systems and the yield losses were 33-57% higher in aerobic rice systems than in conventional flooded rice (Mahajan *et al.* 2009). More than 50 weed species infest direct-seeded rice which is the major bottleneck in DSR cultivation especially in dry field conditions. It has been observed that several cohorts of diverse grasses, broad-leaf weeds and sedges infest DSR. For post-emergence control of grasses, herbicides are recommended specifically for a particular grass weed species. For example, post-emergence herbicides, bispyribac-sodium 25 g/ha for control of *Echinochloa crus-galli*, *E. colona*, *Digitaria sanguinalis* and fenoxaprop-ethyl 67 g/ha for control of *Dactyloctenium aegyptium*, *D.*

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sanguinalis, *Eleusine indica*, *Leptochloa chinensis* at 20-25 DAS is being used in DSR (Bhullar *et al.* 2016). Continuous use of herbicides for control of annual grass weeds has shifted the dominance to broad-leaf weeds and sedges and from annual weeds to perennial weeds particularly *C. rotundus*. Moreover, alternate wetting-drying regimes in DSR favoured aerobic broad-leaf weeds and sedges. Amongst sedges, *Cyperus iria* and *C. rotundus* have become highly competitive with the crop of DSR (Yaduraju and Mishra 2008). Several sulfonyl urea herbicides and pre-mixes such as metsulfuron-methyl 15 g/ha, bensulfuron 60 g/ha (Peterson *et al.* 1990), metsulfuron plus chlorimuron 4 g/ha (Gopinath and Kundu 2008, Singh *et al.* 2008), ethoxysulfuron 18.75 g/ha (Bhullar *et al.* 2016), azimsulfuron 0.020 kg/ha (Mahajan and Chauhan 2013) is being used as post-emergence weed control option for controlling sedges and broad-leaf weeds in rice paddies.

For pre-emergence control of grass and small-seeded broad-leaf weeds, pendimethalin 750 g/ha is recommended in DSR. However, there is no pre-emergence option for controlling complex weed flora comprising of grasses, sedges and broad-leaf weeds. To control complex weed flora, herbicide combinations can give effective weed control than single herbicide application. Keeping in view the above ideas, field experiment was conducted for three consecutive years to evaluate the bio-efficacy of pendimethalin plus pyrazosulfuron, a pre-mix herbicide for managing grasses, sedges and broad-leaf weeds and achieving highest productivity from dry seeded rice.

MATERIALS AND METHODS

Experimental sites and treatment details

Field experiment was conducted at Agronomy research farm, Punjab Agricultural University, Ludhiana, India located in central plain zone which is characterized by sub-tropical semi-arid type of climate with hot summers (maximum temperature above 38 °C is common during summer) and very cold winters. The variable doses of pre-mix/ready-mix herbicide, pendimethalin plus pyrazosulfuron were evaluated in field studies for three consecutive *Kharif* (June to November) season during 2016, 2017 and 2018. The experimental field was selected where DSR was continuously being cultivated from last 5 years so that representative weed flora must be ensured in the field. The soil of experimental field was normal in soil reaction (pH 7.5-8.0) and electrical conductivity (0.13-0.18 dS/m), medium in organic carbon (0.39-0.41%), nitrogen (243.3-263.9 kg/ha), high in phosphorus (18.8-19.2 kg/ha) and potassium (316-337 kg/ha). The experiment was conducted in randomized complete block design with nine treatments namely, pendimethalin plus pyrazosulfuron 690 g/ha (675+15 g), 920 g/ha (900+20 g) and 1150 g/ha (1125+25 g), pyrazosulfuron 20 g/ha and 25 g/ha, pendimethalin 750 g/ha and 1125 g/ha, weedy (unsprayed) and weedfree. Herbicides were applied as pre-emergence after sowing on moist field with battery-operated knap sack sprayer using 500 litres of water. In weedy plots, weeds were allowed to grow for whole season while in weed free plots, weeds were controlled with the help of integrated weed control methods (both, chemical and mechanical) for whole crop season.

Crop husbandry

The seed of rice cultivar '*PR 126*' was treated with carbendazim 50 g/ha and was air-dried under shade. After seedbed preparation in moist field, treated seed was sown with single-row seed drill at 20 cm row spacing in the first week of June (*Kharif* season) during three years of study. Nitrogen (187.5 kg/ha N) was applied as broadcast in four equal splits at 2, 4, 7 and 10 weeks after sowing. Phosphorus (30 kg/ha P), potassium (30 kg/ha K) and zinc sulphate heptahydrate (62.5 kg/ha) were applied at the time of seedbed preparation by broadcasting. The iron deficiency was corrected with three sprays of 0.5% $FeSO_4$ done at weekly interval starting at 15 days after sowing. The plots of direct-seeded rice were kept moist at least for 2 weeks with light irrigation after sowing was completed. Thereafter, irrigation was applied at 5-7 days intervals to avoid water stress to the crop. No irrigation was applied on rainy days. Irrigation was stopped 15 days before harvesting of the crop. Plant protection measures for insect-pests and diseases were taken to grow healthy crop. The crop was harvested manually from net plot area when grains were mature and straw had turned yellow in first week of November.

Weed, crop growth and yield observations

Observation on weed density was recorded at 20 and 60 DAS from a randomly selected quadrat at two spots in each plot at both the location. Grasses, broad-leaf weeds and sedges were collected separately from the same area at 40 DAS for recording the weed biomass of grasses, sedges and broad-leaf weeds. Weed samples were oven dried before weighing at 60±2°C till constant weight was achieved. Weed control efficiency (WCE) and weed index (WI).

Crop growth parameters namely plant height, tillers and crop biomass were recorded at 40 DAS. Plant height was recorded from 5 randomly selected plants. Tillers were counted from third row from two spots of 50 cm row length in each plot. Tillers were harvested separately from the same area for recording the crop biomass. Crop samples were oven dried before weighing at 60±2 °C till the constant weight was achieved. Effective tillers were recorded from third row from two spots of 50 cm row length in each plot at harvest. Yield attributing characters like number of grains/panicle and 1000 grain weight were recorded at harvest from 5 randomly selected plants. The grain yield (at 14% moisture) and straw yield was recorded. The cost of cultivation was worked out based on the labour and input cost incurred towards rice cultivation in different treatments. Economics of cultivation was worked out and benefit-cost ratio was calculated by dividing gross returns with variable cost of cultivation.

Statistical analysis

The pooled analysis of data of three years was done after verifying the homogeneity of variance. The years by treatment interactions were non-significant. Weed density and biomass data were subjected to square root transformation ($\sqrt{x+1}$) before performing ANOVA. The data was analyzed using Proc GLM in SAS 9.3 and differences among treatment means were determined using ANOVA. When the F-test was significant, Fisher's protected least significant difference (LSD) post hoc test was used to test significant difference between treatment means values at 5% level of significance.

RESULTS AND DISCUSSION

The major weed flora in the experimental field at Ludhiana consisted of grasses, *viz. Digitaria sanguinalis, Echinochloa colona, Dactyloctenium aegyptium*; sedges, *viz. Cyperus rotundus, Cyperus iria* and broad-leaf weeds, *viz. Phyllanthus niruri, Mollugo nudicaulis, Digera arvensis, Alternanthera philoxeroides.*

Weed density and biomass

Amongst herbicide treatments, pre-mix of pendimethalin plus pyrazosulfuron 1150 g/ha resulted in significantly lower weed population and biomass than its lower dose of 690 g and 920 g/ha. Pendimethalin plus pyrazosulfuron 1150 g/ha (pre-mix) recorded the lowest weed density of *Cyperus iria* at 30 DAS which was statistically similar to weed free (**Table 1**). However, density of *Cyperus rotundus* was the lowest in weed free treatment, and tested pre-emergence herbicides did not give efficient control of *C. rotundus*. Pre-emergence application of pendimethalin plus pyrazosulfuron 1150 g/ha was recorded as the best herbicide treatment for the control of sedges as compared to alone application of pendimethalin and pyrazosulfuron. Pendimethalin 750 g and 1125 g/ha effectively controlled grasses however, it failed to control sedges and some broad-leaf weeds. Significant reduction in population of broad-leaf weeds (*Phyllanthus niruri, Alternanthera philoxeroides, Mollugo nudicaulis, Digera arvensis*) was recorded with different herbicides application as compared to weedy check. Pyrazosulfuron 25 g/ha was more effective than its lower dose (20 g/ha) for the control of sedges, although similar control of broad-leaf weeds was observed.

Pendimethalin plus pyrazosulfuron 1150 g/ha continued to show the best results by reducing weed density and biomass of grasses, broad-leaf weeds and sedges at 60 DAS (**Table 1**). Grass weed density in pendimethalin plus pyrazosulfuron 690 g/ha were statistically like grass weeds observed in weedy plots. Standalone application of pendimethalin 750 g and 1125 g/ha was equally effective in controlling grasses (*Digitaria sanguinalis, Dactyloctenium aegyptium, Echinochloa colona*) as its pre-mix with pyrazosulfuron. The density of sedges (*Cyperus rotundus, C. iria*) and broad-leaf weeds (*Alternanthera philoxeroides, Mollugo nudicaulis, Digera arvensis*) in pendimethalin treated plots were statistically similar to that observed in weedy plot. However, grasses (*Digitaria sanguinalis, Dactyloctenium aegyptium, Echinochloa colona*) and *Phyllanthus niruri* were effectively controlled with pendimethalin.

The critical period of crop-weed competition ranges from 11.8–83.2 days after sowing (DAS) for short-duration rice varieties (Chauhan *et al.* 2012, Singh *et al.* 2014). Weeds in DSR systems are mainly managed by using herbicides and manual weeding. However, Manual weeding is becoming less popular because of the labour scarcity and high wages. In the absence of manual weeding, farmers in irrigated areas mainly rely on herbicides to control weeds in DSR systems. In DSR systems, weeds come in large numbers along with the crop due to frequent irrigations, and manual or mechanical weeding is not economical and some weeds especially mimic weeds are hard to be controlled with hand weeding, therefore, herbicide use become a necessity to keep crop weed free in critical period of crop-weed competition. Most upland and aerobic rice growers in Asia mechanically weed their crops two or three times per season, investing up to 190 person days/ha in hand weeding which is very easy and environment-friendly but it is tedious, time consuming, highly labour intensive and expensive. In addition, during peak period, the availability of labour is becoming a serious problem by time. So, herbicides are used successfully for weed control in rice fields for their rapid effect, easier application and low-cost involvement in comparison to the traditional methods of hand weeding. Herbicides having narrow spectrum of weed control are used for the control of grasses and broad-leaf weeds in DSR. In the present study, it was observed that the highest weed control efficiency among the herbicidal treatments was recorded with pendimethalin plus pyrazosulfuron at 1150 g/ha. Singh *et al.* (2005, 2008) also observed that pre-mix of pendimethalin plus pyrazosulfuron resulted in effective control of mixed weed flora in rice field due to pendimethalin which was effective in controlling annual grasses and broad-leaved weeds and pyrazosulfuron gave effective control against broad-leaved weeds and sedges, hence provided over all control of weed flora. These results were in confirmation with the findings of Kaur and Singh (2015), which showed that pendimethalin resulted in effective control of grasses and broad-leaved weeds, and sedges was controlled with pyrazosulfuron. Pendimethalin plus pyrazosulfuron 1150 g/ha as pre-emergence application helped in managing mixed weed flora at critical crop-weed competition period of rice and showed no phytotoxic effect on rice. Uncontrolled growth of grasses, sedges and broad-leaf weeds for whole crop season in direct seeded rice resulted in 68.7% reduction in rice grain yield.

Crop growth, yield attributes and grain yield of rice

Herbicide application resulted in more plant height as compared to weedy (**Table 2**). Pre-emergence application of pendimethalin plus pyrazosulfuron 1150 g/ha resulted in significantly a greater number of tillers and crop biomass as compared to other herbicide treatments. The largest number of effective tillers and grains per panicle was observed in weed free which was statistically similar to pendimethalin plus pyrazosulfuron 1150 g/ha, but

Table 1. Effect of weed control treatments on weed density at 20 and 60 days after sowing (DAS)

Treatment	Weed density [a,b,c] (no./m²)																	
	Digitaria sanguinalis		*Dactylocteniu m aegyptium*		*Echinochlo a colona*		*Cyperus rotundus*		*Cyperus iria*		*Phyllanthus niruri*		*Alternanthera philoxeroides*		*Mollugo nudicaulis*		*Digera arvensis*	
	20 DAS	60 DAS	20 DAS	60 DAS	20 DAS	60 DAS	20 DAS	60 DAS	20 DAS	60 DAS	20 DAS	60 DAS	20 DAS	60 DAS	20 DAS	60 DAS	20 DAS	60 DAS
Pendimethalin plus pyrazosulfuron 690 g/ha	14 c	57 d	9 c	50 bc	17 c	55 c	47 c	58 c	26 c	56 c	11 b	12 b	11 b	41 b	8 ab	20 b	10 ab	15 c
Pendimethalin plus pyrazosulfuron 920 g/ha	6 b	39 bc	5 b	55 bc	7 b	39 b	19 b	45 bc	6 b	39 b	2 a	3 a	1 a	39 b	0 a	17 b	0 a	10 bc
Pendimethalin plus pyrazosulfuron 1150 g/ha	2 a	33 b	1 a	45 b	1 a	28 b	4 a	34 b	1 a	29 b	0 a	0 a	0 a	19 b	0 a	10 b	0 a	8 b
Pyrazosulfuron 20 g/ha	16 c	52 cd	8 c	68 c	19 c	61 c	30 bc	69 c	18 c	46 bc	5 a	9 b	6 a	36 b	5 a	15 b	4 a	26 c
Pyrazosulfuron 25 g/ha	14 c	44 c	11 c	65 c	17 c	57 c	16 b	56 c	7 b	38 b	4 a	8 b	4 a	28 b	4 a	14 b	2 a	16 bc
Pendimethalin 750 g/ha	1 a	34 b	0 a	44 b	1 a	31 b	88 d	109 d	71 d	123 d	6 a	11 b	7 ab	39 b	7 ab	17 b	6 a	23 c
Pendimethalin 1125 g/ha	0 a	27 b	0 a	47 b	0 a	26 b	89 d	119 d	70 d	113 d	5 a	9 b	8 ab	34 b	6 ab	11 b	6 a	19 c
Weedy	18 c	58 d	10 c	60 c	21 c	48 c	91 d	101 d	83 d	108 d	14 b	20 c	13 b	33 b	13 b	15 b	18 b	22 c
Weed free	0 a	0 a	0 a	0 a	0 a	0 a	0 a	0 a	0 a	0 a	0 a	0 a	0 a	0 a	0 a	0 a	0 a	0 a

Table 2. Effect of weed control treatments on crop growth and weed biomass at 40 days after sowing (DAS)

Treatment	Plant height at 40 DAS[a] (cm)	Tiller density at 40 DAS[a] (no./m²)	Crop biomass at 40 DAS[a] (g/m²)	Weed biomass at 40 DAS[a,b,c] (g/m²)				Weed control efficiency (%) at 40 DAS[a]			
				Grasses	Broad-leaf weeds	Sedges	Total	Grasses	Broad-leaf weeds	Sedges	Total
Pendimethalin plus pyrazosulfuron 690 g/ha	9.8 a	226.8 bc	30.4 c	30.1 bc	5.8 b	43.4 c	78.9 b	24.8	76.9	64.3	56.8
Pendimethalin plus pyrazosulfuron 920 g/ha	10.3 a	264.8 b	43.6 b	22.5 b	1.5 a	40.8 c	64.8 b	5.2	93.6	66.1	65.9
Pendimethalin plus pyrazosulfuron 1150 g/ha	11.0 a	298.6 a	56.8 a	8.6 a	0 a	18.8 b	26.1 a	81.3	100.0	84.2	85.3
Pyrazosulfuron 20 g/ha	10.2 a	210.3 c	40.9 b	38.8 c	6.8 b	49.2 c	93.8 b	4.8	73.1	59.4	49.2
Pyrazosulfuron 25 g/ha	10.4 a	221.3 c	46.6 b	34.4 c	2.3 a	28.1 b	69.0 b	2.5	90.9	76.8	62.9
Pendimethalin 750 g/ha	9.9 a	216.4 c	32.7 c	25.6 b	6.4 b	98.8 d	130.6 c	36.8	74.7	18.4	30.6
Pendimethalin 1125 g/ha	10.1 a	222.3 c	39.7 bc	15.1 ab	5.8 b	103.4 d	124.4 bc	63.0	77.0	14.6	33.8
Weedy	6.5 b	131.2 d	28.1 c	40.3 c	25.3 c	121.1 d	186.1 d	-	-	-	-
Weed free	10.9 a	302.1 a	58.6 a	0 a	0 a	0 a	0 a	100	100	100	100

[a] DAS, days after sowing.

[b] The data were square root transformed for homogenous variance prior to analysis; however, data presented are the means of actual values for comparison.

[c] Least square means within columns with no common letters are significantly different according to Fisher's protected least significant difference (LSD) test where $P < 0.05$.

Table 3. Effect of weed control treatments on yield attributes and yield at harvest

Treatment	Effective tiller[a] (no./m²)	Grains/ panicle[a] (no.)	1000 grain weight[a] (g)	Weed index (%)	Grain yield[a] (t/ha) 2016	2017	2018	Pooled	Straw yield[a] (t/ha)	Benefit: Cost ratio
Pendimethalin plus pyrazosulfuron 690 g/ha	256.8 c	119.8 b	22.6 a	30.7	3.982 bc	4.098 bc	4.021 bc	4.034 bc	5.547 b	1:2.05
Pendimethalin plus pyrazosulfuron 920 g/ha	312.1 b	121.6 b	22.7 a	28.9	4.321 b	4.151 bc	4.236 bc	4.236 bc	6.025 ab	1:2.45
Pendimethalin plus pyrazosulfuron 1150 g/ha	354.6 a	135.9 a	23.0 a	18.6	5.587 a	4.648 b	4.388 b	4.874 b	6.246 a	1:2.87
Pyrazosulfuron 20 g/ha	248.4 c	117.5 b	22.5 a	45.9	3.103 c	3.323 c	3.244 c	3.223 c	5.467 b	1:2.12
Pyrazosulfuron 25 g/ha	259.6 c	120.8 b	22.8 a	45.3	3.112 c	3.389 c	3.293 c	3.265 c	5.624 b	1:2.28
Pendimethalin 750 g/ha	258.9 c	121.4 b	21.9 a	48.8	2.533 cd	3.452 c	3.221 c	3.069 c	5.501 b	1:2.17
Pendimethalin 1125 g/ha	265.8 c	127.6 b	22.7 a	48.1	3.069 c	3.148 c	3.108 c	3.108 c	5.613 b	1:2.20
Weedy	168.9 d	65.8 c	21.6 a	68.7	1.689 d	1.899 d	2.013 d	1.867 d	3.014 c	1:1.49
Weed free	360.2 a	138.1 a	23.3 a	-	5.897 a	6.041 a	6.021 a	5.987 a	6.987 a	1:2.33

[a] Least square means within columns with no common letters are significantly different according to Fisher's protected least significant difference (LSD) test where $P < 0.05$.

was significantly more as compared to standalone application of pendimethalin and pyrazosulfuron (**Table 3**). No significant difference in thousand grain weight was recorded. Different weed control treatments had significant effect on the grain yield of rice. The highest grain and straw yield of rice was obtained with weed free and it was followed by pre-mix application of pendimethalin + pyrazosulfuron. This indicated that sequential application of some post-emergence herbicide (depending upon weed flora) is also required to achieve the potential yield. Pendimethalin + pyrazosulfuron at 1150 g/ha resulted in significantly more grain yield than standalone application of pendimethalin and pyrazosulfuron herbicides. The highest returns were obtained with pre-emergence application of pendimethalin plus pyrazosulfuron 1150 g/ha and it was followed by pendimethalin + pyrazosulfuron at 920 g/ha.

Conclusion

With change in rice production system from puddled transplanted to DSR, weed flora changes dramatically. Pre-emergence application of pyrazosulfuron plus pendimethalin 1150 g/ha provided effective control of grasses, sedges and broad-leaf weeds in dry seeded rice during early period of crop-weed competition. At later stages, a suitable post-emergence herbicide for control of emerged weeds may be advised to realize the potential grain yield.

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RESEARCH ARTICLE

Broad-leaved weed management in wheat through herbicide mixture in sub-tropical Shivalik Himalayan foothills

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ABSTRACT

Weed infestation is one of the major biotic factors limiting wheat production and productivity in absence of weed management practice. In order to control the broad-leaved weed infestation in wheat, the herbicides and their mixtures were tested in a field experiment under All India Coordinated Wheat and Barley Improvement Project, Sher-e-Kashmir University of Agricultural Sciences and Technology of Jammu, India during *Rabi* (winter) seasons of 2016-17 and 2017-18. Results showed that herbicide mixtures (broad-leaved weed killer) were found better in compared to alone application of broad-leaved weed herbicides. Among herbicide mixtures, application of metsulfuron 4 g/ha + carfentrazone 20 g/ha + surfactant 625 ml/ha resulted in highest growth, yield attributes, grain yield and weed control efficiency and it was followed by 2,4-D E 500 g/ha + carfentrazone 20 g/ha. Hence, the highest net returns (₹ 72209 and ₹ 69762/ha) and B: C (2.81 and 2.60) were recorded by application of metsulfuron 4 g/ha + carfentrazone 20 g/ha+ surfactant 625 ml/ha.

Keywords: 2,4-D, Carfentrazone, Economics, Florasulam, Halauxifen-methyl, Wheat, Weed management

INTRODUCTION

In India, wheat a major staple food crop, provides a significant proportion of the daily calorie intake for millions of people. The mean national wheat yield consistently falls below its maximum achievable potential in numerous countries including the Indian subcontinent. Weeds are considered as a primary biotic impediment for achieving maximum wheat yield and are often the costliest inhibitory factor, contributing food insecurity. The magnitude of weed-induced losses in agricultural systems is influenced by several factors, including weed species, density, duration of infestation, crop competition, and prevailing climatic conditions (Kaur *et al.* 2021). To effectively manage a diverse and intricate array of weeds, it is often necessary to utilize different herbicides in combination. This practice not only enhances the overall efficacy of weed management against particularly challenging weed species, but it also serves to mitigate the development and onset of herbicide resistance, as evidenced by previous research (Singh *et al.* 2011). Recent findings have demonstrated that both broad-leaved and grassy weeds possess the potential to drastically curtail wheat grain production by as much as 40-52.2% and 55.7-57%, respectively (Pawar *et al.* 2017 and Chand and Puniya 2017). Another study conducted by Sharma *et al.* (2011) reported a significant reduction of 47.5% in wheat grain yield in the weedy check as compared to other treatments. In order to adequately address the complexities posed by such intricate and diverse weed populations, the use of a diverse range of herbicides is often necessary. As such combinations are typically more effective in terms of controlling composite weed populations and serve to delay the emergence of herbicide resistance (Shaktawat *et al.* 2019). In the context of wheat production, the efficacy and economic feasibility of novel herbicides need to be continually assessed to ensure their effectiveness, because the use of less efficacious herbicides is a critical bottleneck that hampers the productivity and profitability of conventional wheat farming in India.

The current investigation was carried out with the objective of identifying the most appropriate herbicide mixture to achieve optimal broad-leaved weed suppression in wheat, while simultaneously evaluating the economic feasibility of various herbicide options in relation to wheat productivity in the region.

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MATERIALS AND METHODS

The present field experiment was carried out in All India Coordinated Wheat and Barley Improvement Project, Sher-e-Kashmir University of Agricultural Sciences and Technology of Jammu, located in the Union Territory of Jammu and Kashmir in the sub-tropical Shivalik Himalayan foothills in India during *Rabi* (winter) seasons of 2016-17 and 2017-18**.** The soil of the experimental field was clay loam in texture, slightly alkaline in reaction (pH 7.5), low in organic carbon (0.45%) and available nitrogen (171 kg/ha) but medium in phosphorus (14.4 kg/ha) and potassium (140 kg/ha). Total rainfall received during 2016-17 and 2017-18 was 264.2 and 80.8 mm, respectively.

The study employed a randomized block design (RBD) in three replication with 11 herbicide treatments, *viz*. halauxifen + florasulam 12.76 g/ha + 750 ml/ha surfactant, metsulfuron 4 g/ha + surfactant 625 ml/ha, carfentrazone 20 g/ha, 2,4-D Na 500 g/ha, 2,4-D E 500 g/ha, metsulfuron 4 g/ha + carfentrazone 20 g/ha+ surfactant 625 ml/ha, 2,4-D Na 500 g/ha + carfentrazone 20 g/ha, 2,4-D E 500 g/ha + carfentrazone 20 g/ha, halauxifen+ florasulam 12.76 g/ha + carfentrazone 20 g/ha + surfactant 625 ml/ha, weedy check and weed free. Wheat variety "*HD 2967*" was sown with *Kera* method (seed is dropped in furrows by hand) in the first week of November during 2016 and 2017 at a row spacing of 20 cm using seed rate of 100 kg/ha. Before sowing, one pre-sowing irrigation was applied. All the herbicidal treatments were applied at 35 days after sowing by using a knapsack sprayer fitted with flat fan nozzle with spray volume of 500 L/ha. To control grassy weeds, a blanket spray of clodinafop propargyl 60 g/ha was given at 40 days after sowing in all the plots. The recommended dose of 150:60:40 kg/ha NPK was applied. Nitrogen was applied into three equal splits, one as basal dose along with the full dose of P and K, while the remaining two doses were applied at CRI and before booting stages. Crop was raised under irrigated condition.

Growth parameter (plant height), yield attributes (earhead/m^2, grains/earhead, test weight) and grain yield were recorded at harvest. The weed density, weed biomass and weed control efficiency of broad-leaved weeds were recorded at 60 and 90 days after sowing. Weed control efficiency (WCE) was calculated with the formula: WCE= (x-y) 100/x, where; x = weed dry weight in weedy check and y = weed dry weight in treated plot. The mean data on weeds were subjected to square root transformation ($\sqrt{x+1}$) to normalize their distribution. The grain yield of wheat is adjusted at 14% moisture.

RESULTS AND DISCUSSION

Plant height

The highest plant height was observed with weed free which was statistically at par with all the treatments except weedy check during both the years (**Table 1**). The results of this study were in correspondence with the findings of Cheem and Akhter (2005) and Ali *et al*. (2022) who stated that the expression of plant height is more associated with inheritance than herbicidal treatments.

Earheads/m^2

Herbicides had a significant effect on earhead count per m^2 (**Table 1**). The highest number of ear heads counted per m^2 of wheat were observed with weed free during both years, which was statistically at par with treatments metsulfuron 4 g/ha + carfentrazone 20 g/ha+ surfactant 625 ml/h, 2,4-D Na 500 g/ha + carfentrazone 20 g/ha, 2,4-D E 500 g/ha + carfentrazone 20 g/ha and halauxifen + florasulam 12.76 g/ha + carfentrazone 20 g/ha + surfactant 625 ml/ha. In these treatments, there was less competition due to better weed control leading to higher earhead per m^2. On the other hand, the lowest count of earheads/m^2 was observed in weedy check and among herbicidal treatments, 2,4-D Na 500 g/ha recorded the lowest count of ear heads/m^2 during both years of experiment.

Number of grains per earhead

The highest number of grains per ear head was observed under metsulfuron 4 g/ha + surfactant 625 ml/ha and halauxifen + florasulam 12.76 g/ha during 2016-17 and 2017-18, respectively, although not affected significantly (**Table 1**).

Test weight

The grain weight is an important factor that affects the quality and value of crops. The highest grain weight was recorded with weed free treatment. Among herbicidal treatments, the highest grain weight was attained by metsulfuron 4 g/ha + carfentrazone 20 g/ha + surfactant 625 ml/ha during 2016-17 and halauxifen+ florasulam 12.76 g/ha + carfentrazone 20 g/ha + surfactant 625 ml/ha during 2017-18.

Grain yield

The grain yield is the net product of all the yield attributes and environmental conditions. The grain yield in weedy check was reduced by 32.96 and 29.69% during 2016-17 and 2017-18, respectively as compared to weed free treatment (**Table 1**). All the weed control treatments recorded significantly higher grain yield than weedy check treatment. The highest grain yield reordered in weed free treatment was statistically at par with metsulfuron 4 g/ha + carfentrazone 20 g/ha + surfactant 625 ml/ha, 2,4-D Na 500 g/ha + carfentrazone 20 g/ha, 2,4-D E 500 g/ha + carfentrazone 20 g/ha and halauxifen+ florasulam 12.76 g/ha + carfentrazone 20 g/ha + surfactant 625 ml/ha during both the years, whereas treatment carfentrazone 20 g/ha was also statistically at par during 2017-18. The herbicidal treatment, metsulfuron 4 g/ha + carfentrazone 20 g/ha+ surfactant 625 ml/h recorded 148.0 and 138.2% higher grain yield than weedy check but had 0.7 and 2.9% less than weed-free treatment during 2016-17 and 2017-18, respectively. Mitra *et al.* (2019) and Ram and Kaur (2020) also reported similar results and concluded that better weed control helped the crop to attain better yield attributes resulting in better grain yield.

Broad-leaved weed density and biomass

The experimental field was infested with broad-leaved weeds namely, *Anagallis arvensis*, *Rumex maritimus, Medicago denticulata*, *Chenopodium album*, *Vicia sativa*, *Melilotus indica*, *Lathyrus aphaca*, *Fumaria parviflora, Cirsium arvense* and *Trachyspermum* spp. The weed density and biomass recorded at 60 and 90 days after sowing were highest in weedy check and were significantly higher than all the herbicidal treatments during both years of experiment (**Table 2**). Among the herbicidal treatments, the lowest weed density and biomass at 60 and 90 days after sowing were recorded in treatment metsulfuron + carfentrazone + surfactant and 2,4-D E 500 g/ha + carfentrazone 20 g/ha, respectively and these treatments were statistically at par to each other during both years of experimentation. Weed density in the best herbicidal treatment of metsulfuron + carfentrazone + surfactant was 94.0 - 95.7% less as compared to the weedy check. The herbicide mixture was more effective in controlling the weeds. The lower weed biomass recorded in herbicide mixture treatments was due to better weed control as the weed density was low in these treatments. Chhokar *et al.* (2015) and Ram and Kaur (2020) also reported that pre-mix formulation of metsulfuron + carfentrazone + surfactant was more effective in controlling broad-leaved weeds.

Weed control efficiency

The weed control efficiency depicts the comparative performance of the herbicides. The higher weed control efficiency was recorded in treatment 2,4-D E 500 g/ha + carfentrazone 20 g/ha followed by treatment metsulfuron 4 g/ha + carfentrazone 20 g/ha+ surfactant 625 ml/ha during 60 days after sowing but at 90 days after sowing metsulfuron 4 g/ha + carfentrazone 20 g/ha+ surfactant 625 ml/ha performed better than treatment 2,4-D E 500 g/ha + carfentrazone 20 g/ha (**Table 2**). It was due to better diverse broad-leaved weed control in these treatments. Singh *et al.* (2011) also reported effectiveness of pre-mix carfentrazone + metsulfuron for broad-leaved weed control in wheat. The weed control efficiency recorded in 2,4-D (ethyl ester) + carfentrazone was the highest, however, it was almost similar to 2,4-D (Na salt) + carfentrazone, metsulfuron + carfentrazone + surfactant and carfentrazone alone.

Table 1. Effect of weed control treatments on plant height, yield attributes, grain yield of wheat

Treatment	Plant height (cm)		Ear head/m^2		Grains/ ear head		Test weight (g)		Grain yield (t/ha)	
	2016-17	2017-18	2016-17	2017-18	2016-17	2017-18	2016-17	2017-18	2016-17	2017-18
Halauxifen + florasulam 12.76 g/ha	82.3	84.1	366.7	369.0	31.7	33.6	36.4	35.6	4.18	4.40
Metsulfuron 4 g/ha + surfactant 625 ml/ha	84.1	85.7	376.7	378.7	32.3	30.4	36.7	37.8	4.46	4.31
Carfentrazone 20 g/ha	86.6	88.2	377.7	375.7	31.3	34.5	36.9	35.4	4.31	4.56
2,4-D Na 500 g/ha	83.5	84.1	360.0	362.3	31.1	31.4	36.6	37.2	4.10	4.22
2,4-D E 500 g/ha	82.4	84.7	370.0	374.0	31.5	31.8	36.9	37.3	4.27	4.39
Metsulfuron 4 g/ha + carfentrazone 20 g/ha+ surfactant 625 ml/ha	86.2	88.6	431.7	428.3	31.3	31.1	38.0	37.3	5.09	4.89
2,4-D Na 500 g/ha + carfentrazone 20 g/ha	89.1	90.2	415.0	422.0	30.5	30.1	37.9	36.7	4.81	4.67
2,4-D E 500 g/ha + carfentrazone 20 g/ha	90.1	89.9	411.7	416.3	32.2	30.3	37.8	38.1	4.97	4.80
Halauxifen + florasulam 12.76 g/ha + carfentrazone 20 g/ha + surfactant 625 ml/ha	88.1	87.5	407.3	410.3	31.2	28.9	37.5	38.5	4.74	4.56
Weedy check	74.9	73.3	316.7	326.3	31.4	32.9	34.9	33.4	3.44	3.54
Weed free	90.4	90.2	435.0	440.3	31.0	29.4	38.1	39.0	5.13	5.03
LSD (p=0.05)	10.0	8.5	51.9	49.4	NS	NS	NS	NS	0.49	0.52

Economics

The weeds cause the loss in gross returns, net returns and B: C. Gharde *et al*. (2018) also recorded significant economic loses in wheat due to weeds. The highest gross returns were recorded in weed-free treatment but net returns and B:C were the highest under treatment metsulfuron 4 g/ha + carfentrazone 20 g/ha + surfactant 625 ml/ha (**Table 3**). It was due to higher grain yield and less cost of cultivation than weed free treatment. Among herbicidal treatments, the highest gross returns were recorded in treatment metsulfuron 4 g/ha + carfentrazone 20 g/ha + surfactant 625 ml/ha followed by 2,4-D E 500 g/ha + carfentrazone 20 g/ha and 2,4-D Na 500 g/ha + carfentrazone 20 g/ha. Treatment, metsulfuron 4 g/ha + carfentrazone 20 g/ha+ surfactant 625 ml/ha recorded 5.9 and 2.9 per cent higher net return than weed free and 72.0 and 56.6 per cent higher than weedy check, and recorded 26.0, and 21.4 per cent higher B:C ratio than weed free and 62.4 and 47.7 per cent higher than weedy check during 2016-17 and 2017-2018, respectively. It was due to higher weed control efficiency and grain yield in this treatment. Nekhat *et al*. (2020) and Ram and Kaur (2020) also reported similar results and concluded that better weed control helped to attain better profitability.

Conclusion

Based on two years field experimentation, it was concluded that among various herbicide treatments, the mixed application of herbicides was better than alone application. Among herbicide mixtures, metsulfuron 4 g/ha + carfentrazone 20 g/ha+ surfactant 625 ml/ha was found the most effective against broad-leaved weeds in wheat and gave higher weed control efficiency, net return and B: C. Therefore, mixture of metsulfuron 4 g/ha + carfentrazone 20 g/ha + surfactant 625 ml/ha can be used in wheat crop to control broad-leaved weeds.

Table 2. Effect of weed control treatments on weed density, weed of biomass and weed control efficiency in wheat

Treatment	Weed density of broad-leaved (no./m^2)				Biomass of broad-leaved weeds (g/m^2)					
	60 DAS		90 DAS		60 DAS			90 DAS		
	2016-17	2017-18	2016-17	2017-18	2016-17	2017-18	Mean WCE	2016-17	2017-18	Mean WCE
Halauxifen+ florasulam 12.76 g/ha	5.51(29)	5.20(26)	5.92(34)	6.11(36)	7.32(53)	6.50(41)	75.00	8.42(70)	7.3 1(52)	77.59
Metsulfuron 4 g/ha + surfactant 625 ml/ha	3.96(15)	4.28(17)	4.40(18)	4.65(21)	5.21(26)	5.03(24)	86.59	6.24(38)	6.31(39)	86.00
Carfentrazone 20 g/ha	4.20(17)	4.55(20)	4.58(20)	5.20(26)	5.62(31)	5.43(28)	84.29	6.43(40)	6.36(40)	85.44
2,4-D Na 500 g/ha	5.66(31)	5.77(32)	5.89(34)	5.86(33)	7.47(55)	6.62(43)	73.97	8.33(68)	7.64(57)	77.00
2,4-D E 500 g/ha	4.16(16)	4.24(17)	4.20(17)	4.51(19)	5.47(29)	5.59(30)	84.29	5.88(34)	6.15(37)	87.17
Metsulfuron 4 g/ha + carfentrazone 20 g/ha + surfactant 625 ml/ha	2.38(5)	2.83(7)	2.58(6)	2.83(7)	3.06(8)	3.42(11)	94.94	3.64(12)	3.85(14)	95.25
2,4-D Na 500 g/ha + carfentrazone 20 g/ha	3.00(8)	3.16(9)	3.21(9)	3.51(11)	3.90(14)	4.14(16)	91.94	4.59(20)	4.57(20)	92.72
2,4-D E 500 g/ha + carfentrazone 20 g/ha	2.45(5)	2.65(6)	2.77(7)	3.11(9)	3.14(9)	3.33(10)	94.97	3.92(14)	4.22(17)	94.33
Halauxifen + florasulam 12.76 g/ha + carfentrazone 20 g/ha + surfactant 625 ml/ha	3.16(9)	2.83(7)	3.46(11)	3.65(12)	4.14(16)	4.46(19)	90.71	4.86(23)	4.91(23)	91.66
Weedy check	10.5(109)	10.8(116)	11.5(131)	11.8(138)	13.6(184)	13.9(192)	0.00	16.4(267)	16.8(282)	0.00
Weed free	1.00(0)	1.00(0)	1.00(0)	1.00(0)	1.00(0)	1.00(0)	100.00	1.00(0)	1.00(0)	100.00
LSD (p=0.05)	0.43	0.53	0.40	0.61	0.59	0.55	-	0.64	0.62	-

Data in parentheses are original values. Note: All herbicides were applied at 35 days after sowing; A blanket application of clodinafop 60 g/ha at 40 days after sowing was common for all plots.

Table 3. Effect of weed control treatments on economics of wheat crop

Treatment	Cost of cultivation (x10^3 `/ha)		Gross returns (x10^3 `/ha)		Net returns (x10^3 `/ha)		B: C ratio (`/ha)	
	2016-17	2017-18	2016-17	2017-18	2016-17	2017-18	2016-17	2017-18
Halauxifen+ florasulam 12.76 g/ha	26.18	27.28	80.41	86.86	54.23	59.58	2.07	2.18
Metsulfuron 4 g/ha + surfactant 625 ml/ha	24.76	25.86	85.85	85.12	61.10	59.26	2.47	2.29
Carfentrazone 20 g/ha	25.16	26.26	83.02	89.98	57.87	63.72	2.30	2.43
2,4-D Na 500 g/ha	25.65	26.75	78.87	83.40	53.22	56.65	2.07	2.12
2,4-D E 500 g/ha	25.52	26.62	82.14	86.64	56.62	60.02	2.22	2.26
Metsulfuron 4 g/ha + carfentrazone 20 g/ha + surfactant 625 ml/ha	25.72	26.82	97.92	96.58	72.21	69.76	2.81	2.60
2,4-D Na 500 g/ha + carfentrazone 20 g/ha	26.61	27.71	92.53	92.33	65.93	64.62	2.48	2.33
2,4-D E 500 g/ha + carfentrazone 20 g/ha	26.48	27.58	95.67	94.74	69.20	67.16	2.61	2.44
Halauxifen+ florasulam 12.76 g/ha + carfentrazone 20 g/ha + surfactant 625 ml/ha	27.13	28.23	91.19	90.10	64.05	61.87	2.36	2.19
Weedy check	24.20	25.30	66.16	69.89	41.96	44.59	1.73	1.76
Weed free	30.56	31.66	98.69	99.42	68.13	67.76	2.23	2.14

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RESEARCH ARTICLE

Residual effect of organic manure on weed population and nitrogen uptake in greengram under rice-maize-greengram system

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ABSTRACT

Intensive cropping system exploits huge amount of costly inputs. Continuous intensification causes a decline in factor productivity and soil health. Apart from the integrated nutrient management, legume inclusions also mitigate the problem. But the weed dynamics in zaid (grown during March to June) legume crop like greengram are not taken care of earlier. This study emphasizes the residual impact of integrated nutrient management with Brassicaceous seed meal (BSM) and neem cake on weed population in greengram under rice-maize-greengram system. Results showed that the major weed flora in summer greengram was *Echinochloa colona* (L.) Link., *Oplismenus composites* (L.) P. Beauv., *Cyperus rotundus* L., *Caesulia axillaris* Roxb., *Phyllanthus virgatus* G. Forst., *Alternanthera philoxeroides* (Mart.) Griseb. and *Physalis minima* L. The minimum density of *O. composites* was recorded with BSM and neem cake applied plots. Integrated nutrient management significantly reduced the nitrogen uptake by weeds, hence resullted better crop growth and yield of greengram which was also higher in the treatment where BSM and neem cake was applied. Better weed control and higher greengram yield were obtained with the application of pendimethalin (750 g/ha) as pre-emergence herbicide followed by hoeing at 25 days after sowing under residual fertility of neemcake applied plots. This result emphasized the inclusion of legume crop in the intensive cropping system with residual fertility which does not require any nutrient addition for yield sustainability.

Keywords: Brassicaceous seed meal, Greengram, Neem cake, Weed dynamics, Nutrient uptake

INTRODUCTION

In tropical and subtropical environments of South Asia, the predominant cropping systems are rice–wheat; rice–rice and rice–maize, among which rice-maize system has less acreage in spite of higher system productivity (Deep *et al.* 2018). Presently, the productivity of these cropping systems have reduced resulting gradual decline in farmer's income due to continuous increment in input cost. Legume incorporation in cropping sequence is a good alternative for improving soil health. Sustaining system productivity in a crop sequence, and nutrient management are major concerns because system productivity increases when availability of plant nutrients is in higher amount. But continuous and indiscriminate use of chemical fertilizers in long term after green revolution has deteriorated the soil health and ecological parameters (Rakshit *et al.* 2018) which have become the major constraints for crop production and food security. Correction of soil health parameters and enhancement of system productivity can be achieved successfully through a combination of different organic and inorganic sources of nutrients (Sukhla *et al.* 2008, Das *et al.* 2014). The role of farmyard manure (FYM) and vermicompost for improving soil health has been tested by different researchers but the ability of concentrated organic manures like Brassicaceous seed meal (BSM) and neem cake as a nutrient source as well as to suppress weeds in rice–maize–greengram sequence have never been explored.

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Weeds compete with crops for solar radiation, space, nutrients and moisture, resulting in a severe reduction in productivity thus being considered as a major biotic constraint in crop production (Ghosh *et al*. 2016). However, the degree of yield losses due to weeds varies due to weed diversity which is greatly influenced by the agronomic management practices applied to the crop (Ghosh *et al.* 2017a, Kumar *et al.* 2018). To be more specific, variation and infestation of weed flora as well as crop growth are much dependent on nutrient management of crop sequence (Ghosh *et al.* 2020). Currently, herbicides are quite popular among farmers as they are easy to apply in the field. A combination of herbicide and mechanical weed management approaches can be more effective in managing weeds compared to sole herbicides (Ghosh *et al.* 2017b).

The management practices of the presiding crops of any crop sequence greatly influence the growth and yield of succeeding crops. Thus, rather than the individual crops, more attention is needed in terms of management for whole system. Different researchers have confirmed that incorporation of organic manures in previous crop fields has a residual effect in succeeding crops as a nutrient source. Here, an effort has been made to explore the residual effect of various bulky and concentrated organic manures applied in rice and maize crops with synthetic fertilizer on succeeding greengram crop. Few studies have examined how prevailing crop management practices affect weed diversity in successive crops. Keeping all these priorities in mind, this experiment was conducted to investigate the residual effect of organic nutrient sources and weed management practices on weed growth, nutrient uptake and yield of greengram in rice–maize–greengram crop sequence.

MATERIALS AND METHODS

Experimental site

The experiment was carried out at a farmers' field in Uttar Chandamari village, Muratipur, Nadia, West Bengal, India (88°27' E longitude and 22°59' N latitude) during the zaid (summer) season of 2015 and 2016. The experimental site had a humid and subtropical climate and an average annual precipitation of 1400 mm. The rainfall, mean maximum and minimum temperature during the experimentation were 149 mm; 39.8 and 18.9 °C in 2015; and 213 mm; 41.7 and 21.8 °C in 2016, respectively. The soil of the study area was clay loam in texture (*Entisol*) with pH of 6.27, electrical conductivity of 0.19 dS/m and medium in organic carbon (0.52%), low in available nitrogen (215 kg N/ha), high in available phosphorus (36.3 kg P/ha) and medium in available potassium (173 kg K/ha).

Details of treatment

The experiment was carried out in a factorial randomized block design having two factors *viz*. nutrient and weed management. The nutrient management practices in previous rice and maize crops comprised sole sources of chemical fertilizer [$Fert_{100}$:100% NPK]; integration of chemical fertilizer ($Fert_{75}$: 75% nitrogen) with bulky organic manures (FYM_{25} and $vermicompost_{25}$) and concentrated organic manures [Brassicaceous seed meal (BSM_{25}) and neem $cake_{25}$] for 25% of recommended N requirement for rice and maize. On the other hand, recommended doses of P and K were supplied through chemical sources. The nitrogen, phosphorus and potassium content in vermicomcost were 1.57-1.59, 0.52-0.54 and 1.02%, in FYM 0.62-0.66, 0.22-0.24 and 0.40-0.48%, in BSM 4.89-4.90, 1.70-1.81 and 1.15-1.25%, and in neemcake 5.13-5.30, 1.11-1.19 and 1.33-1.36%, respectively. Greengram was grown after rice and maize under residual soil fertility. For rice and maize crops, the recommended dose of fertilizer was 60-30-30 and 200-60-60 kg N-P-K/ha, respectively. For supplying nutrients through chemical sources, urea, single superphosphate and muriate of potash were applied. Among the weed management practices, weedy (unweeded), chemical method [imazethapyr 100 g/ha at 25 days after sowing (DAS) as post-emergence (PoE)] and integrated approach [pendimethalin 1000 g/ha at 2 DAS as pre-emergence (PE) followed by hoeing at 25 DAS] were considered. Knapsack sprayer of 16 litres capacity with flat fan nozzles was used for herbicide application and the spray volume was 500 L/ha.

Crop management

On the 25^{th} and 23^{rd} March of 2015 and 2016, respectively the greengram crop (cv. *PDM 139*) was sown at 30 cm row-to-row and 5-7 cm plant-to-plant distances with a seed rate of 25 kg/ha. The size of individual treatment plots was 7.2 × 3.0 m which were separated from each other by 1.0 m. Irrigation was given after sowing of crop for uniform germination whereas subsequent irrigations were applied as per requirement of the crop. Biometric observations of plants were recorded through destructive sampling from second and third rows of both sides of each plot and middle rows were harvested manually for yield estimation.

Biometric measurements and nutrient analysis

Observation pertaining to weed density and biomass accumulation was recorded at 50 DAS from two quadrats (60 × 60 cm) for each plot. After cutting at ground level, the weeds were counted, cleaned with water and dried in the sun followed by hot-air oven-dried at 65°C for 72 hr and weighed. The N uptake by weeds was measured by micro-Kjeldahl method. From each plot, five plants were selected for observations on number of pods/ plant, number of seeds/ pod and 1000 seed weight (test weight). The seed and stover yield of greengram was estimated from net plot area after harvesting and threshing of seeds. The final weight was taken at 14% moisture content.

Due to high variance, the actual weed density (X) data were transformed [$\sqrt{x+0.5}$] before statistical analysis. The analysis was made by SAS 9.3 software and data were subjected to analysis of variance.

RESULTS AND DISCUSSION

Weed growth

The major weed flora in summer greengram during the study period was *Echinochloa colona* (L.) Link., *Oplismenus compositus* (L.) P. Beauv., *Cyperus rotundus* L., *Caesulia axillaris* Roxb., *Phyllanthus virgatus* G. Forst., *Alternanthera philoxeroides* (Mart.) Griseb. and *Physalis minima* L. Different nutrient management practices applied to the former crop had a significant impact on the densities of *O. compositus* in greengram (**Table 1**). The minimum density of *O. compositus* was recorded with BSM and neemcake applied plots (in rice and maize) of greengram in first and second years, respectively. Researchers reported that organic manures release allelopathic phytochemicals after soil application, subsequently diminishing weed emergence and persuades weed seed mortality (Hoagland *et al*. 2008, Abdulla and Kumar 2014). Both the weed management practices *i.e*. chemical (imazethapyr as PoE) and integrated (pendimethalin *fb* hoeing) executed a positive role in reducing different weed densities except that of *Alernanthera philoxeroides* (data not presented). The integrated approach was significantly better than sole chemical approach in reducing the densities of *E. colona*, *O. compositus* and *C. rotundus* in both years of research. Similarly, in case of *C. axillaris* in year 1 and *P. virgatus* in year 2, the integrated approach resulted in lower weed density at 50 DAS as compared to the sole chemical method. Ghosh *et al*. (2017b) reported that a single weed management approach may not be adequate for effective management of diverse weed flora in a crop. Integration of two or more approaches like herbicide followed by hand weeding or mechanical weeding results in better weed control than a single one.

Biomass accumulation by *E. colona*, *C. axillaris* and *P. minima* in the first year, and *E. colona*, *O. compositus*, and *P. virgatus* in second year was influenced statistically by different nutrient management practices (residual). Similar to density, the application BSM and neemcake in previous crop had significant residual effect in lowering the dry biomass of *E. colona* at 50 DAS in both the years of study, and it was also effective in reducing the biomass of *O. compositus* and *P. virgatus* in second year and *C. axillaris* in first year (**Table 2**). Analogous to density, biomass accumulation of *A. philoxeroides* was not influenced by supplementation of organic manures in previous crop. The addition of concentrated organic manures like BSM and neem cake restricted the growth and biomass accumulation

Table 1. Effect of different nutrient sources (residual) and weed management practices on weed density (no./m²) at 50 DAS in summer greengram

Treatment	*E. colona*		*O. compositus*		*C. rotundus*		*C. axillaris*		*P. virgatus*	
	2015	2016	2015	2016	2015	2016	2015	2016	2015	2016
Nutrient management										
R-Fert$_{100}$	6.91(47.3)	3.67(13.0)	7.05(49.2)	5.47(29.4)	9.47(89.1)	7.18(51.0)	6.82(46.0)	1.45(1.59)	6.09(36.6)	3.09(9.04)
R-Fer$_{75}$+Vermicompost$_{25}$	7.17(50.9)	3.31(10.5)	7.62(57.6)	5.95(34.9)	8.54(72.5)	8.13(65.7)	5.99(35.4)	1.35(1.32)	6.15(37.3)	2.34(4.98)
R-Fer$_{75}$+FYM$_{25}$	6.94(47.7)	4.04(15.9)	7.38(54.0)	6.21(38.1)	9.66(92.9)	7.09(49.8)	6.66(43.9)	1.73(2.51)	5.67(31.7)	2.66(6.55)
R-Fer$_{75}$+BSM$_{25}$	6.38(40.3)	2.87(7.7)	5.91(34.4)	4.47(19.5)	9.56(90.9)	7.04(49.1)	6.05(36.1)	1.44(1.58)	5.78(32.9)	2.41(5.30)
R-Fer$_{75}$+Neemcake$_{25}$	5.62(31.1)	2.91(7.9)	6.18(37.7)	4.10(16.3)	10.01(99.6)	7.40(54.2)	5.99(35.4)	1.54(1.86)	4.80(22.5)	2.63(6.40)
LSD(p=0.05)	NS	NS	1.62	1.20	NS	NS	NS	NS	NS	NS
Weed management										
Un-weeded	12.23(149)	6.85(46.4)	12.57(156)	11.14(124)	11.34(128)	9.29(85.8)	10.25(105)	1.73(2.48)	9.96(98.7)	4.49(19.64)
Imazethapyr 100 g/ha	4.70(21.6)	2.26(4.6)	5.74(32.4)	3.87(14.5)	11.60(134)	8.36(69.3)	5.65(31.4)	1.69(2.36)	4.31(18.0)	2.06(3.76)
Pendimethalin 750 g/ha *fb* hoeing	2.89(7.9)	0.98(0.5)	2.18(4.3)	0.71(0.0)	5.41(28.7)	4.46(19.4)	3.01(8.6)	1.09(0.68)	2.82(7.5)	1.32(1.25)
LSD(p=0.05)	1.41	0.97	1.26	0.93	2.18	1.40	1.51	NS	1.75	0.68

R-Fert, Recommended dose of N through fertilizer; N, Nitrogen; P, Phosphorus; K, Potassium; FYM, Farm yard manure; BSM, Brasecacious seed meal; *fb*, followed by; Original figures in parentheses were subjected to square-root transformation $\sqrt{x+0.5}$ before statistical analysis; NS, Non-significant of predominant weeds by releasing allelo-chemicals (Ghosh *et al.* 2022). In reducing the dry biomass of various weeds except a few, both the weed management practices have shown their statistical equality throughout the investigation. The biomass of *C. rotundus* was significantly reduced with addition of hoeing following application of pendimethalin as PE. The application of imazethapyr as PoE was not effective in controlling the growth of *C. rotundus* at 50 DAS.

Nutrient uptake by weeds

During the study, the primary macronutrients, *viz*. nitrogen (N), phosphorus (P) and potassium (K) uptake by weed flora were analyzed; and uptake of N is presented in **Table 3**. In greengram, different N sources applied in previous rice and maize crop played a significant role in N uptake by *E. colona* in both the years of experimentation and by *O. compositus* and *P. virgatus* in second year only, whereas, the N uptake by *C. rotundus* at this stage was not varied statistically throughout the experimentation. In the first year of experimentation, N supplementation through different organic manures in earlier crop significantly reduced the N uptake by *E. colona* in greengram as compared to N application through synthetic fertilizer. The N supplementation through BSM and neemcake in former crop effectively reduced the N uptake by *E. colona* and *O. compositus* at 50 DAS of crop in second year. Lower weed growth and biomass accumulation due to addition of BSM and neemcake resulted in lesser nutrient removal by weeds. The repetitive addition of organic manure over years enhanced its efficacy in reducing weed growth and restricting nutrient removal by weeds (Ghosh *et al. 2022*).

Table 2. Effect of different nutrient sources (residual) and weed management practices on weed dry weight (g/m²) at 50 DAS in summer greengram

Treatment	*E. colona*		*O. compositus*		*C. rotundus*		*C. axillaris*		*P. virgatus*	
	2015	2016	2015	2016	2015	2016	2015	2016	2015	2016
Nutrient management										
R-Fert$_{100}$	65.4	20.5	30.59	11.57	40.4	24.6	8.21	1.15	7.81	7.24
R-Fer$_{75}$+Vermicompost$_{25}$	36.1	18.9	23.25	13.21	33.1	25.4	6.61	1.06	6.86	11.20
R-Fer$_{75}$+FYM$_{25}$	40.3	18.2	29.08	16.78	39.1	20.8	6.49	0.97	6.93	6.82
R-Fer$_{75}$+BSM$_{25}$	36.1	11.1	26.38	11.55	40.4	26.5	4.07	0.70	5.42	3.81
R-Fer$_{75}$+Neemcake$_{25}$	31.6	9.8	21.39	10.53	42.2	25.3	5.81	0.90	5.24	2.72
LSD (p=0.05)	14.2	6.7	NS	4.07	NS	NS	3.38	NS	NS	2.99
Weed management										
Un-weeded	102.7	43.2	68.03	34.43	52.1	32.7	15.35	1.07	14.62	17.13
Imazethapyr 100 g/ha	16.2	3.7	8.26	3.75	56.0	35.2	2.38	1.34	3.26	1.35
Pendimethalin 750 g/ha *fb* hoeing	6.8	0.2	2.12	0.00	9.0	5.7	0.98	0.46	1.47	0.60
LSD (p=0.05)	11.0	5.2	8.07	3.15	10.3	6.5	2.62	NS	3.60	2.32

R-Fert, Recommended dose of N through fertilizer; N, Nitrogen; P, Phosphorus; K, Potassium; FYM, Farm yard manure; BSM, *Brasecacious* seed meal; *fb*, followed by; NS, Non-significant

Table 3. Effect of different nutrient sources (residual) and weed management practices on N uptake (kg/ha) by weeds in summer greengram

Treatment	*E. colona*		*O. compositus*		*C. rotundus*		*C. axillaris*		*P. virgatus*	
	2015	2016	2015	2016	2015	2016	2015	2016	2015	2016
Nutrient management										
R-Fert$_{100}$	10.25	3.21	5.40	2.04	5.99	3.64	1.84	0.26	2.36	2.19
R-Fer$_{75}$+Vermicompost$_{25}$	5.66	2.97	4.10	2.33	4.91	3.76	1.48	0.24	2.08	3.39
R-Fer$_{75}$+FYM$_{25}$	6.31	2.85	5.13	2.96	5.80	3.08	1.45	0.22	2.10	2.06
R-Fer$_{75}$+BSM$_{25}$	5.66	1.74	4.65	2.04	5.99	3.93	0.91	0.16	1.64	1.15
R-Fer$_{75}$+Neemcake$_{25}$	4.96	1.53	3.77	1.86	6.26	3.76	1.30	0.20	1.58	0.82
LSD (p=0.05)	2.23	1.05	NS	0.72	NS	NS	NS	NS	NS	0.91
Weed management										
Un-weeded	16.10	6.77	12.00	6.07	7.73	4.85	3.44	0.24	4.42	5.18
Imazethapyr 100 g/ha	2.54	0.58	1.46	0.66	8.31	5.22	0.53	0.30	0.99	0.41
Pendimethalin 750 g/ha *fb* hoeing	1.06	0.03	0.37	0.00	1.34	0.84	0.22	0.10	0.44	0.18
LSD (p=0.05)	1.73	0.81	1.42	0.56	1.53	0.96	0.59	NS	1.09	0.70

R-Fert, Recommended dose of N through fertilizer; N, Nitrogen; P, Phosphorus; K, Potassium; FYM, Farm yard manure; BSM, *Brasecacious* seed meal; *fb*, followed by; NS, Non-significant

The different weed management practices had a significant role in preventing weed growth and these had a simultaneous significant effect on N uptake by different weeds. Throughout the experimentation, as compared to unweeded situation, the application of pendimethalin as PE significantly reduced the N uptake by *E. colona* and *O. compositus*. In both years of research, application of imazethapyr as PoE had no significant effect in reducing N uptake by *C. rotundus*. On the other hand, integration of hoeing with PE herbicide effectively lowered down the N removal by *C. rotundus* throughout the experimentation. The P and K uptake by weeds were also followed more or less similar trend like N uptake by weeds.

Yield attributes and yield

Yield attributes of greengram *i.e.* number of pods/plant, number of seeds/pod and 1000 seed weight (g) or test weight (g) were recorded at the time of harvest and the data are represented in **Table 4**. During first year, different nutrient management practices in former crop showed significant variation in test weight, whereas, in second year variation was significant with respect to number of pods/plant and test weight. The number of seeds/pod was not influenced statistically in both years of experimentation. The maximum number of pods/ plant was recorded from N supplementation through neemcake in earlier crops and it was statistically superior to N application through synthetic fertilizer. The maximum weight of greengram seeds was observed with vermicompost and BSM application in the previous crop in first and second year, respectively. The different nutrient management practices in early season crop had no significant effect on seed yield of greengram in first year, but significance was observed in the next year. The stover yield of greengram plant was not varied significantly with the different nutrient sources (residual) in both years of research. The N supplementation through neemcake in former crop resulted in the maximum seed yield of greengram (752 and 813 kg/ha in first and second year, respectively) and this treatment was statistically superior to N application through synthetic fertilizer in second year. As compared to sole inorganic fertilizer, the addition of organic manures had a more residual effect due to the release of plant nutrients progressively, which finally ensured its better performance in the succeeding crops (Xu *et al.* 2003, Srivastava *et al.* 2007).

Weed management practices in greengram represented a significant variation in number of pods/ plant and seeds/pod throughout the experimentation, but the test weight of greengram seed was not varied statistically. Both the weed management practices *viz.* chemical and integrated were statistically superior to unweeded check in respect of number of pods/plant and seeds/pod of greengram . The maximum number of pods/plant and seeds/pod were recorded with the application of pendimethalin as PE followed by hoeing at 25 DAS. The integrated practice increased the number of pods/plant and seeds/pod of greengram in a significant manner over the sole herbicidal method. In both years of research, as compared to unweeded situations both the weed management practices, *viz.* chemical and integrated produced significantly higher seed and stover yields of greengram . The integrated practice improved the greengram seed and stover production in a significant manner over sole herbicidal method in both years.

Table 4. Effect of different nutrient sources (residual) and weed management practices on yield attributes and yield of summer greengram

Treatment	No. of pods/plant		No. of seeds/pod		Test weight (g)		Seed yield (kg/ha)		Stover yield (t/ha)	
	2015	2016	2015	2016	2015	2016	2015	2016	2015	2016
Nutrient management										
R-Fert$_{100}$	21.6	20.9	12.2	12.5	30.2	30.0	737	756	2.89	2.99
R-Fer$_{75}$+Vermicompost$_{25}$	22.4	23.6	12.6	12.6	30.9	30.8	727	767	2.91	3.09
R-Fer$_{75}$+FYM$_{25}$	20.9	22.9	11.7	12.8	29.4	31.1	735	804	2.83	3.00
R-Fer$_{75}$+BSM$_{25}$	21.9	23.4	12.2	12.9	30.5	31.5	750	790	2.92	3.11
R-Fer$_{75}$+Neemcake$_{25}$	21.2	24.2	12.0	12.7	30.2	30.8	752	813	2.82	3.00
LSD (p=0.05)	NS	2.69	NS	NS	1.18	1.20	NS	48.7	NS	NS
Weed management										
Un-weeded	15.2	16.4	10.1	10.4	29.9	30.5	623	662	2.51	2.77
Imazethapyr 100 g/ha	23.0	24.4	12.4	13.5	30.5	31.1	753	812	2.96	3.05
Pendimethalin 750 g/ha *fb* hoeing	26.7	28.2	14.1	14.1	30.3	30.9	845	884	3.15	3.29
LSD (p=0.05)	2.07	2.08	0.87	0.71	NS	NS	38.6	37.8	0.18	0.17

R-Fert, Recommended dose of N through fertilizer; N, Nitrogen; P, Phosphorus; K, Potassium; FYM, Farm yard manure; BSM, *Brasecacious* seed meal; *fb*, followed by; NS, Non-significant

It was concluded that the addition of organic manures plays an important role in the growth and productivity of subsequent crops. The supplementation of nitrogen through neemcake and BSM suppressed the growth and nutrient removal by weeds and ultimately enhanced the productivity of greengram. Integration of hoeing with herbicide (pendimethalin) reduced the weed growth and increased the greengram productivity.

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RESEARCH ARTICLE

Tillage, residue, nitrogen and herbicides effects on weeds and greengram productivity and profitability in conservation agriculture-based maize-wheat-greengram system

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ABSTRACT

Conservation agriculture (CA) based intensification of maize (*Zea mays* L.)-wheat (*Triticum aestivum* L. emend Fiori and Paol) system through inclusion of greengram (*Vigna radiata* L. Wilczek) during summer may improve productivity and promote sustainability. However, weeds are the major biotic constraint that limit productivity of short-duration greengram severely, if not controlled timely. Therefore, a field experiment was conducted during 2018-19 and 2019-20 to evaluate the residual effects of nitrogen (N) applied to the preceding crops, and the concurrent effects of tillage, residue and herbicide on weeds and greengram productivity and profitability under a maize-wheat-greengram cropping system. Four main plot treatments comprised of three zero-till (ZT) flat-bed with retention of residues (R) of greengram (in maize), maize (in wheat) and wheat (in greengram) and 50, 75 and 100% N of the recommended 150 and 120 kg N/ha applied to maize and wheat, respectively (~ZT+R+50N, ZT+R+75N, ZT+R+100N), and a conventional tillage (CT) with incorporation of these three crops residue and 100% of the recommended N to the preceding crops (~CT+R+100N). The sub-plot treatments were: ready-mix Na-acifluorfen (16.5%) + clodinafop-propargyl (8%) at 245 (165+80) g/ha applied post-emergence (PoE), pendimethalin at 1000 g/ha pre-emergence (PE) followed by (*fb*) imazethapyr at 75 g/ha PoE, pendimethalin at 1000 g/ha PE *fb* spot hand weeding (HW) at 25 days after sowing (DAS), and unweeded control (UWC). Results indicated that ZT with residue retention (ZT+R), irrespective of previous season N applications led to significant reduction in weed interference compared to CT+R+100N and gave better greengram plant growth, rhizobial symbiosis, yields and profitability over CT+R+100N. Among weed management treatments, sequential application of pendimethalin *fb* imazethapyr was comparable with ready-mix Na-acifluorfen + clodinafop-propargyl, but led to better weed suppression, and higher greengram growth, yields and net income. Thus, summer greengram in a CA based maize-wheat system with appropriate weed control employing herbicides may be a promising strategy for sustainable crop intensification in north-western Indo-Gangetic Plains of India.

Keywords: Conservation agriculture, Crop residues, Greengram, Herbicides, Weeds, Zero-tillage

INTRODUCTION

The cereal-centric cropping systems dominate in the Indo-Gangetic Plains (IGP), which is most significant food producing belt of India. Rice-wheat and maize-wheat are two most important cropping systems in the IGP, and largely contribute to total food grain production. However, the sustainability of these cereal-based systems is under question due to several soil, water, nutrients, weeds, and environment related problems. Further, continuous monoculture of cereal-cereal rotations has led to yield plateaus. Therefore, cropping system intensification through inclusion of legumes in the prevailing cereal-cereal rotations is widely recommended to be a sustainable approach for improving system productivity (Ladha *et al*. 2003, Jat *et al*. 2018). In IGP, the fields remain fallow for almost 70-80 days from harvest of *Rabi* (winter) crops to sowing of the succeeding *Kharif* (rainy) crops. Greengram, being a short-duration crop and having wider adaptability across varied agroclimatic situations can be grown during this period with 1-2 irrigations (Hazra *et al*. 2019). Its inclusion in conservation agriculture (CA) based cereal-cereal rotation can drive sustainable intensification of agricultural production system of the IGP (Gathala *et al*. 2013). It is a good source of dietary protein for majority of vegetarian Indian people. Additional income, N fixation, and improvement in soil health are other benefits accruing from its cultivation may improve cereals system sustainability.

However, greengram often fails to achieve acceptable seed yield primarily due to severe weed interference, low soil fertility (Ezung *et al*. 2020) and overall poor management. Weeds compete with

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greengram for resources more vigorously, reducing yield. Poor competitiveness of greengram against weeds is mainly due to initial slow growth, leading to recurrent flushes of weeds after every rainfall and/or irrigation (Singh and Singh 2020). Moreover, short duration nature (~60-65 days) of greengram allows little scope for crop recovery from the initial setback due to weeds in later stages of growth (Maji *et al.* 2020). Relatively weed-free period of 20-30 days after emergence is critical for greengram (Singh *et al.* 1991, Singh and Singh 2020). Weeds may cause yield losses to the tune of 30-85%, depending on the intensity and spectrum of weeds, soils, and environmental conditions (Singh *et al.* 2015, Kaur *et al.* 2016).

Effective weed management is, therefore, key for sustainable greengram production. Herbicides offer timely, effective, economical and practical weed control, therefore, assumed to be most important weed management tool. In the absence of tillage, the success of CA largely depends on herbicides (Sharma and Singh 2014). Minimum/zero tillage, surface residue retention may alter the efficacy of the applied herbicides. Therefore, crop stubbles should be managed properly, and the timing, rate and method of herbicide application need to be optimized in CA systems for higher herbicide efficacy. The use of herbicides mixture (pre-mix or tank-mix) or sequential application of herbicides along with tillage and residue management leads to integrated weed management, which assumes a great importance for better weed management in summer greengram. Moreover, the location-specificity of herbicides action depending on climate, soils, and weeds calls for enough studies across locations. Therefore, this study was undertaken to evaluate the carryover effects of N applied to preceding crops, and concurrent effects of tillage, residue, and herbicides on weeds, crop productivity and profitability in summer greengram in a maize-wheat-greengram rotation.

MATERIALS AND METHODS

Field experiments were carried out at the ICAR–Indian Agricultural Research Institute (IARI), New Delhi (28°38` N, 77°10` E and 228.6 m above mean sea level) during the summer seasons of 2019 and 2020. The site falls under Trans-Gangetic Plains zone of Indian IGP with sub-tropical and semi-arid climate. Rainfall received during greengram growing seasons were 76.6 and 97.3 mm in 2019 and 2020, respectively. Soil (Inceptisol) was sandy loam in texture with mean pH 7.5 and electrical conductivity 0.31 dS/m.

Four main-plot treatments, involving tillage, crop residue and previous N application, and four sub-plot treatments involving weed management treatments were laid out in a split plot design with three replications. The experiment was part of a long-term CA system initiated in 2008. The main plot treatments were fixed for all three crops, *i.e.*, maize, wheat, and greengram, but the sub-plot weed management treatments were different for these crops based on the selectivity of herbicides. The main plot treatments comprised of three zero-till (ZT) flat-bed with retention of residue (R) of greengram (in maize), maize (in wheat) and wheat (in greengram) and 50, 75 and 100% of the recommended N dose applied to maize and wheat (~ZT+R+50N, ZT+R+75N, ZT+R+100N), and a conventional tillage (CT) with incorporation of three crops residue and 100% of the recommended N to the preceding crops (~CT+R+100N). The sub-plot treatments were: application of ready-mix Na-acifluorfen (16.5%) + clodinafop-propargyl (8%) at 245 (165+80) g/ha post-emergence (PoE), pendimethalin at 1000 g/ha pre-emergence (PE) followed by (*fb*) imazethapyr at 75 g/ha PoE, pendimethalin at 1000 g/ha PE *fb* spot hand weeding (HW) at 25 days after sowing (DAS), and unweeded control (UWC). Around 40% residue of maize and wheat and entire residue (100%) of greengram were retained on the surface (in case of ZT) or incorporated into soil (in case of CT). Recommended dose of N for maize and wheat was 150 and 120 kg N/ha, respectively. Unweeded control (UWC) was a natural uninhibited weed infestation, adopted for comparing the efficacy of weed control/ herbicides treatments (Das 2001). The PE and PoE herbicides were applied at 1 and 25 DAS, respectively using a knapsack sprayer fitted with a flat fan nozzle and 400 litters water/ha. Main and sub-plots were 25.5 × 3.0 m and 6.0 × 3.0 m, respectively. The CT plots were ploughed by a tractor-drawn disc plough and wheat residue was incorporated using a rotavator followed by planking.

Greengram variety '*SML 668*' was sown using a Happy Seeder at a row-space of 20 × 5 cm and 20 kg/ ha seed rate. A common 18 kg N/ha through diammonium phosphate (DAP; 100 kg/ha) was applied as basal to counter N immobilization resulting from the addition (retention/ incorporation) of fresh wheat residue along with phosphorus (20 kg P/ha). An area of 50 cm (along the rows) × 40 cm (across the rows), which included 2 rows of greengram was randomly selected from two places in each plot outside the net plot area, leaving the border rows. Weed species were collected from those areas, counted, and categorized into grassy, broad-leaved, and sedge weeds, which were summed up to total weed population. The collected weeds were first sun-dried and kept in a hot-air oven at 70 °C until constant dry weight. Weed control efficiency (WCE) and weed control index (WCI) that reflect per cent reduction in weed density and dry weight across the treatments over control treatments, respectively were calculated using the following equations (Das 2001 2008).

$$WCE (\%) = [(WP_C - WP_T)/WP_C] \times 100$$

$$WCI (\%) = [(WDW_C - WDW_T)/WDW_C] \times 100$$

where, WP_C and WP_T are the weed population (number/m^2) in control and treatment plots, and WDW_C and WDW_T are the weed dry weight (g/m^2) in control and treatment plots, respectively.

Five green plants were randomly selected from each plot (outside of net plot area) for recording observations on root nodulation and plant growth parameters. Leaf chlorophyll content in terms of SPAD value of four fully expanded uppermost leaves was estimated using a SPAD chlorophyll meter (SPAD-502 Minolta Camera Co., Ltd., Japan). Greengram was harvested when 80-90% of pods were mature from net plot area, threshed manually after sun drying, and seed yields recorded. Yield components were recorded from five randomly selected plants at harvest. The 1000-seed weight of greengram was recorded from sub-samples of harvested seeds of each plot and weighed separately. Seed moisture content was determined for each seed sample, and seed yields and 1000-seed weight were adjusted to 12% moisture (w/w). The prevailing market prices of all inputs/operations applied to a treatment were used to estimate the total cost of cultivation of that treatment. The minimum support price (MSP) of greengram seeds declared by the Government of India during 2018 and 2019, and the local market price of greengram stover were considered for calculating the gross returns. The difference between gross returns and total cost of cultivation constituted the net returns. The ratio of net returns to cost of cultivation indicated the net benefit: cost. Data were analyzed using the analysis of variance (ANOVA) technique by adopting the general linear model (GLM) procedure for split plot design in SAS 9.3 software (SAS Institute Inc., Cary, NC, USA). As wide variation existed, data on weed density and dry weight were subjected to square-root [$(x + 0.5)^{1/2}$] transformation prior to the ANOVA in order to improve the homogeneity of variance (Das 1999). Pairwise comparisons of treatment means were made using Fisher's least significant difference (LSD) (Fisher 1960; Gomez and Gomez 1984) at 5% level of significance.

RESULTS AND DISCUSSION

Weed growth and its control in greengram

The dominant weed species in summer greengram were *Trianthema portulacastrum* L., *Commelina benghalensis* L., and *Digera arvensis* Forsk. (broad-leaved weeds); *Digitaria sanguinalis* (L.) Scop. and *Dactyloctenium aegyptium* (L.) Willd. (grassy weeds); and *Cyperus rotundus* L. (sedge). Among them, broad-leaved weeds (BLW) were dominant, posing higher interference than grasses and sedges (**Tables 1** and **2**). There were differences in density and biomass of BLW, grasses and sedges at 40 DAS owing to tillage, residue, N and weed management. Among tillage, residue and N management practices, CT+R+100N was least effective in suppressing weed growth with significantly higher density and biomass of BLW, grasses, sedges and total composite weeds compared to ZT+R+100N, ZT+R+75N, and ZT+R+50N, which showed similar efficacy on these weeds. On average, CA-based treatments (ZT+R+100N, ZT+R+75N, and ZT+R+50N) appeared to be superior to CT treatments, while reducing population and biomass of composite weeds by 42.7-49.7 and 41.5-46.1% over CT+R+100N, respectively (**Table 1** and **2**). Higher interference of weeds in CT plots might be attributed to the inversion of soil through repeated tillage operations, which redistributed weed seeds lying below the soil surface throughout the soil profile and stimulate germination (Chauhan and Johnson 2009). Moreover, surface residue cover in ZT-based treatments could reduce or delay weed emergence by intercepting solar radiation reaching the ground surface, and by creating a physical barrier to germination and emergence of weeds, altogether leading to significantly lower weed interference in ZT plots (Nichols *et al*. 2015, Baghel *et al*. 2020). The UWC unweeded control treatment resulted in significantly higher population and biomass of BLW, grasses and sedges than the remaining treatments at 40 DAS, leading to substantially higher total weed interference. The weed control treatments significantly reduced weed population and biomass by 58.0-61.8% (WCE) and 73.9-77.1% (WCI), respectively compared to the UWC. Among the weed management treatments, sequential applications of pendimethalin PE *fb* imazethapyr PoE resulted in highest WCE and WCI due to significant reduction in density and biomass of BLW, grasses, and sedges as well as total composite weeds compared to UWC, respectively (**Table 1** and **2**). However, pendimethalin *fb* HW or Na-acifluorfen + clodinafop (ready-mix) were comparable with it in this regard. Although all weed control treatments had similar efficacy against weeds, the post-emergent control of weeds (either by herbicides or by hand weeding) following the application of PE pendimethalin had an edge over single application of post-emergence herbicides. This could be due to the fact that, pendimethalin PE controlled initial flushes of weeds, and later-emerging weeds were effectively controlled by either broad-spectrum imazethapyr or hand weeding. Later, greengram through quick canopy formation covered the ground surface (low light penetration) and smothered late-emerging weeds and reduced weed interference. As there is no vertical mixing of soil under ZT, the below-ground weed seeds do not appear on soil surface and remain dormant. Further, in continued ZT with surface residue retention, surface-lain seeds get disposed of through predation or through microbial decomposition (Govaerts *et al*. 2007, Yang *et al*. 2013, Nichols *et al*. 2015), and weed seedbanks gradually get exhausted, if new recruit of weed seeds is prevented. This called for control of existing weed species effectively for long-term sustainable weed management. Thus, combining ZT with surface residue retention, and appropriate

Table 1. Weed density in greengram across tillage, residue, and herbicides treatments (mean of two years)

Treatment	Weed density (number/m^2) at 40 DAS*				WCE (%)
	BLW	Grass	Sedge	Total	
Tillage, residue and N management					
ZT+R+50N	8.1 (69.6)	4.3 (17.8)	2.1 (3.9)	9.4 (91.3)	42.7
ZT+R+75N	7.9 (64.2)	4.0 (16.2)	2.1 (3.8)	9.1 (84.3)	46.8
ZT+R+100N	7.7 (62.2)	4.0 (15.4)	1.9 (3.4)	8.9 (81.0)	49.7
CT+R+100N	10.5 (125.8)	7.5 (67.1)	3.5 (12.3)	13.4 (205.3)	-
LSD (p=0.05)	0.86	0.40	0.48	0.84	-
Weed management					
Na-acifluorfen + clodinafop 245 g/ha	7.4 (55.3)	4.4 (19.4)	2.3 (5.3)	8.9 (80.0)	58.0
Pendimethalin 1000 g/ha *fb* imazethapyr 75 g/ha	7.1 (49.8)	4.2 (17.9)	2.1 (4.2)	8.4 (71.8)	61.8
Pendimethalin 1000 g/ha *fb* HW	7.2 (52.1)	4.6 (21.3)	2.2 (4.7)	8.8 (78.1)	58.9
Unweeded control	12.5 (164.7)	6.6 (57.8)	3.0 (9.4)	14.6 (232.0)	-
LSD (p=0.05)	0.49	0.47	0.34	0.55	-

ZT: zero tillage, R: residue, N: nitrogen, CT: conventional tillage, HW: spot hand weeding, BLW: broad-leaved weeds, WCE: weed control efficiency, *original/ observed values (in parentheses) were subjected to square-root transformation [$\sqrt{x+0.5}$]

Table 2. Weed dry biomass in greengram across tillage, residue, and herbicides treatments (mean of two years)

Treatment	Weed dry weight (g/m^2) at 40 DAS*				WCI (%)
	BLW	Grass	Sedge	Total	
Tillage, residue and N management					
ZT+R+50N	3.5 (13.3)	2.1 (3.9)	1.2 (1.0)	4.1 (18.2)	41.5
ZT+R+75N	3.4 (12.0)	2.0 (3.8)	1.2 (0.9)	4.0 (16.6)	46.1
ZT+R+100N	3.3 (11.7)	2.0 (3.7)	1.1 (0.9)	3.9 (16.3)	46.0
CT+R+100N	4.5 (26.9)	3.9 (20.1)	2.0 (4.5)	6.2 (51.4)	-
LSD (p=0.05)	0.25	0.23	0.15	0.23	-
Weed management					
Na-acifluorfen + clodinafop 245 g/ha	2.9 (8.0)	2.0 (3.6)	1.1 (0.8)	3.6 (12.3)	73.9
Pendimethalin 1000 g/ha *fb* imazethapyr 75 g/ha	2.8 (7.1)	1.9 (3.2)	1.1 (0.7)	3.4 (11.0)	77.1
Pendimethalin 1000 g/ha *fb* HW	2.8 (7.4)	2.2 (4.5)	1.1 (0.7)	3.6 (12.6)	74.8
Unweeded control	6.3 (41.4)	3.9 (20.2)	2.2 (5.1)	7.7 (66.6)	-
LSD (p=0.05)	0.24	0.23	0.12	0.27	-

ZT: zero tillage, R: residue, N: nitrogen, CT: conventional tillage, HW: spot hand weeding, BLW: broad-leaved weeds, WCI: weed control index, *original/observed values (in parentheses) were subjected to square-root transformation [$\sqrt{x+0.5}$]

Table 3. Greengram crop growth parameters at 45 DAS across tillage, residue, and herbicides treatments

Treatment	Plant height (cm)		DMA (g/m^2)		LAI	
	2019	2020	2019	2020	2019	2020
Tillage, residue and N management						
ZT+R+50N	34.3	36.1	208.2	220.4	3.14	3.29
ZT+R+75N	35.2	37.0	217.3	227.0	3.23	3.33
ZT+R+100N	35.6	37.0	219.4	232.0	3.27	3.41
CT+R+100N	30.9	32.5	192.1	202.7	2.90	3.00
LSD (p=0.05)	3.01	2.61	14.82	15.64	0.18	0.22
Weed management						
Na-acifluorfen + clodinafop 245 g/ha	34.8	36.1	230.0	241.2	3.39	3.57
Pendimethalin 1000 g/ha *fb* imazethapyr 75 g/ha	35.7	37.3	234.9	250.8	3.49	3.61
Pendimethalin 1000 g/ha *fb* HW	35.0	37.0	232.4	243.9	3.42	3.59
Unweeded control	30.4	32.1	139.8	146.2	2.24	2.26
LSD (p=0.05)	2.68	2.61	15.80	15.57	0.18	0.13

ZT: zero tillage, R: residue, N: nitrogen, CT: conventional tillage, HW: spot hand weeding, DMA: dry matter accumulation, LAI: leaf area index herbicidal weed control led to considerably lower weed interference in summer greengram.

Crop growth, nodulation, and leaf chlorophyll content

Crop growth parameters, nodulation, and chlorophyll content in greengram differed significantly amongst the tillage, residue, N and weed management practices. The CA-based ZT+R+100N, being at par with ZT+R+75N and ZT+R+50N led to significantly higher plant height, dry matter accumulation, leaf area index (LAI), nodule number and dry weight, and chlorophyll content compared to the CT+R+100N at 45 DAS. The CA-based ZT+R systems resulted in 13.4 and 12.9%, 11.9 and 11.7%, and 10.8 and 11.4% higher plant height, dry matter accumulation, and LAI in summer greengram in 2019 and 2020, respectively compared to CT (**Table 3**). Considerably lower weed interference in ZT+R systems allowed the crop to gain an advantage over weeds, which resulted in better crop growth compared to CT system. Among the weed control practices, pendimethalin *fb* imazethapyr being at par with Na-acifluorfen + clodinafop and pendimethalin fb HW led to significantly greater plant height (14.6-15.7%), dry matter (66.3-67.8%), and LAI (53.3-58.8%) at 45 DAS due to greater weed suppression by these treatments compared to UWC in both the years (**Table 3**). Greengram nodulation (nodule count and dry weight of effective nodules) at 45 DAS was significantly higher in CA-based ZT+R systems compared to CT-based greengram, the highest being in ZT+R+100N (**Table 4**). The ZT-based systems accounted for 26.6-33.5% and 34.4-42.5% higher number of effective nodules and nodules dry weight, respectively compared to CT. Better soil health and lower weed interference for available resources in ZT-based systems played a role. Severe weed competition in UWC plots affected overall growth of greengram and led to least effective nodulation. The extent of reduction in count and dry weight of nodules in UWC treatments ranged from 43.5 to 45.1% and 51.4 to 55.1%, respectively over the weed control practices during both years of study. Among weed control practices, the highest count and dry weight of nodules were recorded with pendimethalin fb imazethapyr, which was at par with pendimethalin fb HW and Na-acifluorfen + clodinafop (**Table 4**). Application of herbicides (pre-plant incorporation, PE or PoE) has been found to reduce nodulation in greengram, particularly with PE herbicides (Kaur *et al.* 2010, Singh *et al.* 2015, Maji *et al.* 2020). Zaidi *et al.* (2005) observed considerable negative effect of metribuzin on nitrogenase activity in a greengram-rhizobial symbiosis. However, in this study, negative effect of PE herbicide (pendimethalin) on nodule functioning in greengram was not observed or initial setback, if any, was recovered at the later stages; whereas, PoE application of herbicides also showed no inhibition of nodulation as evident from higher nodulation in these treatments. This could be attributed to application of herbicides at proper rate (up to the recommended dose) and time, which might have avoided inhibitory effects on greengram-rhizobial symbiosis (Komal *et al.* 2015, Kumar *et al.* 2016, 2017, Mishra *et al.* 2017, Singh *et al.* 2017). Similar to nodulation, ZT-based systems had significantly higher SPAD values (chlorophyll content) compared to CT system. Similarly, all the weed control treatments recorded significantly higher SPAD values (chlorophyll content) compared to UWC (**Table 4**). As chlorophyll content is directly correlated with plant N status, higher SPAD values suggested better availability and uptake of N by greengram. This could be due to better crop and root growth, soil fertility, and nodulation in greengram under ZT systems, and lower weed competition.

Table 4. Greengram root nodules and leaf chlorophyll content (SPAD value) at 45 DAS across tillage, residue, and herbicides treatments

Treatment	Effective nodules/plant		Nodule dry weight (mg/plant)		Chlorophyll content (SPAD value)
	2019	2020	2019	2020	
Tillage, residue and N management					
ZT+R+50N	26.2	28.0	76.53	80.26	39.48
ZT+R+75N	27.0	28.3	79.57	82.19	40.03
ZT+R+100N	27.7	28.8	83.00	84.18	40.15
CT+R+100N	20.2	22.4	55.94	61.16	36.37
LSD (p=0.05)	3.04	3.69	8.20	11.37	2.62
Weed management					
Na-acifluorfen + clodinafop 245 g/ha	27.3	28.9	82.19	86.64	39.43
Pendimethalin 1000 g/ha *fb* imazethapyr 75 g/ha	29.2	31.6	86.60	90.97	40.00
Pendimethalin 1000 g/ha *fb* HW	28.5	30.3	85.16	90.08	39.67
Unweeded control	16.0	16.6	41.09	40.09	36.93
LSD (p=0.05)	2.97	2.74	6.39	6.80	1.74

ZT: zero tillage, R: residue, N: nitrogen, CT: conventional tillage, HW: spot hand weeding

Yield attributes and yields

Tillage, residue, N and weed management practices caused significant variations in yield attributes and yields of greengram during both years of experimentation (**Table 5**). Number of pods per plant didn't differ across the tillage and residue management practices. However, on average, ZT-based systems recorded 4.5-4.6% higher number of pods/plant compared to CT+R+100N. Number of seeds per pod was significantly higher under ZT+R+100N compared to CT+R+100N, and remained at par with ZT+R+75N and ZT+R+50N. On average, ZT-based systems, resulted in 11.2-11.6% higher number of seeds per pod in greengram compared to CT+R+100N. The tillage, residue and N management practices led to similar 1000-seed weight of greengram. Relative improvements in yield attributing traits in greengram led to significantly higher seed yields under ZT+R+100N, which was at par with ZT+R+75N and ZT+R+50N compared to CT+R+100N during both the years (**Table 5**). The ZT-based systems accounted for 14.1-16.9 and 14.8-21.3% increase in seed yields of greengram in 2019 and 2020, respectivel compared to CT+R+100N. The harvest index was similar across all the tillage, residue and N treatments. The yield traits, *viz*. number of pods/plant and number of seeds/pod were significantly lower in UWC plots in both the years (**Table 5**). The extent of reduction in number of pods/plant and number of seeds/pod in UWC treatments ranged from 16.9 to 18.4% and 13.5 to 13.8%, respectively over the weed control practices. Among the weed control treatments, pendimethalin *fb* imazethapyr led to highest number of pods/plant and number of seeds/pod, comparable with pendimethalin fb HW and Na-acifluorfen + clodinafop. The 1000-seed weight was not significantly influenced by weed control treatments. The extent of yield reduction in control plots due to severe crop-weed competition was substantially higher, with average yield penalty ranged from 17.2 to 18.8% compared to treatment plots where weed control was adopted. On contrary, weed control treatments remained at par with each other and led to significantly higher seed yields compared to control, with the highest yields obtained with pendimethalin fb imazethapyr treatment in both the years (**Table 5**). With adoption of weed control practices, seed yields of greengram increased to the tune of 17.4-23.2 and 20.3-25.4% compared to UWC in 2019 and 2020 respectively. The weed control treatments resulted in significant improvements in harvest index compared to control treatment. Crop yield is largely influenced by the source-sink characteristics of plants, and translocation of the photosynthates from source to sink. Weed interference and crop yield are negatively correlated, implying that crop yield decreases with increasing weed interference and *vice-versa* (Sen *et al*. 2020, 2021). Higher crop-weed competition for light, water and nutrients adversely affected plant growth, symbiosis, and yield traits (sink formation), and translocation of photosynthates, which ultimately influenced crop yield as observed in control plots. Thus, comparatively lower weed interference in ZT-based systems and greater suppression of density and biomass of weeds (BLW, grasses, sedges and total) facilitated by efficient weed control led to higher yields of greengram compared to that in CT system. Moreover, better soil physical, chemical and biological properties in CA-based ZT + R systems (Bhattacharyya *et al*. 2018, Das *et al*. 2018, Hazra *et al*. 2019, Modak *et al*. 2019, Nath *et al*. 2019, Borase *et al*. 2020, Mondal *et al*. 2020) might have a positive impact on crop growth with greater photosynthetic rate, higher N_2 fixation through better nodule efficiency, larger sinks, and higher translocation of photosynthates to sinks, and it was reflected in yield attributes and yields in greengram (Nath *et al*. 2016). Further, improved soil water balance by means of reducing evaporation through retention of crop residues on soil surface under ZT systems also might have positively impacted crop growth and yields, particularly during hot-dry summer months.

Table 5. Greengram yield attributes and seed yield across tillage, residue, and herbicides treatments

Treatment	No. of pods/plant		No. of seeds/pod		1000-seed weight (g)		Seed yield (t/ha)		Harvest index (%)	
	2019	2020	2019	2020	2019	2020	2019	2020	2019	2020
Tillage, residue and N management										
ZT+R+50N	19.55	18.34	8.21	7.97	40.25	38.62	0.81	0.70	23.8	22.1
ZT+R+75N	19.74	18.54	8.63	8.39	40.31	39.65	0.82	0.72	24.0	22.5
ZT+R+100N	19.81	18.43	8.95	8.71	40.16	40.32	0.83	0.74	24.1	22.4
CT+R+100N	18.85	17.63	7.73	7.49	40.24	39.05	0.71	0.61	22.9	20.7
LSD (p=0.05)	NS	NS	0.79	0.79	NS	NS	0.08	0.07	NS	NS
Weed management										
Na-acifluorfen + clodinafop 245 g/ha	20.07	18.94	8.43	8.19	40.03	39.20	0.81	0.71	25.0	22.4
Pendimethalin 1000 g/ha *fb* imazethapyr 75 g/ha	20.36	19.12	8.83	8.58	40.63	40.09	0.85	0.74	24.6	22.8
Pendimethalin 1000 g/ha *fb* HW	20.23	18.86	8.65	8.40	40.07	40.24	0.84	0.73	25.3	22.5
Unweeded control	17.29	16.02	7.61	7.37	40.24	38.12	0.69	0.59	20.0	20.0
LSD (p=0.05)	1.58	1.60	0.66	0.66	NS	NS	0.05	0.06	1.89	1.55

ZT: zero tillage, R: residue, N: nitrogen, CT: conventional tillage, HW: spot hand weeding

Table 6. Profitability of greengram cultivation across tillage, residue, and herbicides treatments

Treatment	Net returns (×10³ ₹/ha)		Net benefit: cost	
	2019	2020	2019	2020
Tillage, residue and N management				
ZT+R+50N	28.03	20.04	0.88	0.60
ZT+R+75N	28.64	20.85	0.90	0.63
ZT+R+100N	29.49	22.67	0.93	0.69
CT+R+100N	17.66	9.90	0.50	0.28
LSD (p=0.05)	5.50	4.94	0.17	0.15
Weed management				
Na-acifluorfen + clodinafop 245 g/ha	28.11	21.13	0.90	0.65
Pendimethalin 1000 g/ha *fb* imazethapyr 75 g/ha	29.08	21.24	0.88	0.62
Pendimethalin 1000 g/ha *fb* HW	24.73	16.42	0.68	0.43
Unweeded control	21.88	14.68	0.76	0.49
LSD (p=0.05)	3.67	4.08	0.11	0.12

ZT: zero tillage, R: residue, N: nitrogen, CT: conventional tillage, HW: spot hand weeding

Economics

The profitability in terms of net returns and net benefit: cost differed across treatments (**Table 6**). Higher yields under the ZT systems resulted in significantly higher net returns and net benefit: cost than those under CT, the highest being in ZT+R+100N which was statistically at par with ZT+R+75N and ZT+R+50N during both years. The CA-based ZT systems, on average, led to 62.6 and 114.0% higher net returns, while the net benefit: cost increased by 80.7 and 128.6% over CT+R+100N in 2019 and 2020, respectively. Lower net returns and net benefit: cost in CT system could be due to higher cost incurred in land preparation and residue incorporation coupled with lower yields. Among the weed control practices, pendimethalin *fb* imazethapyr, being statistically at par with Na-acifluorfen + clodinafop resulted in significantly higher net returns than the remaining treatments, with 32.9 and 44.7% increase compared to UWC in 2019 and 2020 respectively. Similarly, Na-acifluorfen + clodinafop and pendimethalin *fb* imazethapyr were comparable in terms of net benefit: cost. Lower yields under control plots ultimately resulted in lowest net returns, while net benefit: cost was lowest under pendimethalin *fb* HW. Despite having sizeable amount of yield, substantially lower profitability was observed under pendimethalin *fb* HW, which was statistically at par with UWC. It was due to higher cost involved in manual weeding. It, thus, indicated the importance of selecting a weed control option, *i.e.*, herbicides that results in a compounding effect on profitability by providing low-cost (cost-effective) weed control.

This study showed that CA-based systems, *i.e.*, ZT with residue retention had substantially lower density and dry weight of weeds, and led to considerable improvements in plant growth, symbiosis, productivity and profitability in greengram. Considerable yield reduction was observed when weeds were left unchecked, indicating the need of adopting a suitable cost-efficient weed control strategy in summer greengram. Sequential application of pendimethalin (1000 g/ha) as pre-emergence followed by imazethapyr (75 g/ha) as post-emergence led to better weed suppression that ultimately reflected in higher yields and net income. In situations where application of pre-emergence herbicides becomes difficult due to inappropriate soil and weather conditions, post-emergent control of weeds through a broad-spectrum herbicide appears to be beneficial towards improving yields and profitability. However, continuous use of herbicides may hasten weed shift and development of herbicide-resistant weed biotypes. Therefore, combining ZT with surface residue retention, and supplementing it with appropriate herbicidal weed control may be adopted as a multi-pronged integrated approach of managing weeds in CA-based greengram for long-term sustainability under maize-wheat-greengram cropping system in north-western IGP of India.

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RESEARCH ARTICLE

Tillage and weed management practice influences on weed dynamics and yield of greengram in maize-wheat-greengram cropping system

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ABSTRACT

Weed management plays an important role in the success of conservation agriculture (CA) and help in gaining optimum crop yields. The knowledge of CA and weed management practices in a particular area allows to study, ecological interaction between crops and weeds to develop sustainable management strategies. A field study was conducted at research farm at ICAR-Directorate of Weed Research, Jabalpur (M.P.) between 2021-23 with an objective to study the influence of tillage and weed management practices on weed dynamics, and yield of greengram [*Vigna radiata* (L.) Wilczek] under long-term maize-wheat-greengram cropping system. The experiment was laid out in a split-plot design and replicated thrice. The main plots was assigned to two crop establishment methods [conventional tillage (CT) and zero tillage with retention of previous crop residues (ZT+R) in system] and four weed management practices [weedy check, recommended herbicide (RH), integrated weed management (IWM), herbicide rotations (HR)] in sub-plot. Results revealed that the lowest total broad leaved weeds density (11.8 and 10.2 no./m^2) and total sedges (22.1 and 11.8 no./m^2) were obtained with ZT+R. Similarly, total biomass of total broad-leaved weeds (13.6 and 11.0 g/m^2), total sedges (16.8 and 8.9 g/m^2) and more weed control efficiency (56.55% and 59.10%) with ZT+R in the year 2021-22 and 2022-23, respectively. Integrated weed management obtained lowest weed density of total broad-leaved weeds (8.5 and 6.5 no./m^2), total grassy weeds (9.7 and 10.8 no./m^2) and total sedges (10.7 and 7.0 no./m^2). The total biomass of broad-leaved weeds (5.3 and 4.7 g/m^2), grassy weeds (4.9 and 5.3 g/m^2), sedges (7.5 and 2.2 g/m^2) with highest WCE 84.80% and 85.28% during 2021-22 and 2022-23, respectively. Lower weed parameters under ZT+R noted with higher seed yield of 908 and 994 kg/ha, respectively) In IWM, seed yield was highest with 1129 and 1203 kg/ha during 2021-22 and 2022-23, respectively. Phytosociological analysis revealed the dominance of *Cyperus rotundus* (L.) and *Echinochloa colona* (L.) with the highest importance value index.

Keywords: Conservation tillage, Relative density, Relative abundance, Relative frequency and Importance value index

INTRODUCTION

Greengram [*Vigna radiata* (L.) Wilczek] is one of the important pulses that occupies 3% of the gross cropped area (Annual Report 2021-22) It provides about 24-28% protein and 60% carbohydrate thus plays an important role in ensuring nutritional security (Nath *et al.* 2017). In Central India, three cropping systems, *viz.* rice-wheat, maize-wheat and soybean-wheat are mostly followed by the farmers as per the land suitability and water adequacy. Cereal crops exhaust a large amount of nutrients without returning to the soil and nutrition depletion adversely affects soil quality (Tan *et al.* 2008). The inclusion of leguminous crop in the cropping system could help to improve soil fertility by fixing atmospheric nitrogen (Page *et al.* 2020). Incorporation of greengram crop residue helps to add organic matter to the soil thereby improving soil quality for succeeding crop. Furthermore, greengram is a good option for the farmers leaving fallow during summer season, greengram as a summer crop provides some extra income during this period (Ghosh *et al.* 2021). With the increase in minimum support price (MSP) of greengram, farmers raised their interest in taking greengram that resulted in an increase in its area and production. With the advancement in agriculture technology, farmers are moving more towards mechanizations and time-saving technology that drifted farmers economic conditions but excessive mechanization like continuous tillage and clean cultivation has increased soil compactness and organic matter decomposition in soil. Conservation agriculture (CA) based technology such as zero tillage (ZT), stubble mulch tillage, raised bed planting, and crop diversification are used as an alternative for

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machine intensive tillage practices in India as it minimises the labour and machinery while enhancing profitability (Das *et al.* 2014, Bhattacharyya *et al.* 2015, Jat *et al.* 2020). Adoption of CA along with greengram can be a restorative measure with less C: N promote rapid mineralization of nutrient in maize-wheat cropping system (Hazra *et al.* 2019). It enhances soil health, reduces soil erosion by engaging farm round the year, hence, utilises all the resources efficiently, thereby, providing extra income to the farmer.

Weeds are one of the major problems in CA as it provides favourable conditions for perennial weeds in most of the cropping system. Depending upon the infestation of weeds, yield reduction of about 30-80% in summer and rainy and 70-80% during *Rabi* seasons in greengram was observed (Algotar *et al.* 2015). Adoption of ZT with crop residue retention can reduce biomass of weeds and enhance yield than conventional tillage (CT) in various crops (Ghosh *et al.* 2022). Under ZT conditions viable weed seeds remains near the soil surface that provides favourable condition for their germination and emergence but also susceptible for herbicide, weather variability and predation (Nichols *et al.* 2015). Presence of crop residue on soil surface, hinders the germination, growth, light interception and also releases allelo-chemicals on weeds (Franke *et al.* 2007). Crop diversification could be an effective option to minimise weed density and dry weight due to change in production strategies caused by various cropping system (Buhler *et al.* 2001, Kaur *et al.* 2015). Moreover, phyto-sociological parameters enable to study co-existence between the crops and weeds as it is helpful determining weed species prevalence in the different periods of crop growth (Silva *et al.* 2018) also in identification of particular weed species distribution in an ecosystem. The weed which are frequent and dominant in a particular environment are more important in that area. Different weed management practices are being followed in order to minimize the weed pressure, among them, cultural and chemical weed management are most common and widely used. Moreover, weeds are susceptible to herbicide and when used repetitively leaves tolerant weed species that often thrive reduced competition (Tuessca *et al.* 2001, Suresha 2014). In summer greengram, pre-emergence (PE) application of pendimethalin at 0.45 kg/ha followed by (*fb)* one hand weeding had the lowest weed dry matter. Imazethapyr has been reported to provide effective control of weeds in greengram (Singh *et al.* 2014). Similarly, application of pendimethalin at 1.0 kg/ha (PE) *fb* imazethapyr at 55 g/ha at 15-20 DAS considerably reduced weed density and biomass resulting in higher seed yield (Bahar *et al.* 2017). CA along with different weed management practices to control various weed flora reduced herbicide retention in soil thereby protect the environment from pollutions by opting integrated weed management. Keeping all the above facts in view, the present study seeks to compare the effect of CT and ZT with weed management practices to assess the influence of conservation tillage and weed management practices on weed dynamics, and yield of greengram [*Vigna radiata* (L.) Wilczek] under maize-wheat-greengram cropping system.

MATERIAL AND METHODS

The field experiment was carried out at ICAR-Directorate of Weed Research, Jabalpur (M.P.) during the summer seasons of 2021-22 and 2022-23. The experiment was laid out in a split-plot design with three replications. The main plot consists of two crop establishment methods, conventional tillage [CT (greengram residue; GR)-CT(Maize residue; MR)-CT (Wheat residue; WR)] and conservation tillage [ZT+R(GR)-ZT+R(MR)-ZT+R(WR)] in the system and four weed management practices [weedy check, recommended herbicide [RH; pendimethalin 678 g/ha (pre-emergence, PE) *fb* imazethapyr at 100 g/ha (post-emergence, PoE)], integrated weed management [IWM; pendimethalin 678 g/ha (PE) *fb* hand weeding at 30 DAS], herbicide rotations [HR; pendimethalin 678 g/ha (PE) *fb* imazethapyr at 100 g/ha (PoE) during first year, pendimethalin 678 g/ha (PE) *fb* quizalofop 60 g/ha during second year] in the sub-plot. The soil of the experimental field was clayey in texture with neutral pH, medium organic carbon (OC; 0.76%) and available nitrogen (256.5 kg/ha) and potassium (342.6 kg/ha), and high in phosphorus (62.5 kg/ha). The greengram variety '*Virat*' was selected for the experiment. The field was prepared by ploughing with two pass of tractor drawn cultivator followed by one pass rotavator in CT. Water management was done as per the need of the crop. The seed of greengram was sown in line at 30 cm apart using normal seed drill in CT and happy seed drill in ZT+R with the seed rate of 25 kg/ha. Entire residues of wheat crop were left in the field before sowing of greengram. The recommended dose of nutrient N:P:K of 22.5:60:00 kg/ha was applied as basal. For spraying herbicide, knapsack sprayer fitted with a flat fan nozzle was used for spraying herbicide of 500 L/ha for PE and 375 L/ha at 20 DAS as PoE. Weed density and weed dry weight were recorded at 60 days after sowing by placing 0.25 m^2 (0.5 m x 0.5 m) quadrat at two places in each plot and the mean was converted to 1 m^2. The collected weeds were initially shade-dried and then placed in an oven for drying at 65±2 ÚC until constant weight was achieved. The data was then subjected to square root transformations to normalize the variations. The original values of weed dry weight were used for the calculation of weed control efficiency. Similarly, weed phytosociology parameters (density, frequency and abundance, important value index) were worked out by using formula suggested by Hetta *et al.* (2022).

$$\text{Density} = \frac{\text{Total number of individuals of species in all quadrates}}{\text{Total number of quadrates studied}}$$

$$\text{Frequency (\%)} = \frac{\text{Total number of quadrates in which the species occurred}}{\text{Total number of quadrates studied}}$$

$$\text{Abundance} = \frac{\text{Total number of individuals of a species in all quadrates}}{\text{Total number of quadrates in which the species occurred}}$$

Importance value index (IVI) = Relative density + Relative frequency + Relative abundance

Statistical analysis

The data obtained over two years were subjected to statistical analysis of variance (ANOVA) using F-test as suggested by Gomez and Gomez (1984). The significant difference between treatment means were compared with critical differences at 5% levels of significance.

RESULTS AND DISCUSSION

Weed flora

Mean data revealed that greengram crop was mainly infested with *Echinochloa colona* (L.) (22.3%), *Dinebra retroflexa* (Vahl.) (17.0%), *Cyperus rotundus* (L.) (17.4%) and *Digitaria sanguinalis* (L.) (14.2%). However, *Convolvulus arvensis* (L.) (4.7%), *Alternanthera sessilis* (L.) (3.9%) and *Eleusine indica* (L.) (3.3%) also recorded as minor weeds during the study.

Weed density and dry weight

The field was infested with complex weed flora comprising of broad-leaved, grasses and sedges (**Table 1**). Among the crop establishment methods, significantly minimum total broad-leaved weeds (11.8 and 10.2 no./m^2) and sedges (22.1 and 11.8 no./m^2) were recorded in ZT+R over CT except, total grassy weeds (43.5 and 37.7 no./m^2), which was significantly minimum in CT during both the years of experimentations. This might be because of residue retention in ZT that significantly supressed the weed seed germination and emergence in ZT+R. The density of grassy weeds was more in ZT+R may be due to the well established grassy weeds of previous crop. As also observed by Suryawanshi *et al.* 2018a, Choudhary and Sharma (2023). Among the weed management practices, the minimum density of total broad-leaved weeds (8.5 and 6.5 no./m^2), total grasses (9.7 and 10.8 no./m^2) and total sedges (10.7 and 7.0 no./m^2) in IWM during both the years of experimentation. This might be because of effective weed controlled by pendimethalin *fb* HW during early stages that favoured better crop growth which ultimately supressed weeds. As also reported by Shilurenla *et al.* (2022) that maximum reduction in weed density was observed in pendimethalin *fb* HW.

Among the crop establishment methods, significantly minimum weed dry weight of total broad-leaved weeds (13.6 and 11.0 g/m^2) and sedges (16.8 and 8.9 g/m^2) was recorded in ZT+R over CT except total grassy weeds (40.5 and 33.4 g/m^2), which was more in CT during both the years of experimentation. This might be due to lower weed density in ZT+R, which ultimately resulted in lower weed biomass, however grassy weeds were higher in ZT which resulted in more weed dry weight. Ghosh *et al.* (2022a) also observed reduction in total weed density and biomass under CA-based practices. IWM practices recorded significantly minimum weed dry weight of total broad leaved weeds (5.3 and 4.7 g/m^2), total grassy weeds (4.9 and 5.3 g/m^2) and total sedges (7.5 and 2.2 g/m^2) over the others during both the years of experimentations. This might be due to better weed control by pendimethalin *fb* HW that favoured crop growth, which resulted in quick coverage of ground and more shading affect by crop thereby reducing growth of weeds. Singh *et al.* (2015), lower dry matter of weeds by application of pendimethalin + 1 HW.

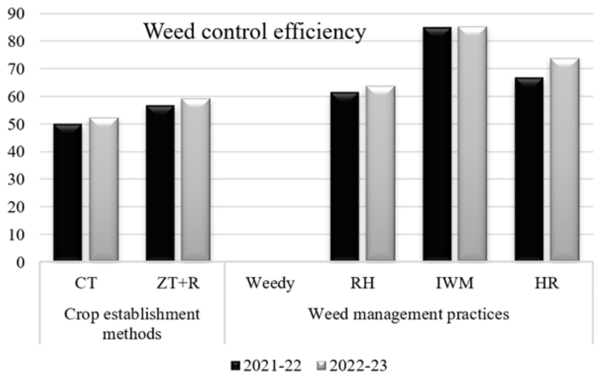
The interaction effect of crop establishment methods and weed management practices during both the years was found to be significant for total broad-leaved weeds. The combination of ZT+R with IWM recorded minimum weed density and biomass over the other treatment combinations. However, the interaction effects for total grassy weeds and total sadges was non-significant during both the years of experiments.

Weed control efficiency (WCE)

The WCE were recorded under different crop establishment methods and weed management practices at 60 DAS and is presented in **Figure 1**. The maximum weed control efficiency was recorded under ZT+R than CT during both the year. This may be because of crop residue in ZT+R that might have hindered weed seed germination and emergence. The fewer weeds those got germinated were controlled by applying herbicides. Choudhary and Sharma (2023) also noted the highest weed control efficiency in ZT+R than CT. Among the weed management practices, maximum weed control was recorded under IWM and HR. This was due to application of pendimethalin *fb* hand weed weeding at 30 DAS that completely removed weeds resulted in higher WCE in IWM. The result are in accordance with Shilurenla *et al.* (2022) that the highest WCE in pendimethalin *fb* hand weeding. In general, the weed control efficiency was more in second year of the experiment. This might be due to better control of weeds that resulted in fewer weeds and lesser dry weight.

Phytosociological parameters

Phytosociology is the study of various communities of weeds which reflect the pattern of particular species present in an agro-ecosystem. Weed phytosociology is useful in identifying weed species that are more important during the various growth stages of the crop and make sure for efficient methods that can be used for weeds control (Concenco *et al*. 2017). Phytosociological parameters, *viz*. relative density (RD), relative frequency (RF), relative abundance (RA), and important value index (IVI) were estimated based on seasonal observation for two years **Tables 2 to 5**. These parameters were used to determine frequently occurring, abundant, and more important weed species in a particular area.



CT; Conventional tillage, ZT+R; Zero tillage with crop residue, RH; Recommended herbicide, IWM; Integrated weed management, HR; Herbicide rotation

Figure 1. Conservation tillage and weed management practice influences weed control efficiency in greengram under maize-wheat-greengram cropping system

Relative density

The relative density reflects the density of a particular species in relation to all the species and is expressed in percentage. It shows the extent of the species in that particular community **Table 2**. It is clear that among the crop establishment methods, *Cyperus rotundas* (L.), was most dominant in CT (35.9% and 33.9%) than ZT+R (27.3% and 27.7% during both the years, respectively). However, *Echinochloa colona* (L.) (21.8%) and *Dinebra retroflexa* (Vahl.) (17.3%) were more dominant in ZT+R than CT during 2021-22. Contrarily to this, the foresaid weeds were more dominant in CT over

Table 1. Effect of conservation tillage and weed management practices on density and dry weight of total broad leaved, total grassy weeds and total sedges in greengram under maize-wheat-greengram cropping system

Treatment	Total broad-leaf weeds				Total grassy weeds				Total sedges			
	Total density		Total dry weight		Total density		Total dry weight		Total Density		Total dry weight	
	2021-22	2022-23	2021-22	2022-23	2021-22	2022-23	2021-22	2022-23	2021-22	2022-23	2021-22	2022-23
Crop establishment method (M)												
CT	4.57 (22.2)	3.91 (16.5)	4.63 (24.4)	4.00 (18.3)	6.14 (43.5)	5.46 (37.7)	5.50 (40.5)	4.93 (33.4)	5.35 (29.7)	4.63 (22.1)	4.44 (20.9)	3.78 (15.5)
ZT+R	3.41 (11.8)	3.19 (10.2)	3.57 (13.6)	3.24 (11.0)	6.44 (49.3)	5.84 (43.7)	5.72 (43.2)	5.32 (40.0)	4.61 (22.1)	3.39 (11.8)	4.02 (16.8)	2.85 (8.9)
p=0.05	0.48	0.68	0.62	NS	0.19	0.33	0.21	0.35	0.69	0.29	0.39	0.80
Weed management practice (S)												
Weedy check	5.68 (33.2)	5.10 (26.5)	6.43 (42.5)	5.67 (32.8)	10.94 (118.5)	10.31 (107.2)	11.07 (122.2)	10.57 (111.8)	6.41 (41.2)	5.20 (27.3)	5.96 (35.3)	4.56 (21.2)
RH	3.75 (13.8)	3.11 (9.3)	3.84 (14.5)	3.11 (9.3)	5.66 (30.7)	5.63 (32.3)	4.74 (22.1)	4.80 (22.7)	5.31 (27.8)	3.79 (14.3)	4.05 (16.1)	2.92 (8.3)
IWM	2.97 (8.5)	2.63 (6.5)	2.40 (5.3)	2.25 (4.7)	3.26 (9.7)	3.21 (10.8)	2.32 (4.9)	2.39 (5.3)	3.30 (10.7)	2.66 (7.0)	2.82 (7.5)	1.59 (2.2)
HR	3.55 (12.3)	3.35 (11.0)	3.73 (13.6)	3.45 (11.8)	5.31 (26.8)	3.44 (12.3)	4.31 (18.2)	2.73 (6.9)	4.92 (23.8)	4.41 (19.2)	4.09 (16.4)	4.19 (17.2)
p=0.05	0.46	0.46	0.68	0.46	0.48	0.71	0.37	0.58	0.53	0.50	0.56	0.45
M×S												
p=0.05	0.65	0.65	0.96	0.66	NS	NS	NS	NS	NS	NS	NS	NS

ZT+R in 2022-23. Similar to our findings, Kumar *et al.* (2022) also observed the dominance of *Cyperus* spp. in CT. Chhokar *et al.* (2021) observed more density of *Dinebra retroflexa* (Vahl.) and *Digitaria sanguinalis* (L.) in ZT+R. Among the weed management practices, thick population of *Cyperus rotundus* (L.) was present in IWM (38.0%) than other weed management practices during the year of 2021-22. However, *Echinochloa colona* (L.) (25.4%), *Dinebra retroflexa* (Vahl.) (17.0%) and *Digitaria sanguinalis* (12.6%) were more in weedy check plot than other weed management practices. *Dinebra retroflexa* (Vahl.) followed significant ($p<0.05$) trend with the highest in weedy check > HR > RH > IWM. In 2022-23, density of *Cyperus rotundus* (L.) (53.7%) was more than other weed management practices, whereas *Echinochloa colona* (L.) (29.5%), *Dinebra retroflexa* (Vahl.) (20.6%) and *Digitaria sanguinalis* (22.2%) were higher in weedy check plots.

Relative frequency

It is a useful index to monitor and compare plant community changes over a time (Bonham 2013). It reflects either presence or absence of a species and it is distributed within a community. It is clear from **Table 3**, that among the crop establishment methods, during both the year *Echinochloa colona* (L.) (15.2% and 15.4%, respectively) and *Cyperus rotundus* (L.) (15.2% and 15.4%, respectively) were the most frequently occurring weeds in ZT+R (12.9% and 13.1%, respectively) than CT (13.9% and 14.4%, during 2021 and 2022, respectively). Among the weed management practices during both the years, *Echinochloa colona* (17.8% and 17.1%, respectively) and *Cyperus rotundus* (17.8% and 17.1%, respectively) were most frequent in IWM than other weed management practices during 2021 and 2022, respectively. In 2021-22, *Cyperus rotundus* was significantly more frequent in IWM followed by HR and RH. However, *Cyperus rotundus* was more frequent in IWM followed by HR in 2022-23.

Relative abundance

It is the measure of weed species occurrence in a particular area. The data on relative abundance is presented in **Table 4**. Among the crop establishment methods, *Cyperus rotundus* (L.) was the most abundant weed in CT (35.1% and 31.9%) than ZT+R

Table 2. Effect of conservation tillage and weed management practices on relative density in greengram under maize-wheat-greengram cropping system

Weed species	Crop establishment method				p=0.05		Weed management practice								p=0.05	
	CT		ZT+R				Weedy check		RH		IWM		RH			
	2021-22	2022-23	2021-22	2022-23	2021-22	2022-23	2021-22	2022-23	2021-22	2022-23	2021-22	2022-23	2021-22	2022-23	2021-22	2022-23
Echinochloa colona (L.)	19.5	22.6	21.8	21.7	NS	NS	25.4	29.5	18.6	25.2	19.5	23.3	19.3	10.9	NS	6.05
Dinebra retroflexa (Vahl.)	11.0	11.1	17.3	8.1	1.86	NS	17.0	20.6	15.3	19.0	7.7	11.1	16.6	7.7	6.81	5.78
Digitaria sanguinalis (L.)	10.2	10.8	10.2	13.8	NS	NS	12.6	22.2	11.0	13.2	8.3	10.4	8.9	3.4	NS	5.60
Alternanthera sessilis (L.)	6.0	4.4	4.9	2.8	NS	NS	7.9	2.1	5.3	2.0	4.8	4.9	3.7	5.3	NS	NS
Phyllanthus niruri (L.)	8.0	5.5	4.3	2.9	NS	NS	8.6	4.7	4.7	2.6	5.8	3.0	5.5	6.6	NS	NS
Cyperus rotundus (L.)	35.9	33.9	27.3	27.7	NS	NS	22.6	14.5	28.5	22.0	38.0	33.0	37.2	53.7	NS	1.91
Convolvulus arvensis (L.)	8.1	8.1	7.1	5.9	NS	NS	6.8	5.3	6.4	5.8	10.7	6.6	6.4	10.7	NS	NS
Eleusine indica (L.)	3.5	4.9	3.6	4.4	NS	NS	3.1	3.8	3.3	4.7	5.2	8.3	2.6	1.9	NS	2.66

CT; Conventional tillage, ZT+R; Zero tillage with crop residues, RH; Recommended herbicide, IWM; Integrated weed management, HR; Herbicide rotation

Table 3. Effect of conservation tillage and weed management practices on relative frequency in greengram under maize-wheat-greengram cropping system

Weed species	Crop establishment method				p=0.05		Weed management practice								p=0.05	
	CT		ZT+R				Weedy check		RH		IWM		RH			
	2021-22	2022-23	2021-22	2022-23	2021-22	2022-23	2021-22	2022-23	2021-22	2022-23	2021-22	2022-23	2021-22	2022-23	2021-22	2022-23
Echinochloa colona (L.)	12.9	13.1	15.2	15.4	NS	NS	12.5	12.6	13.3	14.6	17.8	17.1	12.6	12.6	NS	NS
Dinebra retroflexa (Vahl.)	10.9	10.8	13.5	14.7	NS	NS	12.5	12.6	13.3	14.6	8.3	11.3	14.7	12.7	NS	NS
Digitaria sanguinalis (L.)	13.3	12.4	11.4	13.2	NS	NS	12.5	12.6	13.3	14.6	12.3	15.6	11.3	8.6	NS	4.66
Alternanthera sessilis (L.)	12.1	11.9	9.6	9.0	1.39	NS	12.5	11.5	12.0	8.4	8.7	9.6	10.1	12.4	NS	NS
Phyllanthus niruri (L.)	12.7	11.7	11.9	9.5	NS	NS	12.5	12.6	13.3	9.3	11.1	6.7	12.4	13.9	NS	NS
Cyperus rotundus (L.)	13.9	14.4	15.2	15.4	NS	NS	12.5	12.6	13.3	14.6	17.8	17.1	14.7	15.4	3.63	1.71
Convolvulus arvensis (L.)	13.0	12.5	13.7	11.2	NS	NS	12.5	12.6	13.3	10.8	14.6	8.6	13.0	15.4	NS	NS
Eleusine indica (L.)	10.3	11.7	9.5	11.5	NS	NS	12.2	12.6	8.5	13.3	9.4	14.2	9.3	6.4	NS	NS

CT; Conventional tillage, ZT+R; Zero tillage with crop residues, RH; Recommended herbicide, IWM; Integrated weed management, HR; Herbicide rotation during 2021 and 2022, respectively. In 2021-22, abundance of *Echinochloa colona* (20.6%) and *Dinebra retroflexa* (Vahl.) (18.0%) was more in ZT+R but in 2022-23, the abundance of *Dinebra retroflexa* (Vahl.) (18.0%) and *Digitaria sanguinalis* (13.8%) was more as compared to CT. Among the weed management practices, *Cyperus rotundus* (36.4 and 51.7% during 2021 and 2022, respectively) was most abundant weed among all the weed species in HR and *Echinochloa colona* was the second most abundant species in weedy check during both the year of experiment.

Important value index

It is a standard tool for estimating overall importance of a species in a particular area. It is sum of the percentage value of relative density, relative frequency and relative abundance. Among the crop establishment methods, *Cyperus rotundas* registered highest IVI (84.9 and 80.3%) in CT than ZT+R (75.3 and 75.5%) during 2021 and 2022, respectively. *Echinochloa colona* registered the second most important weed among all the species during both the years. Among the weed management practices, *Cyperus rotundus* registered the highest IVI in HR among all the weed species during both the year and *Echinochloa colona* registered second weed species in weedy check during both the years (**Table 5)**.

Seed and stover yield

Seed yield varied significantly among crop establishment methods and weed management practices (**Table 6)**. The highest seed yield 908 kg/ha in 2021-22 and 994 kg/ha in 2022-23 was recorded in ZT+R than CT (715 and 869 kg/ha during 2021 and 2022, respectively). The higher seed yield in ZT+R was mainly due to reduction in weed density that favoured utilization of light, space, and nutrients, which helped in synthesizing higher growth and yield attributing characters and ultimately, resulted in higher seed yield than CT. The results were in agreement with Ghosh *et al.* (2022a). Among the weed management practices, the highest seed yield was recorded in IWM practices (1129 and 1203 kg/ha, respectively) than other weed management practices. The lowest seed yield (323 and 462 kg/haduring 2021 and 2022, respectively) was obtained in weedy check. Application of pendimethalin *fb* hand

Table 4. Effect of conservation tillage and weed management practices on relative abundance in greengram under maize-wheat-greengram cropping system

Weed species	Crop establishment method				p=0.05		Weed management practice								p=0.05	
	CT		ZT+R				Weedy check		RH		IWM		RH			
	2021-22	2022-23	2021-22	2022-23	2021-22	2022-23	2021-22	2022-23	2021-22	2022-23	2021-22	2022-23	2021-22	2022-23	2021-22	2022-23
Echinochloa colona (L.)	19.3	21.6	20.6	21.2	NS	NS	25.4	29.5	18.5	24.5	17.2	21.2	18.8	10.5	NS	5.67
Dinebra retroflexa (Vahl.)	10.8	11.0	18.0	18.0	4.14	NS	17.0	20.5	15.1	18.6	9.2	10.6	16.1	8.4	NS	5.49
Digitaria sanguinalis (L.)	10.4	11.3	9.9	13.8	NS	NS	12.6	22.2	10.9	13.0	8.4	10.4	8.8	4.7	NS	5.31
Alternanthera sessilis (L.)	5.9	5.2	5.4	3.4	NS	NS	7.9	2.2	5.6	2.8	4.9	6.9	4.0	5.9	NS	3.5
Phyllanthus niruri (L.)	6.3	4.6	4.6	3.4	NS	0.8	4.6	2.2	2.6	3.2	6.6	3.7	6.1	7.0	NS	NS
Cyperus rotundus (L.)	35.1	31.9	29.3	29.7	NS	NS	22.6	14.4	35.1	26.9	34.7	30.2	36.4	51.7	8.17	7.23
Convolvulus arvensis (L.)	8.3	9.0	7.3	5.6	NS	NS	6.8	5.3	6.4	6.1	11.3	7.6	6.7	10.3	3.15	NS
Eleusine indica (L.)	4.1	5.4	4.9	4.9	NS	NS	3.1	3.6	3.8	5.0	7.6	9.6	3.3	2.3	NS	3.07

CT; Conventional tillage, ZT+R; Zero tillage with crop residues, RH; Recommended herbicide, IWM; Integrated weed management, HR; Herbicide rotation

Table 5. Influence of conservation tillage and weed management practices on important value index in greengram under maize-wheat-greengram cropping system

Weed species	Crop establishment method				p=0.05		Weed management practice								p=0.05	
	CT		ZT+R				Weedy check		RH		IWM		RH			
	2021-22	2022-23	2021-22	2022-23	2021-22	2022-23	2021-22	2022-23	2021-22	2022-23	2021-22	2022-23	2021-22	2022-23	2021-22	2022-23
Echinochloa colona (L.)	52.7	58.7	57.6	58.3	NS	NS	63.2	71.6	50.3	64.2	54.4	61.5	52.7	36.7	NS	11.37
Dinebra retroflexa (Vahl.)	32.6	32.9	48.8	50.9	7.30	NS	46.5	53.7	43.6	52.1	25.2	32.9	47.3	28.8	16.92	13.23
Digitaria sanguinalis (L.)	33.9	34.5	31.6	40.8	NS	NS	37.7	57.0	35.1	40.8	29.1	36.4	29.0	16.6	NS	12.80
Alternanthera sessilis (L.)	23.9	21.5	19.8	15.1	NS	NS	28.4	15.9	23.0	13.2	18.5	21.4	17.7	22.7	NS	NS
Phyllanthus niruri (L.)	24.9	20.6	20.9	15.8	NS	NS	21.6	17.0	22.5	15.1	23.5	13.4	24.0	27.5	NS	NS
Cyperus rotundus (L.)	84.9	80.3	75.3	75.5	NS	NS	57.8	41.5	83.9	69.0	90.5	80.2	88.2	120.8	14.35	13.88
Convolvulus arvensis (L.)	29.4	29.5	28.1	22.7	NS	NS	26.1	23.2	26.5	22.7	36.6	22.2	26.1	36.3	NS	NS
Eleusine indica (L.)	17.8	22.1	18.0	20.8	NS	NS	18.8	20.2	15.5	23.0	22.2	32.1	15.1	10.6	NS	8.82

CT; Conventional tillage, ZT+R; Zero tillage with crop residues, RH; Recommended herbicide, IWM; Integrated weed management, HR; herbicide rotatio

Table 6. Effect of conservation tillage and weed management practices on seed and stover yield of greengram under maize-wheat-greengram cropping system

Treatment	Seed yield (kg/ha)		Stover yield (kg/ha)	
	2021-22	2022-23	2021-22	2022-23
Crop establishment method (M)				
CT	714	869	1869	1925
ZT+R	908	994	2223	1950
p=0.05	76.24	64.73	317.20	NS
Weed management practice (S)				
Weedy check	323	462	1141	1352
RH	790	939	2194	1984
IWM	1129	1203	2273	2253
HR	1000	1121	2577	2201
p=0.05	91.43	45.46	228.43	193.95
M×S				
p=0.05	NS	64.30	NS	NS

weeding at 30 DAS efficiently controlled weeds during the initial as well as later stages of the crop which offered lesser competition for the available resources at sites resulted in better growth and development of the crop thereby enhancing seed yield. Similar to this, Ghosh *et al.* (2022b) also stated that the application of pendimethalin *fb* hoeing obtained higher seed yield over herbicide alone.

After the critical review of data of both the years, it was observed that ZT+R recorded significantly higher stover yield (2223 kg/ha) than CT (1869 kg/ha) during the first year of the experiment. However, it was non-significant in the second year. It might be due to favourable conditions provided by ZT+R that resulted in better crop-establishment hence, more stover yield. Among the weed management practices, in the first year of experiment, the highest stover yield (2527 kg/ha) was harvested in HR whereas in second year, IWM harvested the highest yield (2253 kg/ha) although it was at par to HR. This might be due to the application of PoE herbicide in HR that extended the vegetative growth phase but shortened the reproductive stage that ultimately helped in higher stover yield in HR than IWM. Suryavanshi *et al.* (2018b) also found significant effect of crop establishment methods and weed management practices on seed and stover yield of greengram. Lower weed density and dry weight with higher weed control efficiency helped in obtaining higher seed and stover yield.

The interaction effect among crop establishment and weed management was found to be significant for the second year of experimentation with treatment combination of ZT+R with IWM, which recorded maximum grain yield over the others treatment combinations.

Conclusion

Based on the study it was be concluded that ZT with retention of entire crop residues of wheat crop resulted in a noticeable reduction in density and dry weight of weeds. Similarly, application of pendimethalin 678 g/ha *fb* hand weeding at 30 DAS outperformed than herbicides alone. In greengram, under long-term maize-wheat-greengram cropping system, greater weed flora diversity with eight species during both the years of experiment was observed. Weed importance value varied greatly due to the crop establishment methods and weed management practices in greengram. Therefore, ZT+R with IWM (pendimethalin *fb* hand weeding) practices had significant importance in achieving higher seed yield and weed control in greengram under maize-wheat-greengram cropping system.

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RESEARCH ARTICLE

Seed production potential of *Medicago denticulata* in relation to growth stage at the time of herbicide application

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ABSTRACT

Medicago denticulata Willd. is a winter annual weed infesting wheat. The present study was aimed to evaluate the effect of weed growth stage at the time of herbicide application (2,4-D, carfentrazone-ethyl and pre-mix herbicide metsulfuron-methyl plus sulfosulfuron) on efficacy of different post-emergence herbicides and herbicide carryover effects onto future generations. Herbicide sprays done at four-leaf stage of *M. denticulata* provided effective control whereas delayed application resulted in poor control with no visual injury. Significant increase in weed density was observed as the herbicides were sprayed at advanced growth stages of *M. denticulata*. Delayed application of all the herbicides at eight and twelve-leaf stage caused decrease in weed control efficiency than herbicide sprays done at four-leaf stage. However, application of herbicides at eight and twelve-leaf stages caused significant reduction in seed production potential of *M. denticulata* as compared to herbicide sprays done at four-leaf stage. Carfentrazone-ethyl had more pronounced effect on seed production potential of *M. denticulata* than 2,4-D. Whereas, metsulfuron-methyl plus sulfosulfuron was least effective in reducing fruit and seed number of *M. denticulata*. Seeds produced by *M. denticulata* plants after herbicide exposure were viable but dormant and exhibited decreased germination.

Keywords: Germination, Herbicide, Seed heteromorphism, Weed control efficiency

INTRODUCTION

M. denticulata is a winter annual weed native to Mediterranean basin but has also infested western and central Asia (Graziano *et al.* 2010). In India, this weed has invaded many states, *viz.* Punjab, Haryana, Jharkhand, Bihar, Madhya Pradesh and West Bengal. Among various dicotyledonous weeds, *M. denticulata* is the major problematic weed prevalent in wheat fields of Punjab (Kaur *et al.* 2015). The fruit (bur) is a prickly, flattened and coiled pod containing 3-5 kidney shaped seeds (Walsh *et al.* 2013).

Major herbicides used in India for control of dicotyledonous weeds in wheat are metsulfuron, 2,4-D and carfentrazone (Chhokar *et al.* 2015). Although herbicides provide cost-effective weed control but over-reliance on herbicides with a similar mode of action can rapidly lead to evolution of herbicide resistance in weeds (Bhullar *et al.* 2017). Weed growth stage at the time of herbicide application strongly influences the uptake, translocation and metabolism of herbicides. Herbicides applied at advanced weed growth stage increase the rate of herbicide degradation resulting in decreased herbicide efficacy (Singh and Singh 2004). Annual weeds mainly rely on renewable seed production to ensure their persistence; therefore, spraying herbicides at or near flowering can be used as an alternate approach for managing weeds by cutting down their seed production potential. Application of selective herbicides to dicotyledonous weeds during the reproductive stage of development affects the germination behavior of seeds by reducing the seed viability (Madafiglio *et al.* 2006). Herbicide application may have effects on the subsequent germination of seeds derived from herbicide treated weeds. The information on effect of post-emergence herbicides, *viz.* 2,4-D, carfentrazone-ethyl and metsulfuron plus sulfosulfuron various physiological, seed production potential and seed quality parameters of *M. denticulata* is lacking, when applied at different growth stages. Also, the potential of these herbicides in affecting germination of *M. denticulate* seeds derived from herbicide treated plants is also not known. Therefore, present study was undertaken with the objective to evaluate the effect of weed growth stage at the time of herbicide application on efficacy of different post-emergence herbicides and possible herbicide carryover effects onto future generation.

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MATERIAL AND METHODS

General information

Field experiments were conducted during *Rabi* 2016-17 and 2017-18 at Research farm of Punjab Agricultural University (PAU), Ludhiana, India. The experimental field had been under irrigated rice-wheat cropping system. The seedbed was prepared by one ploughing with disc harrow followed by two ploughings with cultivators and each ploughing was followed by planking. Wheat (cv. *PBW-677*) was sown during November 2016 and 2017 at a row spacing of 22.5 cm using 100 kg seed rate/ha. The seeds of *M. denticulata* were broadcasted uniformly in the field before sowing of wheat crop. Experiment was laid out in split plot design replicated thrice, with three growth stages of *M. denticulate, viz.* four, eight and twelve-leaf stages as main-plot treatments and seven weed control treatments as subplot, *viz.* 2,4-D sodium salt at 250 and 500 g/ha, carfentrazone-ethyl at 10 and 20 g/ha, pre-mix herbicide metsulfuron-methyl plus sulfosulfuron at 15 and 30 g/ha and water sprayed control. Fifteen plants of *M. denticulata* with leaf-stage as per treatment was maintained in each experimental plot (2.5 × 4.0 m). The herbicides were sprayed using a knap sack sprayer fitted with flat fan nozzle at 4, 8 and 12 leaf stages of *M. denticulata* which corresponded to 35, 50 and 60 days after sowing of wheat crop.

The data of chlorophyll fluorescence and chlorophyll content index was recorded from tagged plants at flowering using chlorophyll fluorometer (Model - OS-30p, Opti-Sciences, Inc.) and portable chlorophyll content meter (Model – CCM-200, Opti-Sciences, Inc.). For recording the observations, the middle portion of the leaf was dark-adapted with plastic clips before exposing to the light emitted by the fluorometer. The fluorescence readings were expressed as F_v/F_m (variable fluorescence/maximum fluorescence).

Density of *M. denticulata* was recorded from each plot at 20 DAS (days after spray) and was expressed as numbers of plants/m^2. For recording biomass, plants were cut; dried in sunlight and then placed in the paper bags for oven drying at 60 ^oC for 48 hours. Dry weight was taken till constant weight was achieved. The data was later expressed in g/m^2. Weed control efficiency (WCE) was calculated as:

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

Where, WDC = weed dry weight from control plot, WDT = weed dry weight from treated plot

At the maturity stage, five plants of *M. denticulata* were selected randomly from each plot for recording the number of fruits and seeds per plant.

Seeds collected from water sprayed control and herbicide treated plants of *M. denticulate* were tested for following seed quality parameters. Germination counts were daily made for 15 days after start of the experiment. The seeds showing visible protrusion of radicle were considered as germinated. Germination percentage was calculated as: Per cent Germination = [Number of seeds germinated /total number of seeds] × 100

Speed of germination (germination index) was calculated using the following formula given by the Association of Official Seed Analysts (1983)

$$GI = \frac{Number\ of\ germinated\ seeds}{Days\ of\ first\ count} + - - + \frac{Number\ of\ germinated\ seeds}{Days\ of\ final\ count}$$

Mean germination time (MGT) was calculated using the following equation of Ellis and Roberts (1981)

$$MGT = \frac{\Sigma\ (Dn)}{\Sigma\ n}$$

Here *n* is the no. of seeds that had germinated on day D, and D is the no. of days counted from the beginning of germination.

The results of both the years were pooled before subjecting to ANOVA in randomized block design using statistical analysis software version 9.2 (SAS 2009). Means were separated at 0.05 using Fisher's Protected Least Significant Difference (LSD) test (Cochran and Cox 1966).

RESULTS AND DISCUSSION

Crop yield

The highest and lowest grain and straw yield of wheat were recorded when herbicides were sprayed at four and twelve-leaf stages of *M. denticulata,* respectively (**Table 1**). Herbicide sprays at twelve-leaf stage during both years caused > 7 and 4% reduction in grain and straw yield, respectively than sprays done at four-leaf stage. The highest grain and straw yield during both cropping seasons were recorded in plots treated with 20 g/ha of carfentrazone-ethyl which remained at par with other herbicide treatments, *viz.* carfentrazone-ethyl 10 g/ha, metsulfuron-methyl plus sulfosulfuron at 15 and 30 g/ha and 2,4-D at 500 g/ha but significantly superior to 2,4-D at 250 g/ha and unweeded control. Biological yield was similarly affected as that of grain and straw yield, with the highest biological yield being

Table 1. Effect of weed and crop growth stage at the time of herbicide spray and different herbicides on yield of *Triticum aestivum* L. (pooled data of 2016-17 and 2017-18)

Treatment	Biological yield (t/ha)	Grain yield (t/ha)	Straw yield (t/ha)
Weed growth stage at the time of herbicide spray			
4 leaf stage (35 days)	13.22	5.48	7.74
8 leaf stage (50 days)	12.55	5.13	7.42
12 leaf stage (60 days)	12.30	5.00	7.26
LSD (p=0.05)	0.24	0.11	0.13
Herbicide treatment			
2,4 D sodium salt 250 g/ha	12.48	5.11	7.37
2,4 D sodium salt 500 g/ha	12.71	5.22	7.49
Carfentrazone-ethyl 10 g/ha	12.81	5.27	7.53
Carfentrazone-ethyl 20 g/ha	12.91	5.31	7.60
Metsulfuron + sulfosulfuron 15 g/ha	12.72	5.22	7.50
Metsulfuron + sulfosulfuron 30 g/ha	12.77	5.25	7.52
Untreated control	12.41	5.07	7.34
LSD (p=0.05)	2.02	0.12	0.13
Interaction LSD (p=0.05)	NS	NS	NS

produced by 20 g/ha of carfentrazone during both years. The results of present study revealed that carfentrazone-ethyl and metsulfuron methyl plus sulfosulfuron at both 0.5X and 1X dose were equally effective in increasing yield and yield attributes of wheat over untreated control. However, 0.5X dose of 2,4-D was ineffective in improving productivity of wheat.

Chlorophyll fluorescence

The interaction effect of weed growth stage at the time of herbicide spray and different herbicides was found significant on chlorophyll fluorescence of *M. denticulata* (**Table 2**). *M. denticulata* plants treated with different herbicides at four-leaf stage recorded least F_v/F_m values. Whereas, chlorophyll fluorescence recorded highest values in plants treated with herbicides at twelve-leaf stage. Complete mortality of plants treated with 10 and 20 g carfentrazone at four-leaf stage was observed and hence no F_v/F_m values could be recorded in these plants.

Table 2. Interaction effect of weed growth stage at the time of herbicide spray and different herbicide treatments on chlorophyll fluorescence (F_v/F_m) of *Medicago denticulata* Willd. (pooled data of 2016-17 and 2017-18)

Herbicide treatment	Weed growth stage at the time of herbicide spray		
	4 leaf	8 leaf	12 leaf
2,4 D sodium salt 250 g/ha	0.700	0.749	0.757
2,4 D sodium salt 500 g/ha	0.698	0.749	0.755
Carfentrazone-ethyl 10 g/ha	0.00*	0.748	0.755
Carfentrazone-ethyl 20 g/ha	0.00*	0.747	0.756
Metsulfuron-methyl + sulfosulfuron 15 g/ha	0.356	0.746	0.754
Metsulfuron-methyl + sulfosulfuron 30 g/ha	0.347	0.746	0.754
Untreated control	0.703	0.749	0.758
Interaction LSD (p=0.05)		0.050	

* No F_v/F_m values recorded due to complete mortality of plants

Chlorophyll fluorescence (F_v/F_m) provides a measure of PSII photochemical efficiency and reflects the potential photochemical capacity of PSII. High values of F_v/F_m indicate high light transformation rate, providing more energy for CO_2 assimilation in dark reaction of photosynthesis. The herbicide application may block synthesis/cause degradation of photosynthesis related intermediate metabolites and affect fluorescence emission (Varshney *et al.* 2015). A lower value of F_v/F_m indicates that a proportion of PSII reaction centers are damaged, a phenomenon called photoinhibition, often observed in plants under stress conditions (Hess 2000, Hiraki *et al.* 2003). Reithmuller *et al.* (2003) reported that application of metsulfuron-methyl resulted in significant reduction in chlorophyll fluorescence of black nightshade (*Solanum nigrum*) and redshank (*Polygonum persicaria*).

Chlorophyll content index

Chlorophyll content index of *M. denticulata* was significantly influenced by both growth stage of *M. denticulate* by different time of herbicide spray and herbicides (**Table 3**). At flowering, *M. denticulata* plants sprayed at eight and twelve-leaf stages recorded higher values of chlorophyll content index which were statistically at par to each other. Whereas, complete mortality with carfentrazone application at four-leaf stage indicated higher sensitivity of younger growth stages of weed to this herbicide.

Table 3. Interaction effect of weed growth stage at the time of herbicide spray and different herbicide treatments on chlorophyll content index (CCI) of *Medicago denticulata* Willd. at flowering stage at PAU, Ludhiana (pooled data of 2016-17 and 2017-18)

Herbicide treatment	Weed growth stage at the time of herbicide spray		
	4 leaf	8 leaf	12 leaf
2,4 D sodium salt 250 g/ha	7.4	12.5	13.4
2,4 D sodium salt 500 g/ha	7.2	12.4	13.4
Carfentrazone-ethyl 10 g/ha	0.0*	12.5	13.2
Carfentrazone-ethyl 20 g/ha	0.0*	12.3	13.1
Metsulfuron-methyl + sulfosulfuron 15 g/ha	1.4	12.5	13.4
Metsulfuron-methyl + sulfosulfuron 30 g/ha	0.9	12.4	13.4
Untreated control	7.6	12.6	13.5
Interaction LSD (p=0.05)		1.40	

* No CCI values recorded due to complete mortality of plants

Chlorophylls are the essential photosynthetic pigments in plants and the amount of chlorophyll per unit leaf area indicates the overall condition of plants (Silla *et al.* 2010). There is a direct relation between chlorophyll content and light transformation in photosynthesis. The decrease in chlorophyll content due to herbicide application may be due to an increase of chlorophyll degradation or by reduction in chlorophyll synthesis (Santos 2004). It has also been reported that herbicide stress may induce reduction in the number of chloroplasts (Cakmak *et al.* 2009). Carfentrazone-ethyl is a diphenyl-ether herbicide, which is readily absorbed by foliage but has limited translocation. The herbicidal action of carfentrazone on susceptible plants involves inhibition of enzyme protoporphyrinogen oxidase which is involved in chlorophyll biosynthesis pathway. Initial symptoms appear as quickly as one day after treatment and plant mortality occurred within seven days of application (Obenland *et al.* 2019). In present study also, carfentrazone-ethyl at 10 and 20 g/ha resulted in complete killing of *M. denticulata* within 7 days when sprayed at four-leaf stage; whereas no phytotoxicity was observed when herbicide sprays were done at eight or twelve leaf stages of this weed.

Weed biomass, density and weed control efficiency

Delayed application of all the herbicides at eight leaf stage resulted in significant increase in number of surviving plants of *M. denticulata* with concomitant increase in weed biomass than herbicide sprays done at four-leaf stage during both years (**Table 4**). Carfentrazone-ethyl application at 10 and 20 g/ha to four-leaf stage of *M. denticulata* resulted in complete mortality with minimum biomass and > 95% weed control efficiency, whereas its delayed application at eight and twelve-leaf stages resulted in significant increase in number of *M. denticulata* plants with increased biomass leading to reduced efficiency. Similarly, 2,4-D and metsulfuron-methyl plus sulfosulfuron sprayed at both the doses were also more effective in reducing weed density and biomass of *M. denticulata* when applied at four-leaf stage than their application at eight and twelve-leaf stages.

Delayed application of all the herbicides at eight leaf stage resulted in significant increase in number of surviving plants of *M. denticulate* than herbicide sprays done at four-leaf stage during both years (**Table 3**). Carfentrazone-ethyl application at 10 and 20 g/ha to four-leaf stage of *M. denticulata* resulted in complete mortality with > 90% weed control efficiency, whereas its delayed application at eight and twelve-leaf stages resulted in significant increase in number of *M. denticulata* plants leading to reduced efficiency. Density of *M. denticulata* was statistically similar in response to 2,4-D application at either eight or twelve-leaf stage. Whereas, carfentrazone-ethyl and metsulfuron plus sulfosulfuron sprayed at twelve-leaf stage recorded significant increase in number of surviving plants of *M. denticulata* as compared to sprays done at eight-leaf stage.

Greater susceptibility of weeds at earlier growth stages as compared to later growth stages is because of rapid herbicide translocation *via* plasmodesmata during earlier stages (Kieloch and Domaradzki 2011). Size exclusion limit is a major factor which determines the size of molecules that can pass through plasmodesmata and therefore allows only restrictive macromolecular transport (Yadav *et al.* 2014). In older plants, size exclusion limit of plasmodesmata is reduced to > 50 times as compared to younger plants suggesting it to be one of the major reasons for reduced susceptibility of older plants to

Table 4. Interaction effect of weed growth stage at the time of herbicide spray and different herbicide treatments on *Medicago denticulata* Willd. density, weed control efficiency and biomass (pooled data of 2016-17 and 2017-18)

Treatment	Weed growth stage at the time of herbicide spray		
	Weed density (no. per plot)		
Herbicide treatment	4 leaf	8 leaf	12 leaf
2,4 D sodium salt 250 g/ha	13.33	14.83	14.83
2,4 D sodium salt 500 g/ha	7.66	14.16	14.00
Carfentrazone-ethyl 10 g/ha	0.00	12.16	14.50
Carfentrazone-ethyl 20 g/ha	0.00	11.83	14.00
Metsulfuron-methyl + Sulfosulfuron 15 g/ha	8.50	13.33	14.50
Metsulfuron-methyl + Sulfosulfuron 30 g/ha	5.33	13.00	14.16
Untreated control	15.00	15.00	15.00
Interaction LSD (p=0.05)		0.52	
Weed control efficiency (%)			
2,4 D sodium salt 250 g/ha	23.24	2.58	2.50
2,4 D sodium salt 500 g/ha	65.71	3.76	3.80
Carfentrazone-ethyl 10 g/ha	95.24	14.00	3.82
Carfentrazone-ethyl 20 g/ha	97.44	19.83	4.63
Metsulfuron-methyl + Sulfosulfuron 15 g/ha	87.34	11.73	3.84
Metsulfuron-methyl + Sulfosulfuron 30 g/ha	89.20	12.21	4.16
Untreated control	0	0	0
Interaction LSD (p=0.05)		2.41	
Weed biomass (g/plant)			
2,4 D sodium salt 250 g/ha	2.17	4.20	7.05
2,4 D sodium salt 500 g/ha	1.32	4.19	6.95
Carfentrazone-ethyl 10 g/ha	0.20	3.70	6.92
Carfentrazone-ethyl 20 g/ha	0.15	3.47	6.86
Metsulfuron-methyl + Sulfosulfuron 15 g/ha	0.47	3.83	6.87
Metsulfuron-methyl + Sulfosulfuron 30 g/ha	0.40	3.79	6.82
Untreated control	3.00	4.29	7.14
Interaction LSD (p=0.05)		0.37	

herbicides due to reduced translocation of herbicides (Concenco and Galon 2007). In present study, delayed application of carfentrazone at eight and twelve-leaf stages resulted in significant increase in number of surviving plants of *M. denticulata* as compared to carfentrazone sprayed at four-leaf stage. Results of present study are in agreement with Cauchy (2000) who reported that carfentrazone-ethyl was active at low dose rates (20 g/ha) and provided outstanding efficacy on a wider range of weeds with better results against young weeds, which were controlled within 1 to 2 weeks of herbicide application. Efficacy of auxinic herbicides has been reported to be reduced with delay in herbicide application (Eure *et al.* 2013). For example, Sellers *et al.* (2009) reported that control of dog fennel (*Eupatorium capillifolium*) was dramatically reduced when 2,4-D plus dicamba were applied to 154 cm tall plants as compared to 38 cm tall plants. In present study also 2,4-D was more effective when sprayed at four-leaf stage of *M. denticulata* than at eight and twelve-leaf stage.

Seed production potential

The seeds of *M. denticulata* are enclosed in coiled pods called burs (fruit) with seed number varying from 3-5 seeds per pod. The interaction effect of weed growth stage at the time of herbicide spray and different herbicides on seed production of *M. denticulata* was significant (**Table 5**). Maximum and minimum fruit and seed number per plant of *M. denticulata* was recorded with herbicide application at four and twelve-leaf stages, respectively. All the herbicides when applied at eight and twelve-leaf stages of *M. denticulata* caused significant decline in fruit and seed number than herbicide sprays done at four-leaf stage during both the years. *M. denticulata* plants sprayed with 30 g/ha of metsulfuron plus sulfosulfuron at eight and twelve-leaf stages recorded > 30 and 40 % decline in seed number/plant as compared to plants treated at four-leaf stage. Application of carfentrazone-ethyl at four-leaf stage of *M. denticulata* resulted in complete mortality of plants thereby completely inhibiting fruit and seed set. However, *M. denticulata* plants treated with carfentrazone-ethyl at eight and twelve-leaf stage were able to set seeds. Targeting weed seed production provides an effective tool for reducing the spread of herbicide-resistant weeds by preventing their establishment, spatial distribution and build-up of seed reservoirs in the soil seed bank (Bagavathiannan and Norsworthy 2012). Herbicide application at or near flowering or seed set has the advantage of decreasing weed seed production, eventually allowing the addition of lesser seeds in the soil seed bank in the next cropping seasons (Jha and Norsworthy 2012). Ganie *et al.* (2018) reported that single or sequential applications of 2,4-D or dicamba resulted in 96% inflorescence injury and reduction in seed production of giant ragweed (*Ambrosia trifida*) in the field as well as in greenhouse studies. The results indicated that 2,4-D or dicamba were effective options for reducing seed production of glyphosate-resistant *A. trifida* even if applied late in the season. Goroee and Saeedipour (2015) reported that metsulfuron plus sulfosulfuron at 30 g/ha was effective in suppressing seed formation in *Malva parviflora*.

Table 5. Interaction effect of weed growth stage at the time of herbicide spray and different herbicide treatments on *Medicago denticulate* Willd. fruit and seed number per plant (pooled data of 2016-17 and 2017-18)

Treatment	Weed growth stage at the time of herbicide spray		
	Fruit number/plant		
	4 leaf	8 leaf	12 leaf
Herbicide treatment			
2,4 D sodium salt 250 g/ha	166	132	110
2,4 D sodium salt 500 g/ha	149	100	73
Carfentrazone-ethyl 10 g/ha	0*	149	129
Carfentrazone-ethyl 20 g/ha	0*	118	90
Metsulfuron-methyl + sulfosulfuron 15 g/ha	166	132	108
Metsulfuron-methyl + sulfosulfuron 30 g/ha	157	111	84
Untreated control	177	181	179
Interaction LSD (p=0.05)		5.41	
Seed number/plant			
2,4 D sodium salt 250 g/ha	664	528	440
2,4 D sodium salt 500 g/ha	596	400	292
Carfentrazone-ethyl 10 g/ha	0*	594	516
Carfentrazone-ethyl 20 g/ha	0*	472	358
Metsulfuron-methyl + sulfosulfuron 15 g/ha	662	528	432
Metsulfuron-methyl + sulfosulfuron 30 g/ha	626	444	334
Untreated control	706	724	716
Interaction LSD (p=0.05)		31.5	

* There was no fruit and seed set due to complete mortality of plants

Germination potential of *Medicago denticulata* seeds after herbicide exposure

Seeds collected from unsprayed plots (control) recorded higher germination as compared to seeds collected from plants treated with 2,4-D, carfentrazone-ethyl and metsulfuron methyl plus sulfosulfuron (**Table 6**). Application of herbicides at eight and twelve-leaf stage of *M. denticulata* produced seeds with decreased germination as compared to plants sprayed at four-leaf stage. However, there was no effect on time to start germination, speed of germination and mean germination time. In present study, *M. denticulata* seeds collected from unsprayed plots (control) recorded higher germination as compared to seeds collected from plants treated with 2,4-D, carfentrazone-ethyl and metsulfuron-methyl plus sulfosulfuron.

However, in contrast to our study, Tanveer *et al.* (2009) reported that *Chenopodium album* seeds collected from herbicide treated plants recorded higher germination as compared to seeds collected from unsprayed control plants. Qi *et al.* (2017) reported that *Amaranthus retroflexus* plants sprayed with atrazine or tribenuron-methyl both at vegetative and reproductive stages produced seeds with inhibited germination. Whereas in present study decreased germination of *M. denticulata* seeds was recorded only from plants sprayed at near reproductive (eight-leaf stage) or at reproductive stage (twelve-leaf stage). Wu *et al* (2016) reported that application of glyphosate and paraquat at late budding stage did not stop the growth of fleabane (*Conyza bonariensis*) plants which continued to develop, flower and set seeds. However, significant effects on seed viability and dormancy were recorded. Application of glyphosate alone or as a tank mix with pyraflufen-ethyl, glufosinate and flumioxazin has been reported to significantly reduce the germination percentage in red lentil (*Lens culinaris* L.) seeds compared to the untreated control (Subedi *et al.* 2017). It is important to note that present findings are more relevant only in the context of intended problem and objectives for making more balanced and wiser decisions in any given situation in general and delayed application of herbicides against the target weed(s), in particular.

Conclusion

Herbicide sprays done at four-leaf stage of *M. denticulata* provided effective weed control whereas delayed application resulted in poor control with no visual injury. Delayed application of all the herbicides at eight and twelve-leaf stage caused significant increase in weed density with concomitant decrease in weed control efficiency than herbicide sprays done at four-leaf stage. Poor weed control at advanced weed stages indicate importance of early herbicide application for effective control of *M. denticulata*. Seed production potential of *M. denticulata* was significantly decreased when herbicides were sprayed at advanced growth stages of weed. *M. denticulata* plants sprayed at eight and twelve-leaf stage survived the herbicide application; but great reduction in seed production was recorded as compared to herbicide sprays done at four-leaf stage. Seeds collected from plants sprayed at eight and twelve-leaf stages recorded decrease in germination as compared to seeds collected from plants sprayed at four-leaf stage. This indicates possibility of herbicide carry-over effect from parent plants.

Table 6. Interaction effect of weed growth stage at the time of herbicide spray and different herbicide treatments on germination potential of *Medicago denticulata* Willd. (pooled data of 2016-17 and 2017-18)

Treatment	Weed growth stage at the time of herbicide spray Germination (%)		
	4 leaf	8 leaf	12 leaf
Herbicide treatment			
2,4-D sodium salt 250 g/ha	93.0	92.1	90.0
2,4-D sodium salt 500 g/ha	91.1	89.4	81.1
Carfentrazone-ethyl 10 g/ha	0*	88.3	86.1
Carfentrazone-ethyl 20 g/ha	0*	81.7	79.4
Metsulfuron-methyl + sulfosulfuron 15 g/ha	90.0	91.1	85.5
Metsulfuron-methyl + sulfosulfuron 30 g/ha	86.6	83.7	77.5
Untreated control	95.3	97.2	95.0
Interaction LSD (p=0.05)		4.23	
Speed of germination			
2,4-D sodium salt 250 g/ha	10.48	10.40	10.38
2,4-D sodium salt 500 g/ha	10.45	10.35	10.30
Carfentrazone-ethyl 10 g/ha	-	10.3	10.25
Carfentrazone-ethyl 20 g/ha	-	10.25	10.20
Metsulfuron-methyl + sulfosulfuron 15 g/ha	10.40	10.36	10.23
Metsulfuron-methyl + sulfosulfuron 30 g/ha	10.38	10.33	10.18
Untreated control	10.50	10.52	10.5
Interaction LSD (p=0.05)		0.25	
Mean germination time			
2,4-D sodium salt 250 g/ha	3.20	3.38	3.42
2,4-D sodium salt 500 g/ha	3.23	3.6	3.65
Carfentrazone-ethyl 10 g/ha	-	3.56	3.78
Carfentrazone-ethyl 20 g/ha	-	3.62	3.80
Metsulfuron-methyl + sulfosulfuron 15 g/ha	3.23	3.66	3.85
Metsulfuron-methyl + sulfosulfuron 30 g/ha	3.26	3.70	3.90
Untreated control	3.18	3.20	3.20
Interaction LSD (p=0.05)		0.04	

* There was no fruit and seed set due to complete mortality of plants

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RESEARCH ARTICLE

Productivity and economics of cotton under different weed management practices and intercropping systems

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ABSTRACT

Field experiments were conducted during summer 2016 and winter 2016 -17 at Agricultural College and Research Institute, Madurai, Tamil Nadu, India to study the effect of intercropping systems and weed management practices on productivity and economics of irrigated cotton. The results indicated that, sole cotton and cotton + sesame intercropping system in 1:1 row proportion resulted in significantly higher seed cotton yield (SCY) of 1.43, 1.38 t/ha and 1.61, 1.56 t/ha, during summer 2016 and winter 2016-17, respectively and it was followed by cotton + sunflower intercropping system in 1:1 row proportion. The lower SCY was obtained with cotton + sorghum intercropping system in 1:1 row proportion. Among the different weed management practices, hand weeding twice at 20 and 40 DAS recorded significantly higher seed cotton yield. It was followed by pre-emergence (PE) application of pendimethalin at 1.0 kg/ha + hand weeding at 40 DAS. Considering the overall economics of the system, the maximum mean net return of ₹ 48822/ha and B: C ratio of 1.97 were recorded in cotton + sunflower intercropping system with PE application of pendimethalin at 1.0 kg/ha + hand weeding at 40 DAS. This was closely followed by cotton + sesame intercropping system with PE application of pendimethalin at 1.0 kg/ha + hand weeding at 40 DAS. Intercropping of sunflower and sesame in cotton with 1:1 row proportion found remunerative over sole cotton.

Keywords: Allelopathy, Economics, Leaf extracts, Intercropping, Productivity, Sesame, Sunflower, Seed cotton yield, Weed management

INTRODUCTION

Cotton the "*white gold or the king of fibres*" is one of the most important commercial crops in India. The initial slow growth and adoption of wider spacing favours the weeds to grow luxuriously in cotton fields (Javaid and Anjum 2006). Weeds, besides removing moisture and nutrients, harbour insects and diseases. Poor crop stands due to weed competition has been found to lower production by 30-90% depending upon weed pressure (Samunder 2014). Manual weed management practices are laborious and expensive (Hozayn *et al*. 2011). Despite herbicides being effective in increasing yield, indiscriminate use of herbicides has resulted in serious ecological implications such as development of herbicide resistance weeds and shift in weed population. Recently, research attention has been focused to find out alternative strategies for chemical weed control in several crops. Allelopathy is considered as an effective, economical and environment friendly weed management approach (Iqbal and Cheema 2009). Singh *et al.* (2003) indicated that growing companion plants, which are selectively allelopathic to weeds, may provide a cost-effective alternative to the use of synthetic chemicals. The allelopathic crops can be used as intercrops, mulches or water extracts (Fujii 2003). The slow initial growth coupled with indeterminate growth habit favours the growing of intercrops without affecting yield of cotton. Intercropping is the growing of two or more crops simultaneously in the alternative rows on the same piece of land in order to utilize available resources efficiently and obtaining more production per unit area (Lithourgidis *et al*. 2011). Two crops differing in rooting ability, nutrient requirements, height and canopy grow simultaneously with least competition (Lithourgidis *et al*. 2006). Weed density and biomass may substantially be reduced through intercropping (Poggio 2005). Intercropping has unique capacity to raise the unit profitability without disturbing the cotton ecosystem. The present study was conducted to find out a suitable

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intercropping and weed management options without affecting the productivity of cotton.

MATERIALS AND METHODS

Field experiments were conducted at Agricultural College and Research Institute, Madurai during summer 2016 and winter 2016-17. Twenty four treatment combinations comprised of four intercropping, cotton + sorghum (1:1), cotton + sunflower (1:1), cotton + sesame (1:1), sole cotton and six weed management practices, *viz*. pre-emergence (PE) *Prosopis juliflora* leaf extract 30% + one hand weeding at 40 DAS, PE *Annona squamosa* leaf extract 30% + one hand weeding at 40 DAS, PE *Mangifera indica* leaf extract 30% + one hand weeding at 40 DAS, PE pendimethalin 1.0 kg/ha+ one hand weeding on 40 DAS, two hand weeding at 20 and 40 DAS, control (no weeding or spray). The experiment was laid out in split-plot design with three replications. The soil of the experimental field was well drained and sandy clay loam in texture. The soil was neutral in reaction and low in available nitrogen, medium in available phosphorus and available potassium. Healthy and viable seeds of '*SVPR 4'* cotton variety was sown as base crop at the rate of 15 kg/ha. Main cotton crop was sown with row to row spacing of 75 cm and plant to plant spacing of 30 cm, on the same day intercrops, *viz.* sorghum (*CO 30*), sunflower (*COSFV 5*), sesame (*SVPR 1*) was sown in between two rows of cotton crop following 1:1 ratio for main and intercrops. The plant to plant spacing adopted for intercrop was 30 cm. The recommended dose of NPK (80:40:40 kg NPK/ha) were applied to cotton crop in the form of urea, phosphorus and potassium. Entire dose of phosphorus, 50% of N and K were applied to cotton as basal placement by the side of seed line. The remaining 50% of recommended dose of nitrogen and potassium was top dressed on 45 DAS by placement method. The fertilizers were placed 5 cm away from seed row and covered with soil. Based on the plant populations of intercrops, *viz.* sorghum, sunflower and sesame were applied with 100% recommended dose of fertilizer 90:45:45, 60:30:30 and 35:23:23 kg of NPK/ha in the form of urea, P and K, respectively. Leaves of *Prosopis juliflora, Annona squamosa* and *Mangifera indica* species at vegetative stage were collected and washed gently with tap water for few seconds for removing contaminants like dust *etc*. The fresh leaves of above species were cut into small pieces, soaked in alcohol and water in 1:1 proportion and kept for overnight. After 12 hours, soaked leaves were grounded with the help of mixer grinder. From the paste, the leaf extract of each botanical species was prepared by filtration, which represented 100 per cent stock solution (Sripunitha 2009). From the stock solution, 30 per cent concentration was prepared and sprayed on 3 DAS by using knapsack sprayer as per the treatment schedule. The data were statistically analysed following the procedure given by Gomez and Gomez (1984) for split plot design. Weed control efficiency (WCE), weed control smothering efficiency (WSE) and weed index (WI) were worked out using formulae suggested by Mani *et al.* (1973) and by Gil and Vijayakumar (1969).

RESULTS AND DISCUSSION

Weed control efficiency (%)

Among the weed management practices, higher WCE was recorded in PE application of pendimethalin at 1.0 kg/ha with 74.5% at 20 DAS during both the years (**Table 1**). The hand weeding twice at 20 and 40 DAS registered higher WCE (84.0 and 94.6% at 40 and 60 DAS, respectively) during both the seasons. This might be due to lesser weed competition by the hand weeding which favoured the growth and development of cotton, thereby higher weed control efficiency was obtained during later stages of crop growth than other weed management practices (Nithya and Chinnusamy 2013). Lower WCE (24.6, 20.0 and 21.1 at 20, 40 and at 60 DAS, respectively) was recorded under control.

Weed smothering efficiency (%)

Intercropping and weed management treatments appreciably influenced the weed smothering efficiency (**Table 2**). Cotton + sorghum intercropping system registered higher WSE with 45.5, 52.4 and 76.0% at 20, 40 and at 60 DAS, during both the seasons, respectively. This was followed by cotton + sesame intercropping system. This is only because the lower availability of space and light led to lower density of weeds and ultimately recorded lower weed dry weight in intercropping and suppressed the weed species by more canopy cover. These findings were in conformity with those reported by Haque *et al.* (2008) and Tripathi *et al.* (2008).

Weed index

Weed index (WI) is a measure of yield loss caused due to varying degree of weed competition compared to the relatively weed free condition throughout the crop period leading to higher productivity (**Table 3**). Sole cotton registered the lower weed index with the value of 26.6 and 25.9% during summer 2016 and winter 2016-17. Among the intercropping system, cotton + sesame recorded minimum weed index of 29.1 and 28.8% during both the years. Among the weed management practices, hand weeding twice at 20 and 40 DAS registered lower weed index of 15.0 and 15.1% during both the seasons. This might be due to effective weed control achieved by above treatments in terms of reduced density and biomass of weeds. The maximum weed index of 69.1 and 72.0% cent was recorded under control during summer 2016 and winter 2016-17. This might be due to reduction of seed cotton yield under increased pressure of weed competition for space, light, nutrients *etc*. Similar results were also reported by Sarkar (2006).

Number of sympodia

Perceptible difference in the number of sympodia/plant was observed with intercropping system and weed management practices (**Table 4**). Sole cotton produced the greater number of sympodia/plant in cotton. This was followed by cotton + sesame and cotton + sunflower intercropping systems during summer 2016 and winter 2016-17. The increase in sympodia under sole cotton might be attributed to the increased plant height resulting in production of more nodal points /

Table 1. Intercropping system and weed management practices on weed control efficiency (%) in cotton during summer 2016 and winter 2016-17

Treatment	20 DAS					40 DAS					60 DAS				
	I_1	I_2	I_3	I_4	Mean	I_1	I_2	I_3	I_4	Mean	I_1	I_2	I_3	I_4	Mean
PE *Prosopis juliflora* leaf extract 30% + one HW on 40 DAS	68.8	66.9	68.1	54.7	64.6	65.6	56.7	62.7	46.8	58.0	85.9	84.2	84.8	78.7	83.4
PE *Annona squamosa* leaf extract 30% + one HW on 40 DAS	62.5	60.6	61.1	49.9	58.5	55.7	50.8	53.8	42.5	50.7	82.4	81.1	81.8	76.2	80.4
PE *Mangifera indica* leaf extract 30% + one HW on 40 DAS	78.5	73.7	74.6	71.0	74.5	74.0	70.2	71.8	68.0	71.0	88.7	87.4	87.9	86.4	87.6
PE Pendimethalin 1.0 kg/ha + one HW on 40 DAS	87.0	82.4	84.8	80.8	83.8	82.6	77.5	80.6	75.9	79.2	92.3	89.8	91.2	89.4	90.7
Two HW at 20 and 40 DAS	41.9	38.1	40.7	6.5	31.8	89.2	86.1	87.5	84.0	86.7	95.7	94.3	94.8	93.5	94.6
Control (no weeding or spray)	35.4	29.7	33.2	-	24.6	35.0	18.3	26.5	-	20.0	33.4	23.2	27.6	-	21.1
Mean	62.3	58.5	60.4	43.8		67.0	59.9	63.8	52.8		79.7	76.7	78.0	70.7	

I_1- Cotton + Sorghum (1:1), I_2 - Cotton + Sunflower (1:1), I_3 - Cotton + Sesame (1:1), I_4- Sole cotton

Table 2. Intercropping system and weed management practices on weed smothering efficiency (%) in cotton during summer 2016

Treatment	20 DAS					40 DAS					60 DAS				
	I_1	I_2	I_3	I_4	Mean	I_1	I_2	I_3	I_4	Mean	I_1	I_2	I_3	I_4	Mean
PE *Prosopis juliflora* leaf extract 30% + one HW on 40 DAS	47.5	44.0	46.4	-	46.0	50.7	44.2	48.9	-	47.9	82.0	79.8	81.1	-	81.0
PE *Annona squamosa* leaf extract 30% + one HW on 40 DAS	40.5	33.4	37.8	-	37.2	42.2	30.3	36.7	-	36.4	79.4	77.1	78.6	-	78.4
PE *Mangifera indica* leaf extract 30% + one HW on 40 DAS	60.9	51.3	56.2	-	56.1	61.5	56.8	62.0	-	60.1	87.5	84.9	86.2	-	86.2
PE Pendimethalin 1.0 kg/ha + one HW on 40 DAS	75.9	71.6	74.6	-	74.0	67.0	66.1	66.5	-	66.5	92.7	91.1	91.7	-	91.8
Two HW at 20 and 40 DAS	28.4	24.5	27.0	-	26.6	76.8	72.4	75.7	-	75.0	95.1	94.3	94.8	-	94.7
Control (no weeding or spray)	20.0	11.2	16.3	-	15.8	16.4	7.1	13.1	-	12.2	19.5	8.0	13.6	-	13.7
Mean	45.5	39.3	43.0	-		52.4	46.1	50.5	-		76.0	72.5	74.3	-	

I_1- Cotton + Sorghum (1:1), I_2 - Cotton + Sunflower (1:1), I_3 - Cotton + Sesame (1:1), I_4- Sole cotton

Table 3. Effect of intercropping system and weed management practices on weed index (WI) in cotton during summer 2016 and winter 2016-17

Treatment	Summer 2016					Winter 2016-17				
	I_1	I_2	I_3	I_4	Mean	I_1	I_2	I_3	I_4	Mean
PE *Prosopis juliflora* leaf extract 30% + one HW on 40 DAS	60.5	32.6	28.9	28.5	37.6	61.3	29.3	27.0	26.4	36.0
PE *Annona squamosa* leaf extract 30% + one HW on 40 DAS	63.5	41.8	35.3	34.6	43.8	64.0	41.7	32.6	31.2	42.4
PE *Mangifera indica* leaf extract 30% + one HW on 40 DAS	59.3	25.7	23.1	17.5	31.4	58.8	26.4	23.5	17.6	31.6
PE Pendimethalin 1.0 kg/ha + one HW on 40 DAS	46.7	16.9	15.9	12.8	23.1	53.4	14.5	11.9	11.5	22.8
Two HW at 20 and 40 DAS	46.2	10.0	3.6	0.0	15.0	44.8	8.3	7.1	0.0	15.1
Control (no weeding or spray)	72.3	70.7	67.5	65.9	69.1	75.0	73.5	70.6	68.7	72.0
Mean	58.1	33.0	29.1	26.6		59.6	32.3	28.8	25.9	

I_1- Cotton + Sorghum (1:1), I_2 - Cotton + Sunflower (1:1), I_3 - Cotton + Sesame (1:1), I_4- Sole cotton plant which happened to be the seating points of sympodial branches. The relationship between increased number of sympodia due to increase in plant height in cotton was observed by Kuppusamy (1993) and Rajakumar (2000). Cotton + sorghum intercropping recorded lesser number of sympodia/ plant. Decrease in sympodia/plant of cotton under intercropped plots was possibly due to increased plant population per unit area resulting in severe competition between cotton and allelopathic intercrops for different growth resources and due to suppressive allelopathic effects exhibited by sorghum. Our results were at par with the findings of Aladakatti *et al*. (2011). Among the weed management practices, hand weeding twice at 20 and 40 DAS recorded a maximum number of sympodia/ plant during both the years. It was followed by the PE application of pendimethalin at 1.0 kg/ha + hand weeding at 40 DAS. Lesser number of sympodia/ plant was produced by the control.

Number of bolls

Intercropping system and weed management practices had significant bearing on number of bolls/ plant (**Table 4**). Sole cotton registered increased number of bolls/plant during both the seasons. However, it was at par with cotton + sesame intercropping system. The increase in boll numbers may be due to increase in plant height and corresponding increase in the sympodia/plant under sole cotton. Increased number of bolls under sole cotton was observed by Aladakatti *et al.* (2011). The suppressive effect on boll production was more pronounced in cotton + sorghum intercropping system. Reduction in boll number in cotton with sorghum as intercrop was mainly due to reduction in plant height, leaf area index and number of sympodia/ plant. Increased competition for growth factors with increased plant population per unit area under intercropped plots and allelopathic interference by intercrops might account for the decrease in number of bolls /plant. The reduction in yield parameters of cotton and in many other crops under various intercropping systems has also been documented by earlier researchers (Rathod *et al.* 2011). Among the weed management practices, hand weeding twice at 20 and 40 DAS produced higher number of bolls/ plant and it was followed by the application of PE pendimethalin at 1.0 kg/ha + hand weeding at 40 DAS. Lower number of bolls/plant was produced by the control.

Boll weight

Intercropping system and weed management practices had significant influence on boll weight during both summer 2016 and winter 2016-17 (**Table 4**). Higher boll weight was recorded in sole cotton, which was at par with boll obtained from cotton + sesame intercropping system. The increase in boll weight under sole cotton could be attributed to higher plant height, larger leaf area and improvement in leaf number resulting in increased photosynthesis leading to more accumulation of photosynthates in the bolls. This is in line with the findings of Aladakatti *et al.* (2011) and Ravindra Kumar *et al.* (2017). Lower boll weight was registered under cotton + sorghum intercropping system. Lower boll weight of cotton under sorghum intercropping condition was attributed to the insufficient supply of photosynthates for the development of bolls created by competitive nature of sorghum. Regarding weed management practices, hand weeding twice at 20 and 40 DAS resulted in heavier boll weight of cotton. This was at par with PE application of pendimethalin at 1.0 kg/ha + hand weeding at 40 DAS. Lower boll weight was observed from the control during both the years. The

Table 4. Pooled analysis of intercropping system and weed management practices on number of monopodia, number of sympodia, no. of bolls and boll weight of cotton during summer 2016 and winter 2016-17

Treatment	No. of monopodia/plant					No. of sympodia/plant					No. of bolls/plant					Boll weight (g)				
	I_1	I_2	I_3	I_4	Mean	I_1	I_2	I_3	I_4	Mean	I_1	I_2	I_3	I_4	Mean	I_1	I_2	I_3	I_4	Mean
W_1	1.07	1.43	1.47	1.47	1.36	5.8	9.8	10.3	10.8	9.2	12.3	21.2	21.7	22.0	19.3	2.42	2.7	2.77	2.82	2.68
W_2	1.07	1.27	1.30	1.37	1.25	5.5	8.5	9.1	9.5	8.2	11.8	18.7	20.0	20.6	17.8	2.36	2.6	2.64	2.68	2.57
W_3	1.07	1.47	1.50	1.74	1.45	6.4	11.5	11.9	12.5	10.6	12.9	24.5	25.6	25.9	22.2	2.44	3.0	3.06	3.18	2.92
W_4	1.20	1.74	1.80	1.83	1.64	7.0	13.0	13.5	13.8	11.8	13.3	26.8	27.1	27.4	23.7	2.49	3.2	3.32	3.34	3.09
W_5	1.27	1.94	2.00	2.10	1.83	7.9	14.3	14.9	15.7	13.2	13.5	28.9	29.2	30.4	25.5	2.55	3.4	3.44	3.54	3.23
W_6	1.07	1.07	1.07	1.07	1.07	4.1	4.3	4.6	5.1	4.5	10.4	10.6	11.0	11.2	10.8	2.24	2.3	2.30	2.34	2.30
Mean	1.12	1.48	1.52	1.59		6.1	10.2	10.7	11.2		12.3	21.8	22.4	22.9		2.41	2.9	2.92	2.98	
	I	W	I at W	W at I		I	W	I at W	W at I		I		I at W	W at I		I	W	I at W	W at I	
LSD (p=0.05)	0.07	0.08	0.16	0.16		0.3	0.5	1.1	1.1		0.8	0.9	2.0	1.9		0.12	0.16	0.32	0.32	

I_1- Cotton + Sorghum (1:1), I_2 - Cotton + Sunflower (1:1), I_3 - Cotton + Sesame (1:1), I_4- Sole cotton, W_1 - PE *Prosopis juliflora* leaf extract 30% + one HW on 40 DAS, W_2 - PE *Annona squamosa* leaf extract 30% + one HW on 40 DAS, W_3 - PE *Mangifera indica* leaf extract 30% + one HW on 40 DAS, W_4 - PE Pendimethalin 1.0 kg/ha + one HW on 40 DAS, W_5 - Two HW at 20 and 40 DAS and W_6 - Control (No weeding or spray) yield attributes, *viz*. number of sympodia/plant, number of bolls/plant and boll weight was more with hand weeding twice at 20 and 40 DAS. This could be due to the enhanced plant height, dry matter production and nutrient uptake of the crop. This might also be due to the season long weed control which was favourable for better growth and enhanced leaf area contributing for the activated photosynthesis and translocation of more photosynthates to sink which increased the boll weight (Nalini 2010).

Seed cotton yield

During both the seasons of experimentation, intercropping and weed management practices had significant influence on seed cotton yield (**Table 5**). Higher seed cotton yield was recorded in sole cotton during summer 2016 and winter 2016-17 and it was at par with cotton + sesame intercropping system. This might be due to vigorous and quick growth of intercrops during early vegetative stage and slow growth of cotton which caused severe competition for the available resources leading to reduced plant height, leaf area index, dry matter production and all the yield components in cotton as evidenced in this study. These results were in conformity with Ravindra kumar *et al*. (2017). Intercropping of cotton + sorghum registered lower seed cotton yield.

Cotton + sorghum intercropping system resulted in maximum reduction of seed cotton yield to tune of 42.1 and 41.7% during summer 2016 and winter 2016-17, respectively, which was ascribed to much shading effect of sorghum on associated cotton due to its fast growth at earlier stage resulting in taller plants and possibly due to inter-specific competitive effect of sorghum on cotton. The reduction in seed cotton yield was also attributed to significant reduction in plant growth, sympodia/plant, number of boll/plant and boll weight. Reduction in seed cotton yield of cotton under intercropped plots may be reflective of competition and allelopathic effects of sorghum and sunflower. The results were in accordance with the findings of Aladakatti *et al*. (2011). The decrease in yield of cotton and other crops under various intercropping systems has also been reported by Rathod *et al*. (2011) and Oliveira *et al*. (2011).

Weed management practices on cotton had significant impact on seed cotton yield. Hand weeding twice at 20 and 40 DAS recorded higher seed cotton yield. This was at par with PE application of pendimethalin at 1.0 kg/ha + hand weeding at 40 DAS. The control registered lower seed cotton yield during both the seasons. The higher seed cotton yield under hand weeding twice at 20 and 40 DAS might be due to the least weed density which has shifted the competitive equilibrium in favour of crop over weeds. Thus, the crop under this treatment faced the least weed competition right from germination till the critical period. Nithya and Chinnusamy (2013) reported higher seed cotton yield of 69.3 to 72.0% with two hand weeding.

Cotton being a wide spaced and slow growing crop is sensitive to weed competition at early stages of growth than at later stages. Due to heavy infestation of weeds under unweeded control severe reduction in seed cotton yield was recorded. The crop under control might not be able to obtain the growth factors in optimum quantity resulting in reduced leaf area, dry matter production and poor yield. Presence of weeds throughout the growing season caused poor crop growth and caused yield reduction in unweeded check (Bhoi *et al*. 2007). Venugopalan *et al.* (2012) reported that cotton yield was directly related to increasing density of weed and it's duration of interference. In cotton, unweeded check registered upto 94.2% yield loss (Srinivasan and Venkatesan 2002). The reduction in yield was attributed to the cumulative effect of competition for space, nutrients and water.

Table 5. Effect of intercropping system and weed management practices on seed cotton yield (kg/ha) during summer 2016 and winter 2016-17

Treatment	Summer 2016					Winter 2016-17				
	I_1	I_2	I_3	I_4	Mean	I_1	I_2	I_3	I_4	Mean
PE *Prosopis juliflora* leaf extract 30% + one HW on 40 DAS	738	1436	1447	1453	1269	848	1511	1586	1652	1399
PE *Annona squamosa* leaf extract 30% + one HW on 40 DAS	689	1245	1347	1422	1176	788	1427	1458	1507	1295
PE *Mangifera indica* leaf extract 30% + one HW on 40 DAS	882	1457	1508	1614	1365	973	1694	1705	1816	1547
PE Pendimethalin 1.0 kg/ha + one HW on 40 DAS	1078	1699	1704	1731	1553	1226	1928	1949	1956	1765
Two HW at 20 and 40 DAS	1130	1738	1762	1799	1607	1237	1968	1997	2037	1810
Control (no weeding or spray)	444	470	522	556	498	559	592	657	689	624
Mean	827	1341	1382	1429		939	1520	1559	1610	
	I	W	I at W	W at I		I	W	I at W	W at I	
LSD (p=0.05)	57	78	153	156		63	87	171	174	

I_1- Cotton + Sorghum (1:1), I_2 - Cotton + Sunflower (1:1), I_3 - Cotton + Sesame (1:1), I_4- Sole cotton

Table 6. Intercropping system and weed management practices on economics of cotton during summer 2016 and winter 2016-17

Treatment	Cost of cultivation (x10^3 `/ha)	Gross return (x10^3 `/ha)	Net return (x10^3 `/ha)	B:C ratio
I_1W_1 - Cotton + sorghum (1:1) + PE *Prosopis juliflora* leaf extract 30% + HW at 40 DAS	60.59	47.59	-13.00	0.79
I_1W_2 - Cotton + sorghum (1:1) + PE *Annona squamosa* leaf extract 30% + HW at 40 DAS	60.59	44.85	-15.74	0.74
I_1W_3 - Cotton + sorghum (1:1) + PE *Mangifera indica* leaf extract 30% + HW at 40 DAS	60.59	53.92	-6.67	0.89
I_1W_4 - Cotton + sorghum (1:1) + PE pendimethalin 1.0 kg/ha + HW at DAS	49.48	64.28	14.80	1.30
I_1W_5 - Cotton + sorghum (1:1) + two hand weeding at 20 and 40 DAS	53.00	66.01	13.01	1.25
I_1W_6 - Cotton + sorghum (1:1) + control (no weeding or spray)	41.37	28.47	-12.90	0.69
I_2W_1 - Cotton + sunflower (1:1) + PE *Prosopis juliflora* leaf extract 30% + HW at 40 DAS	61.18	81.17	19.99	1.33
I_2W_2 - Cotton + sunflower (1:1) + PE *Annona squamosa* leaf extract 30% + HW at 40 DAS	61.18	74.12	12.94	1.22
I_2W_3 - Cotton + sunflower (1:1) + PE *Mangifera indica* leaf extract 30% + HW at 40 DAS	61.18	87.17	25.99	1.43
I_2W_4 - Cotton + sunflower (1:1) + PE pendimethalin 1.0 kg/ha + HW at 40 DAS	50.08	98.90	48.82	1.97
I_2W_5 - Cotton + sunflower (1:1) + two hand weeding at 20 and 40 DAS	53.59	101.56	47.97	1.90
I_2W_6 - Cotton + sunflower (1:1) + control (no weeding or spray)	41.96	29.84	-12.12	0.71
I_3W_1 - Cotton + sesame (1:1) + PE *Prosopis juliflora* leaf extract 30% + HW at 40 DAS	56.55	80.47	23.91	1.43
I_3W_2 - Cotton + sesame (1:1) + PE *Annona squamosa* leaf extract 30% + HW at 40 DAS	56.55	74.49	17.93	1.32
I_3W_3 - Cotton + sesame (1:1) + PE *Mangifera indica* leaf extract 30% + HW at 40 DAS	56.55	84.79	28.24	1.51
I_3W_4 - Cotton + sesame (1:1) + PE pendimethalin 1.0 kg/ha + HW at 40 DAS	49.20	96.22	47.02	1.96
I_3W_5 - Cotton + sesame (1:1) + two hand weeding at 20 and 40 DAS	52.71	99.30	46.59	1.88
I_3W_6 - Cotton + sesame (1:1) + control (no weeding or spray)	41.08	31.63	-9.45	0.77
I_4W_1 - Sole cotton + PE *Prosopis juliflora* leaf extract 30% + HW at DAS	56.54	69.86	13.32	1.23
I_4W_2 - Sole cotton + PE *Annona squamosa* leaf extract 30% + HW at 40 DAS	56.54	65.90	9.36	1.17
I_4W_3 - Sole cotton + PE *Mangifera indica* leaf extract 30% + HW at 40 DAS	56.54	77.17	20.63	1.37
I_4W_4 - Sole cotton + PE pendimethalin 1.0 kg/ha + HW at 40 DAS	45.43	82.96	37.52	1.82
I_4W_5 - Sole cotton + two hand weeding at 20 and 40 DAS	48.95	86.31	37.36	1.77
I_4W_6 - Sole cotton + control (no weeding or spray)	37.32	28.01	-9.31	0.75

Economics

The cost of cultivation was maximum under cotton + sunflower intercropping system. This was due to high cost of fertilizers and labour charges for harvesting (**Table 6**). Cost of cultivation was minimum with sole cotton. The highest net return and B: C ratio were obtained from the cotton + sunflower 1:1 proportion with pendimethalin 1.0 kg/ha as PE application followed by one hand weeding at 40 DAS and it was followed by cotton + sesame with pendimethalin 1.0 kg/ha as PE application followed by one hand weeding at 40 DAS. This was due to increased seed cotton yield and sunflower yield obtained in the above promising cropping system. Vekariya *et al.* (2015) reported that higher gross return, net return and B: C ratio were registered under cotton + sesame intercropping system. Cotton + sunflower intercropping system in 2:1 row proportion recorded higher gross income, net income and B: C ratio (Aladakatti *et al.* 2011). Lower net return, gross return and B: C ratio were obtained from cotton + sorghum intercropping system. This could be due to reduced cotton yield under above intercropping system.

Based on the experimental results, it could be concluded that cotton + sunflower intercropping system with PE application of pendimethalin at 1.0 kg/ha + hand weeding at 40 DAS or cotton + sesame intercropping system with PE application of pendimethalin at 1.0 kg/ha + hand weeding at 40 DAS was found ideal intercropping system for better weed control, higher yield and economic return.

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RESEARCH ARTICLE

Efficacy of diuron on the management of broad-leaf weeds in sesame (*Sesamum indicum* L.) fields in Tigray, Ethiopia

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ABSTRACT

Sesame (*Sesamum indicum* L.) is a poor competitor with weeds during the first four weeks due to the slow growth of its seedlings. Diuron is a systemic urea herbicide used to control broad-leaf weeds in sesame in different countries. Hence, the objective of this study was to assess the efficacy of diuron and thereby for registration in the country. The study, comprised of 12 treatments of combination of diuron and hand weeding was conducted in 2018 and 2019 cropping season in Western Tigray, Ethiopia. The weed control measures were carried out at 10 and 30 days after seedling emergence (DAE) and the weed counting and weighing of weed biomass were undertaken at 10, 17, 30 and 37 DAE. An average number of 197.03 weeds/m^2 were counted before the control measure while weed count decreased to 20.8 weeds/m^2 after deploying the control measure. The weed biomass was reduced from 889.66 to 166.66 g/m^2 and from 175.33 to 61.33 g/m^2 after first and second application of the control measures, respectively. The highest crop injury (10%) at 10 days after treatment (DAT) was observed from the application of diuron WG 650 g/ha two times as well as diuron WP 650 g/ha two times equally. The highest efficacy (92.2%) against *Commelina foecunda* was obtained from diuron WP 650 g/ha. The ANOVA for sesame grain yield showed significant (P<0.001) difference and the highest yield (669.9 kg/ha) with the application of diuron WP 650 g + hand weeding. Yield losses in sesame ranged between 20- 83% because of weed infestation. The diuron has been registered in Ethiopia to be used as post-emergence herbicide in sesame due to its effective weed control ability.
The diuron has been registered in Ethiopia to be used as post-emergence herbicide in sesame due to its effective weed control ability.

Keywords: Diuron, Sesame, Weed biomass, Weed count, Yield loss

INTRODUCTION

Sesame (*Sesamum indicum* L.) is a very important component of semi-tropical and tropical agriculture, providing easily available and highly nutritious human and animal food. Sesame is an industrial crop that grows chiefly for its vital seed that contains about 57.8-59.3% oil, 21.4-23.2% protein (Hassan 2012) and 18.2-20.2% carbohydrates (Adegunwa *et al.* 2012). About 6.4 million tons of sesame seed was produced from 12.5 million hectare worldwide in 2021 (FAOSTAT 2023). Sesame is susceptible to different biotic and abiotic stresses that significantly lower sesame quality and productivity and weed is among the major biotic stresses. Sesame is a poor competitor with weeds during the first four weeks due to the slow growth of its seedlings (Tyagi *et al.* 2013). Sesame yield losses are mainly due to delayed weeding or insufficient weed control (Tepe *et al.* 2011), and therefore, an effective weed control method required to be developed (Bukun 2011). Weed infestation in sesame can cause a significant yield loss up to 74% (Singh *et al.* 1992), 80% (Amare 2011), 30% (Grichar *et al.* 2018) and 70% (Ijlal *et al.* 2011). Hence, studies have been conducted around the world to determine critical period for weed control (CPWC) in sesame, with a range of environmental conditions to avoid the yield losses thereby increasing productivity and quality. Beltrao *et al.* (1997) reported that sesame required weed free period of 60 days after emergence (DAE) in Sousa and 30 to 35 DAE in Monterio of Brazil. However, Venkatakrishnan and Gnanamurthy (1998) reported critical weeding periods in sesame crop as 30-45 DAE in India, 7-35 DAE in Ethiopia (Amare 2011) and 15-45 DAE in West Bengal, India (Duary and Hazra 2013). Variation in CPWC values can be attributed to changes in weed species composition, weed-ground cover and climatic conditions, in which crops and weeds interfere (Knezevic *et al.* 2003).

Weeds are the most severe biological constraint to agricultural production systems that can cause damage in cropped and non-cropped lands; degrade quality of the produce and increase the cost of production besides harboring and serve as alternate

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hosts to several insect pests and diseases (Rao *et al.* 2020, Rao and Nagamani 2010). Broad-leaf weeds are the most important weeds in the sesame producing areas of Tigray (Amare 2011) and these weeds are becoming difficult to eradicate by hand weeding. Langham *et al.* (2007) reported that there are approximately 16 herbicides that are used or have the potential to be used in commercial sesame production in the world based on assessment from 21 sesame producing countries. Alachlor, fluchloralin, fluometuron, linuron, metobromuron plus metolachlor, pendimethalin and trifluralin are among the effective pre-emergence herbicides while linuron, diuron and prometryn are the effective post emergence herbicides in sesame (Grichar *et al.* 2011). Sesame injury is common by most of the herbicides. However, nowadays sesame farmers need to plant extra sesame seeds with the principle "some for the herbicide is, and most for me". Diuron is a systemic urea herbicide which inhibits photosynthesis and this herbicide is used in broad-leaf crops like cotton to control various weeds (Sosnoskie and Culpepper 2014). Grichar *et al.* (2011) reported that minimum crop injury has been reported when diuron was applied in the late juvenile stage. On the other hand, applications of herbicide on the seedling stage severely damage the sesame which cause reduction in yield. However, the rate and formulation of the herbicides, the application method, spray height from ground, and the edaphic and agro-climatic conditions significantly affects the efficacy of the herbicides and crop injury. So far, studies have not been conducted in Ethiopia in sesame crop to control weeds using diuron as post-emergence herbicide. The objective of this experiment was to evaluate the efficacy, and thereby for registration, of WP and WG formulations and different rates of diuron for the management of broad-leaf weeds in sesame (*Sesamum indicum* L.) at Humera, Tigray, Ethiopia.

MATERIALS AND METHODS

Experimental design

A field study was conducted in 2018 and 2019 cropping season at Humera, Western Tigray, Ethiopia under rainfed condition to investigate the efficacy of diuron (800 g/kg). The experimental site was situated at 13 °48' N, 36 °30' E in the altitude of 619 meters above sea level (masl) receiving an average annual rainfall of 506 mm and the soil is characterized as vertisol with 56, 26 and 18% of clay, sand and silt, respectively. The herbicide is originated from the manufacturing Company called Jiangsu Golden Chemical Co. Ltd. W3, 16F Huatai Securities Mansion, 90 Zhongshan Road (east), Nanjing, P.R. China, and supplied by the company called Issachor Agro Input Importer and Distributer Plc, principal office at Addis Ababa, Ethiopia. The herbicide was applied in two forms, *viz.* wettable powder (WP) named as "Diuron WP" and wettable granular (WG) named as "Diuron WG" for management of broad-leaf weeds. The weed control measure (both the herbicide application and hand weeding) carried out at 10 and 30 days after seedling emergence (DAE) for the control measures applied once and twice, respectively. The herbicide was diluted in water (1 liter diuron in 200 liter of water) and the hand weeding was done using a local weeding material tool "*mewled*". The experimental design was randomized complete block design with three replications. Each plot had a net harvestable plot sizes of 10 m^2, containing 5 rows with 5 m length and 40 cm row spacing, from which both the yield and weed data were collected. All agronomic practices carried out as per the recommendation for the crop and the area and. Sesame variety '*Setit-2*' was shown in this study. The study consisted of 12 treatments as described in (**Table 1**).

Table 1. Treatment set up and its description

Treatment	Weeding practice	Herbicide rate (g/ha)	Remark
Diuron WP 650 g one time	H	650	Applied once
Diuron WP 650 g two times	H+H	1300	Applied in two splits
Diuron WG 650 g one time	H	650	Applied once
Diuron WG 650 g two times	H+H	1300	Applied in two splits
Diuron WP 650 + hand weeding	H+HW	650	Applied once followed by hand weeding
Diuron WG 650 + hand weeding	H+HW	650	Applied once followed by hand weeding
One hand weeding	HW		Once hand weeding
Two hand weeding	HW+HW		Twice hand weeding
Diuron WP 487.5 g two times	H+H	975	Applied in two splits
Diuron WP 325 g two times	H+H	650	Applied in two splits
No weeding			Season long
Weed free	HW		Season long

H: Herbicide only; HW: Hand weeding

Data collection

Data on weed distribution was assessed before and after control measures were implemented. The weed population and weed biomass from each of the net plot was recorded with quadrate measuring 100 x 100 cm. The weed counting and weed biomass weight were carried out at 10, 17, 30 and 37 days after seedling emergence (DAE). This means during or pre-1st application/weeding and 7 days after 1st application/weeding, during or pre-2nd application and 7 days after 2nd application, respectively. Yield was harvested from the net plot sizes, converted to yield per hectare and analyzed. Yield components data like number of branches per plant, number of pods per plant, plant height, length of pod bearing zone and others were also collected on plot basis from ten selected and representative plants located in the center of the plots. The crop and weed injury because of the herbicide application were recorded in the scale of 0-10 or 1-100% according to (Rao, 2000) where 0% means no weed control or no sesame injury and 100% means complete weed control or complete sesame death. This visual injury was evaluated at 10 days after herbicide treatment (DAT).

Weed distribution: The frequency, abundance and dominance of major weeds in the experiment was assessed before any control measure was taken. Moreover, the frequency, abundance and dominance of the major broad-leaf weed was also estimated after the control measures were applied and computed using excel spread sheet as described by Tesema and Lema (1998) as follows:

- **Frequency (constancy):** is the percentage of sampling plots (vegetation registrations) on which a particular weed species is found. It explains how often a weed species occurs in the survey area. Frequency is calculated for the major weed species as follows:
- **F= 100*X/N**, Where, F= frequency; X = number of occurrences of a weed species; N= sample number
- **Abundance:** population density of weed species expressed as the number of individuals of weed plants per unit area.

  A=**Σ**W/N; Where, A = abundance; W = number of individual species/sample; N = sample number
- **Dominance:** abundance of an individual weed species in relation to total weed abundance and is computed as:

D = A*100/ΣA Where, D = dominance; A = abundance; **Σ**A= total abundance

Coefficient of efficacy (KE) and crop injury: The efficacy of herbicides on the major broad-leaf weeds is estimated by comparing herbicide treated plots and the untreated or control plots and this was carried out 10 DAT. The efficacy of herbicides is calculated using the following formula as described by (Šariæ, 1991): $KE\ (\%) = \frac{A}{B} x100$ where KE% is the coefficient of efficacy, A is the number of killed weeds/m^2, and B is the number of weeds/m^2 in the control (untreated) plots. Moreover, the sesame and weed injury is sketched in excel spread sheet to easily visualize the crop and weed injury level of the herbicide formulations and rates. Sesame injury is described and scaled based on the stunting, leaf chlorosis and necrosis status of the plants and leaves.

Grain yield, yield components and yield loss

Yield loss (%) was determined for each individual plot and the average yield from the weed free treatment was used to estimate the yield loss and was calculated as follows:

$$Yield\ Loss\ (\%) = \frac{Yield\ from\ the\ weed\ free - Yield\ from\ the\ weedy\ check}{Yield\ from\ the\ weed\ free} X100$$

Both the yield, yield components and yield loss data were subjected to ANOVA and the means were separated using Tukey's test at 5% probability using R statistical software (R Core Team, 2022).

RESULTS AND DISCUSSIONS

Weed distribution

An average number of 197.03 weeds/m^2 (both broad and grass weeds) were counted before any control measure was taken in the experimental field. The major broad-leaf weeds observed in the field were *Commelina foecunda, Corchorus fascicularis, Rahynochosia malacophyla, Convolvulus arvensis, Xanthium strumarium, Traxacum officinale* and the major grass weeds were *Dinebra retroflexa* and *Sorghum halepense,* which were in accordance to the reports of Amare (2011) and Gebregergis *et al.* (2019).

The frequency, abundance and dominance of the weeds in the study site is depicted in **Figure 1**. Generally, 90.8% of the total weeds from the study area were broad-leaves while 8.4% were grassy weeds and the remaining 0.8% were not identified weeds. *C. foecunda* and *D. retroflexa* were the most frequently occurred weeds with 100% frequency followed by *Corchorus fascicularis* with 93.3% frequency. The relative weed density or abundance of the weeds ranged from 1 to 160 where the highest

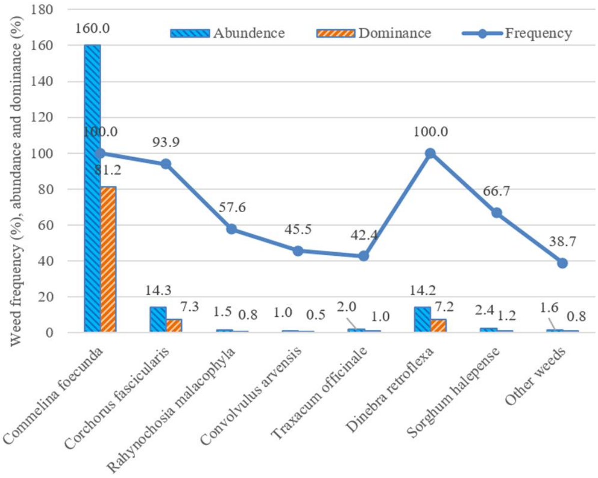

Figure 1. Weed frequency, abundance and dominance in the experimental site

weed abundance (160) was recorded from *C. foecunda* while the lowest was recorded from *Convolvulus arvensis*. *C. foecunda* (81.2%), *C. fascicularis* (14.2%), and *D. retroflexa* (14.2%) were the most dominant weeds in the field, where the first two were broad-leaf weeds while the latter was grassy weed. Zenawi *et al.* (2018) also reported that the frequency, abundance, and density of *C. foecunda* in Western Tigray was found to be 82.9%, 53.7/m^2, and 859/m^2, respectively.

Commelina foecunda, the most dominant and frequently occurred weed was the utmost important weed in the sesame growing areas of Western Tigray and it was also the most difficult weed to control using manpower. A survey conducted for five years in the United States revealed *Commelina* weed as troublesome weeds in cotton, maize, and wheat production areas (Webster and Nichols 2012). Therefore, a sesame field once infested with *C. foecunda* can never be free of the weed unless weeded frequently or sprayed herbicides. *Commelina* spp. species are capable of rooting and re-establishing after cultivation or disking from broken vegetative cuttings of stems (Webster *et al.* 2009) and produce areal and subterranean seeds and can regenerate from fragmented stems (Riar *et al.* 2016, Riar *et al.* 2014). From the field observation, the infestation was very high from early vegetative growth stage to reproductive stage (end of flowering) and the weeds became dry during maturity stage of the sesame. Unlike to this weed, *C. fascicularis* and *Ocimum* spp. were among the major late growing weeds in the sesame fields that deteriorated sesame productivity and quality since the infestation started at vegetative growth stage and continues to maturity.

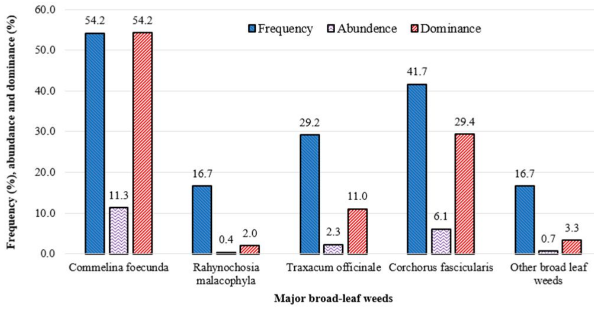

Figure 2. Frequency, abundance and dominance of major broad-leaf weeds after control measure is taken

Weed distribution after hand weeding and herbicide application

The frequency, abundance and dominance of the major broad-leaf weeds in the sesame fields were assessed after the control measures were deployed (after the second application or hand weeding) and depicted in **Figure 2**. An average of 20.8 weeds/m^2 was recorded, which was very low *vis-à-vis* the weed density prior to weed control measure was taken which was 197.03 weeds/m^2. This indicated that both the diuron herbicide and the hand weeding were effective in controlling the broad-leaf weeds. *Commelina foecunda* (54.2%) and *C. fascicularis* (41.7%) were the most frequently occurred weeds in the field. Similar to the frequency, *C. foecunda* (54.2%) and *C. fascicularis* (29.4%) were also the most dominant weed species. The abundance for all weeds was decreased except for *C. fascicularis* after the control measure was employed. This was because of the late growing habit of the weed which emerged and grew densely after the weed control measures were implemented and hence, due attention is required in developing weed control measure against this weed.

Weed biomass at pre-first and post-first treatment: The average weed biomass (g/m^2) of the broad-leaf weeds was weighed four times at different time intervals (pre- and post- 1st application, pre- and post- 2nd application). The weed biomass was measured at 10 DAE (pre- 1st application) and 17 DAE (post 1st application) to evaluate the efficacy of the hand weeding and diuron application on weed biomass reduction. The weed biomass was decreased after the 1st application of the herbicide and after the 1st hand weeding. The highest weed biomass reduction (about 96%) was observed from the hand weeding indicating that hand weeding is preferable over one time spray of diuron. The weed biomass was decreased more or less similarly in the treatments where 650 g diuron in both formulations were applied (**Figure 3**). However, the weed biomass was

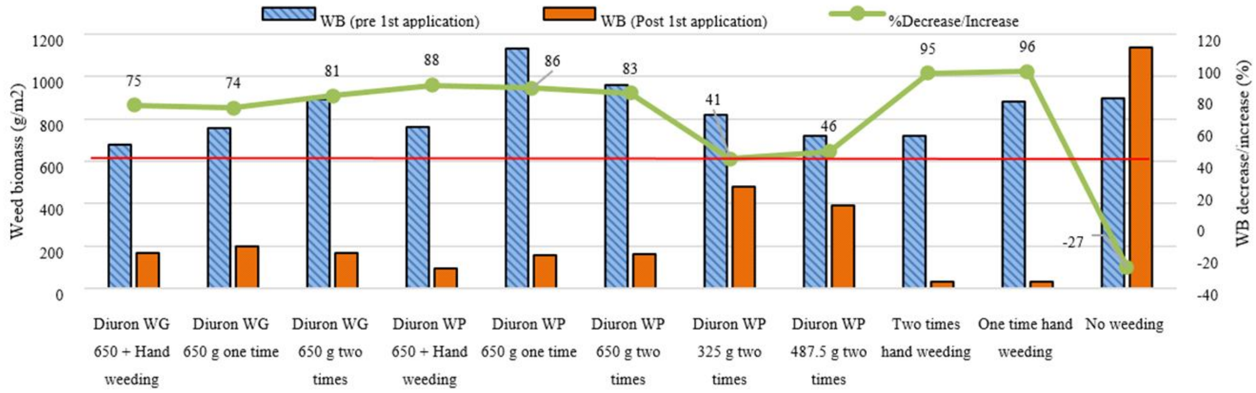

Figure 3. Weed biomass of major broad-leaf weeds at pre-and post-1st treatment

recorded lower in the treatments which received reduced rate of diuron (325 and 487.5 g/ha with 41 and 46% weed biomass decrease, respectively). On the other hand, the weed biomass was increased by 27% in the weedy check, where no control measure was applied and which is obviously expected.

Weed biomass at pre-second and post-second treatment: After the 2nd weeding practice (both the herbicide application and hand weeding) was executed, the weed biomass was decreased significantly for the treatments received twice weed control practice. On the other hand, weed biomass was significantly increased for the treatments, which received only once weed control practice (for both the herbicide application and hand weeding practices) and which is expected. The highest weed biomass reduction (94%) was observed from the treatment iuron WG 650 g + hand weeding" which was the application of diuron WP 650 g/ha in the 1st weeding and hand weeding in the 2nd weeding followed by the application of diuron WP 650 g + hand weeding with weed biomass decrease of 88% (**Figure 4**). The lowest weed biomass decrease was observed from two times application of diuron 325 g indicating lowering the rate of diuron decreased the weed control potential of the herbicide.

Weed biomass at pre-first and post-second treatment: The average weed biomass from all experimental plots was 837 g/m^2 at 10 DAE and the biomass in the weedy check treatment was reached 1901 g/m^2 at 37 DAE. The weed biomass increased by more than 100% which indicated that weed was among the most important constraints in sesame production. Sesame yield can be highly influenced by the relative leaf area or the biomass of the weeds that in turn affects the weed completion for different resources (Kropff and Spitters 1991). The highest weed biomass reduction (97.9%) was observed from the treatment diuron WG 650 g + hand weeding followed by diuron WP 650 g + hand weeding (96.6%) (**Figure 5**). This means the weed biomass decreased from 675 g/m^2 to 14 g/m^2 and from 759 g/m^2 to 26 g/m^2 from the former and the latter treatments correspondingly. This indicated that combining the herbicide and hand weeding (diuron at the 1st weeding time and hand weeding at the 2nd weeding time) is very important to control broad-leaf weeds in sesame fields. Exceptionally, the weed biomass was increased by 50.8% in the one-time hand weeding where the weed biomass was increased from 881 g/m^2 to 1328 g/m^2 indicating one-time hand weeding could not significantly reduce

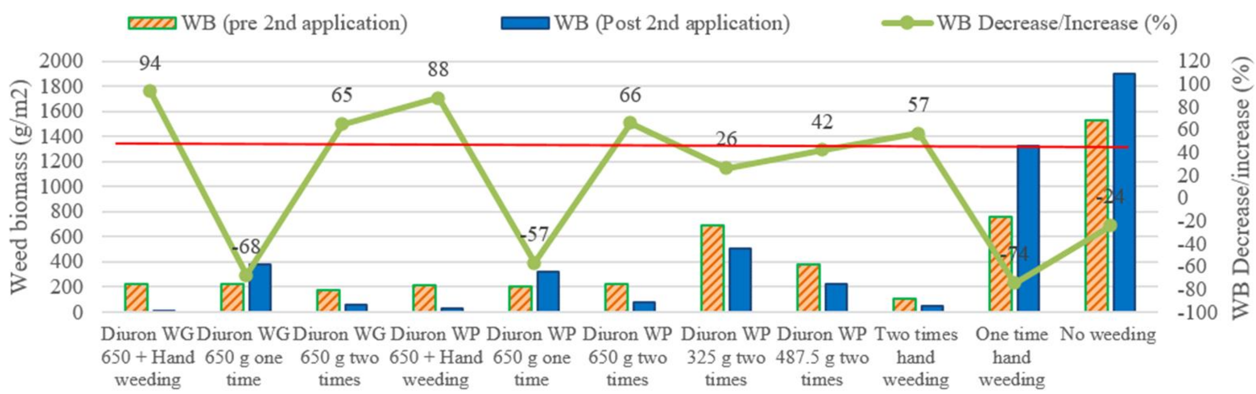

Figure 4. Weed biomass of broad-leaf weeds at pre-and post-2nd treatment

weed infestation. Moreover, the weed biomass was increased by 112% (from 896 g/m^2 to 1901 g/m^2) in the weedy check which indicated that the weed can significantly dominate the sesame crop if no control measure is taken. Generally, diuron is effective to minimize the weed biomass of broad-leaf weeds in the sesame field and this could result in an increase of the sesame biomass and thereby sesame productivity. This is in line with the findings of Bukun (2011) who reported that as the weed density and biomass decreased, the total biomass of the crop and productivity increased and vice versa. Furthermore, Bennett (1998) reported 1.3 times increased biomass of weeds that of sesame 42 days after planting while Eagleton *et al.* (1987) recorded 6 times increase in weed biomass that of sesame 48 days after planting.

Weed count of major broad-leaf weeds: Weed count of *C. foecunda* decreased in all treatments after a control measure was deployed (**Figure 6**). Weed count decreased from 180 to 2, 263 to 3 and 241 to 3 weeds/m^2 in the treatments of diuron WP 650 g + hand weeding, diuron WG 650 g + hand weeding and diuron WP 650 g two times, respectively. This was about 99% reduction indicating the application of diuron twice and application of diuron followed by hand weeding could be effective in controlling the *C. foecunda*. Grichar *et al.* (2014) and Ibrahim *et al.* (1988) also reported that integration of this herbicide with other control measures is crucial to increase synergy. Reduced rate of diuron (325 and 487.5 g/ha) decreased the efficacy of the herbicide in controlling *Commelina* spp. This study suggests the application of diuron 650 g/ha twice could be better than twice hand weeding. Hence, herbicide can be considered as best option to control this weed since this weed is very difficult to control effectively by hand weeding because of its reproduction capabilities.

The application of diuron was also effective to control *C. fascicularis.* The application of diuron 650 twice or diuron 650 combined with hand weeding during the second weeding reduced the *C. fascicularis* infestation from 21 to 2 weeds/m^2 (90% weed decrease). The weed count for this weed increased by 267 and 404% for the one- time hand

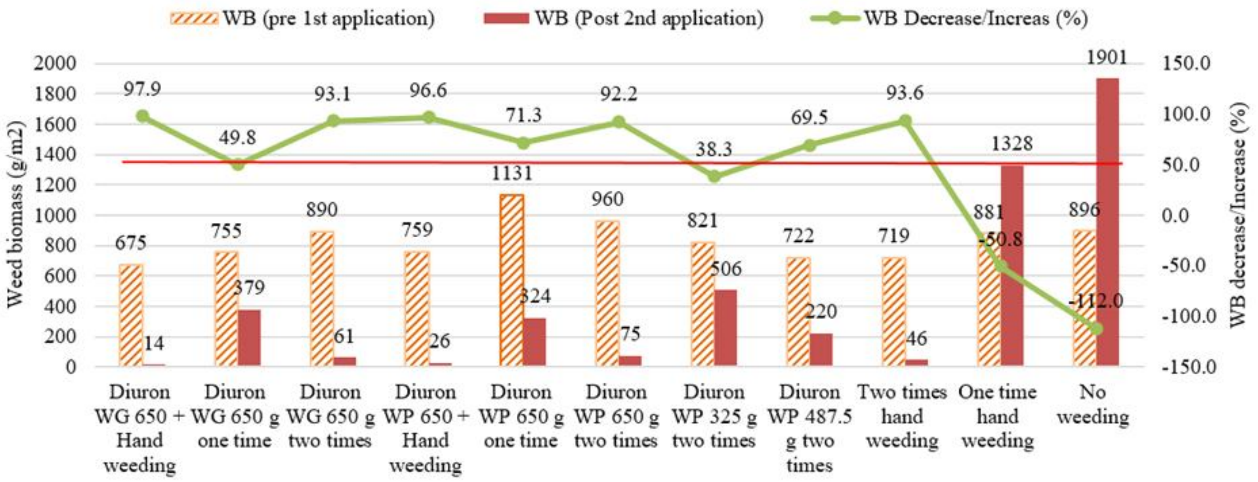

Figure 5. Weed biomass of major broad-leaf weeds at Pre-1st and post 2nd treatment

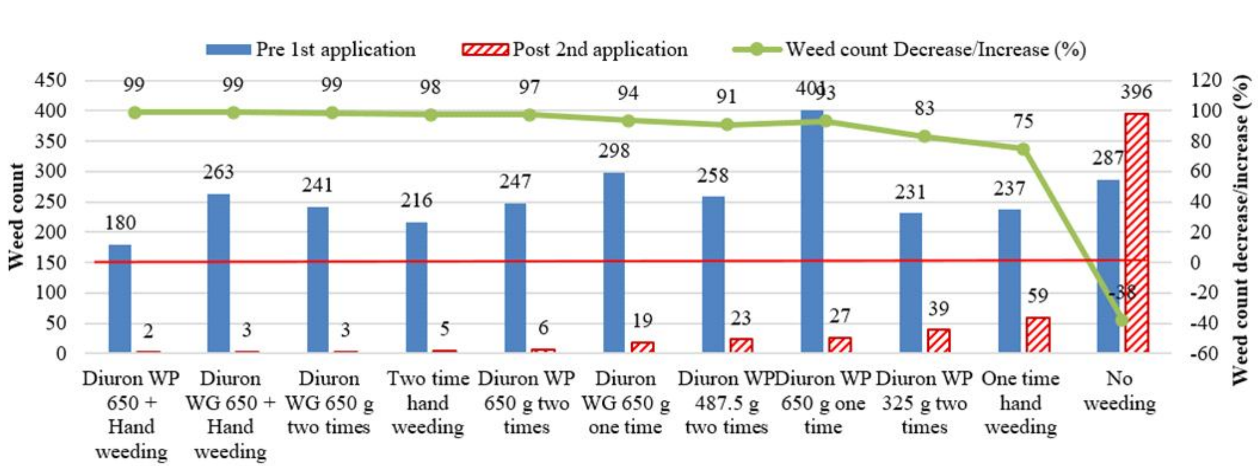

Figure 6. Weed count of *Commelina foecunda* at pre-1st and post 2nd treatment

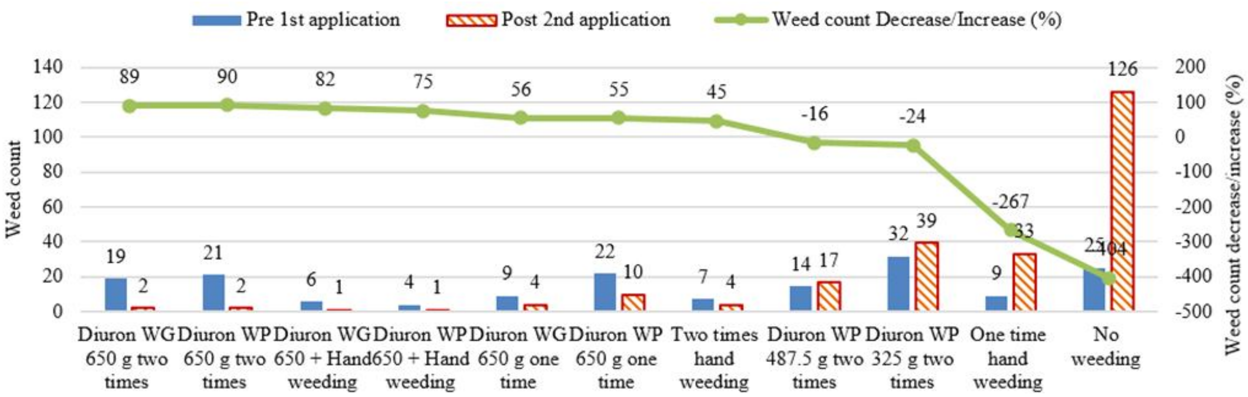

Figure 7. Weed count of *Corchorus fascicularis* at pre-1st and post 2nd treatment

weeding and no weeding, respectively. Diuron was found more effective in controlling *C. foecunda* than *C. fascicularis* (**Figure 6 and 7**). However, this might be because of inappropriate time of application against the latter weed since this is a late growing weed and hence an investigation on the time of application is crucial. Generally, the application of diuron is effective to control major broad-leaf weeds like *Convolvulus arvensis, Xanthium strumarium* and other broad-leaf weeds in addition to the above-mentioned weeds. Similar to this investigation, Grichar *et al.* (2014) and Langham *et al.* (2007) also reported that this herbicide as very effective in controlling broad leaf weeds in sesame fields.

Sesame and weed injury

All post-emergence herbicides that control broad-leaf weeds in sesame production have caused sesame injury, reduced plant stand or reduced sesame production (Grichar *et al.* 2009, Grichar *et al.* 2001). Crop injury consisted of leaf chlorosis, stunting growth, leaf necrosis, brooming effect and complete death of plants that results in decreased plant population and thereby reduced crop yield. In some cases, crop injury can also be expressed as absence of branching and no flower formation even from the available branches (Langham *et al.* 2010). The crop injury because of the herbicides rate and formulation was statistically significant ($P<0.001$) and depicted in **Figure 8**. The highest crop injury (10%) at 10 days after treatment (DAT) observed from the application of diuron WG 650g two times as well as diuron WP 650g two times equally. The lowest crop injury (3.3%) was recorded from the application of 487.5 g/ha two times while no crop injury was observed from the application of 325 g/ha twice. This indicates that the sesame injury depends on the rate of the herbicide and the formulation difference has no effect on crop injury. Grichar *et al.* (2018) reported that diuron applied at 1.12 kg/ha active ingredient on sesame after seedling emergence (post) caused leaf necrosis and

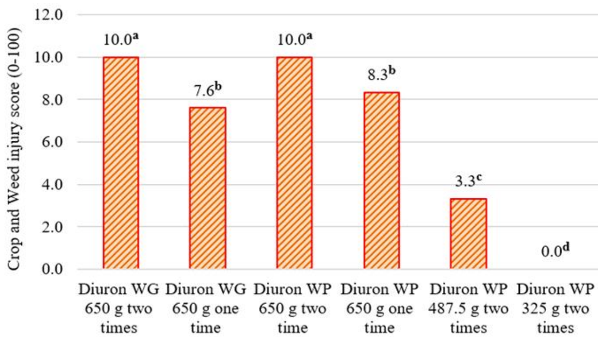

Figure 8. Crop injury score/damage score/ (0-100) as affected by the herbicide rate and formulation

chlorosis at Texas locations reaching up to 50% sesame injury but little to no injury was observed at the Lane location when rated early season, while late-season injury was 4% or less. This indicated that sesame injury from diuron is reversible and the plants can slowly recover. Furthermore, the authors also reported that the diuron applied 2 WAE can cause more injury (48% plant injury) than that of applied 4 WAE (23% plant injury). Grichar *et al.* (2011) also reported that diuron injury with post applications to sesame is temporary, and by late-season, only slight leaf chlorosis may be occurred on lower leaves. Furthermore, Grichar *et al.* (2014), Langham *et al.* (2007) and Grichar *et al.* (2011) also reported that diuron is effective in controlling broad-leaf weeds with minimum damage on the crop although the chemical resulted a crop damage at above 1.7 l/ha (Culp and Mcwhorter 1959). However, no adverse effects with diuron were seen in two-year study in south Texas. Hence, herbicide rate, time of application other agro-climatic and edaphic factors can significantly affect the sesame injury. Similar to the cop injury score, weed injury score is also depicted in **Figure 9**. The highest weed injury score (80%) was recorded from diuron WG 650 g two times followed by diuron WP 650g two times (77%) and diuron WG 650 g one time (77%) indicating the WG formulation is more effective to control broad-

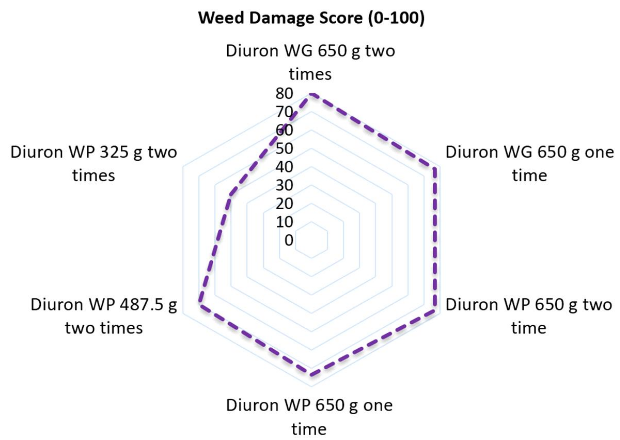

Figure 9. Weed injury score/damage score/ (0-100) score as affected by the herbicide rate and formulation

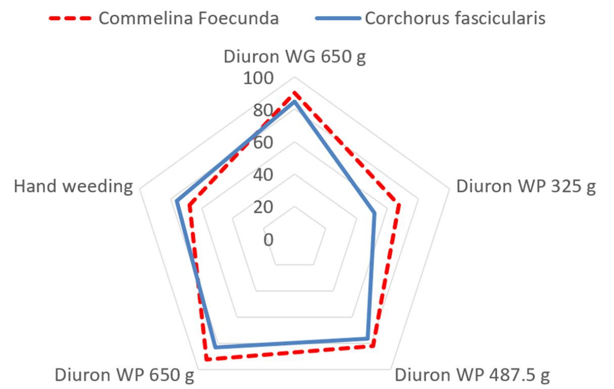

Figure 10. Coefficient of Efficacy (KE) of diuron on *Commelina foecunda* and *Corchorus fascicularis*

leaf weeds although it needs further detailed investigation. The lowest weed injury (50%) was recorded from the application of 325 g/ha two times indicating the rate of diuron matters in reflecting the efficacy of the herbicide.

Mehmeti *et al.* (2012) used the coefficient of efficacy (KE) to evaluate the efficacy of herbicides and the authors reported that this KE is vital in herbicide trials. The efficacy of the different rates and formulations of diuron on the major broad-leaf weeds was evaluated and depicted in Figure 10. The highest efficacy (92.2%) of the major broad-leaf weed *C. foecunda* was obtained from the application of diuron WP 650 g followed by the application of diuron WG 650 g. The lowest rate of the herbicide (325 g diuron WP) resulted into less efficacy (67%) against this weed. On the other hand, diuron WG 650 g was more effective (85%) followed by diuron WP 650 g (83%) against *Corchorus fascicularis*. Similar to that of *Commelina foecunda*, the lowest rate of diuron at 325 g showed lowest efficacy to control *C. fascicularis*. Generally, diuron at different rates is more effective to control *C. foecunda* vis-à-vis *C.fascicularis*. Moreover, as the rate of the herbicide decreased, the efficacy also decreased indicating the need for further investigation to optimize the rate of application.

Yield, yield loss and yield components of sesame

The ANOVA for grain yield showed significant (p=0.001) difference for grain yield, yield loss, number of branches per plant, number of pods per plant and plant height while non-significant (P<0.01) for length of pod bearing zone. The highest yield (837.5 kg/ha) was obtained from plots which were frequently hand weeded (weed free treatment) while the lowest yield was obtained from the weedy check 145.9 kg/ha (**Table 2**). Diuron WP 650 g/ha + hand weeding (669.9 kg/ha), diuron WG 650 g/ha + hand weeding (666.7 kg/ha), diuron WG 650 g/ha two times (621.1 kg/ha), diuron WP 650 g/ha two times (611.5 kg/ha), two times hand weeding (606.4 kg/ha) produced better sesame yield following to the weed free and these treatments were statistically non-significant to each other and hence, these management practices could be best options to control the major broad-leaf weeds in sesame production in the study areas and other similar production areas. This was in accordance with the findings of different workers (Audu *et al.* 2021, Joshi *et al.* 2022, Neetu *et al.* 2023) who reported the application of herbicide increased sesame yield and yield components.

Grichar *et al.* (2009) and Grichar *et al.* (2014) also reported higher sesame yield after post-emergence application with diuron. The lowest yield was obtained from one-time hand weeding, one-time diuron application and from the application of reduced rate of diuron (diuron WP 325 g/ha two times). Moreover, some of late growing weeds like *Ocimum* spp. and *Corchorus fascicularis*, which are other most important weeds in the study area, can significantly deteriorate the sesame quality in addition to the productivity. Although, hand weeding is effective and environmental friendly but it is time-

Table 2. Treatment set up and its description

Treatment	Weeding practice	Herbicide rate (g/ha)	Remark
Diuron WP 650 g one time	H	650	Applied once
Diuron WP 650 g two times	H+H	1300	Applied in two splits
Diuron WG 650 g one time	H	650	Applied once
Diuron WG 650 g two times	H+H	1300	Applied in two splits
Diuron WP 650 + HW	H+HW	650	Applied once *fb* HW
Diuron WG 650 + HW	H+HW	650	Applied once *fb* HW
One hand weeding	HW		Once hand weeding
Two hand weeding	HW+HW		Twice hand weeding
Diuron WP 487.5 g two times	H+H	975	Applied in two splits
Diuron WP 325 g two times	H+H	650	Applied in two splits
No weeding			Season long
Weed free	HW		Season long

H: Herbicide only; HW: Hand weeding

Table 3. Effect of weed management on grain yield and yield traits of sesame

Treatment	Yield (kg/ha)	Yield loss (%)	BPP	PPP	PH	LPBZ
Diuron WG 650 g + hand weeding	666.7^{b}	20.4^{d}	3.3^{bc}	38.2^{abc}	149.6^{b}	67.4
Diuron WG 650 g one time	432.9^{d}	48.3^{b}	1.9^{de}	25.2^{cd}	147.7^{b}	70.2
Diuron WG 650 g two times	621.1^{bc}	25.8^{cd}	3.8^{ab}	38.4^{ab}	149.5^{b}	67.2
Diuron WP 325 g two times	410.0^{d}	51.0^{b}	1.8^{de}	12.8^{d}	122.7^{bc}	61.7
Diuron WP 487.5 g two times	497.2^{cd}	40.6^{bc}	2.7^{cd}	25.3^{bcd}	128.5^{bc}	69
Diuron WP 650 + hand weeding	669.9^{b}	20^{d}	3.8^{ab}	41.4^{a}	144.4^{b}	70
Diuron WP 650 g one time	407.7^{d}	51.3^{b}	2.4^{cd}	23.8^{d}	146.5^{b}	74.3
Diuron WP 650 g two times	611.5^{bc}	26.97^{cd}	3.3^{bc}	41.8^{a}	142.6^{b}	72.2
One time hand weeding	437.3^{d}	47.8^{b}	1.9^{de}	20.0^{d}	129.8^{bc}	70
Two times hand weeding	606.4^{bc}	27.6^{cd}	3.2^{bc}	39.8^{a}	144.5^{b}	67.4
Weedy check	145.9^{e}	82.6^{a}	1.2^{e}	17.7^{d}	98.9^{c}	66
Weed free	837.5^{a}		4.3^{a}	45.7^{a}	182.2^{a}	74
Mean	528.7	40.2	2.8	30.8	140.6	69.1
CV (%)	163.8	19.9	1.0	13.2	30.9	10.8
LSD (<5%)	14.4	16.8	11.7	14.5	7.4	NS

BPP=Branches per plant; **PPP**=Pods per Plant; **PH**= Plant Height (cm)**; LPBZ**=Length of Pod Bearing Zone (cm); NS: non-significant

consuming and hence, it is important to use herbicides since they are effective as they are quick in action and selective (Jain and Badkul 2013).

Sesame yield loss ranging from 20-82.6% was because of weed infestation. This was in accordance to the findings of Amare (2011). However, the yield loss can reach up to complete failure (100% yield loss) if the production system is conventional like poor pest management and land preparation in addition to weed infestation. The highest number of branches per plant (3.8 branches/plant) was obtained from diuron WP 650 g/ha + Hand weeding and diuron WG 650 g/ha two times following the weed free treatment (4.3 branches/plant). Similar to the number of branches per plant, the trend of number of pods per plant was also obtained from these treatments, this is because of the reduced competition from weeds, and the plants become vigor.

Conclusions

The highest grain yield (669.9 kg/ha) followed by weed free (837.5 kg/ha) was obtained from the application of diuron WP 650 kg/ha + hand weeding, which was statistically at par with the application of diuron WG 650 kg/ha + hand weeding, diuron WP 650 g/ha two times, diuron WG 650 g/ha two times and two times hand weeding. Sesame yield loss of 82.6% was found in the weedy check.

Combining the herbicide and hand weeding (diuron at the 1st weeding time and hand weeding at the 2nd weeding time) is very important to control broad-leaf weeds in sesame fields. This study, therefore, recommends the application of diuron WG or WP at the rate of 650 g/ha applied twice at 10 and 30 DAE for the control of annual broad-leaf weeds in sesame in the sesame producing areas of Western Tigray and North Western Ethiopia. Ethiopian Ministry of agriculture reviewed the report on the efficacy of diuron to evaluate at the testing site and accepted and registered the herbicide to be used as post-emergence sesame herbicide in the country. However, further investigations on the optimum rate, time and method of application, integration with other cultural and chemical weed control measures should be carried out.

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RESEARCH ARTICLE

Efficacy of pre- and post-emergence herbicides in vegetable pea

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ABSTRACT

A field experiment was carried out at Research Farm of AICRP-Weed Management, Chatha, SKUAST-Jammu during the *Rabi* (winter) season of 2016-17 and 2017-18 to study the efficacy of different herbicides against weeds and their effect on growth and yield of vegetable peas. Results revealed that among the ready-mix herbicidal treatments, pendimethalin + imazethapyr at 1250 g/ha as pre-emergence produced less weed density (m^2) for both broad-leaved and grassy weeds during both the years. It was also found that the pendimethalin + imazethapyr at 1250 g/ha as pre-emergence significantly enhanced the growth attributes at 50 days after sowing compared to the other herbicidal applications. Pendimethalin + imazethapyr at 1250 g/ha as pre-emergence and pendimethalin + imazethapyr at 1000 g/ha as pre-emergence proved as effective weed management treatments and recorded significantly higher green pod yield, net returns, and benefit: cost ratio compared to other treatments.

Keywords: Herbicides, Pre-emergence, Post-emergence, Vegetable pea

INTRODUCTION

Vegetable pea *(Pisum sativum* L.) also known as Garden pea is an herbaceous annual belonging to Leguminosae family, originally from the Mediterranean region of Southern Europe and Western Asia, widely grown in India for its green seed pod. Pea is the third most important pulse crop at global level, after dry bean and chickpea and third most popular *Rabi* (winter) pulse of India after chickpea and lentil. Vegetable/garden/green pea is largely grown during the *Rabi* season in the states of Karnataka, Madhya Pradesh, Rajasthan, West Bengal, Punjab, Assam, Haryana, Uttar Pradesh, Uttarakhand, Himachal Pradesh, Bihar and Odisha. India contributes to around 7-10% of the world's total produce of dry pea. Vegetable pea is a highly nutritive crop with a high percentage of protein (22.5%), carbohydrate (62.1%), fat (1.8%), calcium (64 mg/ 100 g), and iron (4.8 mg/100 g) with moisture content around 11%.

One of the main obstacles to pea production worldwide is weeds. Weeds are well-adapted in crop fields due to various morphological (seed mimicry, phenotypic/vegetative mimicry) and phenological characteristics (discontinuous germination, quick growth, very short parental dependence to seedling independence, high seed production, large seed bank, chronological mimicry *etc*.). Due to the short life cycle, shallow root system, and sparse canopy, pea is considered a highly sensitive crop to the competition of weeds. Being a direct-seeded crop, pea has a longer critical period of weed interference (Medina 1995). In addition to reducing crop output by competing for moisture, nutrients, space and light, weeds can contaminate a pea crop by harbouring insects and fungi, which makes harvesting more challenging (Bithell 2004). It is also noticed that the variability in climatic conditions and soil types also influence the severity and diversity of weeds in crops. Hence, early season weed control is extremely important and a major emphasis on control should be made during this period.

Weeds have been reported to cause 81% loss in its yield (Singh *et al*. 1996). According to Bhyan *et al*. (2004), the critical period for crop-weed competition in pea ranged from 40 to 60 days after sowing. Manual weeding is effective but it is cumbersome, time consuming and uneconomical, while mechanical means generally lead to root injury (Casarini *et al*. 1996). However, the information on post-emergence herbicides to control weeds is very scanty. Many times, the extension workers and farmers of the state demand information on post-emergence herbicides especially when they fail to apply pre-emergence herbicides due to one or the other reasons. There are no integrated weed management strategies for peas that are location-specific (Ali *et al.* 2014). Most of the weeding is done by hand, which is labour-intensive,

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expensive and time-consuming. Pendimethalin, a broad-spectrum herbicide that is selective to pea (Kulshrestha *et al.* 2000) and effective against annual grassland weeds and a few broad-leaved weeds, is the principal pre-emergence herbicide used by large and commercial pea growers. Yet, because different weeds have different morphologies, physiologies and tolerances, merely pre-emergence spraying is insufficient to control them. A single herbicide used continuously may encourage weed resistance and shift. Therefore, new strategies should be adopted in order to control the menace caused by weeds. According to Eskin (2000), post-emergence herbicides were found to be more effective at controlling broad-leaved weeds than pre-emergence herbicides in suppressing grassy weeds that were already germinating. Mixing herbicides is a common practice in agriculture, to optimize farm management practices, widen the weed control spectrum, enhance application efficiency, and manage herbicide resistance. Also, the mixed herbicide applications have been found to improve broad-spectrum weed control, minimise weed shift and postpone resistance (Das *et al.* 2014). Therefore, herbicide mixture may be used as a prominent strategy for weed management. Considering these points, the present investigation was therefore, done with the objectives to study the efficacy of different herbicides against weeds and their effect on growth and yield of vegetable peas.

MATERIALS AND METHODS

The present field experiment was conducted during the *Rabi* season of 2016-17 and 2017-18 at Research Farm of AICRP-Weed Management, Chatha, SKUAST-Jammu in a randomized block design with three replications having fifteen treatments namely clodinafop 60 g/ha as PoE, pinoxaden 50 g/ha as PoE, pendimethalin at 1.0 kg/ha as PE, pendimethalin + imazethapyr at 800 g/ha as PE, pendimethalin + imazethapyr at 1000 g/ha as PE, pendimethalin + imazethapyr at 1250 g/ha as PE, imazethapyr at 70 g/ha as PE, imazethapyr at 60 g/ha at 2-4 leaf stage, imazethapyr at 70 g/ha at 2-4 leaf stage, imazethapyr 80 g/ha at 2-4 leaf stage, imazethapyr+ imazamox 60 g/ha at 2-4 leaf stage, imazethapyr+ imazamox 70 g/ha at 2-4 leaf stage, imazethapyr+ imazamox 80 g/ha at 2-4 leaf stage, weed free, and weedy check.

The experimental site was situated at 32.6529° N latitude and 74.8071° E longitude at an elevation of 332 meters above mean sea level. The soil of the experimental field was sandy clay loam in texture, slightly alkaline in reaction, low in organic carbon and available nitrogen but medium in phosphorus and potassium. The pea variety '*Arkel*' was sown on second week of October during the year 2016 and 2017 in a gross plot size of 4.6 x 3.2 m. All the herbicides were applied by using a knapsack sprayer fitted with flat-fan nozzle with spray volume of 500 liters /ha. Data on weed density and biomass were recorded at 25 and 50 days after sowing of crop by using 1x1 m quadrant. Phytotoxicity symptoms were recorded using visual score scale of 0-10 at 10 days after the application of herbicides. Growth and yield attributes and yield were recorded to draw the valuable inferences.

RESULTS AND DISCUSSION

Weed flora in the experiment field

Both broad-leaved and grassy weeds were found to be dominant in the experimental field. Among the broad-leaved weeds, the most dominant weed species found in experimental field during crop growth period were mainly *Vicia sativa, Anagallis arvensis, Melilotus indica* and *Medicago denticulata* and the grassy weeds were *Phalaris minor and Cynodon dactylon*. In general, the broad-leaved weeds were more dominant in experiment field compared to the grassy weeds.

Effect on weeds

During both the years, various weed control treatments considerably reduced the density of grassy and broad-leaved weeds when compared to weedy check. Weed management treatments had significant effect on weed density and weed biomass at 25 and 50 DAS (**Table 1** and **2**). Among the herbicidal treatments, lowest density and biomass of broad-leaved weeds were recorded in pendimethalin + imazethapyr 1250 g/ha as pre-emergence which was statistically at par with pendimethalin + imazethapyr 1000 g/ha as pre-emergence during both the years except weed density during 2017-18. Imazethapyr and pendimethalin are two classes of herbicides that have different mechanisms of action and are broad-spectrum and selective to pea (Wagner and Nadasy 2006, Kukharchik *et al.* 2013, Shalini and Singh 2014). Hajebi *et al.* (2016) also observed similar kind of trend when the applications of these herbicides were made in sequence, resulting in the reduce the weed population. Shalini and Singh (2014) also reported similar results with pendimethalin and imazethapyr. Among the post-emergence herbicides, imazethapyr 80 g/ha recorded lowest broad-leaved weed density and biomass as compared to other treatments. Different doses of imazethapyr + imazamox recorded almost statistically at par weed density and weed biomass (broad-leaved as well as grassy). Imazethapyr + imazamox and pinoxaden showed phytotoxicity (slightly yellowing of leaves) initially but that recovered 25 days after application. The lowest density and biomass of grassy weeds were recorded in pinoxaden 50 g/ha which was statistically at par with clodinafop propargyl 60 g/ha and significantly lower than other treatments. This showed that clodinafop propargyl and pinoxaden herbicides are grassy weed killer.

Effect on growth and yield attributes

Different weed management treatments had significant effect on growth and yield attributes as compared to weedy check (**Table 3**). Among the weed management treatments, all the weed management treatments recorded significantly higher plant height, plant dry matter, and number of nodules, number of pods, and number of seeds/pod for both 2016-17 and 2017-18 as compared to weedy check. Among the herbicidal treatments, pendimethalin + imazethapyr 1250 g/ha as pre-emergence recorded higher plant height (48.70 cm for 2016-17 and 51.77 cm for 2017-18), plant dry matter (2.72 g/m^2 for 2016-17 and 2.63 g/m^2 for 2017-18), number of nodules (17.57 for 2016-17 and 18.40 for 2017-18), number of pods (16.70 for 2016-17 and 18.50 for 2017-18) and number of seeds/pod (8.00 for 2016-17 and 8.20 for 2017-18). Pendimethalin + imazethapyr 1250 g/ha pre-emergence was at par with pendimethalin + imazethapyr at 1000 g/ha pre-emergence during both 2016-17 and 2017-18 crop growing years with respect to growth and yield attributes. Reduced weed density allowed crop canopies to expand horizontally across more branches and have greater leaf areas, which increased photosynthesis and the build-up of dry matter (Singh and Tripathi 2004, Wagner and Nadasy 2010, Bhullar

Table 1. Effect of different weed management practices on weed density in vegetable pea

Treatment	Weed density (m^2) at 25 DAS				Weed density (m^2) at 50 DAS			
	Broad-leaved weeds		Grassy weeds		Broad-leaved weeds		Grassy weeds	
	2016-17	2017-18	2016-17	2017-18	2016-17	2017-18	2016-17	2017-18
Clodinafop 60 g/ha at 2-4 LS	7.15 (50.3)	6.55 (41.9)	1.79 (2.3)	2.16 (3.7)	6.47 (41.0)	6.01 (35.2)	2.13 (3.7)	2.54 (5.5)
Pinoxaden 50 g/ha at 2-4 LS	7.23 (51.3)	6.64 (43.1)	1.73 (2.0)	2.06 (3.3)	6.71 (44.0)	6.07 (35.9)	1.93 (3.0)	2.47 (5.1)
Pendimethalin at 1.0 kg/ha as PE	5.07 (25.0)	3.95 (14.7)	3.37 (10.7)	3.6 (12.0)	4.60 (20.3)	3.05 (8.4)	3.39 (10.7)	3.85 (13.8)
Pendimethalin + imazethapyr at 800 g/ha as PE	4.11 (16.0)	3.68 (12.5)	3.20 (9.3)	3.14 (9.0)	3.63 (12.3)	2.55 (5.5)	3.10 (8.7)	3.43 (10.8)
Pendimethalin + imazethapyr at 1000 g/ha as PE	3.51 (11.3)	2.58 (5.6)	2.99 (8.0)	2.82 (7.0)	3.07 (9.0)	2.21 (3.9)	2.99 (8.0)	3.13 (8.8)
Pendimethalin + imazethapyr at 1250 g/ha as PE	3.05 (8.3)	1.90 (2.6)	2.94 (7.7)	2.76 (6.7)	2.70 (6.3)	1.75 (2.1)	2.69 (6.3)	3.00 (8.1)
Imazethapyr at 70 g/ha as PE	4.43 (18.7)	4.38 (18.2)	3.23 (9.7)	3.23 (9.7)	3.90 (14.3)	3.49 (11.2)	3.36 (10.3)	3.51 (11.4)
Imazethapyr at 60 g/ha at 2-4 LS	6.02 (35.3)	5.40 (28.3)	3.46 (11.0)	3.55 (11.7)	5.65 (31.0)	4.72 (21.4)	3.46 (11.0)	3.80 (13.5)
Imazethapyr at 70 g/ha at 2-4 LS	5.32 (27.3)	5.67 (31.3)	3.45 (11.0)	3.26 (9.7)	5.03 (24.3)	5.01 (24.3)	3.31 (10.0)	3.53 (11.4)
Imazethapyr 80 g /ha at 2-4 LS	5.09 (25.0)	4.71 (21.2)	3.36 (10.3)	3.31 (10.0)	4.64 (20.7)	3.91 (14.4)	3.21 (9.3)	3.57 (11.8)
Imazethapyr + imazamox 60 g/ha at 2-4 LS	5.69 (31.7)	5.64 (30.8)	3.29 (10.0)	3.19 (9.3)	5.37 (28.0)	4.91 (23.2)	3.17 (9.3)	3.46 (11.1)
Imazethapyr + imazamox 70 g/ha at 2-4 LS	5.78 (32.7)	6.27 (38.4)	3.26 (9.7)	3.26 (9.7)	5.50 (29.3)	5.68 (31.3)	3.26 (9.7)	3.52 (11.5)
Imazethapyr + imazamox 80 g/ha at 2-4 LS	5.60 (30.3)	6.41 (40.2)	3.30 (10.0)	3.10 (8.7)	5.28 (27.0)	5.87 (33.5)	3.36 (10.3)	3.37 (10.4)
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)	1.00 (0.0)	1.00 (0.0)
Weedy check	7.78 (59.7)	8.68 (74.4)	3.73 (13.0)	3.59 (12.0)	7.63 (57.3)	8.44 (70.3)	4.16 (16.3)	3.92 (14.4)
LSD (p=0.05)	0.70	0.51	1.47	0.59	0.65	0.53	0.63	0.40

Table 2. Effect of different weed management practices on weed biomass in vegetable pea

Treatment	Weed dry biomass (g/m^2) at 25 DAS				Weed dry biomass (g/m^2) at 50 DAS			
	Broad-leaved weeds		Grassy weeds		Broad-leaved weeds		Grassy weeds	
	2016-17	2017-18	2016-17	2017-18	2016-17	2017-18	2016-17	2017-18
Clodinafop 60 g/ha at 2-4 LS	8.17(66.0)	7.65(57.6)	1.93(2.8)	2.30(4.3)	11.12(123.0)	9.99(99.0)	3.31(10.0)	4.10(15.9)
Pinoxaden 50 g/ha at 2-4 LS	8.28(67.6)	7.89(61.3)	1.86(2.5)	2.25(4.1)	11.53(132.0)	10.09(100.9)	2.94(8.4)	3.96(14.7)
Pendimethalin at 1.0 kg/ha as PE	5.74(32.3)	4.67(20.8)	3.69(12.7)	3.89(14.2)	7.85(61.0)	4.98(24.0)	5.40(28.7)	6.49(41.2)
Pendimethalin + imazethapyr at 800 g/ha as PE	4.59(20.3)	4.30(17.6)	3.49(11.3)	3.46(11.2)	6.13(37.0)	4.04(15.4)	4.93(23.4)	5.67(31.2)
Pendimethalin + imazethapyr at 1000 g/ha as PE	3.89(14.4)	3.00(8.0)	3.24(9.6)	2.98(8.0)	4.85(23.9)	3.39(10.6)	4.37(21.6)	5.14(25.5)
Pendimethalin + imazethapyr at 1250 g/ha as PE	3.50(11.3)	2.15(3.7)	3.18(9.2)	3.00(8.1)	4.81(22.2)	2.58(5.7)	4.26(17.4)	4.93(23.3)
Imazethapyr at 70 g/ha as PE	5.02(24.3)	5.14(25.5)	3.51(11.6)	3.51(11.4)	6.65(43.7)	5.69(31.5)	4.15(18.7)	5.82(33.1)
Imazethapyr at 60 g/ha at 2-4 LS	4.73(25.6)	6.36(39.6)	3.67(12.5)	3.86(14.0)	9.61(91.3)	7.79(60.1)	5.56(30.0)	6.47(40.9)
Imazethapyr at 70 g/ha at 2-4 LS	6.13(36.7)	6.68(43.8)	3.76(13.2)	3.61(12.0)	8.57(72.7)	8.30(68.3)	5.29(27.0)	5.84(33.2)
Imazethapyr 80 g /ha at 2-4 LS	5.60(30.6)	5.53(29.7)	3.81(13.6)	3.60(12.0)	7.91(62.0)	6.42(40.3)	5.11(25.2)	6.04(35.6)
Imazethapyr + imazamox 60 g/ha at 2-4 LS	6.46(41.2)	6.63(42.9)	2.92(7.6)	3.47(11.2)	9.41(87.7)	8.12(65.1)	5.04(25.2)	5.73(32.3)
Imazethapyr + imazamox 70 g/ha at 2-4 LS	6.57(42.5)	7.41(54.0)	3.50(11.3)	3.53(11.5)	9.51(89.7)	9.43(87.9)	5.19(26.1)	5.84(33.2)
Imazethapyr + imazamox 80 g/ha at 2-4 LS	6.37(39.6)	7.58(56.6)	3.57(11.9)	3.40(10.6)	9.12(82.3)	9.75(94.2)	5.39(28.3)	5.57(30.3)
Weed free	1.0(0.0)	1.0(0.0)	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	9.19(83.7)	10.3(105.5)	4.12(16.0)	4.00(15.1)	13.93(178.3)	11.0(120.3)	6.49(41.3)	6.73(44.3)
LSD(p=0.05)	1.35	1.35	0.59	0.57	1.07	1.24	1.38	0.67

et al. 2015). Similar improvement in production through reduction in weed interference by the pendimethalin+ imazethapyr treatment was reported in dwarf field pea (Shalini and Singh 2014).

Effect on green pod yield

Different weed management treatments registered significant increase in green pod yield compared to weedy check (**Table 4**). Among the weed management treatments, pendimethalin + imazethapyr 1250 g/ha as pre-emergence recorded highest green pod yield (7.37 t/ha for 2016-17 and 7.53 t/ha for 2017-18), which was statistically at par with pendimethalin + imazethapyr 1000 or 800 g/ha as pre-emergence and imazethapyr 70 g/ha as PE during both 2016-17 and 2017-18 crop growing years with respect to green pod yield. It also resulted in 44 to 57% for 2016-17 and 41 to 54% for 2017-18 increase in green pod yield over rest herbicidal weed management treatments. Pendimethalin + imazethapyr 1000 g/ha as pre-emergence was found second best weed management treatment among various weed management treatments in influencing green pod yield. Similar increases in yield through reduction in weed interference by the pendimethalin + imazethapyr 1250 g/ha as pre-emergence treatment was reported in field pea (Shalini and Singh 2014) and chilli (Hajebi *et al.* 2016). The effect might have accentuated from weeds prevention The continuous growth of weeds in the weedy check decreased pea yield by 62.09% in comparison to weed free. The same observations on the effects of pendimethalin fb one hand weeding on yield characteristics and yield were made by Mawalia *et al.* (2017).

Effect on economics

Among the herbicidal weed management treatments, pendimethalin + imazethapyr 1250 g/ha as pre-emergence recorded highest net returns followed by pendimethalin + imazethapyr 1000 g/ha as pre-

Table 3. Effect of different weed management practices on growth and yield attributes in vegetable pea

Treatment	Plant height at 50 DAS (cm)		Plant dry matter at 50 DAS (g/m^2)		No. of nodules/ plant at 50 DAS		No. of pods/plant		No. of seeds/pod	
	2016-17	2017-18	2016-17	2017-18	2016-17	2017-18	2016-17	2017-18	2016-17	2017-18
Clodinafop 60 g/ha at 2-4 LS	39.97	43.70	2.53	2.75	14.97	15.77	12.43	14.23	6.77	7.00
Pinoxaden 50 g/ha at 2-4 LS	38.87	42.17	2.52	2.78	14.90	15.67	11.77	13.53	6.60	6.83
Pendimethalin at 1.0 kg/ha as PE	45.40	48.80	2.62	2.79	16.33	17.10	14.43	16.27	7.43	7.67
Pendimethalin + imazethapyr at 800 g/ha as PE	46.00	48.23	2.68	2.74	16.52	17.32	15.43	15.87	7.53	7.80
Pendimethalin + imazethapyr at 1000 g/ha as PE	47.83	51.23	2.70	2.70	16.73	17.60	16.06	17.80	7.60	7.90
Pendimethalin + imazethapyr at 1250 g/ha as PE	48.70	51.77	2.72	2.63	17.57	18.40	16.70	18.50	8.00	8.20
Imazethapyr at 70 g/ha as PE	45.63	49.03	2.66	2.66	16.13	16.93	14.63	16.40	7.33	7.53
Imazethapyr at 60 g/ha at 2-4 LS	43.83	47.17	2.61	2.65	15.88	16.68	11.83	13.67	7.23	7.43
Imazethapyr at 70 g/ha at 2-4 LS	45.33	45.27	2.56	2.66	15.53	16.33	13.73	15.53	7.07	7.27
Imazethapyr 80 g /ha at 2-4 LS	45.40	48.80	2.58	2.63	15.83	16.63	14.20	16.00	7.20	7.40
Imazethapyr + imazamox 60 g/ha at 2-4 LS	44.03	47.43	2.57	2.92	15.46	16.26	14.03	15.83	7.03	7.23
Imazethapyr + imazamox 70 g/ha at 2-4 LS	44.30	47.70	2.58	2.12	15.63	16.43	12.30	14.10	6.97	7.17
Imazethapyr + imazamox 80 g/ha at 2-4 LS	40.83	43.80	2.55	2.55	14.10	14.90	12.17	13.97	6.80	7.00
Weed free	51.13	54.30	2.81	2.81	19.23	20.37	17.77	19.57	8.77	9.13
Weedy check	32.07	35.47	2.18	2.18	12.97	13.77	9.27	11.10	5.27	5.50
LSD (p=0.05)	3.86	3.91	0.09	0.12	1.92	1.91	2.42	2.11	0.92	0.76

Table 4. Effect of different weed management practices on green pod yield in vegetable pea

Treatment	Green pod yield (t/ha)		Net returns (x10^3 ₹/ha)		B: C ratio	
	2016-17	2017-18	2016-17	2017-18	2016-17	2017-18
Clodinafop 60 g/ha at 2-4 LS	6.86	6.93	95.83	91.26	2.32	1.93
Pinoxaden 50 g/ha at 2-4 LS	6.75	6.90	92.72	89.48	2.18	1.84
Pendimethalin at 1.0 kg/ha as PE	7.07	7.18	99.19	95.21	2.34	1.96
Pendimethalin + imazethapyr at 800 g/ha as PE	7.16	7.20	99.70	95.46	2.35	1.96
Pendimethalin + imazethapyr at 1000 g/ha as PE	7.28	7.47	102.88	100.40	2.41	2.10
Pendimethalin + imazethapyr at 1250 g/ha as PE	7.37	7.53	104.01	101.03	2.40	2.00
Imazethapyr at 70 g/ha as PE	7.10	7.13	101.27	94.50	2.41	1.96
Imazethapyr at 60 g/ha at 2-4 LS	6.88	7.03	95.94	92.70	2.29	1.93
Imazethapyr at 70 g/ha at 2-4 LS	7.03	7.07	98.74	93.30	2.35	1.93
Imazethapyr 80 g /ha at 2-4 LS	7.08	7.10	99.48	93.38	2.36	1.92
Imazethapyr + imazamox 60 g/ha at 2-4 LS	6.93	7.09	96.43	93.46	2.28	1.93
Imazethapyr + imazamox 70 g/ha at 2-4 LS	6.90	6.99	95.62	91.18	2.25	1.87
Imazethapyr + imazamox 80 g/ha at 2-4 LS	6.87	6.94	94.62	89.92	2.21	1.83
Weed free	7.57	7.79	95.34	83.42	1.73	1.15
Weedy check	4.67	4.89	53.12	51.42	1.31	1.10
LSD (p=0.05)	0.44	0.41				

emergence. However, highest benefit cost ratio was attended in pendimethalin + imazethapyr 1000 g/ha as pre-emergence followed by pendimethalin + imazethapyr 1250 g/ha as pre-emergence and imazethapyr at 70 g/ha pre-emergence (**Table 4**). This might be due to the better management of weeds by these herbicides than other herbicidal treatments.

Based on two-year study, it was concluded that pendimethalin + imazethapyr 1000 g/ha as pre-emergence found economically suitable for weed management option in vegetable pea in Jammu area of India.

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RESEARCH ARTICLE

Imazethapyr as post-emergent herbicide in common-bean (*Phaseolus vulgaris* L.) under rainfed temperate condition of Kashmir, India

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ABSTRACT

A research trial was carried out over the course of two years in *Kharif* (rainy) season of 2021 and 2022 at the Agronomic Research Farm of the Faculty of Agriculture, Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, Wadura, India to study the bio-efficacy of imazethapyr as post-emergent herbicide at 25 days after sowing to control weeds and yield of common bean. The herbicide was applied at different doses *i.e.* 25, 50, 75, 100 and 125 g/ha and were compared under randomized completely block design. Application of imazethapyr 75-125 g/ha remarkably decreased the weed density and the weed biomass. The growth and yield parameters were significantly higher with imazethapyr 100 g/ha and were at par to 2 manual weeding. The common bean seed yield was reduced by 67.91% and 72.11% in 2021 and 2022, respectively, due to weed infestation in weedy check plots. Maximum weed control efficiency and index was obtained with application of imazethapyr 125 g/ha. However, imazethapyr 100 to 125 g/ha resulted in considerably higher benefit: cost ratios of 2.52 (2021) and 2.7 (2022) followed by imazethapyr 75 g/ha with benefit: cost ratios of 2.45 (2021) and 2.6 (2022). The results lead to the conclusion that imazethapyr application 100 g/ha as post-emergent herbicide applied at 25 days after sowing was found efficient for weed control with economically higher seed yield of common bean.

Keywords: Common bean, Economics, Growth, Imazethapyr, *Phaseolus vulgaris*, Weed control efficiency, Yield

INTRODUCTION

Common bean (*Phaseolus vulgaris* L.) is extensively grown due to its short duration and nutritional value (Longkumar and Singh 2016) as it contains a high level of protein (25.40 g/100g) with considerable amounts of minerals *i.e*., phosphorus (463 mg/100 g), calcium (167 mg/100 g) and iron (6.24 mg/ 100g). The common bean is an essential grain legume crop that is mostly used for its pods and dry edible seeds around the world (Nadeem *et al*. 2020) and is extremely profitable legume in hilly areas of Jammu & Kashmir, Himachal Pradesh, Uttar Pradesh and some places of Maharashtra by virtue of its distinct adaptation to a cold and extended growth season (Sood *et al*. 2003). It also occupies a significant position among many *Kharif* (rainy) pulses grown in temperate hills of North-Western India. An area of 33.1 million hectares of common beans were harvested worldwide, and 28.9 million tons were produced in 2019 according to FAO (WHO 2020). In Jammu and Kashmir, common beans have acquired the popularity due to its superior taste, texture, flavor and palatability (Choudhary *et al*. 2018, Mir *et al*. 2021). Despite its widespread use, the productivity of this crop in India is very low at 450.90 kg/ha as compared to the global average of 777.40 kg/ha (Anonymous 2010). This is because, the majority of these crops are cultivated in rainfed areas with poor management and are subjected to a variety of biotic and abiotic stresses.

High weed infestation is one of the key biotic constraints that hampers overall crop development and yield as reported by Panotra *et al*. (2018). In addition to lowering the quantity and quality of yield, weeds can make harvesting harder and serve as habitats for pests and pathogen and also compete with crops for natural and applied resources (Rao *et al*. 2015). The first 30-45 days after sowing (DAS) of the growth of common bean is most crucial period for crop-weed competition. At this stage, the growth of the crop is slow and is overrun by weeds, which causes yields to decline by 20-60% (Anonymous

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2009). Therefore, maintaining a weed-free crop environment is crucial for both improving production and revenue and ensuring the crop's security. Pendimethalin, a herbicide from the aniline group, is generally used as a pre-emergence to manage the early weed flush in most pulses including common bean. It suppresses the first flush of annual grasses and some of the broad-leaf weeds but found to be ineffective against sedges and also against grasses and broad-leaf weeds 20 days after application (Singh 2011). Therefore, using pendimethalin alone is insufficient to curb distinct category of weed flora in common bean. Usually pendimethalin 1.0 kg/ha followed by a manual weeding at 25-30 DAS are recommended (Singh 2011, Akter *et al.* 2013) in most of the growing regions. Manual weeding is efficient in controlling weeds, but owing to intermittent rains during *Kharif* season, it is not feasible in addition to time consuming and labour expensive. So, there is an urgent need to go for evaluation of broad spectrum post-emergent herbicide for common bean grown during *Kharif* season of Kashmir valley to optimize production and weed control. Application of post-emergence herbicides controls late emerging weeds and obtain higher yields against timely weed clearance (Pratap Singh *et al.* 2016).

The imidazolinone group of herbicides offers a broad spectrum of weed control with low consumption rates and low toxicity to humans (Tan *et al*. 2005). Imazethapyr, a herbicide from the imidazolinone family is applied as pre-emergence and soon after emergence to control annual grasses, broad-leaf weeds and perennial sedges in numerous pulse crops (Rathod *et al.* 2017, Kumar *et al.* 2020). The selectivity of imazethapyr to control post-emergent weeds in pulses was also reported by Rathod *et al.* (2017). In these conditions, pre- and post-emergent herbicides administered in succession will successfully suppress the weeds. The study was carried out to determine the bio-efficacy of imazethapyr as post-emergence with an objective of optimizing dose of imazethapyr for effective and economically control of weeds and higher seed yield in common bean.

MATERIAL AND METHODS

A research trial was carried out at Agronomic Research Farm, of the Faculty of Agriculture, Sher-e-Kashmir University of Agricultural Sciences and Technology of Kashmir, Wadura, India during *Kharif* season of 2021 and 2022. The soil of the research trial had a silty-clay loam texture with pH of 6.8, 0.74% of soil organic carbon and 275.5 kg/ha, 17.5 kg/ha and 174.2 kg/ha of available nitrogen, phosphorus and potassium respectively. The research trial was laid out in randomized completely block design having eight treatments of weed management, replicated thrice. The treatments of herbicide were applied at different doses *i.e.*, imazethapyr 25 g/ha, imazethapyr 50 g/ha, imazethapyr 75 g/ha, imazethapyr100 g/ha, imazethapyr 125 g/ha. Treatments of two manual weeding (20 and 40 DAS), weed free (20, 40 and 60 DAS) and weedy check were also included. Pendimethalin 1000 g/ha was sprayed as pre-emergence (2 DAS) in all the treatments except weed free and weedy check. Imazethapyr was sprayed as post-emergence (25 DAS) as per treatment of doses using knapsack sprayer equipped with flat-fan nozzle. The seeds of common bean were sown in furrows at 30 × 10 cm apart using 60 kg seed per hectare at 25^{th} and 27^{th} standard meteorological weeks during crop growing period of 2021 and 2022, respectively. The mean weekly maximum and minimum temperature was 32.56 ^{0}C and 11.74 ^{0}C, respectively in 2021, while 32.16 ^{0}C and 4.53 ^{0}C in 2022, respectively. The total rainfalls were 157.8 mm and 295.2 mm during 2021 ND 2022, respectively. The soil moisture at the time of sowing was sufficient for germination and emergence. At the time of sowing, uniform doses of 30, 50 and 30 kg N, P and K, respectively were applied. The data on weed density and weed biomass at 40 and 60 DAS during both the years were recorded by using quadrant (25 × 25 cm) in all the treatments. Five randomly plants from each experimental plot were chosen to record observations on plant height, leaf area index, and dry matter accumulation at 40 and 60 DAS in both years. While observations on grain yield and yield attributing parameters, *viz*. number of pod/plant, seed/pod, seed index were recorded at harvest.

Following indices of weed control performance were recorded:

1. Weed control efficiency (WCE) reflects per cent reduction in weed density by a treatment (Nath *et al.* 2016).

WCE (%) = $[(WD_C – WD_T)*100] / WD_C$.

Where, WD_C and WD_T are, respectively, the weed densities in the control and treated plots.

2. Weed control index (WCI) reflects per cent reduction in weed dry weight by a treatment (Nath *et al.* 2016).

WCI (%) = $[(WM_C – WM_T)*100] / WM_C$.

Where, WM_C and WM_T are the corresponding dry weights of weeds in the control and treated plots.

3. Weed index (WI) is a measure of the efficacy of particular treatment in terms of yield output when compared with weed free treatment. It reflects per cent yield loss. (Asres and Das 2011).

WI (%) = $(Y_F - Y_T) / Y_F$

Where, Y_F and Y_T, respectively, stand for yields in weed-free and treated plots.

With the help of the minimum support price and the current market price of the products, the economics of treatment was computed. The B: C ratio, which is the ratio of net returns to total cost of cultivation, was determined to evaluate the treatments' economic viability. Prior to statistical analysis, the density and biomass of weed were subjected to square root transformation using ($\sqrt{x+0.5}$). The data were subjected to analysis of variance and significant differences among treatments were tested by calculating CD at 5% level of significance differences evaluated by using one-way ANOVA (Gomez and Gomez 1984).

RESULTS AND DISCUSSION

Weed density

Weed flora in research trial consisted of grasses namely *Cynodon dactylon*, *Digitaria sanguinalis*, *Sorghum halepense*; sedges namely *Cyperus rotundus* and Broad-leaf weeds namely *Convolvulus arvensis*, *Euphorbia* spp., *Digera arvensis*, *Portulaca oleracea*, *Ipomoea* spp. *Sorghum halepense*, *Cyperus rotundus*, *Convolvulus arvensis* and *Digera arvensis* dominated in the weedy check plots of common bean. The weed density was significantly lower in the weed free plot at 40 and 60 DAS during 2021 and 2022. In 2021, imazethapyr 0.075 to 125 g/ha was at par at 40 and 60 DAS. However, two manual weeding (20 and 40 DAS) was significantly superior than the herbicide imazethapyr 75 to 125 g/ha. In 2022, the doses of imazethapyr 75 to 125 g/ha at 40 DAS were at par to weed free plots and significantly superior to two manual weeding. At 60 DAS, imazethapyr 100 and 125 g/ha were at par to weed free plots. The remarkable reduction in weed population might be due to increasing the doses of herbicide imazethapyr. Similar findings were also reported by Raj *et al.* (2010) and Chaudhary *et al.* (2016). *Cyperus rotundus* had the highest weed density, followed by *Digitaria* spp. and *Convolvulus* spp., while imazethapyr 75 to 125 g/ha significantly decreased the weed density of all the major weeds (**Table 1**).

Weed biomass

All the herbicide treatments proved very effective against weeds. The minimum dry weight of weeds was recorded in weed-free treatment which was significantly lower than other treatments at 40 DAS during both years. Among different herbicide treatments at 40 DAS during both years, lowest weed dry weight was recorded with imazethapyr 125 g/ha however, it was at par with imazethapyr 100 and 75 g/ha. At 60 DAS, minimum dry weight of weed was observed in weed free treatment which was at par with imazethapyr 125, and 100 g/ha during both years. Imazethapyr 75 g/ha were also at par to 100 and 125 g/ha. Similar findings were also reported by Meena *et al.* (2011) and Ram and Singh (2011). Kumar *et al.* (2016) reported that grasses, broad-leaf weeds and *Cyperus* spp. were controlled effectively at 100 g/ha of imazethapyr (**Table 1**).

Weed control performance

In 2021, the WCE was maximum with imazethapyr 125 g/ha followed by the dose of 100 and 75 g/ha at 40 DAS. At 60 DAS, the WCE was maximum with 100 to 125 g/ha followed by75 g/ha. In 2022, the doses of imazethapyr 75 to 125 g/ha registered above 90% close to weed free plot at 40 DAS. At 60 DAS, the doses of imazethapyr 100 to 125 g/ha registered more than 85% of weed control efficiency. Weed control index (WCI) was found highest with imazethapyr 125 g/ha followed by doses of 100 and 75 g/ha at 40 and 60 DAS during both

Table 1. Effect of imazethapyr as post-emergent herbicide on weed density and weed biomass in common bean

Treatment	Weed density (no./m^2)*				Weed biomass (g/m^2)*			
	40 DAS		60 DAS		40 DAS		60 DAS	
	2021	2022	2021	2022	2021	2021	2021	2022
Imazethapyr 25 g/ha	6.41(40.7)	6.12(37.3)	7.60(57.3)	8.63(74.7)	2.97(8.3)	2.71(6.9)	16.18(261.5)	16.05(257.3)
Imazethapyr 50 g/ha	5.93(34.7)	5.68(32.0)	7.24(52.0)	8.27(69.3)	2.36(5.1)	2.35(5.0)	11.61(134.6)	10.49(110.0)
Imazethapyr 75 g/ha	5.11(25.7)	4.65(21.3)	5.68(32.0)	7.68(58.7)	2.30 (4.8)	2.24(4.5)	8.03(64.0)	7.95(63.0)
Imazethapyr 100 g/ha	5.10(25.7)	4.63(21.3)	5.69(32.0)	6.90(48.0)	2.20(4.3)	2.17(4.2)	7.23 (52.3)	7.17(51.0)
Imazethapyr 125 g/ha	4.84(23.0)	4.61(21.3)	5.69(32.0)	6.90(48.0)	2.16(4.1)	2.15(4.1)	7.02(49.1)	6.91(48.3)
Two manual weeding (20 and 40 DAS)	4.88(23.3)	5.70(32.0)	4.66(21.7)	7.32(53.3)	2.98(8.4)	2.72(6.9)	13.87(192.0)	11.78(138.7)
Weed free (20, 40 and 60 DAS)	3.97(15.3)	4.06(16.0)	3.72(13.7)	5.58(32.0)	1.73(2.5)	1.66(2.3)	6.28(39.8)	6.14 (38.0)
Weedy check	9.68(93.3)	15.5(240.0)	9.99(99.3)	18.19(330.7)	5.40(28.7)	5.15(26.0)	21.73(472.0)	19.53(381.0)
LSD (p=0.05)	0.65	0.91	0.75	1.65		0.19 0.31	1.30	1.38

Note: * values presented in parentheses were original and are subjected to square root transformation.

years. Treatments with the herbicide imazethapyr 75 to 125 g/ha efficiently suppress the weeds. The lower value of WI was recorded with imazethapyr 125 g/ha followed by imazethapyr 100 and 75 g/ha. Similar findings were also reported by Singh (2011) (**Table 2**)

Growth parameters

The plant height was significantly taller with weed free treatment during both years at 40 and 60 DAS than weedy check treatment. The plant height was at par with all the doses of imazethapyr at 40 and 60 DAS during 2021 but during 2022 at 40 DAS significantly taller plant were observed with imazethapyr 125 and 100 g/ha than the doses of 25, 50 and 75 g/ha. All the doses of imazethapyr were at par at 60 DAS. It may be due to reduction in weed competitiveness with the crop which ultimately favoured better environment for growth and development of crop. Singh *et al.* (2014 a.) reported similar results. These outcomes are very close to those of Chattha *et al.* (2009) and Raman and Krishnamorthy (2005).

Leaf area index was significantly maximum in weed free treatment during 2021 at 40 DAS, which were at par with imazethapyr 100 g/ha and two manual weeding and at 60 DAS, LAI was maximum in weed free plot which were at par with two manual weeding followed by imazethapyr 125 g/ha.

Weed free treatment recorded significantly highest leaf area index during 2022 at 40 DAS, which was at par with doses of imazethapyr 100 and 125 g/ha and two manual weeding, but at 60 DAS it was at par with doses of imazethapyr 75 to 125 g/ha and two manual weeding. Dry matter accumulation was significantly maximum in weed free plot during 2021 at 40 DAS, which was at par with doses of imazethapyr 75 to 125 g/ha and two manual weeding at 60 DAS. It was at par with imazethapyr 100 and 125 g/ha. During 2022, highest dry-matter accumulation was observed in weed free treatment, which were at par with remaining herbicidal treatments at 40 and 60 DAS (**Table 3**).

Yield attributing characters

The use of herbicides in respective treatments over weed control throughout both years considerably boosted the yield features of common bean, including number of pods per plant, number of seeds per pod, and seed index. The weed-free treatment recorded significantly maximum number of yield attributes in terms of pods per plant during 2021 and seeds per pod during both years. Amongst the post-emergent herbicide applied treatments; maximum number of yield attributes were observed with imazethapyr 125 g/ha, which were at par with rest of herbicide applied treatments. Seed index is also observed maximum in weed free treatment which

Table 2. Effect of imazethapyr as post-emergent herbicide on weed control performance in common bean

Treatment	Weed control efficiency (%)				Weed control index (%)				Weed index (%)	
	40 DAS		60 DAS		40 DAS		60 DAS			
	2021	2022	2021	2022	2021	2022	2021	2022	2021	2022
Imazethapyr 25 g/ha	55.88	84.54	42.26	77.27	70.90	73.38	44.45	32.48	32.64	23.78
Imazethapyr 50 g/ha	62.32	86.74	47.67	78.94	82.16	80.76	71.31	71.13	22.56	16.61
Imazethapyr 75 g/ha	72.22	91.14	67.78	82.27	83.24	82.56	86.45	83.53	14.95	10.49
Imazethapyr 100 g/ha	72.58	91.21	67.82	85.30	84.85	83.78	88.77	86.58	12.54	8.33
Imazethapyr 125 g/ha	75.04	91.09	67.82	85.30	85.52	84.19	89.61	87.20	11.64	8.28
Two manual weeding (20 and 40 DAS)	74.89	86.63	78.20	83.94	70.65	73.36	59.04	63.69	19.53	11.20
Weed free (20, 40 and 60 DAS)	83.16	93.31	86.27	90.45	91.30	91.15	91.66	90.11	0.00	0.00
Weedy check	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	67.91	72.11

Table 3. Effect of imazethapyr as post-emergent herbicide on growth parameters in common bean

Treatment	Plant height (cm)				Leaf area index				Dry-matter accumulation (g/plant)			
	40 DAS		60 DAS		40 DAS		60 DAS		40 DAS		60 DAS	
	2021	2022	2021	2022	2021	2022	2021	2022	2021	2022	2021	2022
Imazethapyr 25 g/ha	31.8	26.9	52.9	46.0	1.31	1.03	4.61	5.10	4.89	3.23	11.11	11.04
Imazethapyr 50 g/ha	33.5	27.5	53.1	46.9	1.37	1.15	4.65	5.17	5.06	3.34	12.31	11.56
Imazethapyr 75 g/ha	33.6	27.6	53.8	47.0	1.48	1.25	4.67	5.24	5.36	3.89	13.32	12.46
Imazethapyr 100 g/ha	34.0	28.4	54.3	47.2	1.49	1.59	4.69	5.27	5.37	3.72	13.40	12.91
Imazethapyr 125 g/ha	36.7	30.5	55.4	49.3	1.49	1.60	4.82	5.29	5.38	3.67	13.52	12.45
Two manual weeding (20 and 40 DAS)	34.0	28.0	53.9	47.4	1.58	1.56	5.04	5.54	5.38	3.81	12.67	12.75
Weed free (20, 40 and 60 DAS)	37.6	28.8	58.3	51.9	1.68	1.66	5.07	5.84	5.73	3.84	14.36	12.79
Weedy check	25.0	22.9	38.8	41.4	1.19	0.98	3.21	3.83	4.03	2.14	8.55	6.08
LSD (p=0.05)	5.1	2.5	6.8	3.7	0.19	0.30	0.12	0.66	0.51	0.76	1.02	2.09

Table. 4. Effect of imazethapyr as post-emergent herbicide on yield attributes in common bean

Treatment	No. pods/plant		No. seeds/pod		Seed index	
	2021	2022	2021	2022	2021	2022
Imazethapyr 25 g/ha	9.75	9.40	4.67	4.378	39.53	40.13
Imazethapyr 50 g/ha	9.91	9.47	4.84	4.60	40.94	40.97
Imazethapyr 75 g/ha	9.95	9.53	4.86	4.73	41.86	42.47
Imazethapyr 100 g/ha	9.97	9.57	4.88	4.77	42.40	43.80
Imazethapyr 125 g/ha	9.99	9.60	4.95	4.83	42.86	43.87
2 Manual Weeding (20 and 40 DAS)	9.96	9.57	4.91	4.82	44.47	47.12
Weed free (20, 40 and 60 DAS)	10.67	10.10	5.34	5.30	45.00	47.87
Weedy check	7.30	7.20	4.32	3.97	35.40	30.57
LSD (p=0.05)	0.31	1.14	0.38	0.31	5.28	4.25

Table 5. Effect of imazethapyr as post-emergent herbicide on yield and economics in common-bean

Treatment	Seed yield (t/ha)		Stover yield (t/ha)		Harvest index (%)		B: C ratio	
	2021	2022	2021	2022	2021	2022	2021	2022
Imazethapyr 25 g/ha	1.44	1.61	3.09	3.54	31.67	31.25	1.79	2.11
Imazethapyr 50 g/ha	1.65	1.70	3.35	3.56	33.00	32.28	2.18	2.26
Imazethapyr 75 g/ha	1.81	1.90	3.57	3.80	33.67	33.46	2.45	2.62
Imazethapyr 100 g/ha	1.87	1.95	3.62	3.84	34.00	33.71	2.52	2.66
Imazethapyr 125 g/ha	1.89	1.97	3.61	3.99	34.33	32.77	2.52	2.66
Two manual weeding (20 and 40 DAS)	1.72	1.82	3.47	3.63	33.07	32.37	1.40	1.54
Weed free (20, 40 and 60 DAS)	2.14	2.36	3.97	4.26	35.00	35.63	1.67	1.94
Weedy check	0.69	0.67	2.53	2.52	21.33	21.00	0.48	0.43
LSD (p=0.05)	0.19	0.32	0.15	0.29	2.78	3.39	-	-

were at par with doses of 100 and 125 g/ha and two manual weeding. This increment in yield attributes was attributed to higher growth parameter, enhanced root development and nodule formation which might have favoured for significant development of yield attributes. Awan *et al*. (2009) and Madukwe *et al*. (2012) showed similar results (**Table 4**).

Yield

Seed yield and stover yield were varied significantly with the different herbicide treatments. Seed yield was significantly highest with weed free plots during both years. Among the weed management practices, herbicidal imazethapyr with doses of 75 to 125 g/ha were at par but significantly lower than weed free in 2021. However, in 2022, these herbicide treatments were also at par to 2 manual weeding (20 and 40 DAS). Among all the treatments, the weedy check treatment had the noticeably lowest seed output. Stover yield followed the same trend. It can be clearly expressed that higher weed infestation was responsible for reducing seed yield of common bean which faced tremendous competition with vigorous weed infestation. The same observations were made by Vollmann *et al*. (2010). Akter *et al*. (2013) also reported that effective weed management techniques increased yield. Imazethapyr at lower doses (25 to 50 g/ha) was ineffective in controlling weeds and improving the productivity of common bean. However, imazethapyr 75 to 125 g/ha was found to be efficient for managing sedges, grasses and BLW's as well as in improving yield of common bean than at lower doses due to its high WCE. Harvest index was found significantly highest in weed free treatment than weedy check and imazethapyr 25 g/ha. Rest of the treatments were found statistically at par with weed free (**Table 5**).

Economics

Imazethapyr was found to have the highest B: C ratio at 125 and 100 g/ha, followed by 75 g/ha. Imazethapyr treatments at 125, 100, and 75 g/ha had the highest net return and B: C ratio, which was primarily the result of superior weed control at low cost and increased yield. Singh (2011) and Kumar *et al*. (2010) both noted similarities. (**Table 5**).

Conclusion

Under rainfed temperate conditions in Kashmir, post-emergence application of imazethapyr 100 g/ha at 25 days after sowing was found to be more economically viable than other treatments for controlling weeds.

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RESEARCH ARTICLE

Impact assessment of manually operated Ambika rice weeder on the economy of Chhattisgarh, India

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ABSTRACT

The impact assessment of an agricultural technology is a complex process of identifying the consequences of its commercialization, dissemination, multiplication and active adoption on a large scale by the end users. Many agricultural engineering technologies generate two kinds of benefits: reduction in cost of operation by virtue of decreasing time required for operation and saving in input and labour engagement, as well as increase in productivity due to the timeliness and uniform quality of farm operations. The present study attempted to estimate the impact of the adoption of Ambika rice (paddy) weeder for conducting weeding operations in line-sown rice on the economy of Chhattisgarh state in India. The economic surplus methods for assessing the impact of agricultural research was adopted for estimating the benefits attained by rice farmers, millers/processors, retailers and consumers. The study revealed that a net present worth of about ₹ 6450 crore (₹ 64500 million) was realized from the adoption of Ambika rice weeder for weeding in line-shown rice fields whereas, other associated stakeholders like millers/processors, rice retailers *etc.* earned a gross income of about ₹ 515 crore (5150 million) from the processing and value addition of surplus rice produced due to adoption of the technology. The aggregate economic impact was about ₹ 6965 crore (69650 million) as per 2011-12 prices for the period of 2012-13 to 2019-20 due to adoption of Ambika rice weeder by rice farmers in Chhattisgarh.

Keywords: Ambika rice (paddy) weeder, Economic surplus method, Impact assessment, manually operated weeder

INTRODUCTION

Impact assessment is defined as the process of identifying the future consequences of a current or proposed action or intervention. It is assessed in terms of reckonable outcomes such as income and employment generation, poverty reduction, conservation of natural resources, organizational and institutional change, *etc*. Currently, Indian agriculture is facing many challenges like never before. There has been a fall in public investment in agriculture, declining growth in partial and total factor productivity, increasing inter and intra-regional disparities, persistence of wide-spread poverty and decreased quantity and quality of natural resources like land, water and biomass (Singh and Agrawal 2018). Engineering interventions in the agriculture sector have been contributing in enhancement of input use efficiency, augmenting productivity of crops, reducing drudgery associated with various farm operations, ensuring environmental sustainability and also safeguarding nutritional requirements for the people. Agricultural mechanization is also crucial for increasing farm productivity and agrarian income for small and marginal farmers who constitutes about 86% of total cultivators in India. The farmers are also witnessing the shortage of agricultural labourers during peak periods, which can only be resolved by promotion of farm mechanization. As a result, they are adopting farm mechanization than ever before. The Indian government is also trying to transmit the benefits of mechanization to small and marginal farmers through diversified initiatives, such as Sub Mission on Agricultural Mechanization (SMAM), introduced in 2014-15 by the Government of India. During 2014-15 to 2020-21, a sum of about ₹ 45.57 billion was released under this scheme to the states and other implementing institutions. Distribution of various subsidized, improved agricultural equipment and machinery to individual farmers is also one of the objectives of this scheme. As a result, the nation witnessed phenomenal expansion of cropped area, cropping intensity and agricultural production along with an increase in farm power availability from 2.02

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kW/ha in 2016-17 to 2.49 kW/ha in 2018-19 (MoA&FW 2021). To corroborate this initiative, a number of promising and need based engineering technologies were developed by National Agricultural Research System in India, for which an impact assessment exercise needs to be conducted with socio-economic and environmental dimensions.

Rice is the main food grain crop cultivated in Indian state of Chhattisgarh, where it was cultivated in an area of 3.67 million hectares during 2019-20 with a production of 6.77 million tonnes. However, the yield of rice obtained in this state was only 1848 kg per hectare as compared to national average of 2722 kg per hectare (Agricultural Statistics at a Glance 2021). One of the major reasons for low yield could be the traditional cultivation practices in which sprouted rice seeds are broadcasted on puddled field. However, line-showing/ transplanting of rice are recommended for obtaining more yield which also requires efficient weed control practices. Pandey *et al*. (2018) reported that about 75% of rice area is under broadcasting, 15-17% is under transplanting and 8-10% area is covered by direct-drilling method of rice seeding in Chhattisgarh. For controlling weeds in directl-drilled and transplanted rice in marginal and small farms, the agricultural university of Chhattisgarh state namely Indira Gandhi Krishi Vishwa Vidyalaya (IGKVV), Raipur, developed a manually operated Ambika rice weeder which can be operated in line sown rice to cut and uproot the weeds between rows. This equipment became very popular among rice growers in Chhattisgarh because it not only reduced the cost of weeding operation as compared to hand weeding by 54.38% (Tayade 2016), but also contributed in yield increase by 14.35% as reported by Dange *et al.* (2017). They also observed that the average field capacity for Ambika rice weeder was about 0.016 hectare per hour and the working life of the equipment is about 1000 hours spread over a period of eight years. As the maximum crucial time available for each of two weeding operations is about two weeks, this equipment can cover about 1.79 hectare of land in *Kharif* (rainy) rice.

Considering these realized benefits from large scale adoption of Ambika rice weeder by farmers of Chhattisgarh over the last decade, its impact on farm sector as well as economy of the state was systematically assessed at various levels of the society.

MATERIALS AND METHODS

The manually operated Ambika rice weeder has a simple structure comprises of serrated strips, float, a frame and handle for operation. Strips are cut forcefully fit as a fiddle consistently along its length mounted on round cutting edge welded to outline (Tayade 2016). Ambika rice weeder is operated at a standing water of 5-6 cm between the rows of rice by pushing and pulling action of weeder (Netam and Mahilang 2018). Thus, it helps in killing of weeds as well as loosening the soil between rows, enhancing the microbiological activities, aeration and water intake capacity (Verma and Patel 2021). This made the equipment quite popular among the farmers and their demand for this equipment is met from various public and private suppliers. The yearly supply data were collected from records of such sources and various performance and operational parameters were recorded from published literatures and statistical compendiums. Area, production, and average yield of rice in Chhattisgarh during 2012-13 to 2019-20 was recorded from various issues of Agricultural Statistics at a Glance, Directorate of Economics and Statistics, Ministry of Agriculture and Farmers' Welfare, Government of India. The supply of rice to all markets of Chhattisgarh *i.e.*, market arrival of rice and wholesale price offered during these years were recorded from online published data of Directorate of Marketing and Inspection, Ministry of Agriculture and Farmers' Welfare, Government of India. The wholesale and retail prices of processed fine rice were recorded from online published database of Department of Consumer Affairs, Ministry of Consumer Affairs, Food and Public Distribution, Government of India. The conversion factor of rice into fine rice and various by-products such as rice husk, broken rice, rice bran and other feeds for both parboiling and non-parboiling process of rice were adopted from a study on rice hulling and milling in 80 rice mills in Chhattisgarh, which reported that about 3967 tonnes of parboiled fine rice and 3100 tonnes of non-parboiled fine rice were produced from 6067 tonnes and 5900 tonnes of rice, respectively (Thakur *et al.* 2012). The ratio of value of raw material (rice) to various by-products was calculated and used for estimation of value of the all by-products over this period assigning respective weights for parboiling and non-parboiling methods of processing of rice. The findings from the study are summarized in **Table 1**.

Analytical framework

The data were analysed adopting Economic Surplus Model (Masters *et al.* 1996, Sant Kumar *et al*. 2011) for estimating social gain from research. This can be elaborated in **Figure 1**, depicting the shift of supply curve from S_1 to S_2 due to technological

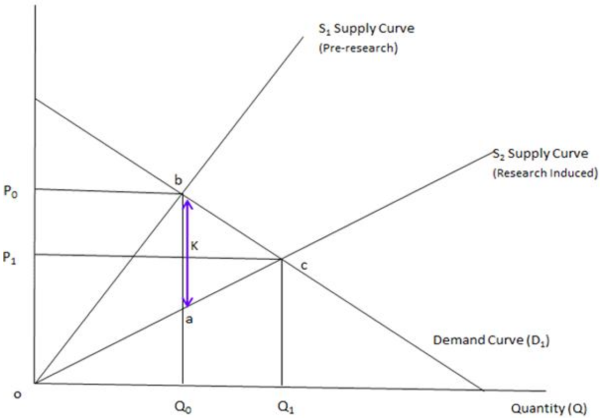

Figure 1. Technology induced vertical shift of supply curve

progress as an outcome of research while demand curve remains unchanged. As a result, the equilibrium point shifts from b to c, highlighting the change of volume of trade from earlier Q_0 quantity at P_0 price to higher quantity of Q_1 at a reduced price of P_1. The social gain from research, obtained by adding both the producers' surplus and consumers' surplus is measured by the area of triangle 'abc'. This is equal to $\frac{1}{2} \times K \times \Delta Q$ where, K is the research-induced vertical shift of supply curve (from b to a) and ∆Q is change in quantity produced. For estimating the K parameter, known as technology induced supply shift in relative terms in comparison with conventional technology (manual weeding by khurpi (hand operated small spade), reduction in cost due to growth in yield was estimated from proportionate increase in yield reported in literature. Further, the change in input cost per unit of output after the adoption of technology was estimated from the proportionate change in production cost due to the adoption of technology. Finally, a net proportionate change in the cost of production per unit of output was obtained by computing the difference between these two parameters. Further, the proportionate reduction in output price due to technology intervention (Z factor) was obtained by multiplying K factor with the ratio of price elasticity of supply (ε) to the sum of price elasticities of supply and demand (η). The change in consumers' surplus was measured as, $\Delta CS = P_0 \times Q_0 \times Z \times (1+0.5Z\eta)$ and annual change in producers' surplus was estimated as $\Delta PS = P_0 \times Q_0 \times (K-Z) \times (1+0.5Z\eta)$. Therefore, the total gain of the society from the research was expressed as, $\Delta CS + \Delta PS = P_0 \times Q_0 \times K \times (1+0.5Z\eta)$, where P_0 is Initial equilibrium price and Q_0 is the Initial equilibrium quantity before adoption of technology. For assigning the value of price elasticity of demand and supply into economic surplus model, appropriate values were taken from published literatures. The price elasticity of supply (ε) was recorded as 0.210 (Mohanakumar and Kumar 2018) whereas, the price elasticity of demand (η) was recorded as 0.247 (Kumar *et al*. 2011). The net present worth of the technology was estimated at a discount rate of 6% per annum (based on average real rate of interest during 2012-19) considering the cost of technology development in base year (2011-12) price. The total impact on economy due to adoption of technology (Ambika rice weeder) is sum total of net present worth of the technology at base year price plus the aggregate margin of millers from rice processing, retailers' surplus margin by selling fine rice and estimated benefit to consumers from an expected price fall due to technology induced growth in production.

The number of total units of Ambika rice weeder was obtained by gradually adding the number of units supplied each year, starting from 2012-13. The area and productivity of rice in the state of Chhattisgarh were recorded from various issues of Agricultural Statistics at a Glance, published by the Directorate of Economics and Statistics, Ministry of Agriculture and Farmers' Welfare, Government of India. The area under line-sown rice in Chhattisgarh was calculated as one-fourth of total area under rice crop which constitutes the potential area for adoption of this technology. The area covered by Ambika rice weeder was obtained by multiplying its area covered annually by one unit (1.792 hectares per annum) with number of units in operation for each year. The adoption rate of Ambika rice weeder was calculated by dividing the area under the technology by the total potential rice area for its adoption. The values of various parameters for estimating technology-induced shift in supply curve to put into the economic surplus model were taken from various published literatures.

RESULTS AND DISCUSSION

During the period under study, the adoption rate of this equipment increased from 3.6% to 27.8% for

Table 1. Conversion of rice into various by-products with their value

Particular	Rice	Fine rice	Broken rice	Rice husk	Rice bran	Other feed
Quantity (tonnes)	11966.7	7066.7	1440.8	2719.9	401.0	338.3
Conversion Factor	1.0	0.59	0.12	0.23	0.03	0.03
Value (million ₹)	111.50	108.24	11.24	3.89	4.01	0.34
Conversion Factor	1.000	---	0.101	0.035	0.036	0.003

Table 2. Adoption of technology and primary benefit to farmers in different years

Year	Number of units in field	Area under rice ('000 ha)♦	Line sown rice area (ha)*	Area under technology (ha)	Adoption rate	Rice Yield (kg/ha)♦
2012-13	19040	3785	946250	34120	0.0361	1746
2013-14	39493	3802	950500	70771	0.0745	1767
2014-15	58097	3809	952250	104110	0.1093	1659
2015-16	73920	3816	954000	132465	0.1389	1516
2016-17	93501	3830	957500	167554	0.1750	2102
2017-18	109168	3761	940275	195629	0.2081	1311
2018-19	125392	3606	901500	224702	0.2493	1811
2019-20	141989	3666	916500	254444	0.2776	1847

*Constitutes 25% of total area under rice in Chhattisgarh state (Pandey *et al.* 2018).

mechanical weeding in rice cultivation (**Table 2**). The yield of rice was always recorded quite low in Chhattisgarh (less than 2 tonnes per hectare) during the period under observation.

The proportionate increase in yield over manually conducted hand weeding was taken as 14.35% (Dange *et al*. 2017) along with a 54.38% reduction in cost of production (Tayade 2016) for estimation. The proportionate reduction in cost solely due to yield increase was 0.6834 and the change in input cost per unit of enhanced output was estimated at 0.4755. The aggregate net change in cost of production per unit of output was 1.1589 under the given circumstances (**Table 3**). As the estimation procedure was an *ex-post* analysis after successful development and commercialization of the technology, the probability of success for the technology was taken as 1. Similarly, with the technology being in early phase of gradual adoption and a superior alternative technology not in sight for replacement, the technology obsolescence rate was ignored with complete preference for adoption as 1.

The incremental shift in supply curve due to adoption of Ambika rice weeder in relation to existing practices for weeding is elaborated in **Table 4**. With progress in adoption of the technology by the users, the supply curve shifted downward from 4.18 to 32.18% during the study period. Consequently, the supply price for rice was also reduced from 1.92 to 14.79% during the same period. The price as well as production of rice in Chhattisgarh before the adoption of the technology was recorded as ₹ 10290 per tonne and 6159000 tonnes, respectively, in 2011-12 which was also designated as the base year for the current inflation index.

The addition in producers' surplus, consumers' surplus and total surplus due to the adoption of technology was assessed with the help of K and Z parameters estimated earlier, price elasticities of supply and demand, as well as price and quantity produced at base period. The producers' share in total surplus was observed to be a little bit higher (54.05%) as compared to that for consumers' (45.95%) for the study period. The total surplus or net social gain, from the development and adoption of the technology was estimated as ₹ 9438.40 crores (₹ 94384 million) (**Table 5**). Considering the spending of about ₹ 0.03 crores (0.30 million) on research and development of the technology, the net present worth of the technology for a period of eight years after its successful commercialization was about ₹ 6450 crores (64500 million) due to adoption of the technology by the rice farmers by virtue of savings in cost of operation as well as returns from additional production.

Table 3. Parameters for estimation of technology induced supply shift for rice

Parameter	Value
Price elasticity of supply for rice (ε)	0.2100
Price elasticity of demand for rice (η)	0.2470
Proportionate increase in yield (ΔY)	0.1435
Proportionate change in cost of production (ΔC)	-0.5438
Cost reduction due to yield growth (ΔY/ε)	0.6834
Change in input cost per unit of output [ΔC/(1+ΔY)]	-0.4755
Aggregate change in net cost of production per unit of output	1.1589
Probability of success for technology	1.00
Preference for adoption due to obsolescence for technology	1.00

Table 4. Technology induced shift of supply curve and reduction in output price

Year	Technology induced proportionate shift of supply curve (κ)	Proportionate reduction in output price (z)	Price of rice before adoption (₹/tonne)♦	Production of rice before adoption (tonnes)
2012-13	0.0418	0.0192		
2013-14	0.0863	0.0397		
2014-15	0.1267	0.0582		
2015-16	0.1608	0.0739		
2016-17	0.2028	0.0932	10290	6159000
2017-18	0.2411	0.1108		
2018-19	0.2889	0.1327		
2019-20	0.3218	0.1479		

♦Source: Directorate of Marketing and Inspection, Govt. of India

Table 5. Producers' surplus, consumers' surplus and total surplus with net present worth

Year	Producers' surplus (₹ crores*)	Consumers' surplus (₹ crores)	Total surplus (₹ crores)	Technology development cost at 2011-12 prices (₹ crores)	Net present worth of technology (₹ crores)
2012-13	143.48	121.99	265.47		
2013-14	297.03	252.54	549.57		
2014-15	437.15	371.67	808.82		
2015-16	555.67	472.43	1028.10		
2016-17	702.69	597.43	1300.12	0.0292	6449.88
2017-18	837.26	711.84	1549.10		
2018-19	1005.73	855.07	1860.80		
2019-20	1122.27	954.15	2076.42		
Total	5101.28	4337.12	9438.40		

*One crore is equal to 10 million

The additional rice produced in different years due to adoption of Ambika rice weeder was assessed from the area covered by technology and the reported yield increase. The quantity and value of additional paddy and fine rice produced due to adoption of technology were estimated from conversion factors given in **table 1** and the average wholesale prices for the commodities at Chhattisgarh markets obtained from the online database of Department of Consumer Affairs, Government of India (**Table 6**). The values of rice and fine rice were estimated at their current price for respective years.

The values of all by-products estimated in proportional rates with value of rice, obtained from conversion factors given in **Table 1** due to non-availability of their price data, are exhibited in **Table 7**. Among by-products, broken rice was contributing maximum (₹ 41.48 crores) to the value, followed by rice bran (₹ 14.79 crores), rice husk (₹ 14.39 crores) and other feeds (₹ 1.23 crores) during the entire study period. Together, the fine rice and all by-products amassed gross revenue of ₹ 521.47 crores from raw rice worth of ₹ 410.82 crores.

During the study period, the rice millers earned a gross income of ₹ 110.65 crores from processing the surplus rice produced due to adoption of technology. The rice retailers earned a gross margin of ₹ 51.91 crores by selling the fine rice at retail prices (**Table 8**). The rice consumers got benefitted from expected proportionate reduction retail prices due to enhanced supply of rice at the market. The anticipated reduction in expenditure for consumers was estimated as ₹ 501.54 crores during the entire study period. Adjusting the paybacks realized by all beneficiaries with GDP deflator values for respective years, the aggregate benefits in real price achieved by all stakeholders was ₹ 515.35 crores at base year (2011-12) price levels. Therefore, adoption of *Ambika* rice weeder in Chhattisgarh contributed a

Table 6. Value added from main product after rice processing

Year	Additional rice produced (Q)	Additional rice produced (Q)	Rice wholesale price (₹/Q)	Rice wholesale price (₹/Q)	Rice retail price (₹/kg)	Value of rice (₹ Crores)	Value of rice (₹ Crores)
2012-13	85519	50502	1125	2010	22.33	9.62	10.15
2013-14	179531	106019	1241	2354	26.12	22.28	24.96
2014-15	247926	146408	1278	2513	27.93	31.68	36.79
2015-16	288164	170169	1236	2467	27.50	35.62	41.98
2016-17	505447	298482	1350	2451	27.32	68.24	73.16
2017-18	368035	217336	1392	2618	29.23	51.23	56.90
2018-19	584009	344875	1550	2688	30.05	90.52	92.70
2019-20	674393	398250	1507	2836	31.68	101.63	112.94

*One crore is equal to 10 million

Table 7. Value added from by-products after rice processing

Year	Broken rice		Rice husk		Rice bran		Other feed	
	Quantity (Q)	Value (₹ crores*)	Quantity (Q)	Value (₹ crores)	Quantity (Q)	Value (₹ crores)	Quantity (Q)	Value (₹ crores)
2012-13	10297	0.97	19438	0.34	2866	0.35	2418	0.03
2013-14	21616	2.25	40805	0.78	6016	0.80	5075	0.07
2014-15	29850	3.20	56351	1.11	8308	1.14	7009	0.10
2015-16	34695	3.60	65496	1.25	9656	1.28	8146	0.11
2016-17	60856	6.89	114883	2.39	16937	2.46	14289	0.20
2017-18	44312	5.17	83650	1.79	12333	1.84	10404	0.15
2018-19	70315	9.14	132739	3.17	19570	3.26	16510	0.27
2019-20	81197	10.26	153282	3.56	22599	3.66	19065	0.30
Total value		41.48	--	14.39	--	14.79	--	1.23

*One crore is equal to 10 million

Table 8. Benefits obtained by various stakeholders from processing and value addition of rice due to adoption of technology

Year	Millers' gross margin (₹ crores*)	Retailers' gross margin (₹ crores)	Rice supply (Ton)		Retail Price (₹ / kg)		Consumers benefit (₹ crores)	GDP Deflator (Base year: 2011-12)	Aggregate benefits of all stakeholders in real price (₹ crores)
			Without adoption	After adoption	Without adoption	After adoption			
2012-13	2.22	1.08	2170227	2175277	22.38	22.33	11.28	107.93	13.51
2013-14	6.58	2.74	3143869	3154470	26.21	26.12	27.69	114.61	32.29
2014-15	10.66	4.10	4006292	4020933	28.03	27.93	40.89	118.43	46.99
2015-16	12.60	4.82	3192447	3209464	27.65	27.50	46.80	121.13	53.02
2016-17	16.86	8.39	3908467	3938315	27.53	27.32	81.55	125.05	85.41
2017-18	14.62	6.63	2945955	2967688	29.45	29.23	63.53	130.02	65.21
2018-19	18.02	10.93	2829378	2863866	30.42	30.05	103.63	134.87	98.30
2019-20	29.09	13.22	3457949	3497774	32.04	31.68	126.17	139.68	120.62
Total	110.65	51.91					501.54		515.35

*One crore is equal to 10 million

total real income of ₹ 6965.23 crores from rice production systems as well as processing and value addition of surplus rice by all associated stakeholders.

Conclusions

The study emphatically established that the technology known as *Ambika* rice weeder offered two simultaneous benefits in a single operation. It had field cpapacity of 0.014 ha/h, weeding efficiency of 80.1% and cost of operation of 1574 ₹/ha. This technology not only reduced the cost of operation to a great extent but also improved the quality of operation, thereby enhancing productivited. As a result, the small-scale rice growers enjoy a higher return at a lower cost which enhances the profitability in rice cultivation. This low -cost and easy to operate technology was adopted on a very large scale and was contributed to the economy of the state despite witnessing a fluctuation in yield as well as price in a volatile market. One of the major hindrances to its faster adoption is that only 25% of the rice growing area in Chhattisgarh practiced line sowing / transplanting of seedlings, therefore, still vast scope of this technology can be adopted. The rice producers were the most benefitted segment of recipients, followed by the consumers and various intermediaries enjoying the advantages of the technology.

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RESEARCH ARTICLE

Mapping of invasive plant species in Jalthal forest of Nepal using high resolution remote sensing data

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ABSTRACT

Invasive alien plant species (IAPS) can have consequential impact on the plant biodiversity, growth of native plant species and functional integrity of ecosystem. For example, in the Jalthal forest with an area of about 6000 ha in Eastern Nepal, *Mikania micrantha* and other invasive plants dominate the forest affecting the growth of native plant species, habitat of wild animals, and plant biodiversity. However, their identification and distribution over the forest is unclear to the management authorities. To address this problem and control, we mapped the distribution of invasive plant species to identify its location over the forest area. Using a high-resolution satellite imagery of ZIYUAN-3A (ZY3A), multispectral 5.8 m and panchromatic 2.1 m. A supervised image classification was performed using ground truth data and NDVI values. Accuracy assessment was performed to find the effectiveness by using high resolution satellite image. An overall accuracy of 82% with 0.74 kappa value was obtained. Results shows that about 1900 ha of the Jalthal forest is covered by the invasive plant species. The mapping of invasive alien plant species gives the current invasion level of the study area which will help in its management as well as in predicting the future distribution of the invasive plants.

Keywords: Invasion, Invasive alien plant species, Jalthal, Mapping, NDVI, ZY3A, Remote sensing

INTRODUCTION

Monitoring the structural and compositional dynamics of an ecosystem is essential to know the status of different biological components. The information obtained from the assessment is important to update the conservation strategies, operational plans and can be used for the effective management of ecosystem (Siwakoti *et al*. 2016). Therefore, reporting the invasion of alien invasive plant species (IAPS) is crucial to implant different control mechanisms and management prescriptions. Identification and prevention of invasion is one of the major challenges for the effective management of IAPS (Bradley and Marvin 2011). The invasive species such as *Mikania micrantha* and *Lantana camara* have the high capability to invade the high conservation and ecosystem value forest rapidly (Siwakoti *et al*. 2016). Invasive alien species are a major threat to native ecosystem, biodiversity and has the potentiality to alters the ecosystem process (Mukul *et al*. 2020, Raizada *et al*. 2008, Shabani *et al*. 2020). They are native to one region or area that are outside their normal distribution and are introduced either inadvertently or purposefully colonizing the new home or threatening the biological diversity (CBD 2010).

Forest fire, deforestation, increased temperature favors the distribution of invasive plants (Tiwari *et al*. 2005). It has been reported that one sixth of the land area and 17% of the earth's biodiversity hotspot are vulnerable to the invasion (Early *et al*. 2016). The morphological, physiological and ecological attributes of the exotic plants make invasive species superior than other plant species in terms of adaptability to the new environment (Li *et al*. 2022). They have the advantage on photosynthetic rate, life-history attributes, genetics and display higher spatial growth capacity as well as productivity than indigenous plants (Qi *et al*. 2014). The major impact of IAPS can be seen on the biodiversity, economy and in the livelihood of the poor people. For instance, the impact from invasive plant- *Lantana camara* in the eastern Africa have created a negative consequence on the crop yield production, and in the forage of the livestock. It has also decreased the abundance of natural resources and medicinal plants of the area (Shackleton *et al*. 2017). Similarly, the forest product offered by the invasive plants are of secondary choice as compared to the primary forests product that supports rural livelihood (Rai *et al*. 2012). The other impacts of IAPS include the reduction in the reproductive capacity of local species, it changes the hydrological structure, affect the plant photosynthesis capacity and reduces the overall ecosystem functionality (Nilsson and Grelsson 1995).

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Numerous studies from the past, monitoring the occurrence of invasive plant species were mostly based from the herbarium records, information from research scientists, and professionals within the institutions, academics and museums (Haber 1997). The environmental data collected were often limited, restricted among subset of biological species, and needed reformatting for future use. They were scattered among the institutions in incompatible formats (Davis *et al.* 1990, Stoms and Estes 1993). Moreover, the inventory technique used in past to know the distribution of invasive plant lacks sufficient data which constraints the researchers to focus on specific taxonomic groups only (Stoms and Estes 1993). With time, the methods of documenting and reporting the IAPS has slightly changed and the methods of mapping the invasive plants are now more advanced. Now most of the studies utilize remote sensing and GIS techniques to demonstrate the change in ecosystem components, level of invasion and threat, which is more effective to address the instant control mechanisms.

With the advancement in both sensors and platforms, a noticeable progress has been made in mapping the invasive plants with increased accuracy. NDVI values, spatial resolution, hyperspectral imagery plays a significant role in precise detection of invasive plants (Dhakal 2021, Skowronek *et al.* 2017, Vidhya *et al.* 2017). For example, the use of Hyperion hyperspectral imagery and the hyperspectral images acquired from unmanned aerial vehicle (UAV) platform has successfully helped in the detection of the invasive plants such as, - *Phragmites australis*, and *Asclepias syriaca* in the study done in the coastal wetlands of the United States and Hungary, respectively. The hyperspectral imagery property has helped in the identification of IAPS with overall good accuracy.

Likewise, the NDVI improves the mapping accuracy and helps to accurately identify the distribution pattern of invasive plants (Bradley and Mustard 2006, Vidhya *et al.* 2017). A very high resolution (VHR) image is preferred for the detection of vegetation and non-native plant species (Bradley 2014, Feng *et al.* 2015). The detail and precise information in the VHR data helps to separate the signatures of different land cover types (Dhakal 2021) and is widely accepted for the recognition of invasive plants (Alvarez-Taboada *et al.* 2017, Carrión-Klier *et al.* 2022). Moreover, the numerous spectral bands of very high spatial resolution of hyper-spectral sensors can even pass through the Near-Infrared (NIR) and Short Wavelength Infrared (SWIR), allowing to differentiates the plant pigments and chemistry in both infra-red and visible bands, making it suitable for the mapping of invasive plants (Bradley 2014).

The invasion of *Mikania* and other non-native species have significantly affected the National Parks and Protected Areas (PA) of Nepal. The three of the world worst invasive plant, *Lantana camara*, *Mikania micrantha* and *Chromolena odorata* have already invaded the Chitwan National Park (CNP) and Parsa National Park (PNP) of Nepal with the potential threat to the habitat of endangered plants and animals. Almost 44% of *Rhinoceros* habitat is affected by the spread of non-native plants in the CNP and the spread is further intensified by the anthropogenic activities occurring in the park (Murphy *et al*. 2013). Similarly, the invasion of IAPS in the core area of PNP has already warned the park authorities for the possible threats to the natural habitats of endangered animals, like, *Rhinoceros* and *Panthera tigris* (Chaudhary *et al*. 2020). Another PA in Nepal with a high threat of IAPS is Jalthal forest area, which harbors, 150 species of trees, 145 species of herbs, 230 species of birds, 32 species of reptiles, 43 species of fishes and 27 species of mammals within 22 different management units (Sharma *et al*. 2021). Jalthal forest is the only remaining patch of the dense sub-tropical forest of Eastern Nepal. It provides an endless ecosystem service, ecotourism opportunity and is a source of subsistence livelihood to the rural communities. So, it is crucial to know the current invasion level in order to implant an adequate management approach. Our study will help the forest managers or responsible institutions to implement the appropriate control mechanism to maintain the biodiversity and forest vitality of this widely important natural landscape.

MATERIALS AND METHODS

Study area

The Jalthal forest of Jhapa district is the moist dense subtropical forest of the Eastern Nepal. The climate of the study area is tropical monsoon type with an annual average rainfall of 2130.4 mm and temperature varying from 10.05 ºC to 33.35 ºC (Bhattarai 2017). It lies in between 87º 55’ and 88º 03’ E longitude and 26º 27’ and 26º 32’ N latitude and covers an area of about 6000 ha (**Figure 1**). It consists of a wide variety of habitat such as lakes, rivers, grasslands, and is the home for the several threatened species of fauna and flora like *Eliphas maximus, Manis crassicaudata, Gavialis gangeticus, Rauvolfia serpentine*, *Cycas pectinata*, *Artocarpus chaplasha*. Initially, this forest patch was ecologically healthy and biologically diverse but with different anthropogenic and natural threats during last few years, it becomes more suitable for non-native plant

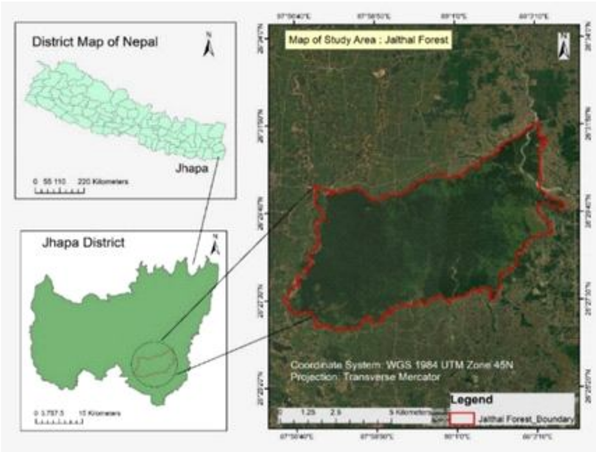

Figure 1. Map of the study area

Figure 2. Systematic sampling points all over the forest

species. Currently, the forest is heavily invaded by the exotic plants like *Mikania micrantha* and *Chromolena Odorata* resulting a higher threat to the natural habitats of Asian elephant. Apart of that, the landscape also has a social significance as, - a notable portion of the community forests user groups rely to the forest product for their subsistence livelihood.

Data collection

The field data were collected during the flowering period of invasive plants, in the month of October 2019. The study area included 22 community forests of Jalthal. A regular spacing of 1000 x 1000 m was set up by selecting create fishnet in ArcGIS 1 to represent the overall samples of the forest **(Figure 2)**. It was then divided in four different quadrants and the availability of the invasive plants were measured on each plot based on their presence. GPS coordinates and the percentage of IAPS as 25, 50, 75 and 100% was recorded if the invasion was observed in 1, 2, 3, and 4 quadrants, respectively. In the field, the coverage of sample sites was mostly affected due to the river, lakes, wetlands and occasionally by dangerous wild animals such as Elephant and Python.

Remotely sensed data

We obtained ZIYUAN-3A (ZY3A) satellite images from Department of Survey (DOS), Government of Nepal (GON) which was provided by Chinese government under Memorandum of Understanding (MoU) signed with each other. ZY3A is equipped with three high resolution panchromatic camera (also called Three-line Array Camera, TAC) with push broom array imager that has a spatial resolution of 2.1 m and the multispectral camera with 5.8 m resolution. The four bands of ZY3A gave the multispectral composite image, which helped to interpret and visualize the vegetation. The sensor specific detail of ZY3A is shown in **Table 1**.

Table 1. Sensor specifications of ZY3A

Bands	Bandwidth	Spatial Resolution	Applications
B1	450 – 520 nm	5.8m	Blue
B2	520 – 590 nm	5.8m	Green
B3	630 – 690 nm	5.8m	Red - Vegetation
B4	770 – 890 nm	5.8m	Infrared - Vegetation

Image pre-processing and NDVI calculation

Image was extracted for the study using sub-setting function in ERDAS Imagine software. A High Pass Filter (HPF) resolution merge was performed under the tool PAN sharpening in the satellite data containing the information of the study area and finally a 2.3 m colored multispectral image was obtained. The brightness as well as the contrast of the study image was improved after performing histogram equalization in ERDAS IMAGINE to better interpret the image. Then the Normalized Differential Vegetation Index (NDVI) of the study area was calculated.

The major land cover species presented at the site were invasive plants, forest, water, agricultural lands, and bare lands during the time of study. So, we divided the forest area into four classes- forest, invasive, water, and other lands (agricultural, bare lands, open spaces). The classification scheme for the agriculture land, bare land and open spaces is the ideal system of classification as our main objective was to classify the invasive plants using high resolution satellite data so we listed them under the single heading of 'Other Lands' during image analysis. To find the spectral reflectance value of different parameters, we calculated the NDVI using the following equation.

$$NDVI = \frac{\mathrm{IR} - \mathrm{R}}{\mathrm{IR} + \mathrm{R}}$$

where the IR and R are the infrared and red bands of the satellite image which gives the

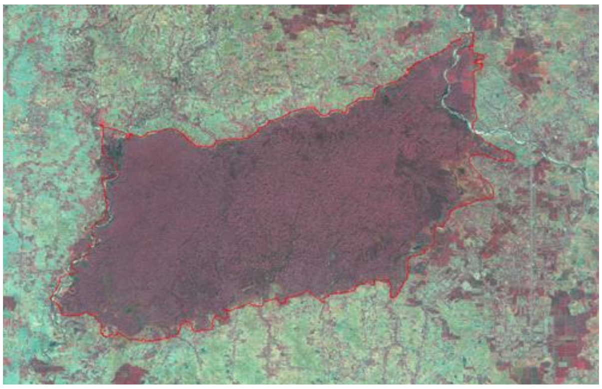

Figure 3. Image obtained after PAN sharpening

information presented in the band 4 and band 3 of ZY 3A. The reflectance value for each class were calculated. Then the image was finally projected to Universal Transverse Mercator (UTM) 45 zone and the training samples were created in ArcGIS. The field data and the GPS coordinates were laid on the image of the study area. For each class, at least ten training samples were created by drawing a polygon. Then a signature file was created from the training sample which was later used for the classification of the image.

Maximum likelihood classification

It is based on the Bayes Classification. In this classification, the classes are represented as C_i, where i = 1 to N, N represents the number of classes (Sisodia *et al.* 2014). The acquired satellite data was classified with (MLC) using the training samples as discussed above. The Maximum likelihood classifies the pixels based on the known properties of individual cover types and with acceptable results with the reference map (Ahmad and Quegan 2012). NDVI was used as a classification parameter while classifying the image with an aim to improve the mapping accuracy. The dense forest, water bodies and bare lands bear bright signatures **(Figure 4)** because of the high reflectance value as compared to the invasive plants. Overall, the NDVI values had helped to differentiate the classes and made the classification simple.

Accuracy assessment

Accuracy of the classified image was tested using the ground collected GPS points and confusion matrix. A field verification for the accuracy assessment was affected due to COVID- 19 pandemic during the later stage of the study. A total twenty-three number of random samples were used to assess the accuracy. The major land cover found for accuracy assessment were forests followed by the invasive plants based on its availability. The confusion matrix presented the overall accuracy and quality of the classification and of the individual class (Campbell and Wynne 2011).

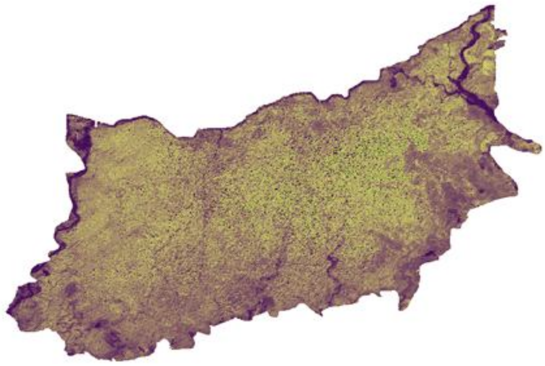

Figure 4. NDVI calculation of the study area

The parameters that give the information of confusion matrix were used to compare the results of different classification methods (Lewis and Brown 2001). Kappa coefficient was calculated and used for the measurement based on original agreement. The confusion matrix was used to calculate for the image classified through MLC. The producer and user accuracy of all classes were also calculated.

$$Kappa = \frac{2\times(TP\times TN-FN\times FP)}{(TP+FP)\times(FP+TN)+(TP+FN)\times(FN+TN)}$$

Where TP, TN, FN, FP represents the true positives, true negatives, false negatives and false positives.

RESULT AND DISCUSSION

NDVI Value of different land cover

The NDVI reflectance measurement values ranged from -1 to +1. It is clear from **Figure 5** that the dense forest has the highest reflectance value ranging from 0.941 to 0.070, which was because of the higher biomass as compared to the other classes like invasive plants (0.1532 to -0.0156), water (-0.015 to -0.714) and other lands (-0.0076 to -0.1889). In mapping, the NDVI with high spatial resolution image played a crucial role in the detection of the invasive plants. NDVI helped in giving more precise results by differentiating the scattered vegetation from a multispectral remote sensing image (Bhandari *et al.* 2012). It aims to assess the biomass quantity and offers the mean for the assessment of the phenological characteristics of the vegetation (Ghorbani *et al.* 2012, Szabo *et al.* 2016). The higher NDVI values represent the healthier and denser vegetation of the forest. For instance, the forest vegetation has the value ranging from 0.80 to 0.876 (Zaitunah *et al.* 2018) or 0.500 to 0.575 depending upon the vegetation coverage. The forest represents healthier and denser vegetation of the individual area. The other land cover classes such as water and soil have sparse vegetation ranging from 0.0175 to -0.328 and -

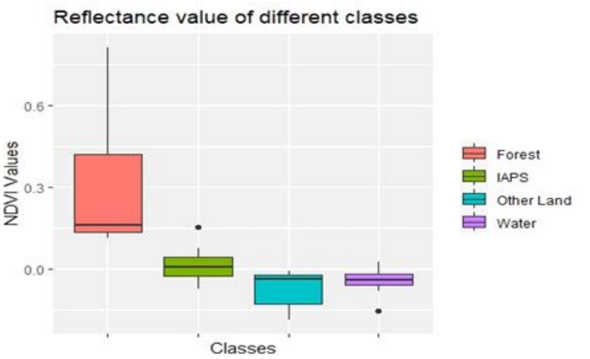

Figure 5. Box plot showing the spectral profile of different classes

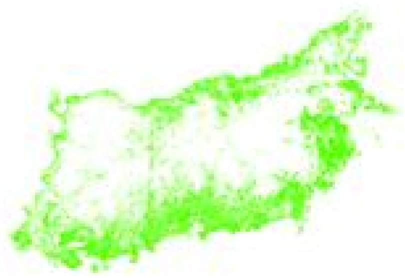

Figure 6. Invasion prone area of Jalthal forest

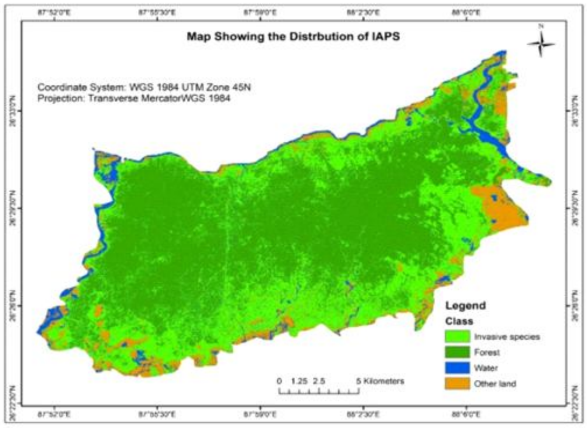

Figure 7. Map showing the distribution of Invasive plant in Jalthal

0.001 to 0.166, respectively (Jeevalakshmi *et al.* 2016). Han *et al.* 2022) has found the median value of maximum NDVI to be 0.56 within one year of invasion.

Distribution of different land cover classes

Overall, the Jalthal forest is dominated mostly with the forests cover with the coverage of 53.7% (**Table 2**), whereas the Water bodies and other lands such as bare and agriculture were found to be covered 5.4% and 8.9% of the study area respectively. The area and percentage coverage by each class of Jalthal forest is shown in the (**Table 2**)

It was clearly observed that the invasion was more concentrated on the periphery of the Jalthal forest area, where the forest cover was comparatively less **(Figure 6)**. These areas are near the roadways, rivers where the interaction of human is abundant. Similarly, while delving in the heart of the forest, it was found that the invasions were prevalent in the open area where there was no tree canopy. It was also noticed that the chance of invasion is higher near the water bodies and agricultural lands. Of the total forest area, the invasive plants covered almost 37% of the forest, spreading in an area of 1932 ha.

This study revealed that the growth and spread of the invasive species is highly influenced by the anthropogenic activities around the surrounding environment. Most of the invasive plants were in the areas near to the road, at the border of agricultural land, in the area close to the rivers and in the opening of the forest. This observation is in alliance with the study of (Pilu *et al.* 2012), who found that the invasion by the plant *Arundo donax* was mainly located in a riparian as well as in simplified ecosystem such as roadside where it could easily grow and flourish, surpassing the native plants. Moreover, the river banks are the preferred habitat of the invasive plants like *Mikania micrantha* in its native region as stated by Sapkota (2007). In the study area, the spread of IAPS inside the forest was most prevalent where there is no tree canopy. This is mainly because the forest has been experiencing immense pressure from outside. Fire, illegal cutting, overgrazing, population pressure for the high demand of the forest product and poaching are some of the disturbances that have been acting as a drivers of forest depletion in the study area. These reasons create a suitable environment for the non-native plant to adapt and grow in the area affecting the forest regeneration and growth. This observation of the present study is also supported by Shrestha and Dangol (2014) who observed the invasion of *Mikania micrantha* in CNP to be dominant in an area where the native vegetation is heavily disturbed. Once invaded the ground cover, the invaders can completely exclude and outcompete the growth of native plants leaving fewer resources for them to grow and thrive (O'Loughlin *et al.* 2021).

Table 2. Area covered by different classes of classified image

Class	Area (ha)	Area Coverage in (%)
Dense forest	3262	53.79
Invasive species	1932	31.86
Water	328	5.40
Other lands	542	8.93
Total	6064	100

Accuracy assessment and Kappa statistics

A field verification from Google earth was used to prepare the error matrix. The user accuracy for the invasive plants were found relatively low as compared to other classes while we obtained an overall good producer accuracy for all other classes. The land cover such as 'Forest' and 'Other Lands'

Table 3. Error matrix

Class	IAPS	Forest	Water	Other lands	Total	User Accuracy (%)
IAPS	4	2	0	1	7	57.14
Forest	1	9	0	0	10	90
Water	0	0	2	0	2	100
Other lands	0	0	0	4	4	100
Total	5	11	2	5	23	Overall accuracy = 82.60%
Producer Accuracy (%)	80	81	100	80		
Kappa coefficient = 0.74						

created the confusion with the IAPS class as they were predicted wrongly. Overall, the error matrix showed good accuracy of 82.60% with the Kappa coefficient 0.74 (**Table 3**).

The results from accuracy assessment and Kappa statistics helped to conclude that the high spatial resolution multispectral sensor is suitable to detect the invasive alien plant species. The improved spectral resolution provides the superior classification of invasive plant because of their biochemical and structural properties (Royimani *et al.* 2019). Like our result, the accuracy in the detection of Bracken fern when using high spatial resolution in the study done in South Africa was found to be 91.67%, which falls down to 72.22% with the use of medium spatial resolution (Ngubane *et al.* 2014). Moreover, the study done with the comparison of mapping invasive plant performed with very high spectral resolution VHR (less than 5 m) to that with the medium spectral resolution MR (15 m), shows that the VHR image produced overall high accuracy with high Kappa values than image produced from medium resolution imagery (Carrión-Klier *et al.* 2022). The strategically positioned bands in high spatial resolution multispectral sensors have better performance in the differentiation of the vegetation than that of low spatial resolution multispectral sensors (Royimani *et al.* 2019). The multi spectral image of ZY3A has a high resolution of 5.8m, and NIR wavelength of up to 890 nm which makes it suitable for the differentiation of the different vegetation types.

Obtaining the cost effective and relevant data in terms of large scale with high spatial information bears considerable challenges. Mapping invasive plant with high resolution data of ZY3A with NDVI produce good accuracy of 82.60%. The invasive plant species covered an area of about 37% in Jalthal forest. Mapping invasive plant in Jalthal forest gives the current invasion trend of the forest which can be beneficial in managing the future invasion of the study area. ZY3A data highlights the importance of high spatial remote sensing technique in mapping of invasive plant. The use of Maxent model and other classification technique can also be tested to further improve the accuracy of the image to know the future level of invasion of the study area.

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RESEARCH NOTE

Farmers' knowledge and herbicide application adoption in rice production systems in Chhattisgarh Plains of India

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ABSTRACT

Weeds are serious biological constraints in the rice production system. A survey was conducted using a structured questionnaire in two major rice-growing districts of Chhattisgarh Plains. There were 136 respondents. The objectives of the survey were to assess farmers' knowledge of current weed management technologies, farmers' adoption of available technologies and identify challenges faced by farmers to help in order to develop need-based sustainable weed management strategies. The majority of the farmers (68.4%) have reported using their seeds for sowing with 58% of the farmers cleaning the seeds before sowing. A seed rate of 120 kg/ha was being used by 55% of the rice growers. The majority of the respondents (58.8%) were aware of chemical weed management in crops. However, 89.7% of farmers were reportedly unaware of the correct dosage rate (45.6%) and correct application time (44.1%) of post-emergence herbicides. Regarding herbicide application timing, 55% of respondents applied at the 6-8 leaf stage of the weeds; 25% at the 5-6 leaf stage, and 20% were unaware of the time of herbicide application. Likewise, 88.2% of respondents spray the herbicide in a swinging pattern. This study highlighted the urgent need for policy intervention to improve the herbicide application technological knowledge level of rice farmers to improve input use efficiency and produce rice sustainably.

Keywords: Farmers' technological knowledge, Herbicide use, Rice, Technology adoption pattern, Weed management

Rice (*Oryza sativa* L.) is a staple food of more than 60% of the world's population. India and China are the leading rice-producing countries and contribute about 50% of the total rice production in the world (USDA-ERS 2021). Rice is cultivated in India in a very wide range of ecosystems from irrigated to shallow lowlands, mid-deep lowlands, and deep water to uplands. In India, about 44 million hectares (MH) area is engaged in a wide range of agro-ecosystems with a production of 119 million tonnes (MT), which account for 27 and 24% of acreages and production of the world, respectively with a productivity of 2-3 t/ha (USDA-ESMIS 2021). By 2025, about 140 MT of rice is required to feed the population in India and to achieve needed rice production, biotic and abiotic stresses are major hurdles (Choudhary and Dixit 2021). Among biotic stresses, weeds are one of the major yield reducers in rice due to their competition for resources like space, light, moisture, nutrients, *etc*. (Rao *et al.* 2017). The rice yield losses due to weeds range from 14-21% with a monetary loss of 4200 million US$ (Gharde *et al.* 2018). Weeds not only cause direct yield loss but also deteriorate the quality of produce, increase production costs, and act as an alternate host to pests (Mishra *et al.* 2021). Thus, to increase rice productivity using available resources judicially, it is essential to manage weeds that are more adaptive to adverse climatic conditions than rice and may cause complete crop loss under extreme conditions. The adoption of diverse technology is essential for weed management because weed communities are highly responsive to management practices (Rahman 2016). Effective and appropriate weed management technologies development and adoption necessitate a proper understanding of weeds.

It is imperative to understand the adoption pattern of the existing weed management practices by rice growers which are mainly influenced by knowledge, attitude, and perceptions of technologies (Singh *et al.* 2018; Laizer *et al.* 2019). The knowledge of the existing management practices adopted by farmers including first-hand information on weed management and herbicide application technologies used by farmers is needed to improve the available technologies, input use efficiency, and obtain higher rice productivity. Thus, this study was conducted in two districts of Chhattisgarh (Raipur and Dhamtari) to record weed management strategies

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followed by rice farmers as well as the constraints faced by them in the technological adoption and suggest needed policy interventions to bridge the knowledge gap.

Survey and data collection

The household surveys were conducted from June 2015 to February 2017 in Raipur and Dhamtari districts (major rice-growing areas) of Chhattisgarh. The areas surveyed have a normal average annual rainfall of 1140 and 1200 mm, respectively, and about 75-80% of the rain received from June to September months from the South-West monsoon. In these districts, rice is the predominant crop during the rainy season, and chickpea, wheat, lathyrus, and summer rice are other crops during the rest of the year. Farmers' rice fields holding are small in size (<2 acres) with a compartment bunded to collect the rainwater.

Data on rice farming, particularly knowledge, and adoption of weed management practices especially herbicide application techniques were collected through structured questionnaire. In the questionnaire, open and close-ended questions were asked and the response of respondents was recorded. During the data collection, group-wise discussions and personal interviews of 136 respondents (Raipur n=92, and Dhamtari n=44) were organized in both districts.

To achieve the main objective of the study, a multistage sampling procedure [selected two districts of Chhattisgarh (Raipur and Dhamtari) with six blocks (Raipur: Tilda, Dharsinwa, and Abhanpur; Dhamtari: Kurud, Dhamtari, and Magarload) and villages were selected randomly from the blocks] was employed in selecting respondents. Survey data were summarized and descriptive statistics were calculated using Microsoft Excel. For multiple answered questions, the percentages were calculated for each group of similar responses. The percentages of farmers in the two districts, who gave responses to a question were calculated based on the total number of farmers.

Seed purity awareness level among farmers: In the study area, the awareness level of the rice growers largely varied (**Table 1**). The majority of the respondents (68%, n=56) were using rice seeds (varieties: Swarna, Mahamaya, MTU 1010, MTU 1001, *etc*.) produced in their farm for sowing followed by seeds procured from neighbors (16%) and purchases from the market (15%). The seed rate of 120 kg/ha was used by 55% of respondents, followed by 100 kg/ha by 38%, while 7% of the respondents used 80 kg/ha of seed rate, which is 20% lower than recommended by the Agriculture Department. Similarly, 58% of the respondents cleaned the rice seeds before sowing, whereas only 23% of the respondents treated their seeds with brine solution or any other means before sowing. Thus, there was a huge variation among the practices followed by the rice farmers in the study site.

Table 1. Seed use pattern by respondent farmers in the study area

Particulars		% of respondents (n=136)
Source of seeds		
	Self	68
	Neighbor	15
	Purchase from market	16
	Change every year	1
Seed rate (kg/ha)		
	120	55
	100	38
	80	7
Cleaning of seeds before sowing		
	No	42
	Yes	58
Use of seed treatment brine solution or any other means		
	No	77
	Yes	23

Farmer's knowledge of weed management practices: Knowledge is the prerequisite for the adoption of innovative technologies. Respondents of 59% knew herbicides [pre-emergence herbicides: pyrazosulfuron-ethyl (dry- and wet-direct seeded rice, DSR), pendimethalin (dry-DSR), and others; post-emergence herbicides: bispyribac-sodium, penoxsulam, metsulfuron-methyl + chlorimuron-ethyl, fenoxaprop-p-ethyl, 2, 4-D amine salt, *etc*. (dry- and wet-DSR)] to be used in the rice crop grown in the area. Around 50% of the respondents knew about herbicides for the rainy season and only 9% of respondents expressed that they knew herbicides for rainy and winter season crops (2, 4-D amine salt, metsulfuron-methyl, clodinafop-propargyl, sulfosulfuron for wheat and pendimethalin for pulses). On the contrary, 41% of respondents were unaware of the use of herbicides in any of the crops. The respondents who were unaware of herbicides to be used are relying on herbicide retailers and neighbors. About 13% of respondents expressed that they are aware of herbicides to be used based on the weed flora, while the majority (87%) did not know about the selection of herbicides.

Regarding timing of herbicide application, the majority (90%) did not know at what stage of the crop or weed, post-emergent herbicides are to be applied, while 44% of respondents have reported using post-emergent herbicides late and only 22% of respondents applied at 2-4 leaf stage of weeds. The above findings indicate the existence of a wider herbicide application technologies knowledge level gaps amongst respondents'. Thus, knowledge level needs to be improved to get broad-spectrum weed control while applying herbicides.

In the survey area, about 82% of respondents were unaware of the importance of soil moisture content while applying pre-emergence herbicides (pyrazosulfuron-ethyl and pendimethalin) under dry-DSR conditions. Apart from these, 63% of rice growers have been applying herbicides as sand mix while 37% are using knapsack sprayers. Ninety-three percent of rice growers are unaware of the kind of nozzles to be used for herbicide applications. Still, the respondents were aware of nozzles but were not changing the nozzles while applying herbicides. While applying post-emergence herbicides water level in the field is important, but 52% of respondents said that they are not aware of how much water to be retained in the paddy. There must be >75% of weed foliage above the water level while applying post-emergence herbicides, as the majority of herbicides are absorbed through the foliage. Under dry conditions, plants are under stress, therefore, the herbicides that fall on foliage won't be properly absorbed and translocated, due to reduced stomatal conductance. Likewise, the herbicides that fall on the ground cannot be absorbed by plants thus resulting in poor weed control (Choudhary and Dixit 2018).

After the application of pre-emergence and post-emergence herbicides, some of the weeds are either escaped or not controlled or emerge late. They produce substantial seeds and are sufficient to cause economic damage during subsequent seasons. Those weeds need to be pulled out and only 36% of rice growers in the area remove the weeds before the crop harvest. Weed utilization is one strategy to manage the weeds, but 25% of respondents are unaware of weeds to be used, whereas, 46% of rice growers use weeds in the flowering or maturing stage in compost units, which should be avoided and 29% of respondents using weeds before flowering (**Table 2**).

Table 2. Weed management practices adopted by the respondent farmers in the study area

Particulars	% of respondents (n=136)
Knowledge about herbicides	
No knowledge	41
Rainy season	50
Rainy + winter season	9
Knowledge level of herbicide use as per weed population	
No	87
Yes	13
Knowledge about post-emergence herbicides	
No	90
Yes	10
Timing of post-emergence herbicide application	
No knowledge	34
Late application	44
Timely application	22
Knowledge about soil moisture content while pre-emergence herbicide application	
No	82
Yes	18
Applying method	
Sand	63
Knapsack sprayer	37
Knowledge about nozzle type used for herbicide	
No	93
Yes	7
Do farmers change nozzle for spraying different pesticides	
No	100
Water level in rice field while application of post-emergence herbicides	
No	52
Yes	48
Removal of weed before crop harvest to avoid seed rain (weed seed harvest)	
No	64
Yes	36
Use of weeds as compost materials	
No knowledge-0	25
After flowering-1	46
before flowering-2	29

Adoption pattern of weed management practices: The adoption pattern of any management practice largely depends on the knowledge level of respondents, the better the knowledge higher the adoption (**Table 3**). Fifty-two percent of respondents have been using 120-135 L/acre of water which is 10-20% less than recommended and 36% reportedly used 90-105 L/acre, which is further lesser by 30-40% than the recommended spray volume. Only 12% of the respondents have been using 150-165 L/acre which is at par with the recommendations. Around 54% of respondents use pre-emergence herbicides for weed management, although 50% were reportedly applying herbicides at 5-6 days after sowing (DAS), by the time weeds emerged and efficacy is expected to be comparatively lower. Thirty-five percent of respondents applied at 3-4 DAS, 13% at 1-2 DAS and only 2% at 0-1 DAS. However, it has been suggested to apply pre-emergent herbicides at 0-3 DAS for broad-spectrum weed control in rice (Choudhary and Dixit 2021). Presently, most of the pre-emergence herbicide molecules (pretilachlor + pyrazosulfuron, pretilachlor + bensulfuron, *etc.*) available in the market have a

Table 3. Herbicide application technologies adopted by the respondent farmers in the study area (n=136)

Particular	% of respondents (n=136)
The volume of water used for post-emergence herbicide application (L/acre)	
90–105	36
120–135	52
150–165	12
Use of pre-emergence herbicides	
No	63
Yes	73
Timing of pre-emergence herbicide use	
5–6 DAS	50
3–4 DAS	35
1–2 DAS	13
0–1 DAS	2
Dose of herbicide	
No	35
Yes	65
Application pattern of herbicide spray	
Swinging	88
Straight	12
Stage of weeds at post-emergence herbicides application	
No knowledge-0	20
>7 leaves	42
5-6 leaves	25
<4 leaves	13
Herbicides adoption level/pattern	
Only pre-emergent *fb* hand weeding (HW)	26
Pre-emergence *fb* post-emergence	40
Pre-emergence *fb* early-post-emergence *fb* HW	27
Pre-emergence *fb* post-emergence *fb* HW	7

wider application window of up to 7 DAS. Under the conditions of using recent herbicide molecules, herbicide efficacy can be enhanced. In the survey area, nearly 65% of respondents were well aware of doses of herbicides. It was also observed that around 88% of respondents used a swinging pattern of herbicide application and only 12% followed the suggested "straight pattern" of herbicide application. However, the knowledge level is gradually increasing. The majority of the respondents (42%) were applying herbicides after 7 leaf stage of weeds followed by 5-6 leaf stages (25%), whereas 20% of respondents were not aware of when to apply. Only 13% of respondents have been applying herbicides at the right stage (<4 leaf stage) (Choudhary *et al.* 2021). Seven percent of the respondents practiced pre-emergence followed by post-emergence, supplemented with hand weeding, whereas 40% relied exclusively on herbicides and 26% of respondents practiced pre-emergence followed by hand weeding in the survey area.

The majority of rice farmers have not adopted recommended rice production packages and weed management practices. Farmers were repeatedly using herbicides inappropriately. Thus, immediate policy intervention is required to enhance the weed management technology, knowledge level of rice farmers as well as extension functionaries working in the area by imparting training and demonstrations. Such efforts would strengthen scientific weed management practices adopted in rice by farmers and ultimately help to improve productivity and profitability judiciously.

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RESEARCH NOTE

Tillage and weed management effect on wheat in inceptisols grown under soybean-wheat cropping sequence

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ABSTRACT

A field experiment was conducted to study the effect of tillage and herbicidal weed management on soybean-wheat sequence during 2021-22. Four tillage treatments were given in main plot for soybean during *Kharif*; conventional tillage (CT: ploughing 2 harrowing tyne cultivator + harrowing with blade harrow), reduced tillage (RT: harrowing with tyne cultivator + rototill), minimum tillage (MT: rototill), zero tillage and in wheat uniform rototill was given to conventional tillage to minimum tillage (MT: rototill) treatments excluding zero tillage treatment where soybean crop residue was used for soil cover while the sub-plot treatments with five weed management treatments namely; sulfosulfuron + metsulfuron 0.030 kg/ha at 30 DAS, mesosulfuron + iodosulfuron 0.0144 kg/ha at 30 DAS, clodinafop + metsulfuron 0.064 kg/ha at 30 DAS, weed-free (3 HW at 20, 40 and 60 DAS), weedy check. The results indicated that the total weed density, weed dry matter and wheat grain yield were significantly influenced by various tillage practices at all stages of crop growth. Conventional tillage in the *kharif* and rototill in *rabi* season was found statistically most superior in respect to lowest weed density, weed dry matter, higher yield and economic returns over rest of the tillage treatments. However, the significantly highest value of total weed density and weed dry matter was recorded with zero tillage. Among the different herbicidal treatments, minimum weed density, weed dry weight, maximum yield and economic benefit was achieved with ready mix application of clodinafop + metsulfuron 0.064 kg/ha applied at 30 DAS.

Keywords: Clodinafop + metsulfuron, Mesosulfuron + iodosulfuron, Sulfosulfuron + metsulfuron, Tillage, Wheat

Wheat (*Triticum aestivum* L.) is the first important strategic cereal crop for the majority of the world's population. It is the most important staple food in the world. It exceeds in acreage and the production of every other grain crop (including rice and maize) and is therefore, the most important cereal grain of the world, which is cultivated over a wide range of climatic conditions. Wheat is infested with diverse weed flora, as it is grown in diverse agro-climatic conditions, under different cropping sequences, tillage and irrigation regimes (Rao *et al.* 2014). For the control of broad-leaf weeds in wheat, the major herbicides used in India are metsulfuron, 2,4-D and carfentrazone (Singh *et al.* 2012). As the wheat fields are infested with diverse weed flora and for their effective management, a combination of herbicides either as a ready mixture, if compatible or tank mixture, or as sequential, if not compatible are required. However, the sole dependence on herbicide of a single mode of action is also not advisable as it has contributed to a shift towards difficult-to-control weeds and the rapid evolution of multiple herbicide resistance, which is a threat to wheat production (Malik *et al.* 2013). The tillage system also influences the vertical distribution of weed seeds in the soil layer and weed diversity. No-till cropping system leaves most of the weed seeds in the top 1.0 cm of the soil profile, while in deep tillage, a significant reduction of weed population was observed due to the inversion of soil with mould board plough which resulted in the deeper placement of most of the weed seeds which could not emerge out (Chahal *et al.* 2003). Diversifying herbicide-based weed management by using rotation, tank mixtures, and sequential application in integration with tillage will help in controlling difficult-to-control weed species (Peerzadaa and Ali 2016). Keeping all these facts in view, the present investigation was carried out to find out the effective crop establishment method and herbicides for effective control of broad-spectrum weeds in wheat crops.

The experiment on conservation tillage practices in wheat was conducted at Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola during *Rabi* 2021-22. Akola is situated in the Sub-tropical zone at the latitude of 22042' North longitude of 770 02' East. The altitude of the place is 307.41 meter above mean sea level. The soil of the experimental plot was medium-deep black with fairly uniform and leveled topography with

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slightly alkaline in reaction with medium status of organic carbon content, available nitrogen and phosphorous and fairly rich status of available potassium. Four tillage treatments were given in main plot for soybean during *Kharif*; T1- conventional tillage (CT: ploughing, 2 harrowing with tyne cultivator + blade harrow), reduced tillage (RT: harrowing with tyne cultivator + rototill), minimum tillage (MT: rototill), zero tillage and in wheat uniform rototill was given to conventional tillage to minimum tillage (MT: rototill) treatments excluding zero tillage treatment where soybean crop residue was used for soil cover while the sub-plot treatments with five weed management treatments to wheat namely; sulfosulfuron + metsulfuron 0.030 kg/ha at 30 DAS, mesosulfuron + iodosulfuron 0.0144 kg/ha at 30 DAS, clodinafop + metsulfuron 0.064 kg/ha at 30 DAS, weed free (3 HW at 20, 40 and 60 DAS), weedy check. The gross plot size of the subplot was 70 m2, while the gross plot size of the main plot was 350 m2. The wheat variety WSM 109-4 during *Rabi* (November) was sown at row-to-row spacing of 22 cm. The application of herbicide was done as per the treatments with a manually operated knapsack sprayer attached to a flat fan nozzle. The recommended practice of fertilizer application was followed for the crop. The N, P and K were given in the form of urea, single super phosphate and muriate of potash to wheat 120:60:60 NPK kg/ha.

Weed flora: The major weed flora during *rabi* season in wheat in the experimental area composed of *Cyperus rotundus*, *Parthenium hysterophorus*, *Boerhavia diffusa*, *P ortulaca oleracea*, *Amaranthus viridis*, *Euphorbia hirta*, *Alternanthera triandra*.

Weed density: At 40 DAS up to harvest, the conventional tillage treatment recorded a minimum total weed count which might be due to good preparatory tillage operation *i.e.* ploughing and harrowing practices were carried out in *Kharif* season (for the previous crop), while maximum total weed count/m2 observed with zero tillage. A minimum number of total weed counts was noticed in treatment weed-free than the rest of the treatments from 40 DAS up to harvest. Among the herbicidal treatments clodinafop + metsulfuron 0.064 kg/ha at 30 DAS recorded the significantly lowest total weed population followed by mesosulfuron + idosulfuron 0.0144 kg/ha at 30 DAS and sulfosulfuron + metsulfuron 0.030 kg/ha at 30 DAS which have effective control of weed than weedy check. Among these herbicides mesosulfuron + idosulfuron 0.0144 kg/ha although found promising in reducing the weed population in wheat these herbicides expressed phytotoxicity on wheat, however, phytotoxicity with this herbicide was recorded 7 days after application of herbicides was minimal (<3) and recovered after two weeks.

Weed dry matter accumulation: The treatment conventional tillage registered significantly lowest weed dry matter from 40 DAS up to harvest while reduced and minimum tillage were at par with conventional tillage. This might be due to favorable conditions available for plant growth under tilled plots with healthy grown plants having fast metabolic activity leading to fast translocation of herbicides to their site of action inside the plant body (Kumar *et al.* 2014). The weed dry matter at 40 DAS up to harvest was significantly influenced by different weed

Table 1. Weed density, weed dry matter, and weed control efficiency as influenced by various tillage and weed management practices

Treatment	Weed density (no./m^2)		Weed dry matter accumulation (g/m^2)		Weed control efficiency (%)		Weed index (%)
	40 DAS	60 DAS	40 DAS	60 DAS	40 DAS	60 DAS	
Tillage management							
MT1 Rototill	3.04(8.7)	4.64(21.1)	3.93(14.9)	5.14(25.9)	79.57	72.34	8.35
MT1 Rototill	3.62(12.6)	5.56(30.4)	4.35(18.4)	5.65(31.5)	74.84	66.37	17.22
MT 1 Rototill	4.12(16.5)	5.87(34.0)	4.57(20.4)	5.89(34.1)	72.04	63.49	20.25
Zero tillage + R	4.64(21.0)	6.56(42.5)	5.46(29.3)	6.20(37.9)	59.88	59.49	26.33
LSD (p=0.05)	0.21	0.19	0.48	0.40	--	--	
Weed management							
Sulfosulfuron + metsulfuron 0.030 kg/ha at 30 DAS	2.17(4.2)	5.13(25.8)	2.97(8.3)	4.30(18.0)	88.64	80.79	17.57
Mesosulfuron + iodosulfuron 0.0144 kg/ha at 30 DAS	2.32(4.9)	5.37(28.3)	3.26(10.1)	5.20(26.5)	86.17	71.65	21.02
Clodinafop + metsulfuron 0.064 kg/ha at 30 DAS	1.51(1.8)	4.41(19.0)	2.32(4.9)	4.09(16.2)	93.35	82.66	7.96
Weed free	2.13(4.04)	2.40(5.2)	1.88(3.0)	2.39(5.2)	95.84	94.44	--
Weedy check	7.47(55.2)	8.77(76.4)	8.58(73.1)	9.70(93.5)	0.00	0.00	43.33
LSD (p=0.05)	0.19	0.14	0.30	0.18	--	--	--
Interaction (A ×B)							
LSD (p=0.05)	NS	NS	NS	NS	--	--	--

Data are subjected to square root transformation $\sqrt{x+0.5}$ and original data presented in parentheses control treatments in which hand weeding thrice (20, 40 and 60 DAS) recorded significantly lowest weed dry matter. The different herbicidal treatments applied, in which clodinafop + metsulfuron 0.064 kg/ha at 30 DAS recorded the lowest weed dry matter accumulation followed by mesosulfuron + iodosulfuron 0.0144 kg/ha at 30 DAS and sulfosulfuron + metsulfuron 0.030 kg/ha at 30 DAS were recorded lower weed dry matter. However, weedy check treatment recorded significantly higher weed dry weight. This might be due to combination of both herbicides effectively controlling the weeds in a broad-spectrum way (Grassy and Non grassy weeds) and showing a significant reduction in weed dry matter accumulation over the weedy check.

Weed control efficiency and weed index (%): The highest weed control efficiency (79.57%) was recorded in the treatment of conventional tillage at 40 DAS and the next best treatment was reduced tillage (74.84%). However, the lowest weed control efficiency (59.88%) was noticed with the treatment of zero tillage + residues. Similar was the trend of treatment differences in weed control efficiency at 60, 80 DAS and harvest. The weed index was significantly influenced by various tillage practices. Significantly lowest weed index (8.35%) was recorded with treatment conventional tillage which was followed by reduced tillage (17.22%). However, treatment of zero tillage recorded the highest weed index (26.33%). All Weed control treatment significantly influenced the dry matter accumulation of weeds, over the weedy check. The highest weed control efficiency was achieved with thrice hand weeding (20, 40 and 60 DAS) at 40 and 60 DAS. In herbicidal treatment at 40 DAS highest weed control efficiency (93.35%) was recorded with clodinafop + metsulfuron 0.064 kg/ha followed by sulfosulfuron + metsulfuron 0.030 kg/ha and mesosulfuron + iodosulfuron 0.0144 kg/ha at 30 DAS. It might be due application of a ready mixture of two herbicides which effectively control or check the growth of weeds in the abroad-spectrum way at the seedling stage. It was noticed that the lowest weed index (7.96%) was registered with post-emergence spray of clodinafop + metsulfuron 0.064 kg/ha at 30 DAS followed by sulfosulfuron + metsulfuron 0.030 kg/ha (17.57%) and mesosulfuron + iodosulfuron 0.0144 kg/ha (21.02%). This might be due to better control of weeds in this treatment which ultimately increases the yield as compared to all other ready-mix applications of herbicides. A combination of clodinafop + metsulfuron resulted in the highest WCE and WCI was reported by Rana *et al*. (2017). The highest weed index was registered by unweeded plots due to maximum yield reduction as well as heavy infestation of weeds and higher competition between weeds and crop plants.

Growth and yield attributes: Significantly highest plant height and total dry matter per plant were recorded with conventional tillage followed by reduced, minimum and zero tillage. Maximum plant height at harvest was recorded in cultural methods of hand weeding thrice but found at par with all post-emergence herbicide treatments. The next best treatments regarding plant height, dry matter accumulation and number of effective tillers were noticed with ready mix application of clodinafop + metsulfuron 0.064 kg/ha at 30 DAS which was at par with another combination of sulfosulfuron + metsulfuron 0.030 kg/ha and mesosulfuron +

Table 2. Growth and yield attributing characters of wheat as influenced by various tillage and weed management treatment

Treatment	Plant height (cm)	Dry matter/ plant (g)	Number of effective tillers (no./m^2)	Earhead length at harvest (cm)	Grain/ earhead at harvest	Test weight (g)
Tillage management						
MT1 rototill	102.72	17.03	427	9.14	50.69	41.88
MT 1 rototill	97.38	15.72	407	8.89	49.42	41.36
MT1 rototill	93.99	15.14	399	8.59	47.54	41.18
Zero tillage + R	88.15	14.66	363	8.18	46.59	40.98
LSD (p=0.05)	2.44	0.24	23.87	NS	NS	NS
Weed management						
Sulfosulfuron + metsulfuron 0.030 kg/ha at 30 DAS	95.89	15.33	419	8.78	50.29	41.42
Mesosulfuron + iodosulfuron 0.0144 kg/ha at 30 DAS	91.6	14.93	395	8.61	49.67	41.11
Clodinafop + metsulfuron 0.064 kg/ha at 30 DAS	98.8	17.26	410	8.88	51.28	41.52
Weed free	101.86	19.27	428	8.41	54.35	41.65
Weedy check	88.49	10.9	329	8.11	39.21	40.98
LSD (p=0.05)	6.27	0.28	14.54	NS	7.54	NS
Interaction (A ×B)						
LSD (p=0.05)	NS	NS	NS	NS	NS	NS

idosulfuron 0.0144 kg/ha applied at 30 DAS. The yield attributing characters namely spike length, spikelet per ear head and test weight could not reach up to a significant level with either ready mix application herbicides or thrice hand weeding. An interaction effect due to various tillage and weed management practices on growth and yield attributing characters was found to be non-significant.

Yield: The grain and straw yield was noticed significantly higher under conventional tillage (3.76 t/ha and 7.95 t/ha) over minimum and zero tillage excluding reduced tillage. Tillage affects the weeds by uprooting, dismembering and burying them deep enough to prevent emergence by changing the soil environment and by inhibiting weeds' germination and establishment, thereby creating favourable soil environment for plant growth, which would result in better yield attributes and yield (Jadhav 2014). The lowest yield was recorded in zero tillage system in soybean and wheat crops. Different weed control treatments significantly affected wheat grain yield. Maximum grain yield was achieved under weed-free situation i.e. thrice hand weeding (4.33 t/ha) followed by the ready mix application of clodinafop + metsulfuron (0.064 kg/ha) applied at 30 DAS (4.40 t/ha). The lowest yield (2.22 t/ha) was registered in weedy check treatment which might be due to severe weed competition with a crop that drastically reduced the grain yield. In respect of straw yield similar trend was also observed in wheat crops. An interaction effect of various tillage methods in soybean and weed management practices in wheat was found to be significant concerning the grain yield of wheat. Significantly higher grain yield was obtained with treatment combination of CT in previous season crop soybean with rototill in subsequent *Rabi* season wheat along with ready mix application of clodinafop + metsulfuron as PoE which in turn was found at par with reduced tillage given in previous season with single rototill to wheat with application of similar herbicide treatment. The ready-mix doses of clodinafop + metsulfuron at 35 DAS in wheat at 60 + 4 g/ha attained grain yields similar to weed-free check Yadav *et al.* (2009), Kumar *et al.* (2012) and Rana *et al.* (2017).

Economics: The net monetary return (NMR) values represent pure profit received by cultivating a specific crop with applied treatments. The statistical analysis revealed that various tillage practices significantly influenced the NMR values. Among tillage treatments minimum tillage with single rototill recorded significantly highest NMR which in turn was found at par with each other. The minimum NMR was recorded with zero tillage of ₹ 32232/ha. Among various weed management treatments, the

Table 4. Interaction between tillage and weed management treatment with respect to grain yield of wheat (t/ha)

Tillage management	Weed management W_1	W_2	W_3	W_4	W_5	Mean
MT1 Rototil	3.93	3.36	4.82	4.33	2.81	3.85
MT1 Rototil	3.67	3.00	4.68	4.23	2.73	3.66
MT1 Rototil	3.62	2.79	4.03	4.26	1.85	3.31
ZT+R	2.75	2.70	3.75	4.18	1.00	2.88
Mean	3.49	2.96	4.32	4.25	2.10	
LSD (p=0.05)			0.30			

W-1: Sulfosulfuron + metsulfuron 0.030 kg/ha at 30 DAS; W-2: Mesosulfuron + iodosulfuron 0.0144 kg/ha at 30 DAS; W-3: Clodinafop + metsulfuron 0.064 kg/ha at 30 DAS; W-4: Weed free; W_5: Weedy check

Table 3. Yield and economics of wheat as influenced by different tillage and weed management treatment

Treatment	Yield (t/ha) Grain	Yield (t/ha) Straw	GMR (x10^3 `/ha)	Cost of cultivation (x10^3 `/ha)	NMR (x10^3 `/ha)	BCR
Tillage management						
MT1 Rototill	3.76	7.95	74.31	30.95	43.35	2.41
MT 1 Rototill	3.65	7.92	72.11	28.31	43.80	2.56
MT1 Rototill	3.60	7.52	71.06	26.94	44.13	2.63
Zero tillage + R	2.88	6.08	56.83	24.60	32.23	2.25
LSD (p=0.05)	0.15	0.29	2.87	--	2.87	--
Weed management						
Sulfosulfuron + metsulfuron 0.030 kg/ha at 30 DAS	3.47	7.13	68.51	24.91	43.60	2.75
Mesosulfuron + iodosulfuron 0.0144 kg/ha at 30 DAS	2.95	6.50	58.31	25.88	32.43	2.26
Clodinafop + metsulfuron 0.064 kg/ha at 30 DAS	4.33	9.26	85.43	28.44	58.39	3.05
Weed free	4.40	9.20	86.83	37.09	48.34	2.31
Weedy check	2.22	4.71	43.80	22.17	21.63	1.94
LSD (p=0.05)	0.15	0.03	3.00	--	3.00	--
Interaction (A×B)						
LSD (p=0.05)	0.31	NS	NS	--	NS	--

Wheat MSP ₹ 19750/t

significantly highest net monetary return was noticed with clodinafop + metsulfuron (₹ 58389/ha) as a result of more productivity and best weed management, and the lowest return was recorded with treatment mesosulfuron + idosulfuron (₹ 33432/ ha) due to phytotoxicity on wheat.

The greater BCR value was delivered by treatment rototill and proved superior over ZT (2.25). Among various weed management treatments, treatment clodinafop + metsulfuron recorded the numerically maximum B: C of 3.05, which was followed by treatment sulfosulfuron + metsulfuron (2.75). This was due to higher grain and straw yield of wheat obtained from the above treatments and less cost of cultivation. Similar monetary benefit was also reported by Singh *et al*. (2004) and Singh (2014).

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RESEARCH NOTE

Weed dynamics, productivity and profitability of wheat as influenced by tillage and weed management practices in Eastern Indo-Gangetic Plains

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ABSTRACT

Wheat (*Triticum aestivum* L.) is infested with several grassy and broad-leaf weeds which create competitive stress resulting in yield losses varying from 10-70% depending upon their density. A field experiment was conducted during winter season of 2021-22 at the Research Farm, Bihar Agricultural University, Sabour, Bhagalpur, Bihar, India to assess the effect of tillage and weed management practices on weed dynamics, yield and economics of wheat. The experiment was carried out in a split plot design, replicated thrice. The main plot comprised of two tillage methods *i.e.*, conventional tillage and zero tillage while subplots consisted different herbicide combinations *i.e.*, weedy, weed free, pinoxaden 5.1% EC 20 g/ha, carfentrazone-ethyl 40% DF 20 g/ha, clodinafop-propargyl 15% WP EC 60 g/ha, carfentrazone-ethyl 20% DF 20 g/ha + pinoxaden 5.1% EC 20 g/ha, carfentrazone-ethyl 20% DF EC 20 g/ha + pinoxaden 5.1% EC 20 g/ha, metsulfuron-methyl 20% WP 4 g/ha + clodinafop-propargyl 15% WP 60 g/ha, metsulfuron-methyl 20% WP 4 g/ha + pinoxaden 5.1% EC 20 g/ha. The low weed density and biomass along with higher grain yield were recorded under zero tillage as compared to conventional tillage. Similarly, zero tillage recorded lower cost of cultivation (₹ 33702 /ha), higher net returns (₹ 69381 /ha) and B: C ratio (2.07). Among herbicide combinations, the treatment metsulfuron-methyl 20% WP 4 g/ha + clodinafop-propargyl 15% WP 60 g/ha followed by metsulfuron-methyl 20% WP 4 g/ha + pinoxaden 5.1% EC 20 g/ha resulted in higher weed control efficiency, yield, net returns and B:C ratio.

Keywords: Chemical control, Metsulfuron, Profitability, Tillage, Weed dynamics, Wheat

Wheat (*Triticum aestivum* L.) is one of the most important food crops in India and it plays an important role in crop production due to its adaptability to wide range of agro-climatic conditions. It is the second most important cereal crop of India after rice and accounts for 31.5% of the total food grain production of the country (Choudhary *et al.* 2017). In India, Bihar ranks 6th in wheat production after Uttar Pradesh, Madhya Pradesh, Punjab, Haryana, and Rajasthan. Rice-wheat has emerged as major cropping system of Indo-Gangetic Plain (IGP). At present, the sustainability of rice-wheat system is in question either due to yield stagnation or decline of rice or wheat across rice-wheat system of IGP, soil degradation, declining groundwater level, and environmental pollution from stubble burning (Verma *et al.* 2017). Heavy infestation of the weed flora in wheat has become a serious problem thereby hindering productivity under rice-wheat cropping systems (Kushwaha *et al.* 2020). *Phalaris minor* and *Avena ludoviciana* are major problematic grassy weeds causing significant reduction in wheat grain yield (Mukherjee *et al.* 2016). Besides *P. minor*, herbicide resistance has also been found in *Rumex dentatus* against metsulfuron-methyl and *Avena ludoviciana* (Kaur *et al.* 2018). Herbicide combinations such as mesosulfuron + iodosulfuron, fenoxaprop + metribuzin, and clodinafop + metribuzin provided alternative option to deal with resistant *P. minor* (Singh *et al.* 2015, Punia *et al.* 2017).

Zero-tillage in wheat in rice –wheat system has been proved as the most resource-conserving technique in IGP. It leads to considerable benefits in terms of production (6-10%) and cost reductions (5-10%) (Shyam *et al.* 2014). The study was carried out to find the effect of tillage and weed management practices on weed dynamics and productivity and profitability of wheat in EIGP.

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A field study was conducted during *Rabi* (winter) season of 2021-22 at Research Farm of Bihar Agricultural University, Sabour, Bhagalpur, Bihar, India. The geographical details of the site are 25°50' N latitude, 87°19' E longitude and 52.73 meter above mean sea level (MSL). The soil of the experimental field was loamy in texture and almost neutral in reaction having pH 7.35, organic carbon 0.58%, available nitrogen 173.45 kg, available phosphorus 22.43 kg and available potassium 148.82 kg/ha. The experiment was laid out in a split plot design with three replications. The treatment details of the experiment were 2 tillage practices namely conventional tillage zero tillage while under weed management practices, there were nine treatment which details are given in **Table 1**. The wheat variety '*HD 2967*' was sown on 23rd December with a seed rate of 125 kg/ha for both zero and conventional tilled plots. Sowing was done mechanically with the help of a national zero-till seed-cum-fertilizer- drill by maintaining a row-to-row spacing of 20 cm.

The number of individual weed species was counted at 30, 60, and 90 DAS and at harvest stage from two spots selected randomly in each plot through a quadrate of 50 x 50 cm and expressed as number per meter square area. The data on weed density was subjected to square root transformation ($\sqrt{x+0.5}$) before statistical analysis to normalize their distribution (Gomez and Gomez 1984). For determining weed biomass (g/m^2), samples were chopped and filled in perforated paper bags separately and sun-dried for two days. Finally, these samples were kept in an oven at 70 °C to obtain a constant weight. These were weighed and expressed in g/m^2 of weed biomass. Weed control efficiency (WCE) is the efficiency of applied treatment for controlling the weeds in comparison of weedy check. The following formula was used to calculate the weed control efficiency of various treatments as suggested by Mani *et al*. (1973) as follows;

$$WCE\ (\%) = \frac{DWC-DWT}{DWC} \times 100$$

where, WCE = Weed control efficiency, DWC = Dry weight of weeds in control plot; DWT = Dry weight of weeds in treated plot.

The crop harvested from each net plot was threshed individually and cleaned grains were sun dried to reduce their moisture content to 12% before being weighed. Then, the grain as well as straw yield were calculated and expressed as t/ha. The proportion of grains recovered from the total harvested yield was used to estimate the harvest index. The harvest index for each experimental plot was calculated using the formula (Singh and Stoskopf 1971).

$$\text{H. I. (\%)} = \frac{\text{Grain yield (q/ha)}}{\text{Biological yields (q/ha)}}$$

Economic analysis was done as per the prevailing cost of inputs and selling price of output during the concerning year. Benefit: cost ratio (B: C) was obtained by dividing the gross income with the cost of cultivation. The experimental data were analyzed statistically by applying the technique of analysis of variance (ANOVA) prescribed for the design to test the significance of the overall difference among treatments by the F-test and conclusions were drawn at a 5% probability level (Gomez and Gomez 1984).

Effect on weed flora

In this study, the wheat crop was infested with heavy population of grassy and broad-leaf weeds, *viz. Polypogon monspeliensis*, *Cynodon dactylon*, *Phalaris minor*, *Cyperus rotundus*, *Rumex dentatus*, *Convolvulus arvensis*, *Anagallis arvensis*, *Chenopodium album*, *Polygonum plebeium* and *Melilotus indica.* The broad-leaf weeds were more dominant than grassy and sedge weeds.

Effect on weed density

The weed density of *Cynodon dactylon* was reduced significantly by tillage and weed management practices at all the stages except 30 DAS (**Table 1**). The lowest weed density 16.13 and 10.78/m^2 of *Cynodon dactylon* was recorded under zero tillage at 60 and 90 DAS, respectively. It was realized that the weed density decreased as the crop growth advanced except in weedy and carfentrazone-ethyl 20 g/ha + clodinafop-propargyl 60 g/ha, where it enhanced at 60 DAS and thereafter it decreased. All the herbicidal treatments recorded significantly lower density of *Cynodon dactylon* than the weedy plot at 60 and 90 DAS. Among the tillage management practices, conventional tillage recorded 31.2 and 21.9% higher weed density of *Polypogon monspeliensis* at 30 and 60 DAS, respectively. The density of *P. monspeliensis* revealed that it decreased as the crop growth advanced except weedy, where it enhanced at 60 DAS and thereafter it decreased. The highest weed density 36.33 and 35.17/m^2 was recorded in the weedy plot at 60 and 90 DAS. Furthermore, similar trend was followed in the density of *Phalaris minor* among tillage management practices. The lowest density of *P. minor* under zero tillage might be due to less soil disturbance; as a result, seeds present in lower soil layers failed to germinate (Singh *et al*. 2015). Weed seeds remained in the subsurface under zero tillage due to puddling carried out during rice transplanting which failed to germinate in wheat because of unfavorable condition (Katara *et al*.

2015). These findings were in conformity with those reported by Shivran *et al*. (2020).

Zero tillage plot recorded lowest weed density 10.64 and 9.81/m^2 of *C. rotundus* at 60 and 90 DAS, respectively (**Table 1**). Weed density decreased as the crop growth advanced except in weedy, where it enhanced at 60 DAS and thereafter it decreased. Application of metsulfuron-methyl 20% WP 4 g/ha + clodinafop-propargyl 15% WP 60 g/ha significantly reduced the density of *C. rotundus* (7.50 /m^2), which was found at par with metsulfuron-methyl 4 g/ha + pinoxaden 20 g/ha, carfentrazone-ethyl 20 g/ha + clodinafop-propargyl 60 g/ha and carfentrazone-ethyl 20 g/ha + pinoxaden 20 g/ha. On the other hand, metsulfuron-methyl 4 g/ha + clodinafop-propargyl 60 g/ha significantly reduced the density of *C. rotundus* (6.10 /m^2) at 90 DAS, which was found at par with carfentrazone-ethyl 20 g/ha + clodinafop-propargyl 60 g/ha, metsulfuron-methyl 4 g/ha + pinoxaden 20 g/ ha, carfentrazone-ethyl 20 g/ha + pinoxaden 20 g/ha and was found significantly superior over rest of the treatments. Weedy plot recorded significantly highest density of 37.50 and 32.83/m^2 *C. rotundus* at 60 and 90 DAS, respectively. It might be due to the optimal dose of these herbicides which controlled the grassy weeds and sedges effectively (Mukherjee 2020 and Hossain and Begum 2015).

In case of tillage practices, the density of *Rumex dentatus* was lowest (11.96 and 9.80 /m^2) under zero tillage at 60 and 90 DAS, respectively (**Table 2**). The lower weed density 15.52 and 13.63 /m^2 of *Polygonum plebeium* was recorded under zero tillage as compared to conventional tillage at 60 and 90 DAS, respectively. The density of other broad-leaf weeds like *Melilotus indica* and *Anagallis* sp., 11.05 and 7.04 /m^2 was also low under zero tillage and it decreased as the crop growth advanced except weedy, where it enhanced at 60 DAS and thereafter it decreased. Herbicide combination of metsulfuron-methyl 20% WP 4 g/ha + clodinafop-propargyl 15% WP 60 g/ha significantly reduced the weed density of other broad-leaved weeds (6.48 and 4.48/m^2), which was found at par with metsulfuron-methyl 4 g/ha + pinoxaden 20 g/ha and 46.7, 45.2% at 60 DAS, and at 90 DAS, it was 45.5 and 48.9% lower as compared to the treatment carfentrazone-ethyl 20 g/ha + pinoxaden 20 g/ha and carfentrazone-ethyl 20 g/ha + clodinafop-propargyl 60 g/ha, respectively. The density of other broad-leaf weeds was found more under conventional tillage. This was largely due to vertical distribution of weed seeds and more soil disturbance under conventional tillage which came up to the soil surface and germinated (Karunakaran and Behera 2013, Makhan *et al*. 2016). However, the density of *Rumex dentatus* was found more under

Table 1. Effect of tillage methods and weed management practices on weed density (no/m^2) of grassy weeds and sedge

Treatment	*Cynodon dactylon*			*Polypogon monspeliensis*			*Phalaris minor*			*Cyperus rotundus*		
	30 DAS	60 DAS	90 DAS	30 DAS	60 DAS	90 DAS	30 DAS	60 DAS	90 DAS	30 DAS	60 DAS	90 DAS
Tillage practice												
Conventional tillage	3.63 (14.61)	4.03 (18.26)	3.69 (15.41)	3.94 (17.17)	3.66 (15.00)	3.28 (12.11)	4.21 (20.34)	3.84 (16.56)	3.61 (14.48)	3.74 (16.42)	3.60 (14.56)	3.25 (11.58)
Zero tillage	3.98 (18.04)	3.79 (16.13)	3.11 (10.78)	3.71 (15.74)	3.22 (11.37)	2.95 (9.93)	3.96 (17.74)	3.40 (12.96)	3.03 (10.41)	3.50 (13.68)	3.09 (10.64)	2.91 (9.81)
LSD (p=0.05)	NS	0.04	0.19	NS	0.21	0.16	NS	0.27	0.06	NS	0.11	0.13
Weed management practice												
Weedy	4.12 (17.33)	6.78 (46.10)	6.19 (38.17)	4.12 (17.17)	6.04 (36.33)	5.94 (35.17)	4.17 (18.83)	6.47 (41.67)	6.24 (38.67)	3.76 (15.60)	6.13 (37.50)	5.71 (32.83)
Weed 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)
Pinoxaden 20 g/ha	4.90 (24.17)	4.53 (20.33)	4.09 (16.30)	4.61 (21.10)	3.92 (15.17)	3.57 (12.33)	4.70 (23.00)	4.20 (17.17)	3.56 (12.33)	4.48 (21.22)	3.91 (15.00)	3.50 (12.00)
Carfentrazone-ethyl 20 g/ha	4.57 (21.83)	4.40 (19.05)	3.84 (14.50)	4.50 (20.50)	3.70 (13.33)	3.26 (10.33)	4.62 (23.42)	4.33 (18.50)	3.85 (14.50)	4.18 (17.57)	3.67 (13.17)	3.22 (10.17)
Clodinafop-propargyl 60 g/ha	4.24 (18.20)	4.24 (17.67)	3.64 (13.20)	4.06 (17.67)	3.79 (14.00)	3.42 (11.50)	4.43 (19.93)	3.70 (13.33)	3.38 (11.17)	4.52 (21.83)	3.51 (12.05)	3.14 (9.50)
Carfentrazone-ethyl 20 g/ha + pinoxaden 20 g/ha	3.99 (16.70)	3.82 (14.20)	3.34 (10.83)	4.03 (18.62)	3.62 (12.83)	3.12 (9.50)	4.51 (20.83)	3.58 (12.50)	3.23 (10.17)	3.94 (16.33)	3.22 (10.13)	3.13 (9.67)
Carfentrazone-ethyl 20 g/ha + clodinafop-propargyl 60 g/ha	3.50 (12.97)	3.83 (14.17)	3.16 (9.67)	4.01 (16.70)	3.32 (10.67)	2.99 (8.50)	4.69 (22.50)	3.36 (10.83)	3.20 (9.83)	3.87 (15.50)	3.09 (9.20)	2.86 (7.83)
Metsulfuron-methyl 4 g/ha + clodinafop-propargyl 60 g/ha	4.02 (16.70)	3.31 (10.67)	2.73 (7.00)	3.89 (16.20)	2.82 (7.50)	2.40 (5.53)	3.99 (17.50)	3.01 (8.67)	2.74 (7.17)	3.70 (14.72)	2.81 (7.50)	2.55 (6.10)
Metsulfuron-methyl 4 g/ha + pinoxaden 20 g/ha	4.18 (19.00)	3.60 (12.55)	2.92 (8.17)	4.48 (20.17)	3.04 (8.83)	2.63 (6.50)	4.98 (25.33)	3.24 (10.17)	2.89 (8.17)	3.44 (12.67)	3.04 (8.83)	2.92 (8.17)
LSD (p=0.05)	NS	0.54	0.41	NS	0.46	0.44	NS	0.38	0.40	NS	0.48	0.63

*Original values given in parentheses was subjected to square root transformation ($\sqrt{x+0.5}$) before analysis; DAS: days after sowing, NS: Non-significant

zero tillage. This might be due to the concentration of *Rumex dentatus* seeds on the upper soil layer particularly on the surface, under zero tillage (Chhokar *et al.* 2007).

Effect on weed biomass

The biomass of *C. dactylon* was significantly affected by tillage and weed management practices at all the stages except 30 DAS (**Table 3**). Significantly lower weed biomass (18.41 and 14.93 g/m^2) of *C. dactylon* was found under zero tillage as compared to conventional tillage at 60 and 90 DAS, respectively. Metsulfuron-methyl 20% WP 4 g/ha + clodinafop-propargyl 15% WP 60 g/ha significantly reduced the biomass of *Cynodon dactylon* (14.98 g/m^2) which was at par with metsulfuron-methyl 4 g/ha + pinoxaden 20 g/ha, carfentrazone-ethyl 20 g/ha + pinoxaden 20 g/ha and carfentrazone-ethyl 20 g/ha + clodinafop-propargyl 60 g/ha. At 90 DAS, metsulfuron-methyl 4 g/ha + clodinafop-propargyl 60 g/ha significantly reduced the weed biomass (9.73 g/m^2) of *Cynodon dactylon* which was 37.4, 31.1, 27.2% lower as compared to treatment Carfentrazone-ethyl 20 g/ha + pinoxaden 20 g/ha, carfentrazone-ethyl 20 g/ha + clodinafop-propargyl 60 g/ha and metsulfuron-methyl 4 g/ha + pinoxaden 20 g/ha. The weedy plot recorded highest weed biomass (56.60 and 50.38 g/m^2) at 60 and 90 DAS. Similarly in *Polypogon monspeliensis*, lower weed biomass (20.65 and 18.30 g/m^2) was recorded under zero tillage at 60 and 90 DAS, respectively. Application of carfentrazone-ethyl 40% DF 20 g/ha + clodinafop-propargyl 15% WP 60 g/ha significantly reduced the biomass of *Polypogon monspeliensis* (17.50 g/m^2), which was at par with metsulfuron-methyl 4 g/ha + clodinafop-propargyl 60 g/ha and carfentrazone-ethyl 20 g/ha + pinoxaden 20 g/ha. However, at 90 DAS, metsulfuron-methyl 4 g/ha + clodinafop-propargyl 60 g/ha significantly reduced the biomass of *Polypogon monspeliensis* (6.97 g/m^2). In case of *Phalaris minor*, lower biomass 20.53 and 17.57 g/m^2 was found under zero tillage at 60 and 90 DAS, respectively. At 60 DAS, metsulfuron-methyl 4 g/ha + clodinafop-propargyl 60 g/ha significantly reduced the biomass of *Phalaris minor* (12.44 g/m^2), which was at par with metsulfuron-methyl 4 g/ha + pinoxaden 20 g/ha. Similarly at 90 DAS, metsulfuron-methyl 4 g/ha + clodinafop-propargyl 60 g/ha significantly reduced the dry weight of *Phalaris minor* (7.66 /m^2). The weedy plot recorded highest weed biomass (77.67 and 87.17 g/m^2) at 60 and 90 DAS. The use of broad-spectrum herbicidal combinations proved more effective as it gave complete control of grassy weeds associated with wheat as reported earlier by Singh *et al.* (2015) and Bharat *et al.* (2012).

Table 2. Effect of tillage and weed management practices on weed density (no./m^2) of broad-leaved weeds

Treatment	*Rumex dentatus*			*Polygonum plebeium*			Other broad-leaf weeds		
	30 DAS	60 DAS	90 DAS	30 DAS	60 DAS	90 DAS	30 DAS	60 DAS	90 DAS
Tillage practice									
Conventional tillage	3.79 (15.93)	3.78 (16.85)	3.38 (13.06)	4.28 (20.63)	4.30 (20.75)	3.87 (16.66)	3.87 (16.76)	3.49 (13.29)	3.14 (10.77)
Zero tillage	3.78 (16.09)	3.25 (11.96)	2.91 (9.80)	3.91 (17.54)	3.73 (15.52)	3.55 (13.63)	3.54 (14.34)	3.19 (11.05)	2.59 (7.04)
LSD (p=0.05)	NS	0.25	0.10	NS	0.40	0.17	NS	0.04	0.36
Weed management practice									
Weedy	4.06 (16.73)	6.79 (46.05)	6.22 (38.37)	4.48 (19.83)	6.80 (46.25)	6.08 (37.10)	3.44 (11.55)	4.90 (23.72)	4.21 (17.73)
Weed 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)
Pinoxaden 20 g/ha	4.35 (18.88)	4.16 (17.83)	3.75 (13.62)	4.46 (21.70)	4.79 (22.73)	4.24 (17.72)	4.64 (23.05)	4.19 (17.58)	3.89 (14.78)
Carfentrazone-ethyl 20 g/ha	4.07 (16.42)	3.96 (15.47)	3.34 (10.75)	4.49 (20.77)	4.52 (20.25)	3.94 (15.50)	4.50 (21.23)	3.88 (14.72)	3.19 (10.03)
Clodinafop-propargyl 60 g/ha	4.05 (16.92)	3.85 (14.43)	3.45 (11.83)	4.71 (22.35)	4.36 (18.93)	4.08 (16.22)	4.08 (18.20)	3.64 (13.25)	3.15 (9.50)
Carfentrazone-ethyl 20 g/ha + pinoxaden 20 g/ha	4.28 (18.77)	3.44 (11.54)	3.13 (9.40)	4.84 (24.75)	4.04 (16.37)	3.91 (14.93)	4.45 (20.57)	3.50 (12.17)	2.88 (8.23)
Carfentrazone-ethyl 20 g/ha + clodinafop-propargyl 60 g/ha	4.01 (17.83)	3.23 (10.00)	2.85 (7.80)	4.66 (22.50)	3.83 (14.50)	3.70 (13.27)	4.30 (19.40)	3.49 (11.83)	3.00 (8.77)
Metsulfuron-methyl 4 g/ha + clodinafop-propargyl 60 g/ha	4.53 (20.17)	2.64 (6.52)	2.27 (4.72)	4.10 (19.03)	3.42 (11.27)	3.18 (9.65)	3.70 (13.68)	2.61 (6.48)	2.16 (4.48)
Metsulfuron-methyl 4 g/ha + pinoxaden 20 g/ha	4.02 (18.37)	2.88 (7.90)	2.59 (6.38)	4.41 (20.83)	3.64 (12.92)	3.51 (11.90)	3.52 (12.27)	3.15 (9.78)	2.62 (6.62)
LSD (p=0.05)	NS	0.47	0.38	NS	0.64	0.55	NS	0.70	0.58

*Original values given in parentheses was subjected to square root transformation ($\sqrt{x+0.5}$) before analysis; DAS: days after sowing, NS: Non-significant

The minimum weed biomass of *Cyperus rotundus i.e.* 20.67 and 15.04 g/m^2 at 60 and 90 DAS respectively was recorded under zero tillage (**Table 3**). Amongst weed management practices, metsulfuron-methyl 4 g/ha + clodinafop-propargyl 60 g/ha recorded lowest biomass (11.83 g/m^2) at 60 DAS. Moreover, at 90 DAS, metsulfuron-methyl 4 g/ha + clodinafop-propargyl 60 g/ha significantly reduced the weed biomass (8.15 g/m^2) of *Cyperus rotundus* which was found at par with metsulfuron-methyl 4 g/ha + pinoxaden 20 g/ha and 86.6% lower than the weedy. The effective weed control by sequentially applied herbicides resulted in the least crop weed competition due to lower weed biomass (Soni *et al*. 2022).

Biomass of *Rumex dentatus* was lower under zero tillage at 60 and 90 DAS, respectively (**Table 4**). Weedy plot recorded significantly highest biomass (97.50 and 55.67 g/m^2) of this weed at 60 and 90 DAS, respectively. In case of *Polygonum plebeium,* a similar trend was followed and lower biomass (23.68 and 16.63 g/m^2) was observed under zero tillage at 60 and 90 DAS, respectively. At 60 DAS, application of carfentrazone-ethyl 40% DF 20 g/ha + pinoxaden 5.1% EC 20 g/ha) significantly reduced the biomass of *Polygonum plebeium* (16.38 g/m^2). However, at 90 DAS, metsulfuron-methyl 4 g/ha + clodinafop-propargyl 60 g/ha significantly reduced the biomass of *Polygonum plebeium* (9.83 g/m^2). Weedy plot recorded significantly highest dry weight (92.75 and 66.93 g/m^2) of this weed at 60 and 90 DAS, respectively. The results revealed that dry weight of other broad-leaved weeds was significantly affected by tillage methods and weed management practices at all the stages except 30 DAS. Among weed management practices, biomass of other broad-leaf weeds at 60 DAS was minimum with metsulfuron-methyl 20% WP 4 g/ha + clodinafop-propargyl 15% WP 60 g/ha. However, at 90 DAS, metsulfuron-methyl 4 g/ha + clodinafop-propargyl 60 g/ha recorded minimum biomass of other broad-leaf weeds (8.54 g/m^2). Higher weed biomass was observed under conventional tillage in wheat because of soil disturbance caused by tillage that could have brought the deep buried weed seeds near to soil surface, where favourable environment, in terms of better availability of light, oxygen and moisture facilitated the germination and emergence of weed seeds (Arora *et al.* 2013). Besides, tillage caused abrasion/rapture of seed coat of weed seeds and thus facilitated germination of weed seeds and in turns had more density and biomass of former weeds (Punia *et al.* 2017).

Effect on yield

The maximum grain yield of 4.01 t/ha and 4.78 t/ha was recorded under zero tillage and weed free (weed free treatment), respectively which was found significantly superior over rest of the treatments

Table 3. Effect of tillage and weed management practices on weed biomass (g/m^2) of grassy weeds and sedge at various crop growth stages

Treatment	*Cynodon dactylon*			*Polypogon monspeliensis*			*Phalaris minor*			*Cyperus rotundus*		
	30 DAS	60 DAS	90 DAS	30 DAS	60 DAS	90 DAS	30 DAS	60 DAS	90 DAS	30 DAS	60 DAS	90 DAS
Tillage practice												
Conventional tillage	3.18 (12.03)	4.63 (23.95)	4.21 (19.89)	3.88 (11.04)	4.41 (24.30)	3.68 (20.36)	2.85 (8.33)	4.28 (23.06)	4.06 (21.71)	3.42 (13.38)	4.56 (23.48)	4.18 (20.27)
Zero tillage	2.97 (10.57)	4.02 (18.41)	3.60 (14.93)	2.83 (10.27)	3.99 (20.65)	3.88 (18.30)	2.93 (7.64)	4.03 (20.53)	3.72 (17.57)	3.16 (11.00)	4.23 (20.67)	3.56 (15.04)
LSD (p=0.05)	NS	0.04	0.03	NS	0.16	0.17	NS	0.26	0.028	NS	0.18	0.17
Weed management practice												
Weedy	3.62 (13.42)	7.54 (56.60)	7.12 (50.38)	4.27 (13.31)	9.92 (98.00)	9.85 (96.83)	2.80 (8.16)	8.50 (77.67)	8.18 (87.17)	3.84 (15.43)	7.94 (62.55)	7.81 (60.72)
Weed free	0.71 (0.00)	0.71 (00.00)	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)
Pinoxaden 20 g/ha	3.69 (14.72)	5.06 (25.17)	4.53 (20.33)	2.24 (12.55)	4.29 (17.95)	3.99 (15.58)	2.79 (9.23)	4.97 (20.33)	4.51 (15.33)	3.76 (14.23)	5.16 (26.27)	4.24 (17.83)
Carfentrazone-ethyl 20 g/ha	3.42 (12.78)	4.77 (22.57)	4.12 (17.08)	4.12 (10.83)	4.03 (15.52)	3.67 (13.10)	3.59 (8.69)	4.46 (22.25)	4.07 (16.66)	3.36 (11.50)	4.91 (23.60)	4.38 (18.88)
Clodinafop-propargyl 60 g/ha	3.47 (13.13)	4.67 (21.58)	4.03 (16.10)	3.92 (11.60)	4.23 (17.78)	3.52 (11.98)	3.3 (9.13)	4.13 (17.96)	3.59 (14.08)	3.79 (15.38)	4.66 (21.53)	3.97 (15.50)
Carfentrazone-ethyl 20 g/ha + pinoxaden 20 g/ha	3.05 (11.67)	4.12 (16.83)	3.97 (15.55)	3.98 (10.25)	3.45 (11.83)	3.44 (11.43)	2.77 (8.61)	3.96 (15.50)	4.06 (13.46)	3.61 (13.75)	4.39 (19.17)	3.86 (14.42)
Carfentrazone-ethyl 20 g/ha + clodinafop-propargyl 60 g/ha	3.14 (10.53)	4.17 (17.32)	3.78 (14.12)	4.07 (12.05)	3.20 (17.50)	4.25 (10.23)	2.11 (7.26)	3.82 (14.86)	3.38 (12.21)	3.43 (12.83)	4.21 (11.45)	3.61 (12.67)
Metsulfuron-methyl 4 g/ha + clodinafop-propargyl 60 g/ha	3.33 (11.38)	3.91 (14.98)	3.18 (9.73)	4.08 (10.57)	3.31 (10.66)	2.72 (6.97)	3.10 (10.54)	3.27 (12.44)	2.86 (7.66)	3.90 (16.42)	3.50 (11.83)	2.92 (8.15)
Metsulfuron-methyl 4 g/ha + pinoxaden 20 g/ha	3.73 (14.05)	3.97 (15.55)	3.69 (13.37)	3.84 (12.52)	3.66 (13.02)	2.86 (7.85)	3.81 (10.21)	3.57 (15.17)	3.65 (10.21)	3.24 (10.15)	4.06 (16.27)	3.30 (10.63)
LSD (p=0.05)	NS	0.42	0.47	NS	0.43	0.48	NS	0.47	0.49	NS	0.42	0.41

*Original values given in parentheses was subjected to square root transformation ($\sqrt{x+0.5}$) before analysis; DAS: days after sowing, NS: Non-significant

(**Table 5**). Among herbicidal treatments, metsulfuron-methyl 4 g/ha + clodinafop-propargyl 60 g/ha recorded significantly highest grain yield (4.36 t/ha) which was 9.0, 6.3 and 3.6% higher as compared to carfentrazone-ethyl 20 g/ha + pinoxaden 20 g/ha, carfentrazone-ethyl 20 g/ha + clodinafop-propargyl 60 g/ha and metsulfuron-methyl 4 g/ha + pinoxaden 20 g/ha respectively. Likewise, higher straw yield (5.58 t/ha) was recorded under zero tillage as compared to conventional tillage. Among herbicides, metsulfuron-methyl 4 g/ha + clodinafop-propargyl 60 g/ha exhibited significantly highest straw yield which was at par with metsulfuron-methyl 4 g/ha + pinoxaden 20 g/ha, carfentrazone-ethyl 20 g/ha + clodinafop-propargyl 60 g/ha, carfentrazone-ethyl 20 g/ha + pinoxaden 20 g/ha and clodinafop propargyl 60 g/ha. The reduced yield under conventional tillage might be due to more crop-weed competition and more dry matter accumulation by the weeds (Kumar *et al*. 2018). Among weed management practices, the highest grain and straw yield were obtained in weed-free treatment due to zero competition with the weeds. In contrast to this, the lowest grain and straw yield was obtained in weedy treatment due to season-long weed competition. Due to reduced weed infestation through these treatments might have helped the crop plants to accumulate more dry matter that might have provided more quantity of photosynthates to developing sink in crop plants produced more yield (Meena *et al*. 2019). The beneficial effects of herbicide mixture and their sequential application for weed management and higher grain and straw yield comparable to weed-free were also reported by Punia *et al*. (2020). This suggests that zero tillage should be accompanied with efficient herbicide combination for achieving higher wheat productivity.

Harvest index and weed control efficiency

Among the tillage management practices, zero tillage recorded highest harvest index (0.42%) **(Table 5)**. The maximum weed control efficiency (WCE) of 73.15% and 75.27% at 60 and 90 DAS respectively was achieved under zero tillage. The maximum weed control efficiency under zero tillage which might be due to better suppression of weed emergence with crop residue cover and less soil disturbance (Meena *et al*. 2016). On the contrary, WCE was less in conventional tillage. This may be attributed to the fact that tillage brought the deep buried weed seeds near to soil surface, where favourable conditions in soil could have facilitated germination and emergence of weed seeds (Mitra *et al*. 2014). In addition to this, no weed control measures were adopted in weedy check plots, which in turn had more dry matter of all weeds and finally lower weed control efficiency.

Table 4. Effect of tillage and weed management practices on weed biomass (g/m^2) of broad-leaved weeds at various crop growth stages

Treatment	*Rumex dentatus*			*Polygonum plebeium*			Other broad-leaf weeds		
	30 DAS	60 DAS	90 DAS	30 DAS	60 DAS	90 DAS	30 DAS	60 DAS	90 DAS
Tillage practice									
Conventional tillage	3.11 (10.72)	4.85 (27.50)	3.86 (17.52)	3.73 (15.52)	4.78 (27.32)	4.09 (20.27)	2.93 (9.81)	4.28 (22.03)	4.06 (19.94)
Zero tillage	3.26 (11.48)	4.49 (25.39)	3.53 (14.45)	3.53 (13.77)	4.41 (23.68)	3.76 (16.63)	2.85 (8.78)	4.03 (19.30)	3.69 (16.5 5)
LSD (p=0.05)	NS	0.20	0.03	NS	0.34	0.06	NS	0.21	0.28
Weed management practice									
Weedy	3.53 (12.66)	9.87 (97.50)	7.48 (55.67)	4.07 (16.46)	9.65 (92.75)	8.17 (66.93)	2.80 (7.71)	8.50 (72.37)	8.08 (65.14)
Weed free	0.71 (0.0)	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)
Pinoxaden 20 g/ha	3.63 (13.63)	4.60 (20.73)	4.05 (15.99)	4.20 (18.21)	4.56 (20.36)	4.13 (16.77)	3.79 (16.38)	4.97 (24.55)	4.45 (19.59)
Carfentrazone-ethyl 20 g/ha	3.27 (10.89)	4.16 (17.07)	3.78 (13.89)	3.71 (13.76)	4.17 (17.15)	3.92 (15.03)	3.59 (13.72)	4.46 (19.56)	4.07 (16.70)
Clodinafop-propargyl 60 g/ha	3.68 (13.45)	5.04 (24.87)	4.07 (16.17)	4.46 (21.72)	4.94 (24.17)	4.22 (17.40)	3.33 (10.72)	4.13 (17.06)	3.59 (12.96)
Carfentrazone-ethyl 20 g/ha + pinoxaden 20 g/ha	3.40 (12.25)	4.48 (19.82)	3.54 (12.20)	3.76 (13.83)	4.06 (16.38)	3.63 (12.98)	2.77 (7.91)	3.96 (15.37)	4.06 (16.80)
Carfentrazone-ethyl 20 g/ha + clodinafop-propargyl 60 g/ha	3.41 (11.33)	4.51 (20.41)	3.66 (12.91)	4.27 (20.50)	4.73 (22.04)	4.11 (16.72)	3.11 (9.54)	3.82 (14.17)	3.38 (11.38)
Metsulfuron-methyl 4 g/ha + clodinafop-propargyl 60 g/ha	3.47 (12.22)	4.24 (17.93)	2.80 (7.41)	3.56 (12.38)	4.37 (19.16)	3.20 (9.83)	3.10 (9.24)	3.27 (10.50)	2.86 (8.54)
Metsulfuron-methyl 4 g/ha + pinoxaden 20 g/ha	3.58 (13.47)	4.45 (19.67)	3.18 (9.63)	3.92 (14.96)	4.17 (17.50)	3.28 (10.37)	2.83 (8.14)	3.57 (12.38)	3.65 (13.10)
LSD (p=0.05)	NS	0.57	0.31	NS	0.47	0.57	NS	0.47	0.77

*Original values given in parentheses was subjected to square root transformation ($\sqrt{x+0.5}$) before analysis; DAS: days after sowing, NS: Non-significant

Among herbicidal treatments, weed free recorded maximum harvest index of 0.45% followed by metsulfuron-methyl 4 g/ha + clodinafop-propargyl 60 g/ha, metsulfuron-methyl 4 g/ha + pinoxaden 20 g/ha, carfentrazone-ethyl 20 g/ha + clodinafop-propargyl 60 g/ha and carfentrazone-ethyl 20 g/ha + pinoxaden 20 g/ha. Highest weed control efficiency (82.45 and 86.91% respectively) was attained with metsulfuron-methyl 4 g/ha + clodinafop-propargyl 60 g/ha at 60 and 90 DAS. This might be attributed to the broad-spectrum activity and persistence of the herbicide which controlled the weeds more effectively than other herbicides (Sarita 2021, Chaudhari *et al.* 2017 and Chopra *et al.* 2015).

Economics

The minimum cost of cultivation (₹ 33702/ha) was incurred under zero tillage as compared to conventional tillage (₹ 37047/ha) (**Table 5**). This difference was due to cost involved for tillage operation in zero and conventional tillage. Among weed management practices, the maximum cost of cultivation (₹ 46427/ha) was incurred in weed free treatment which required more labor wages to keep the field free from weeds and minimum cost of cultivation (₹ 32045/ha) in weedy plot. Among herbicidal treatments, minimum cost of cultivation (₹ 33473/ha) was incurred in metsulfuron-methyl 4 g/ha + clodinafop-propargyl 60 g/ha. In case of gross returns, it was found maximum (₹ 120157/ha) in weed free treatment. Among herbicides, higher gross returns (₹ 110454/ha) were recorded under metsulfuron-methyl 4 g/ha + clodinafop-propargyl 60 g/ha followed by carfentrazone-ethyl 20 g/ha + clodinafop-propargyl 60 g/ha, metsulfuron-methyl 4 g/ha + pinoxaden 20 g/ha and carfentrazone-ethyl 20 g/ha + pinoxaden 20 g/ha. Although, minimum gross returns (₹ 69521/ha) was obtained in weedy plot. Zero tillage recorded highest net returns (₹ 69381/ha) whereas among weed management practices, the maximum net returns (₹ 76981/ha) was under metsulfuron-methyl 4 g/ha + clodinafop-propargyl 60 g/ha . Between tillage practices, the highest B:C ratio of 2.07 was obtained under zero tillage which was 40.8% higher as compared to conventional tillage. Whereas, application of metsulfuron-methyl 20% WP 4 g/ha + clodinafop-propargyl 15% WP 60 g/ha recorded the highest B:C ratio (2.32), which was 45.9% higher as compared to weed free.

The cost of cultivation was more under conventional tillage than zero tillage due to more number of tillage operations carried out under conventional tillage. The maximum cost was incurred on weed free treatment as it was kept weed free throughout the crop growth period. The combination of zero tillage and weedy treatment had the least cost of cultivation due to fewer tillage operations and less labour requirement and more cost incurred on the combination of conventional tillage and weed free treatment due to more tillage operations and more labour requirement for hand weeding. The gross and net returns were higher under zero tillage than conventional tillage due to more yield and less cost of cultivation (Fahad *et al.* 2015 and Kumar *et al.* 2018). This was also partly due to higher yield in this treatment as compared to the other herbicides. Among weed management practices, the higher B:C ratio was noted in metsulfuron-methyl 20% WP 4 g/ha + clodinafop-propargyl 15% WP 60 g/ha due to less cost of cultivation and higher returns (Khatri *et al.* 2020).

It was be concluded that zero tillage along with application of metsulfuron 20% WP 4 g/ha + clodinafop-propargyl 15% WP 60 g/ha should be practiced for minimizing weed density, weed biomass and to attain higher productivity and profitability of wheat.

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Table 5. Effect of tillage and weed management practices on yield, harvest index, weed control efficiency and economics of wheat

Treatment	Grain yield (t/ha)	Straw yield (t/ha)	Harvest index (%)	Weed control efficiency (%)		Cost of cultivation (x10^3 ₹/ha)	Gross returns (x10^3 ₹/ha)	Net Net returns (x10^3 ₹/ha)	B:C ratio
				60 DAS	90 DAS				
Tillage practice									
Conventional tillage	3.53	5.14	0.40	69.33	72.52	37.05	91.63	54.59	1.47
Zero tillage	4.01	5.58	0.42	73.15	75.27	33.70	103.08	69.38	2.07
LSD (p=0.05)	0.13	0.17	0.04	2.67	4.13	-	2.00	2.00	0.07
Weed management practice									
Weedy	2.54	4.59	0.36	0.00	0.00	32.04	69.52	37.48	1.18
Weed free	4.78	5.98	0.45	100.00	100.00	46.43	120.16	73.73	1.59
Pinoxaden 20 g/ha	3.15	5.02	0.38	72.10	76.00	34.95	83.51	48.55	1.40
Carfentrazone-ethyl 20 g/ha	3.27	5.04	0.39	75.13	78.27	33.36	86.06	52.70	1.59
Clodinafop-propargyl 60 g/ha	3.50	5.12	0.40	73.93	78.54	33.32	91.08	57.76	1.76
Carfentrazone-ethyl 20 g/ha + pinoxaden 20 g/ha	4.00	5.59	0.42	79.43	80.11	35.66	102.94	67.28	1.90
Carfentrazone-ethyl 20 g/ha + clodinafop-propargyl 60 g/ha	4.10	5.62	0.42	77.76	81.40	34.03	105.18	71.15	2.11
Metsulfuron-methyl 4 g/ha + clodinafop-propargyl 60 g/ha	4.36	5.65	0.44	82.45	86.91	33.47	110.45	76.98	2.32
Metsulfuron-methyl 4 g/ha + pinoxaden 20 g/ha	4.21	5.62	0.43	80.33	83.82	35.10	107.32	72.22	2.07
LSD (p=0.05)	0.39	0.56	0.03	2.03	1.47	-	9.060	9.06	0.26

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RESEARCH NOTE

Weed management in blackgram with pre- and post-emergence herbicides

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ABSTRACT

A field experiment was conducted during *Kharif* (rainy season) 2019 to study the weed management efficacy of pre-emergence application (PE) of diclosulam, pendimethalin + imazethapyr and pendimethalin at 20, 1000 and 1000 g/ha, respectively and post-emergence application (PoE) of propaquizafop + imazethapyr, sodium acifluorfen + clodinafop propargyl and imazethapyr at 127, 180 and 75 g/ha, respectively and compared with hand weeding (HW) twice and unweeded check. The diclosulam 20 g/ha PE followed by (*fb*) HW resulted in reduced weed density and biomass and recorded higher weed control efficiency at 30 and 60 days after seeding (DAS). The next best treatment in suppressing weed growth was pendimethalin + imazethapyr 1000 g/ha PE *fb* HW. Among the post-emergence herbicides, propaquizafop + imazethapyr 127 g/ha was superior in reducing weed density and biomass. Diclosulam 20 g/ha PE and imazethapyr 75 g/ha PoE showed phytotoxicity rating of '2' and '1', respectively. Initially, blackgram population was reduced by 15.83% due to diclosulam phytotoxicity. Pendimethalin + imazethapyr 1000 g/ha PE *fb* HW resulted in higher plant height, dry matter production, yield components and seed yield of blackgram and it was comparable with HW twice and diclosulam 20 g/ha PE *fb* HW. The highest benefit-cost ratio was obtained with pendimethalin + imazethapyr 1000 g/ha PE**.**

Keywords: Blackgram, Crop productivity, Diclosulam, Economics, Pendimethalin + imazethapyr, Weed management

Blackgram (*Vigna mungo* L.) is a major pulse crop grown in Andhra Pradesh during *Kharif* (rainy) and *Rabi* (winter) seasons. It is valued for high protein in its seeds. Abiotic and biotic factors including severe competition offered by weeds are the major bottlenecks in obtaining higher seed yield of blackgram. Blackgram is usually associated with heavy weed infestation of mixed weed flora during rainy season because of continuous and high rainfall recorded during crop growth period. Further, weed problem is aggravated due to blackgram varieties slow initial growth, compact and early maturing habit. The most sensitive period for competition offered by weeds in blackgram was 15 to 45 DAS (Rana *et al.* 2008). Weed infestation in blackgram reduce the seed yield up to an extent of 45-60% (Upasani *et al.* 2017). The traditional methods of weed control like hand weeding and intercultivation are expensive due to increased cost of labour and tedious. Further, continuous rains during initial stages hinder the intercultivation or hand weeding. Pre-emergence application (PE) of pendimethalin 1000 g/ha has been recommended to control weeds in blackgram, but it is not effective to control purple nutsedge and some of the broad-leaved weeds (BLWs) like *Tricodesma indicum* and *Commelina benghalensis* (Naveen *et al.* 2019). Thus, there is a need to have an alternate herbicide for pendimethalin to obtain broad-spectrum weed control in blackgram. Diclosulam at 22 and 26 g/ha PE was found effective against grassy and broad-leaved weeds in soybean on sandy loam soils (Singh *et al.* 2009). Post-emergence application (PoE) of imazethapyr 75 g/ha was found effective in controlling late emerging weeds, but is limited by the choice of succeeding crops (Singh *et al*. 2018). In recent years, pre-mix post-emergence herbicides like propaquizafop + imazethapyr are available for control of weeds in pulses. Thus, this study was undertaken to identify the suitable pre-and post-emergence herbicide mixtures for broad-spectrum weed control and higher seed yield of *Kharif* blackgram.

A field experiment was conducted at S. V. Agricultural College, Tirupati campus of Acharya N. G. Ranga Agricultural University, Andhra Pradesh during *Kharif*, 2019. The soil of the experimental field was sandy loam with soil pH of 7.46 and EC of 0.68 dS/m. The experimental soil was low, medium and

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high in available nitrogen, phosphorous and potassium, respectively. The experiment was laid out in a randomized block design comprising of ten weed management treatments and replicated thrice. The treatments consisted of diclosulam 20 g/ha PE, pendimethalin + imazethapyr (ready-mix) 1000 g/ha PE and pendimethalin 1000 g/ha PE either alone or followed by (*fb*) hand weeding (HW) at 30 days after seeding (DAS). Other treatments include: propaquizafop + imazethapyr (ready-mix) 127 g/ha PoE, sodium acifluorfen + clodinafop propargyl (ready-mix) 180 g/ha PoE and imazethapyr 75 g/ha PoE; HW twice and unweeded check **(Table 1)**. Pre- and post-emergence herbicides were applied at 1 and 15 DAS, respectively with the help of knapsack sprayer fitted with flat fan nozzle at spray volume of 500 L/ha. The blackgram variety "*TBG-104*" was sown at 30 x 10 cm spacing. A uniform dose of 20 kg N/ha in the form of urea and 50 kg P/ha through single super phosphate was supplied. The entire dose of nitrogen and phosphorous was applied at the time of sowing. The data on weeds were at 30 and 60 DAS and subjected to square root transformation. Weed control efficiency was worked out and expressed as per cent reduction in total weed biomass. The data on black gram growth and yield attributes were recorded at crop maturity by adopting standard procedure. Phytotoxicity rating on blackgram due to pre-and post-emergence herbicides was assessed at 10 and 5 days after herbicide application, respectively as per the scale suggested by Singh and Rao (1976). Benefit-cost ratio was worked out by using current market price of inputs and economic yield of blackgram. All the data recorded on weeds and crop were analysed statistically as per the method suggested by Gomez and Gomez (1984).

Effect on weeds: The major weed flora associated with winter blackgram in the experiment field were *Digitaria sanguinalis*, *Cyperus rotundus*, *Euphorbia thymifolia*, *Boerhavia erecta*, *Borreria hispida*, *Cynodon dactylon*, *Commelina benghalensis* and *Cleome viscosa.* All the weed management practices significantly influenced the total weed density and biomass at 30 and 60 DAS. Diclosulam 20 g/ha PE *fb* HW at 30 DAS proved to be the most effective weed management treatment in suppressing weed density and biomass as well as higher weed control efficiency (WCE) and weed index (WI) compared to rest of the weed management practices **(Table 1)**. Pendimethalin + imazethapyr 1000 g/ha PE *fb* HW at 30 DAS was the next best weed management treatment in suppressing total weed density and biomass and reordering next higher WCE and WI. Diclosulam inhibit acetolactate synthase enzyme, a key enzyme responsible for biosynthesis of branched chain amino acids and lead to reduce the protein synthesis in susceptible weed species (Nainwal *et al.* 2013). Pendimethalin + imazethapyr 1000 g/ha (pre-mix) proved to be effective against mixed weed flora in black gram However, it was inferior than diclosulam 20 g/ha. All the pre-emergence herbicides were found effective in controlling weeds than post-emergence herbicides. Post-emergence application of imazethapyr 75 g/ha resulted in higher weed density and biomass and minimum WCE, among the herbicidal treatments.

Effect on crop: Pre-emergence application of diclosulam 20 g/ha and post-emergence application of imazethapyr 75 g/ha resulted in phytotoxicity rating of '2' and '1' in 0-10 scale, respectively on blackgram at 10 and 5 days after herbicide application. The crop was recovered from its

Table 1. Weed density and biomass, weed control efficiency (WCE) and weed index as influenced by different weed management treatments in Black gram at 30 and 60 days after seeding (DAS)

Treatment	Total weed density* (no./m)		Total weed biomass (g/m)		Weed control efficiency (%)		Weed index
	30 DAS	60 DAS	30 DAS	60 DAS	30 DAS	60 DAS	
Diclosulam 20 g/ha 1 DAS	16.8(4.21)	48.7(7.04)	4.45(2.32)	22.2(4.80)	83.90	65.24	20.4
Pendimethalin + imazethapyr 1000 g/ha 1 DAS	23.1(4.90)	52.0(7.27)	6.94(2.84)	29.5(5.51)	72.72	53.83	10.3
Diclosulam *fb* HW 20 g/ha1 *fb**30 DAS	16.8(4.21)	33.8(5.89)	3.79(2.18)	15.3(4.02)	86.29	75.99	08.3
Pendimethalin + imazethapyr *fb* HW 1000 g/ha 1 *fb* 30 DAS	23.0(4.90)	38.0(6.23)	6.78(2.78)	17.2(4.25)	75.47	73.00	-
Propaquizafop + imazethapyr 127 g/ha 15 DAS	28.1(5.38)	58.7(7.71)	11.08(3.47)	31.3(5.67)	59.91	50.95	22.4
Sodium-acifluorfen + clodinafop-propargyl 180 g/ha 15 DAS	44.1(6.70)	81.7(9.08)	16.85(4.21)	44.9(6.77)	39.04	29.57	26.4
Pendimethalin 1000 g/ha 1 DAS	38.0(6.24)	83.3(9.17)	14.06(3.87)	44.1(6.70)	49.13	30.90	21.1
Imazethapyr 75 g/ha 15 DAS	52.5(7.31)	105.6(10.32)	17.33(4.35)	53.8(7.39)	39.47	15.72	27.0
HW twice 15 *fb* 30 DAS	17.7(4.32)	42.0(6.55)	3.69(2.16)	17.3(4.26)	86.65	72.90	01.0
Unweeded check (control)	61.2(7.88)	119.7(10.97)	27.64(5.34)	63.8(8.04)	-	-	58.4
LSD (p=0.05)	0.09	0.15	0.16	0.07			-

* The figures in parentheses are transformed values; *fb*: followed by; HW: hand weeding

Table 2. Growth and yield components and yield of blackgram as influenced by different weed management practices

Treatment	Phytotoxicity rating	Initial plant population (no/m^2)	Plant height (cm)	Dry matter production (kg/ha)	No. of pods/ plant	No. of seeds/ pod	Test weight (g)	Seed yield (t/ha)	Haulm yield (t/ha)	B:C ratio
Diclosulam 20 g/ha 1 DAS	2	27.59	15.49	1758	16.3	5.1	38.8	0.63	1.01	1.78
Pendimethalin + imazethapyr 1000 g/ha 1 DAS	0	32.40	18.16	1943	17.2	5.3	41.1	0.72	1.14	1.88
Diclosulam *fb* HW 20 g/ha1 *fb**30 DAS	2	28.02	16.70	2097	16.7	5.7	41.3	0.73	1.23	1.79
Pendimethalin + imazethapyr *fb* HW 1000 g/ha 1 *fb* 30 DAS	0	32.53	18.73	2110	17.4	6.3	41.6	0.80	1.25	1.84
Propaquizafop + imazethapyr 127 g/ha 15 DAS	0	32.49	15.66	1731	15.8	5.0	38.0	0.62	1.00	1.75
Sodium-acifluorfen + clodinafop-propargyl 180 g/ha 15 DAS	0	32.03	15.59	1685	15.5	4.9	37.9	0.59	0.99	1.69
Pendimethalin 1000 g/ha 1 DAS	0	32.22	18.09	1769	16.1	5.1	38.2	0.63	1.03	1.72
Imazethapyr 75 g/ha 15 DAS	1	32.62	15.44	1670	15.4	4.6	36.8	0.58	0.98	1.62
HW twice 15 *fb* 30 DAS	0	32.59	18.45	2101	17.3	6.1	41.3	0.79	1.25	1.58
Unweeded check (control)	0	32.79	15.34	1197	12.7	3.9	34.3	0.33	0.79	1.02
LSD (p=0.05)		1.27	1.27	76	0.94	0.58	1.55	0.08	0.02	0.04

The figures in parentheses are original values

phytotoxicity by 30 days after application of diclosulam. Due to its phytotoxicity, the crop was stunted and reduced the initial plant population by 15.18% compared to unweeded check. This might be due to increased concentration of diclosulam as a result of its better leaching potential and low absorption coefficient. Naveen *et al.* (2019) also reported that diclosulam 20 g/ha showed phytotoxicity rating of '1' in 0-10 scale in groundnut on sandy loam soils. It clearly indicate the size of the crop seed and depth of seeding also play an important role in deciding herbicide selectivity.

Pendimethalin + imazethapyr 1000 g/ha *fb* HW recorded significantly higher plant height, dry matter production, higher number of pods/plant, seeds/pod, test weight, seed and haulm yield of blackgram **(Table 2)** and it was comparable with HW twice at 15 and 30 DAS. This might be due to broad-spectrum weed control because of dual mode of action of ready-mix herbicide, pendimethalin + imazethapyr which resulted in better growth and development. The reduction in yield (%) due to weeds was minimum with HW twice followed by diclosulam 20 g/ha PE *fb* HW at 30 DAS. The reduction in seed and haulm yield in blackgram was 58.4 and 37.1 per cent, respectively. Mishra *et al.* (2017) and Mansoori *et al.* (2015) also reported similar results.

It was concluded that pendimethalin + imazethapyr 1000 g/ha (pre-mix) PE *fb* HW at 30 DAS resulted in higher seed yield and benefit-cost ratio, besides broad-spectrum weed control in rainy season shown blackgram and comparable with HW twice at 15 and 30 DAS with respect to seed yield. However, due to higher cost involved, HW twice at 15 and 30 DAS resulted in lesser benefit-cost ratio than former weed management treatment.

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RESEARCH NOTE

Effect of weed management practices on seed yield of berseem (*Trifolium alexandrinum* L.)

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ABSTRACT

Field research was conducted during the winter season of 2020-21 at Central Research Farm of the ICAR-Indian Grassland and Fodder Research Institute, Jhansi, (U. P.) to study the effect of weed management practices on seed yield of berseem (*Trifolium alexandrinum* L.). The study was conducted in a randomized block design with three replications with a set of seven treatments. The treatment combinations consisted of pre-emergence application (PE) of pendimethalin + imazethapyr and post-emergence application (PoE) of imazethapyr + imazamox, glyphosate followed by (*fb*) imazethapyr + imazamox, glyphosate *fb* one hand weeding (HW) along with mechanical stale seedbed, weed free and weedy check. At 30 days after sowing of berseem, application of glyphosate 1.0 kg/ha to kill the existing weed flora before sowing (as chemical stale seedbed) *fb* one hand weeding and at first and second cut glyphosate 1.0 kg/ ha *fb* imazethapyr + imazamox 0.07 kg/ha as post emergence were found to be most effective in reducing weed density and biomass. Weed free treatment registered the significantly highest green fodder (28.98 t/ha), straw (3.20 t/ha) and seed yield (545.00 kg/ha) of berseem followed by glyphosate 1.0 kg/ha *fb* imazethapyr + imazamox 0.07 kg/ha. The highest net returns ₹ 70,597/ha and benefit: cost (2.23) was recorded with glyphosate 1.0 kg/ha *fb* imazethapyr + imazamox 0.07 kg/ha.

Keywords: Berseem, Glyphosate, Imazamox, *Trifolium alexandrinum*, Weed management, Yield

Berseem (*Trifolium alexandrinum* L.) is a most important winter season legume fodder crop of northern and central parts of India. In India it is cultivated in an area of about 2 million hectares (Pandey and Roy 2011). Due to rapid rejuvenation and high yielding potential of this crop, 4-8 cuts of green fodder can be taken. It provides 100-120 t/ha green fodder and 15-20 t/ha dry fodder to livestock during November to April months. Berseem green fodder is very nutritious, succulent and highly palatable to cattle (Mahanta and Karnani 2010) but production related problems still exist. One of the important factors affecting the berseem seed yield as well as quality is weeds menace. The problem of weeds in berseem is very much severe due to the lack of appropriate weed control methods. Weeds reduce the fodder and seed yield because of competition for light, moisture, space, and nutrients with crop plants (Thakur *et al.* 1990). The initial growth of berseem is very slow and the infestation of weeds reduces 23-28% green fodder and 38-44% seed yield of berseem (Wasnik *et al.* 2017). Weed management is an important factor for enhancing the productivity of berseem (Kauthale *et al.* 2016). Therefore, addressing the weeds problem in berseem seed production for higher yield and quality is of prime importance. The success of weed control method depends on its effectiveness and economics (Pathan and Kamble 2012). Mechanical methods of weed control are very labour intensive and costlier. The reduced availability of labour in the agricultural sector not only enhances the cost of production but also severely limits the timely weeding operations, resulting in a reduction of both quality and quantity of fodder and seed. In berseem, mechanical weeding is also not possible due to dense plants population and prevailing moist soil conditions. In such a situation, chemical weed control offers a better alternative to manual or physical weeding when integrated with other weed control approaches as it helps in achieving agronomically superior, economically viable and ecologically safe weed control (Wasnik *et al.* 2020). Therefore, the present study was conducted to understand the effect of various weed management practices on the green fodder and seed yield of berseem.

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The field experiment was conducted during winter season of 2020–21 at the Central Research Farm of ICAR-Indian Grassland and Fodder Research Institute, Jhansi. The farm is geographically situated at an altitude of 270 m above mean sea level on 25°27’ N latitude and 78°33’ E longitude. The region falls under Agro-climatic zone VIII Central Plateau and Hills region [Bundelkhand Agro climatic Zone (6)] of the Uttar Pradesh. The soil of experimental site was clay loam with pH 7.14, organic carbon (0.53%), low available nitrogen (230.96 kg/ha.) and medium available phosphorus (15.17 kg/ha.) and potassium (137.85 kg/ha.). The randomized block design with three replications was used to conduct the experiment. The experiment consisted of seven treatments, *viz.* mechanical stale seedbed (20 days after seedbed preparation killing of emerged weeds and previous year fallen berseem seedling using mechanical means); pre-emergence application (PE) of pendimethalin + imazethapyr 0.75 kg/ha [3 days after seedbed preparation (DASP)]; post-emergence application (PoE) of imazethapyr + imazamox 0.07 kg/ha. [20 days after sowing of berseem (DAS)]; glyphosate 1.0 kg/ha (PoE of herbicide at 20 DASP to kill emerged weeds and previous year fallen berseem seedlings) followed by (*fb)* imazethapyr + imazamox 0.07 kg/ha (PoE at 20 DAS of berseem); glyphosate 1.0 kg/ha (PoE of herbicide at 20 DASP to kill emerged weeds and previous year fallen berseem seedlings) *fb* one hand weeding (20 DAS); weed free and weedy check. Berseem cultivar *‘Wardan’* was sown in the first week of December using 20 kg/ha seed rate at a 40 cm row to row spacing. Recommended dose of fertilizer *i.e.* 20 kg N, 60 kg P and 40 kg K/ha was applied. Full dose of N, P and K was applied as basal at the time of sowing. All the herbicide treatments were applied with the help of knapsack sprayer fitted with flat fan nozzle at a spray volume of 500 liters water/ha. Its first cutting was done for the green fodder when the crop completed 65 days and succeeding two cutting were taken at 25-30 days interval. After two cuttings, the crop was left for the seed production. To record the dry weight, 500 g of fresh samples collected during each cut was sun dried and later oven dried at 65^{o}C to obtain the constant weight.

The weed density (no./m^2) and dry biomass (g/m^2) were recorded from each plot in a quadrat of one square meter at 30 days after sowing, first and second cut of berseem. The weed samples collected after cutting the weeds from the ground level were air dried in shade initially followed by oven dried at 65^{0}C for 48 hours to determine the biomass in g/m^2. The weed density and dry weight data were transformed $\sqrt{x+0.5}$ due to high variance before statistical analysis. (Gomez and Gomez 1984).

Effect on weeds

The major weeds in berseem were *Poa annua* among grasses, *Rumex dentatus*, *Chenopodium album*, *Cichorium intybus*, *Melilotus albus*, *Melilotus indicus*, and *Trifolium resupinatum* among broad leaved weeds and *Cyperus rotundus* a sedge.

Weed management treatments significantly influenced the total weed density and biomass at all the growth stages of berseem. Among the tested weed control treatments glyphosate 1.0 kg/ ha PoE *fb* one hand weeding recorded the significantly lowest total weed density (3.05 /m^2) and biomass (2.18 g/m^2) of weeds at 30 days after sowing of berseem **(Table 1)**. Though at first and second cut of berseem glyphosate 1.0 kg/ha *fb* imazethapyr + imazamox 0.07 kg/ha PoE recorded the significantly lowest density (4.24 and 3.78/m^2) and biomass (2.88 and 2.74 g/m^2) of weeds due to the effective control of weeds with the sequential herbicides application as also recorded by the Swetha *et al.* 2015 and Saimaheswari *et al.* 2022.

The data indicated that at 30 DAS the highest weed control efficiency (88.76%) was registered with glyphosate 1.0 kg/ha PoE (chemical stale seedbed) *fb* one hand weeding treatment. Whereas, at first and second cut of berseem the highest weed control efficiency (84.29 and 83.87%) was registered with PoE of glyphosate 1.0 kg/ha *fb* imazethapyr + imazamox 0.07 kg/ha and the lowest was in mechanical stale seedbed treatment because of the poor weed control. The highest weed index (39.76%) was found in weedy check treatment **(Table 1)**, while the lowest was reported with glyphosate 1.0 kg/ha *fb* imazethapyr + imazamox 0.07 kg/ha (6.73%) PoE. Wasnik *et al.* (2020) also reported the lowest weed index in berseem with imazethapyr PoE.

Effect on berseem

Incremental increase in berseem dry weight with the advancement of crop growth irrespective of treatment was observed **(Table 2)**. The significantly highest dry weight of berseem at first (49.05 g) and second cut (55.70 g) was recorded in weed free treatment and lowest in weedy check treatment (32.49 and 37.66 g). Among all other weed control treatments after weed free, the significantly highest dry weight of berseem at first (46.56 g) and second cut (53.10 g) was with PoE of glyphosate 1.0 kg/ ha *fb* imazethapyr + imazamox 0.07 kg/ha. Weed free also resulted in maximum plant height at harvest

(62.34 cm) which was significantly superior than the plant height recorded with all other weed control treatments. Weedy check recorded the significantly lowest plant height at harvest (40.14 cm) as also reported by Jha *et al.* (2014) and Wasnik *et al.* (2020).

Maximum number of effective tillers (314.75/ m^2), number of heads (748.40/m^2), no. of seeds/ head (97.22), individual head weight. (0.43 g), seed weight/head (0.35 g), test weight (3.38 g), highest total green fodder (28.98 t/ha), straw (3.20 t/ha) and seed (545.00 kg/ha) yield of berseem were recorded with the weed free treatment which was significantly superior to all other treatments **(Table 2** and **3).** Among the treatments chemical stale seedbed by glyphosate 1.0 kg/ha *fb* imazethapyr + imazamox 0.07 kg/ha application recorded the highest total green fodder (27.78 t/ha), straw (2.97 t/ha) and seed (508.33 kg/ha) yield of berseem. The excellent weed control reduced the crop -weed competition and generated significant increase in growth and yield parameters ultimately led to higher green fodder, seed and straw yield of berseem. Increase in berseem green fodder, straw and seed yield due to the post-emergence application of herbicide was also found by the Prajapati *et al.* (2015), Kauthale *et al.* (2016) and Wasnik *et al.* (2020).

Economics

The highest gross returns (₹ 1,36,678/ha) were registered with weed free followed by the glyphosate 1.0 kg/ha *fb* imazethapyr + imazamox 0.07 kg/ha (₹ 1,28,173/ha) PoE **(Table 3)**. The lowest gross returns (₹ 85,790/ha) were obtained with weedy check. Among all the treatments the highest net returns and benefit: cost ratio was obtained with the glyphosate 1.0 kg/ha *fb* imazethapyr + imazamox 0.07 kg/ha PoE followed by imazethapyr + imazamox 0.07 kg/ha PoE. This may be due to the better control of weeds and improvement in yield by the sequential application of herbicides (Kumar and Shivadhar 2008, Wasnik *et al.* 2017, Wasnik *et al.* 2020).

Conclusion

It can be concluded that application of glyphosate 1.0 kg/ha (20 days after seedbed preparation for killing of emerged weeds and previous year fallen berseem seedling) *fb* imazethapyr + imazamox 0.07 kg/ha (20 days after sowing of berseem) produced the maximum green fodder, straw and seed yields and profits.

Table 1. Influence of weed management treatments on weed density and biomass in berseem

Treatment	Weed density (no./m^2)			Weed biomass (g/m^2)			Weed control efficiency (%)			Weed index (%)
	30 DAS	I CUT	II CUT	30 DAS	I CUT	II CUT	30 DAS	I CUT	II CUT	
Mechanical stale seedbed	13.0(168.8)	13.9(192.1)	13.1(170.3)	4.9(23.0)	6.0(34.5)	5.7(31.2)	30.93	25.66	22.88	35.17
Pendimethalin + imazethapyr 0.75 kg/ha PE	5.3(26.7)	7.5(55.1)	6.4(40.5)	3.1(8.6)	4.2(17.0)	4.1(16.1)	74.09	63.39	60.30	20.80
Imazethapyr + imazamox 0.75 kg/ha PoE	10.6(111.8)	5.0(23.7)	4.4(19.0)	4.1(16.1)	3.1(8.7)	3.0(7.9)	51.75	81.23	80.48	11.31
Glyphosate 1.0 kg/ha PoE *fb* imazethapyr + imazamox 0.75 kg/ha PoE	9.7(92.9)	4.2(17.0)	3.8(13.4)	3.8(13.3)	2.9(7.3)	2.7(6.5)	59.93	84.29	83.87	6.73
Glyphosate 0.75 kg/ha PoE *fb* one HW	3.0(8.3)	6.5(42.0)	5.6(31.0)	2.2(3.7)	4.0(14.9)	3.8(13.7)	88.76	67.94	66.14	16.51
Weed free	1.0(0.0)	1.0(0.0)	1.0(0.0)	1.0(0.0)	1.0(0.0)	1.0(0.0)	100.0	100.0	100.0	-
Weedy check	17.3(298.2)	18.7(347.7)	17.6(307.9)	5.9(33.3)	6.9(46.4)	6.4(40.5)	-	-	-	39.76
LSD (p=0.05)	0.42	0.7	0.6	0.22	0.23	0.22	-	-	-	-

Values are $\sqrt{x+0.5}$ transformed and original values are in parenthesis; PE: Pre-emergence application; PoE: Post-emergence application; DAS: Days after sowing; *fb*: Followed by; HW: hand weeding

Table 2. Influence of weed management treatments on growth parameter and yield attributes of berseem

Treatment	Berseem dry weight (g)		Plant height at harvest (cm)	No. of effective tillers/m^2	No. of heads/m^2	No. of seeds/ head	Individu al head wt. (g)	Seed wt./head (g)	Test weight (g)
	I Cut	II Cut							
Mechanical stale seedbed	35.70	41.16	43.38	240.00	655.33	62.00	0.29	0.16	2.75
Pendimethalin + imazethapyr 0.75 kg/ha PE	41.22	46.98	51.69	272.48	695.50	69.63	0.30	0.19	2.93
Imazethapyr + imazamox 0.75 kg/ha PoE	44.50	51.08	56.87	293.00	722.17	83.00	0.34	0.26	3.09
Glyphosate 1.0 kg/ha PoE *fb* imazethapyr + imazamox 0.75 kg/ha PoE	46.56	53.10	59.48	302.07	734.88	89.89	0.39	0.3	3.17
Glyphosate 0.75 kg/ha PoE *fb* one HW	42.84	49.00	54.21	283.33	708.76	76.00	0.32	0.22	3.00
Weed free	49.05	55.70	62.34	314.75	748.40	97.22	0.43	0.35	3.38
Weedy check	32.49	37.66	40.14	229.78	642.13	58.19	0.27	0.14	2.70
LSD (p=0.05)	1.52	1.98	2.42	8.83	11.84	6.19	0.03	0.04	0.19

PE: Pre-emergence application; PoE: Post-emergence application; *fb*: Followed by

Table 3. Influence of weed management treatments on yield and economics of berseem

Treatment	Yield (t/ha) Green fodder I CUT	Yield (t/ha) Green fodder II CUT	Yield (t/ha) Green fodder Total	Yield (t/ha) Straw	Seed yield (kg/ha)	Cost of cultivation (`/ha)	Gross returns (`/ha)	Net returns (`/ha)	Benefit: cost ratio
Mechanical stale seedbed	5.74	16.82	22.56	1.85	353.33	54688	91702	37014	1.68
Pendimethalin + imazethapyr 0.75 kg/ha PE	6.75	18.45	25.20	2.41	431.67	55576	110113	54538	1.98
Imazethapyr + imazamox 0.75 kg/ha PoE	7.39	19.54	26.92	2.79	483.33	56113	122277	66164	2.18
Glyphosate 1.0 kg/ha PoE *fb* imazethapyr + imazamox 0.75 kg/ha PoE	7.70	20.08	27.78	2.97	508.33	57577	128173	70597	2.23
Glyphosate 0.75 kg/ha PoE *fb* one HW	7.06	18.99	26.05	2.59	455.00	61127	115713	54587	1.89
Weed free	8.06	20.92	28.98	3.20	545.00	72526	136678	64153	1.88
Weedy check	5.40	16.29	21.69	1.67	328.33	52901	85790	32890	1.62
LSD (p=0.05)	0.27	0.49	0.51	0.16	20.91	-	-	-	-

PE: Pre-emergence application; PoE: Post-emergence application; *fb*: Followed by; Present market price of berseem: Green fodder: 1000/t; Straw ‘ 3000/t; Seed: ‘ 180/kg

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RESEARCH NOTE

Weed management in kinnow mandarin (*Citrus nobilis* × *Citrus deliciosa*) orchards using various orchard floor management practices in sub-mountainous region of Punjab, India

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ABSTRACT

The study was carried out to ascertain the influence of different floor management practices in kinnow mandarin (*Citrus nobilis* × *Citrus deliciosa*) orchard on weed infestation, fruit yield and quality under sub-mountainous zone of Punjab state of India. Six years old kinnow mandarin plants were subjected to different treatments, *viz.* clean cultivation, weed management with herbicide, mowing of weeds, black polyethylene mulch, silver polyethylene mulch, subabul (*Leucaena leucocephala*) leaf mulch and control (weedy check). No weed growth occurred under synthetic mulches (black and silver polyethylene mulches). The mulching with leaves of subabul plant and the locally abundantly available wild species also exhibited significant reduction in grassy and broad-leaved weeds density and biomass. The fruit yield and quality attributing characteristics were significantly higher under black polyethylene mulch with maximum fruit size (6.29 cm length × 7.74 cm breadth), fruit weight (160.13 g) and the yield (71.63 kg/plant). Fruit quality (10.72ÚB) in terms of total sugars and ascorbic acid (TSS), vitamin C (40.28 mg/100g pulp) was also significantly better with black polythene mulch followed by silver polyethylene mulch and subabul leaves mulch.

Keywords: Biomass, *Citrus nobilis* × *Citrus deliciosa,* Fruit quality, Kinnow, Mulch, Weed management

The Kinnow (*Citrus nobilis* × *Citrus deliciosa*) is a high yield mandarin hybrid plant grown extensively in the Punjab region of India and Pakistan. Weed infestation in Kinnow orchards is a big challenge in the sub-mountainous zone of Punjab (India) for many Kinnow producers. Weeds are the undesirable plants emerging at the place in between the crop plants and compete for nutrients, water, moisture and light. Weeds are considered major obstacle in agricultural production systems particularly in fruit crops as the occurrence of weeds in the orchards effects the growth and establishment of the trees. Rao (2000) reported the annual loss of agricultural produce due to weeds as 45% cultivated crops and established orchards. However, the magnitude of the effect on growth and development depends on the weed species and the combination of methods employed for the weed control. The weeds can be managed by various methods such as chemical, mechanical, manual, biological and by mulching *etc*. Although the chemical weed management is most effective, it has its own constraints like the injury to non-target vegetation, crop injury, residues in soil and water, toxicity to non-target organisms. Conventional methods of hoeing are used for controlling the weeds by removal of weeds by hands, but it is time consuming and labour intensive (Boora *et al.* 2014). Mechanical control of weeds in established orchards is rather difficult and less effective due to spreading canopy of trees, limited coverage of the implements and potential damage to root and shoots of fruit trees. Mulching or covering the soil with organic or synthetic materials has been recorded as a safe method to control weeds in comparison to herbicides application (Ramakrishna 2006). The paddy straw mulch is easily available and cheap, while, the plastic mulch is costly affair for management of weeds in established orchards. Covering or mulching the soil surface can check the germination of weed seeds or physically suppress weed emergence (Stout 1985). Organic mulches reported to be beneficial for plant growth and fruit yield and quality in addition to weed suppression (Childers *et al*. 1995). There was a substantial reduction of weed growth with organic mulches in avocado and citrus over a period of four year (Faber *et al.* 2001). Transparent or white mulch and green covering had slight effect on weeds, while the coloured mulches such as brown, black, blue or

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double-colored films reduce the weed emergence (Bond *et al.* 2003). Abouziena *et al.* (2008) obtained the greater control (94-100%) of weeds occurred with the plastic mulch (200 or 150 ìm) and three mulch layers of rice straw. The higher soil and canopy temperature under clean cultivation led to excessive flower and fruit drop in Kinnow. Thus, the floor management in orchards is of utmost importance. The present study was undertaken to evaluate the response of weeds to different orchards floor management treatments.

The present study was carried out at Dr. D.R. Bhumbla Regional Research Station, Ballowal Saunkhri (Balachaur), Punjab (India) during 2019-21 on six years old, uniform and disease-free trees of Kinnow mandarin raised on rough lemon rootstocks were selected to study the effect of different orchard floor management treatments on productivity of Kinnow mandarin (*C. deliciosa x C. nobilis*) hybrid. There were seven treatments replicated thrice and each replication had a unit of five trees. The treatments were clean cultivation, weed management with herbicide, mowing of weeds, black polyethylene of 50-micron thickness mulch), silver polyethylene mulch), subabul (*Leucaena leucocephala*) leaves mulch, and control (weedy check). The black as well as silver polyethylene mulch of (50µ) thickness was applied by spreading under the tree canopy before the emergence of weeds. The mowing of weeds was carried out throughout the year with mower when the weeds attain a height of 9 inches thrice a year. The herbicide-based management practice was followed as per the recommendation in citrus orchards using post-emergence herbicide paraquat 1.24 litre/ha in second fortnight of March and again in second fortnight of July as per recommended in package of practice for orchards in PAU, Ludhiana. The treatments were initiated in March after cleaning the orchard and application of recommended doses of inorganic fertilizers. The experiment was replicated thrice. The weed density was estimated by using quadrat (1.0 × 1.0 m) placed randomly in all the replications. The grasses, sedges and broad-leaf weeds were counted separately at a monthly interval from May to April. The weed biomass was recorded by drying the weeds at a monthly interval in a hot air oven at 65 ^{0}C temperature for 3-4 days. The weeds were removed at ground level after placing the quadrate at random places for dry weight. The data on weed biomass and density was recorded up to April, 2021 starting from May 2019 after application of different orchard floor management treatments. The orchard floor management with mechanical methods using rotavator was carried out for comparison throughout the year. The subabul (*Leucaena leucocephala*) leaves were spread under the canopy of trees with 3-inch layer of leaves. The cultural practices and inputs were used as per package and practices for cultivation of citrus in Punjab by PAU, Ludhiana. Weight of 10 fruits randomly selected from each replication tree was recorded and average was worked out. The yield (kg/plant) was calculated by multiplying the average fruit weight and number of fruits per plant. The biochemical characteristics were determined by the standard methods. The weed density and biomass were recorded using quadrat method from the month of May, 2019 to April, 2021. The dry weight of weeds was expressed in g/m. The data of the actual number of weeds were transformed by square root transformation for statistical analysis. Statistical analysis of the data was done using CPCS1 software and comparisons were made at 5 per cent level of significance.

The weed species occurred in experimental plot were *Cynodon dactylon, Cyperus rotundus, Eleusine indica, Digera arvensis, Euphorbia hirta* and the commonly found winter weed species in the plots were *Chenopodium album, Anagallis arvensis, Amaranthus viridis* and *Argemone Mexicana.* There were no weeds in black and silver polyethylene mulch till April. The mean weed biomass of grassy and broad-leaved weeds was maximum in control (**Table 1-4**). Different floor management practices influenced the weed biomass. However, the density varied with the season. Similarly, significant reduction in weed density was reported in acid lime with black polyethylene mulch and silver polyethylene mulch (Shirgure *et al.* 2012). Thakur *et al* (2012) also observed that plastic mulch performed best in peach due to physical barriers provided by the mulches. These barriers caused reduction in weed seed germination and seedling growth by reducing light which in turn, caused reduction in photosynthesis. Total soluble solids were influenced by different treatments. The maximum TSS (total sugars and ascorbic acid) was recorded in fruits harvested from trees under black polyethylene mulch (**Table 5**) while minimum TSS was recorded in control trees. These variations in TSS probably may be due to the results of low temperature under organic mulch, whereas under black polyethylene mulch, higher soil temperature may be the principal cause suggested by Tang *et al* (1984). Ali and Gaur (2007) in strawberry and Sheikh (2013) in plum reported maximum TSS in black polyethylene mulch. Fruits harvested from trees under control had higher acidity (0.79%) as compared to all other treatments

(**Table 5**). The black polyethylene mulch recorded minimum fruit acidity (0.72%). This decline in acidity may be due to rapid conversion of some of the acids to sugars under black polyethylene mulch. Nath and Sharma (1994) also recorded maximum acidity under control in Assam lemon. Black polyethylene mulch caused significant increase in the vitamin-C content (40.28 mg/100 g pulp) as recorded by Hasan *et al* (2000) and Ali and Gaur (2007) in strawberry. The minimum vitamin-C content (33.93 mg/100 g pulp) was recorded in control (**Table 5**). Appreciable improvement in fruit quality in terms of ascorbic acid values obtained by various orchard floor management treatments might be associated with increase in conserving soil moisture which ultimately caused mobilization of soluble carbohydrates in the fruit. Fruit size was influenced by different orchard floor management practices (**Table 5**) with maximum fruit length and width and maximum fruit weight with black polyethylene mulch and minimum fruit length (5.42 cm) in control. The influence of mulching on fruit length may be attributed to better moisture availability and nutrients conserved in the soil at the time of fruit development. The moisture stress conditions developed at time of fruit development leads to poor growth, as has been observed under control. These results were in conformity with the findings of Bal and Singh (2011) who reported maximum fruit size in ber (*Ziziphus mauritiana*) under black polyethylene mulching and in strawberry (Sharma *et al* 2013, Shiukhy *et al* 2015). Borthakur and Bhattacharyya (1992) opined that the fruit weight in guava was improved under mulched conditions which may be due to increased absorption of nutrient and moisture. Black polyethylene mulch resulted in maximum yield (71.63 kg/plant) which was

Table 1 Influence of various orchard floor management practices on weed biomass (g/m^2) of grassy leaf weeds (pooled data)

Treatment	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Mean
Clean cultivation	(16.2) 4.02	(17.4) 4.17	(20.0) 4.47	(23.2) 4.82	(27.6) 5.25	(29.1) 5.39	(18.1) 4.25	(13.1) 3.63	(7.1) 2.66	(8.2) 2.86	(10.2) 3.19	(12.3) 3.51	(16.9) 4.01^{c}
Chemical weed management	(10.2) 3.19	(13.3) 3.65	(16.1) 4.02	(3.2) 1.80	(13.2) 3.63	(18.4) 4.29	(15.7) 3.96	(14.7) 3.83	(12.5) 3.54	(9.5) 3.09	(15.4) 3.93	(6.4) 2.53	(12.4) 3.45^{d}
Mowing of weeds	(18.2) 4.26	(20.0) 4.48	(21.8) 4.67	(25.4) 5.04	(29.4) 5.42	(28.5) 5.34	(20.4) 4.52	(18.5) 4.30	(13.5) 3.68	(10.5) 3.24	(24.0) 4.90	(19.5) 4.42	(20.8) 4.45^{b}
Black polyethylene mulch	(0.0) 0.71	(0.0) 0.71	(0.0) 0.71	(0.0) 0.71	(0.0) 0.71	(0.0) 0.71	(0.0) 0.71	(0.0) 0.71	(0.0) 0.71	(0.0) 0.71	(0.0) 0.71	(0.0) 0.71	(0.0) 0.71^{f}
Silver polyethylene mulch	(0.0) 0.71	(0.0) 0.71	(0.0) 0.71	(0.0) 0.71	(0.0) 0.71	(0.0) 0.71	(0.0) 0.71	(0.0) 0.71	(0.0) 0.71	(0.0) 0.71	(0.0) 0.71	(0.0) 0.71	(0.0) 0.71^{f}
Subabul leaf mulch	(3.0) 1.74	(4.3) 2.08	(6.3) 2.52	(7.7) 2.77	(9.3) 3.06	(12.4) 3.52	(10.3) 3.21	(8.7) 2.94	(6.0) 2.45	(6.7) 2.60	(15.5) 3.94	(16.5) 4.06	(8.9) 2.99^{e}
Control	(30.2) 5.50	(36.0) 6.00	(40.1) 6.33	(41.0) 6.41	(43.5) 6.60	(42.8) 6.55	(38.5) 6.21	(33.6) 5.79	(32.1) 5.66	(28.8) 5.37	(30.5) 5.52	(31.5) 5.61	(35.7) 5.96^{a}
Mean	(7.1) 2.89^{g}	(8.4) 312^{ef}	(9.8) 3.35^{c}	(8.8) 3.18^{d}	(11.7) 3.63^{b}	(12.8) 3.79^{a}	(10.0) 3.37^{c}	(8.5) 3.14^{de}	(6.5) 2.78^{h}	(6.0) 2.66^{i}	(8.6) 3.15^{de}	(8.2) 3.08^{f}	
LSD(p=0.05)	Treatment = 0.04 Month = 0.05												

*Data are subjected to square root transformation; values in the parentheses are original values

Table 2 Influence of various orchard floor management treatments on weed biomass (g/m^2) of broad-leaved weeds (pooled data)

Treatment	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Mean
Clean cultivation	(20.4) 4.52	(22.5) 4.75	(24.0) 4.90	(28.3) 5.32	(31.5) 5.61	(34.5) 5.87	(22.4) 4.74	(18.4) 4.30	(11.5) 3.39	(13.4) 3.66	(15.7) 3.97	(17.4) 4.18	(21.7) 4.60^{c}
Chemical weed management	(14.5) 3.81	(18.5) 4.30	(20.4) 4.52	(9.0) 2.99	(17.4) 4.18	(23.6) 4.86	(19.5) 4.42	(19.0) 4.36	(16.4) 4.05	(14.4) 3.80	(19.4) 4.41	(11.4) 3.38	(17.0) 4.08^{d}
Mowing of weeds	(22.7) 4.77	(24.5) 4.95	(25.7) 5.07	(30.5) 5.52	(33.5) 5.79	(34.0) 5.83	(24.4) 4.94	(23.4) 4.84	(17.3) 4.16	(15.4) 3.93	(20.1) 4.49	(24.5) 4.95	(24.3) 4.95^{b}
Black polyethylene mulch	(0.0) 0.71	(0.0) 0.71	(0.0) 0.71	(0.0) 0.71	(0.0) 0.71	(0.0) 0.71	(0.0) 0.71	(0.0) 0.71	(0.0) 0.71	(0.0) 0.71	(0.0) 0.71	(0.0) 0.71	(0.0) 0.71^{f}
Silver polyethylene mulch	(0.0) 0.71	(0.0) 0.71	(0.0) 0.71	(0.0) 0.71	(0.0) 0.71	(0.0) 0.71	(0.0) 0.71	(0.0) 0.71	(0.0) 0.71	(0.0) 0.71	(0.0) 0.71	(0.0) 0.71	(0.0) 0.71^{f}
Subabul leaf mulch	(7.8) 2.80	(9.1) 3.01	(10.3) 3.21	(12.2) 3.49	(13.4) 3.66	(17.5) 4.18	(14.4) 3.80	(13.4) 3.66	(10.7) 3.28	(11.4) 3.38	(14.1) 3.75	(21.4) 4.63	(12.7) 3.56^{e}
Control	(34.4) 5.87	(41.4) 6.44	(43.6) 6.60	(45.4) 6.74	(47.4) 6.89	(47.2) 6.87	(42.4) 6.52	(38.5) 6.21	(36.5) 6.05	(33.5) 5.79	(34.4) 5.87	(36.4) 6.03	(39.9) 6.32^{a}
Mean	(9.6) 3.31^{f}	(11.2) 3.55^{d}	(12.0) 3.67^{c}	(11.8) 3.55^{d}	(13.9) 3.93^{b}	(15.5) 4.14^{a}	(12.1) 3.68^{c}	(11.1) 3.53^{d}	(8.9) 3.19^{g}	(8.6) 3.13^{g}	(10.2) 3.40^{e}	(11.0) 3.51^{d}	
LSD (p=0.05)	Treatment = 0.04 Month = 0.05												

statistically at par with silver polyethylene mulch and subabul leaf mulch (**Table 5**). The minimum yield (63.33 kg/plant) was recorded in control. Plants under black polythene mulch produced maximum yield per plant due to better plant growth owing to favourable hydrothermal regime of soil and complete weed free environment to trees which in turn caused higher crop load. These results are also in line with those of Kaundal *et al* (1995) in peach Gosh and Bauri (2003) in mango Shirgure *et al* (2003) in Nagpur mandarin, Das and Dutta (2018) in mango and Ali and Gaur (2007) in strawberry who recorded highest fruit yield with black polythene mulch.

Thus, it can be concluded that the black and silver polythene mulches were superior in terms of weed suppression improving fruit yield and quality of Kinnow under the lower Shiwaliks hills of Punjab.

Table 3 Influence of various orchard floor management treatments on density (no./m^2) grassy weed (pooled data)

Treatment	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Mean
Clean cultivation	(23.0) 4.80	(26.4) 5.14	(31.0) 5.57	(38.1) 6.18	(42.6) 6.52	(40.4) 6.36	(29.3) 5.42	(18.5) 4.30	(12.3) 3.51	(14.7) 3.83	(18.4) 4.29	(20.0) 4.48	(26.2) 5.03^{c}
Chemical weed management	(15.4) 3.93	(21.0) 4.58	(29.8) 5.46	(8.4) 2.90	(19.3) 4.39	(26.3) 5.13	(24.2) 4.92	(20.4) 4.52	(18.3) 4.27	(15.3) 3.92	(20.3) 4.51	(10.3) 3.22	(19.1) 4.31^{d}
Mowing of weeds	(28.4) 5.33	(30.6) 5.53	(34.6) 5.88	(38.2) 6.18	(43.4) 6.59	(42.2) 6.49	(30.3) 5.50	(28.3) 5.32	(19.2) 4.38	(17.7) 4.20	(22.0) 4.69	(26.1) 5.11	(30.1) 5.43^{b}
Black polyethylene mulch	(0.0) 0.71	(0.0) 0.71	(0.0) 0.71	(0.0) 0.71	(0.0) 0.71	(0.0) 0.71	(0.0) 0.71	(0.0) 0.71	(0.0) 0.71	(0.0) 0.71	(0.0) 0.71	(0.0) 0.71	(0.0) 0.71^{f}
Silver polyethylene mulch	(0.0) 0.71	(0.0) 0.71	(0.0) 0.71	(0.0) 0.71	(0.0) 0.71	(0.0) 0.71	(0.0) 0.71	(0.0) 0.71	(0.0) 0.71	(0.0) 0.71	(0.0) 0.71	(0.0) 0.71	(0.0) 0.71^{f}
Subabul leaves mulch	(5.8) 2.42	(7.2) 2.68	(10.1) 3.17	(13.5) 3.68	(15.9) 3.99	(18.1) 4.26	(15.1) 3.89	(12.2) 3.49	(11.1) 3.34	(10.2) 3.19	(20.5) 4.53	(21.1) 4.59	(13.4) 3.61^{e}
Control	(45.3) 6.73	(54.1) 7.36	(63.3) 7.95	(70.7) 8.41	(79.1) 8.89	(77.5) 8.80	(57.1) 7.56	(48.2) 6.93	(42.0) 6.48	(37.3) 6.10	(40.4) 6.35	(42.1) 6.49	(54.7) 7.34^{a}
Mean	(16.9) 3.53^{h}	(19.9) 3.82^{e}	(24.1) 4.20^{c}	(24.1) 4.11^{d}	(28.6) 4.54^{b}	(29.2) 4.63^{a}	(22.3) 4.10^{d}	(18.2) 3.71^{f}	(14.7) 3.34^{i}	(13.6) 3.23^{j}	(17.4) 3.68^{f}	(17.1) 3.61^{g}	
LSD (p=0.05)	Treatment = 0.01 Month = 0.04												

Table 4 Influence of various orchard floor management practices weed density (no./m^2) on broad-leaved (pooled data)

Treatment	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Jan	Feb	Mar	Apr	Mean
Clean cultivation	(27.4) 5.24	(31.7) 5.63	(34.4) 5.87	(43.9) 6.63	(46.4) 6.81	(45.9) 6.78	(33.9) 5.82	(23.5) 4.85	(16.7) 4.09	(19.8) 4.45	(22.6) 4.75	(25.6) 5.06	(30.1) 5.49^{c}
Chemical weed management	(19.5) 4.41	(26.4) 5.14	(33.5) 5.79	(13.6) 3.69	(23.6) 4.86	(31.9) 5.65	(28.7) 5.36	(25.4) 5.04	(22.8) 4.78	(20.4) 4.51	(24.4) 4.94	(15.6) 3.94	(23.4) 4.84^{d}
Mowing of weeds	(32.8) 5.73	(35.5) 5.96	(39.6) 6.29	(43.6) 6.60	(47.4) 6.89	(46.5) 6.82	(34.4) 5.87	(32.7) 5.72	(23.6) 4.86	(21.5) 4.64	(26.6) 5.16	(31.5) 5.61	(34.1) 5.84^{b}
Black polyethylene mulch	(0.0) 0.71	(0.0) 0.71	(0.0) 0.71	(0.0) 0.71	(0.0) 0.71	(0.0) 0.71	(0.0) 0.71	(0.0) 0.71	(0.0) 0.71	(0.0) 0.71	(0.0) 0.71	(0.0) 0.71	(0.0) 0.71^{f}
Silver polyethylene mulch	(0.0) 0.71	(0.0) 0.71	(0.0) 0.71	(0.0) 0.71	(0.0) 0.71	(0.0) 0.71	(0.0) 0.71	(0.0) 0.71	(0.0) 0.71	(0.0) 0.71	(0.0) 0.71	(0.0) 0.71	(0.0) 0.71^{f}
Subabul leaf mulch	(9.4) 3.07	(12.5) 3.54	(14.4) 3.80	(18.5) 4.30	(19.7) 4.43	(23.5) 4.85	(19.4) 4.41	(17.4) 4.17	(15.4) 3.93	(16.0) 4.00	(24.7) 4.97	(26.7) 5.17	(17.7) 4.21^{e}
Control	(50.4) 7.10	(59.4) 7.71	(67.6) 8.22	(74.7) 8.65	(83.5) 9.14	(81.7) 9.04	(61.5) 7.84	(52.5) 7.25	(47.5) 6.89	(42.4) 6.51	(44.8) 6.70	(47.5) 6.89	(58.7) 7.66^{a}
Mean	(19.9) 3.85^{i}	(23.6) 4.19^{e}	(67.6) 4.48^{c}	(27.8) 4.46^{c}	(31.5) 4.79^{b}	(32.8) 4.96^{a}	(25.4) 4.38^{d}	(21.6) 4.06^{f}	(18.0) 3.70^{j}	(17.2) 3.64^{k}	(20.5) 3.99^{h}	(21.0) 4.01^{g}	
LSD (p=0.05)	Treatment = 0.01 Month = 0.02												

*Data are subjected to square root transformation; values in the parentheses are original values

Table 5 Influence of various orchard floor management treatments on fruit yield and quality parameters

Treatment	Total soluble solids(°Brix)	Acidity (%)	Vitamin-C content (mg/100g pulp)	Fruit length (cm)	Fruit breadth (cm)	Fruit weight (g)	Yield (kg/plant)
Clean cultivation	10.45^{a}	0.77^{ab}	34.98^{b}	5.84^{b}	6.76^{bc}	154.95^{abcd}	66.67^{bc}
Chemical weed management	10.51^{a}	0.78^{a}	35.18^{b}	5.76^{b}	6.64^{c}	154.41^{bcd}	66.03^{bcd}
Mowing of weeds	10.47^{a}	0.75^{bc}	34.88^{b}	5.76^{b}	6.55^{c}	153.69^{cd}	64.90^{cd}
Black polyethylene mulch	10.72^{a}	0.72^{c}	40.28^{a}	6.29^{a}	7.74^{a}	160.13^{a}	71.63^{a}
Silver polyethylene mulch	10.62^{a}	0.74^{c}	39.27^{a}	6.25^{a}	7.10^{b}	159.52^{ab}	70.24^{a}
Subabul leaf mulch	10.45^{a}	0.74^{bc}	38.78^{a}	6.23^{a}	7.03^{b}	158.83^{abc}	68.72^{ab}
Control	9.78^{b}	0.79^{a}	33.93^{b}	5.42^{c}	6.41^{c}	150.19^{d}	63.33^{d}
LSD (p=0.05)	0.54	0.02	1.54	0.25	0.37	5.64	3.13

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