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Research articles

Research notes

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RESEARCH ARTICLE

Deciphering the influence of barnyardgrass (*Echinochloa crus-galli*) density on growth and yield components of dry-seeded rice

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ABSTRACT

Echinochloa crus-galli (L.) P. Beauv. is a dominant and competitive weed in the dry-seeded rice system. It imparts negative competition for various resources and may cause a complete yield loss. Therefore, population-dependent *E. crus-galli* (0–175/m^2) with a fixed level of rice density was evaluated to elucidate the influence on the growth and yield of rice plants and *E. crus-galli* as well. It was revealed that rice plants without *E. crus-galli* produced 60% more tillers and generated 57% more leaves with increased dimensions. This resulted in accumulating 36% more rice plant biomass than density at 175/m^2. Likewise, panicles were 4% longer, contained 40% more grains/panicle, and 37% heavier with fewer un-filled grains/panicle than *E. crus-galli* of 175/m^2. Generally, an increase in the density of *E. crus-galli* from 25–175/m^2 gradually decreased the yield attributes. Among the *E. crus-galli* densities at 25/m^2, *E. crus-galli* plants were shorter by 22%, produced 103% more tillers, 36% more leaves, 72% longer, 53% wider and accumulated 56% more plant biomass, with 52% longer inflorescence, 86% more caryopsis/inflorescence, 62% heavier inflorescence over density of 175/m^2. However, from the density at 100/m^2 onwards, caryopsis/m^2 started declining and inflorescence became lighter.

Keywords: *Echinochloa crus-galli*, Density, Growth parameters, Rice, Yield attributes

INTRODUCTION

The world's more than 50% of the population depends on rice for food and consumes more than 50 kg/capita/year. Globally, ~782 million tonnes (MT) of rice have been produced from ~167 million hectares (MH) area and over 90% was used directly for human consumption (USDA-ERS 2022). Rice is the principal staple food crop of the Asian population; more than 90% of the world's rice is grown and consumed in Asia. The rice is being cultivated under different establishment methods depending upon the resource availabilities. However, manual transplanting of rice seedlings in puddle soil is the most common method in Asian countries (Chauhan *et al.* 2012, Choudhary 2017). However, in recent times, to save water and to manage the non-availability of manpower, the majority of rice growers have shifted from transplanted rice to dry-seeded rice. However, weeds are the major biological constraint in successful rice production. The yield loss in rice due to weeds has been reported at 57% in transplanted rice and 82% in dry-seeded rice (Mahajan *et al.* 2009; Rao *et al.* 2015) with US$ 4.20 billion monetary loss annually (Gharde *et al.* 2018). The rice grain yield reduction by weeds is largely dependent on the level of weed infestation, species richness, their density, dry matter accumulation, and duration of association (Nkoa *et al.* 2015, Travlos *et al.* 2018). The competition period in transplanted rice is shorter due to 'head start' advantage and a thin water layer over germinating weed seeds, whereas in dry-seeded rice this widens and is further extended in aerobic rice (Choudhary *et al.* 2021a).

The rice fields are generally infested with grasses, broad-leaf weeds (BLWs) and sedges. Among the grasses, jungle rice [*Echinochloa colona* (L.) Link], barnyard grass [*Echinochloa crus-galli* (L.) P. Beauv.] and cockspur grass (*Echinochloa glabrescens* Kossenko) are major weeds, apart from this hairy crabgrass [*Digitaria sanguinalis* (L.) Scop.], viper grass [*Dinebra retroflexa* (Vahl) Panz.], bermuda grass [*Cynodon dactylon* (L.) Pers.] and crowfoot grass [*Dactyloctenium aegyptium* (L.) Willd.] is considered to be a threat to rice production and causes considerable yield loss in several countries (Rao *et al.* 2007). In general, the relative density of grasses varies from maximum to minimum *E. colona*> *E. crus-galli*>*E. glabrescens* (Awan *et al.* 2021). These species are highly competitive for various available resources at the site i.e. soil

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nutrients, water, space, light, *etc*. and also morpho-physiological similarities with rice; which make it more difficult to control (Choudhary *et al.* 2021b). Among the weeds, *E. crus-galli* is the most problematic weed infesting rice field in India (Choudhary and Dixit 2021). It is an annual grass weed that mimics rice, especially at tillering stage. This makes it difficult to differentiate the weed from rice plants and by the time gets recognized it already had caused damage. In the last decade, it has been noticed that rice fields are severely infested with *E. crus-galli*. The infestation of *E. crus-galli* further intensifies with alternate wetting and drying, and the absence of a water layer in rice (Choudhary 2017). Further, the adoption of a rice-rice cropping system increased the severity of *E. crus-galli*. It has been reported that season-long interference of one plant/m^2 of *E. crus-galli* can minimize the rice yield by 257 kg/ha (Stauber *et al.* 1991). This weed has the plasticity to shorten the life period under adverse conditions and can produce substantial seeds (Derakhshan and Gherekhloo 2013). Nevertheless of its negative impact, there is limited information available on the competitive ability of *E. crus-galli* upon rice in dry-seeded rice agro-ecosystem. It is also less known to what extent rice plants can compete with *E. crus-galli* without any yield penalty. Therefore, the present study was conducted to optimize the possible yield penalty under different densities of *E. crus-galli* in the dry-seeded rice system. This study is also focused on the varying densities of weeds and tries to decipher the influence of weeds on the growth and yield attributes of rice.

MATERIALS AND METHODS

A pot study was conducted for two consecutive years (2015 and 2016) at the experimental farm of Indian Council of Agricultural Research (ICAR)–National Institute of Biotic Stress Management, Raipur (extends 21°22'50.4" N 81° 49'31.9" E, 289 m above MSL), India. The climate of the study area was sub–tropical, and humid. Fifty years average annual precipitation was 1250 mm. About 80% of total rain is received from July to September months of the year from the South-West monsoon. It records the minimum monthly mean temperature of 12 °C in December and a maximum monthly mean temperature of 45 °C in May. The soil used in the pots was clay–loam in texture with 25% sand, 42% silt and 33% clay, 0.38% organic carbon with a pH of 6.9. Available nitrogen, phosphorus and potassium content in the soil were 225.2, 16.3 and 355 kg/ha, respectively.

The seeds of *E. crus-galli* were collected at a farmers' field that adopted a rice-rice cropping system. The experiment was conducted in a completely randomized design (CRD) with three replications and six pots per replication. In each pot, the density of *E. crus-galli* was maintained at 0, 1, 2, 3, 4, 5, 6 and 7 plants which were about 0, 25, 50, 75, 100, 125, 150, and 175/m^2. A pot with a dimension of 20 × 20 cm was used for the study which was filled with 12 kg of homogenous soil. The rice seeds were dibbled at 2 cm depth, whereas *E. crus-galli* seeds were placed at 0.5 cm depth from the surface of the pots on June 15, 2015 and June 19, 2016 for the two consecutive seasons. Rice seedlings were thinned to two seedlings/pot at 15 days after sowing (DAS), whereas densities of *E. crus-galli* were maintained as per the treatments. The weeds that emerged other than *E. crus-galli* were periodically removed. The rice plants were fertilized with the proportion of 100: 60: 40 kg N, P, and K/ha, through urea (46% N), single super phosphate (16% P) and muriate of potash (60% K). Entire P and K were applied at the time of seeding, whereas nitrogen was applied at 10, 30, 45 and 65 days after seeding (DAS) in both years and irrigated the plots as and when required. Rice plants were harvested on 1st and ^{3rd} November of 2015 and 2016, respectively.

Total leaves/tiller, leaf length and width (cm) of rice were measured at 60 DAS. Plant height was measured from soil surface to tip of the uppermost leaf, tillers/hill, panicle length, grains/panicle, chaffy grains/panicle, and biomass (g/plant) was recorded at maturity. Rice plants were harvested when about 85% of the seed head matured. Irrigation was stopped at maturity and the pots were dried in the sun. After drying, plants were cut from the base. Plants were initially air-dried and later kept in a brown paper bag and then oven-dried at 65±2°C for 48 hours. After getting constant weight, the biomass of rice was measured.

In *E. crus-galli,* total leaves/tiller, leaf length and width (cm) were measured at 60 DAS. Plant height was measured from soil surface to tip of the uppermost leaf, tillers/hill, inflorescence length, caryopsis/inflorescence, chaffy caryopsis/inflorescence, inflorescence weight (g/plant) and biomass (g/plant) was recorded at maturity. For estimating caryopsis production/inflorescence in *E. crus-galli*, two intact seed heads were chosen randomly from each plant. Caryopsis was counted from rachilla segment and later multiplied with the total rachilla for the final caryopsis count per plant.

For statistical analysis, the F-test was used to check the difference between year effects with a significant level of $p<0.05$. Therefore, the data were analyzed with a two-factor CRD, where the year was considered as the first factor and *E. crus-galli* density as the second factor. Both year's data were analyzed using OPSTAT. Treatment effects were compared with Tukey HSD test.

RESULTS AND DISCUSSION

Growth parameters of rice

The effect of years and *E. crus-galli* densities significantly ($p<0.05$) affected the growth parameters of rice (**Table 1**). Between the years, the growth parameters were higher in 2016 than in 2015. In 2016, rice plants were taller by 3%, produced 9% more tillers/hill, more leaves by 7%, longer and broader leaves by 4% and accumulated 20% higher biomass/plant than in 2015.

Rice plants were shorter in the pots without *E. crus-galli* whereas plant height gradually increased with an increase in densities and they were taller by 2–8% with *E. crus-galli* densities from 25–175/m^2. This might be due to intra- and inter-specific competition for light. Plants became taller to overcome the shading effect (Choudhary *et al.* 2021b). Ironically, rice plants produced 4–60% lower tillers, lesser leaves by 3–57%, shorter leaves by 1–21%, narrow leaves by 4–37%, and accumulated lesser plant biomass by 10–36% with the progressive weed density from 25–175/m^2 than without *E. crus-galli* (5.7/hill, 4.1 leaves/plant, 23.0 and 0.81 cm and 3.1 g/plant, respectively). Tiller production was greatly and negatively influenced by the presence of *E. crus-galli*. Lesser, shorter and narrower leaves were produced with higher densities. Overall, lower growth parameters with higher densities of *E. crus-galli* were due to resource competition between rice plants and *E. crus-galli* populations. Consequently, less competitive rice plants availed fewer resources than of robust *E. crus-galli*. The interaction between years and *E. crus-galli* densities was found non-significant in the growth parameters of rice.

Table 1. Effect of *Echinochloa crus-galli* density on growth parameters of rice

Treatment	Plant height (cm)	Tillers / plant	Leaves / plant	Leaf length (cm)	Leaf width (cm)	Plant biomass (g/plant)
Year (Y)						
2015	86.8	4.6	3.3	21.2	0.68	2.5
2016	89.7	5.0	3.6	22.0	0.71	3.0
LSD (p=0.05)	0.59	0.17	0.16	0.27	0.01	0.1
E. crus-galli density/m^2 (E)						
0	84.9	5.7	4.1	23.0	0.81	3.1
25	86.6	5.4	4.0	22.7	0.78	2.9
50	86.4	5.2	3.7	22.6	0.72	2.9
75	87.6	5.1	3.5	22.5	0.72	2.8
100	88.7	4.9	3.4	21.4	0.67	2.7
125	89.9	4.4	3.2	20.9	0.67	2.6
150	90.8	3.9	3.1	20.3	0.61	2.5
175	91.4	3.5	2.6	19.1	0.59	2.3
LSD (p=0.05)	1.18	0.34	0.31	0.54	0.03	0.2
Y x E	NS	NS	NS	NS	NS	NS

Yield attributes of rice

Rice yield attributes were affected significantly ($p<0.05$) by the year of the study and densities of *E. crus-galli* (**Table 2**). Higher yield attributes were obtained during 2016 than in 2015. In 2016, rice panicles were longer by 2%, produced 8% more seeds/panicle and heavier panicles by 7% than in 2015. Whereas unfilled grains were 15% less in 2016 than in 2015. Yield loss due to *E. crus-galli* was higher in 2016 than in 2015. Yield attributes of rice were better without *E. crus-galli* pots. Panicles were 1–4% longer, produced 5–40% more seeds/panicle, heavier panicles by 2–37% in without *E. crus-galli* pots and noticed 16–171% fewer unfilled grains than the density of 25–175/m^2. It was observed that yield attributes decreased with an increase in density of *E. crus-galli* and lowest with 175/m^2 (panicles of 16.5 cm, 86.2 seeds/panicle, 1.7 g/panicle with 25.3 unfilled grains/panicle). Contrarily, an increase in the density of *E. crus-galli* (> 50/m^2) had significantly more unfilled rice grains. The highest yield loss of 27–30% was observed with 175/m^2 whereas the lowest yield loss was obtained with 25/m^2 (by 4–5%). Similar results were also reported earlier by Zhang *et al.* (2021) in the rice ecosystem in China. The interaction between years and *E. crus-galli* densities was found non-significant in yield attributes of rice. It was noted that in rice, tillers/plant and chaffy grains/ panicles followed a negative linear relationship with r=0.83 (**Figure 1a**). This suggests that with an

Table 2. Effect of *Echinochloa crus-galli* density on yield attributes of rice

Treatment	Panicle length (cm)	Seeds / panicle	Chaffy grains / panicle	Panicle weight (g/panicle)
Year (Y)				
2015	17.9	101.3	17.9	2.0
2016	18.4	109.4	15.6	2.1
LSD (p=0.05)	0.25	1.82	1.16	0.04
E. crus-galli density/m^2 (E)				
0	19.9	120.7	9.3	2.4
25	19.4	115.2	10.8	2.3
50	18.7	111.3	15.5	2.2
75	18.4	108.2	16.0	2.1
100	17.9	104.8	17.5	2.0
125	17.4	100.7	18.5	1.9
150	17.2	96.0	21.0	1.8
175	16.5	86.2	25.3	1.7
LSD (p=0.05)	0.50	3.63	2.32	0.09
Y x E	NS	NS	NS	NS

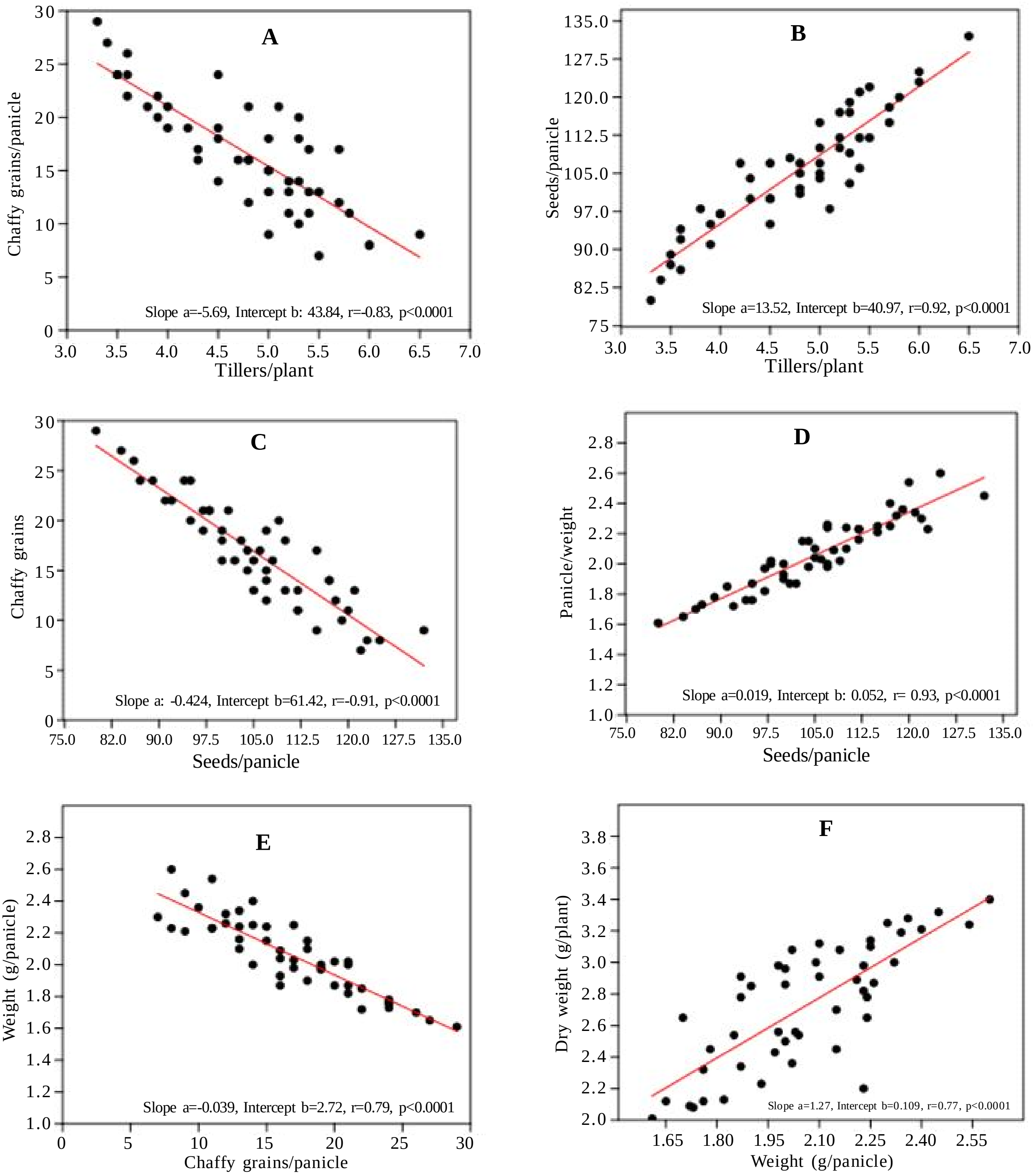

Figure 1. Relationship between a) tillers/plant and chaffy grains/panicle, b) tillers/plant and seeds/panicle, c) seeds/panicle and chaffy grains/panicle, d) seeds/panicle and panicle/weight, e) chaffy grains/panicle and weight/panicle, and f) weight/panicle and dry weight/panicle irrespective of *E. crus-galli* densities

increase in tillers/plant there was a reduction in chaffy grains. Fewer tillers were produced in rice due to competition offered by higher densities of *E. crus-galli*, which lead to the production of more numbers of spikelet, but all the spikelet did not fill resulting in higher chaffy grains. Rice tillers/plant and grains/panicle were linearly but positively associated with r=0.92 (**Figure 1b**). Likewise, chaffy grains and grains/panicle are associated linearly but negatively with r=0.91 (**Figure 1c**). It depicts that with an increase in grains/panicle, the number of chaffy grains declined mainly due to the lower density of *E. crus-galli* which offered less competition. Therefore, panicle weight and grains/panicle also exhibit a positive linear relationship with r= 0.93 (**Figure 1d**). **Figure 1e** illustrated that an increase in the panicle weight of rice reduced the total chaffy grains/panicle linearly with r=0.79. On contrarily, an increase in plant biomass also contributed positively to the panicle weight linearly with r=0.77 (**Figure 1f**).

Growth parameters of *Echinochloa crus-galli*

Growth parameters, *viz*. height, tillers/hill, leaves/plant, leaf length and width, and biomass of *E. crus-galli* were affected significantly by its densities on rice (**Table 3**). Between the years, the plants of *E. crus-galli* were 8% taller, produced 8% more tillers, 4% more leaves, 5% longer and 4% wider leaves and accumulated 21% more biomass in 2016 than in 2015 (106.5 cm height, 6.2 tillers/hill, 7.2 cm leaves, 29.7 cm long and 0.90 cm width and 1.9 g/plant). All the growth parameters in 2016 were significant ($p<0.05$) except leaf width. Densities of *E. crus-galli* influenced different characteristics with fixed rice density. Increase in the density of *E. crus-galli* from 25 to 175/m^2, plants became taller by 4–22% over without *E. crus-galli* (99.2 cm). Contrarily, produced 4–103% fewer tillers, 5–36% lesser leaves, 11–72% shorter, 11–53% narrower leaves and 5–56% lower plant biomass over *E. crus-galli* density at 25/m^2 (7.4/hill, 8.3 leaves/plant, 37.9 cm length and 1.14 cm width). Total tillers per unit area gradually increased with an increase in its density up to 150/m^2 (by 2.45 folds) and a further increase in density (175/m^2) had lesser tillers (by 65%) than 150/m^2. But it largely depended on the total number of tillers which contributed significantly towards more leaf surface area for photosynthesis and thus accumulated higher plant biomass. This resulted in *E. crus-galli* at 150/m^2 densities could accumulate higher plant biomass by 3.5 folds over 25/m^2. This confirmed that excessive density offers competition for resource sharing within the species and thus could accumulate less plant biomass. The rest of the densities were also significant but were less than 150/m^2. The pots with higher densities of *E. crus-galli* had a considerably higher reduction of growth parameters than lower densities. The interaction between years and *E. crus-galli* densities was found non-significant on the growth parameters of *E. crus-galli.*

Table 3. Effect of *Echinochloa crus-galli* density on growth parameters of *E. crus-galli*

Treatment	Plant height (cm)	Tillers / hill	Total leaves / plant	Leaf length (cm)	Leaf width (cm)	Biomass (g/plant)
Year (Y)						
2015	106.5	5.8	7.2	29.7	0.90	1.9
2016	115.1	6.2	7.5	31.2	0.93	2.3
LSD (p=0.05)	1.6	0.07	0.19	1.02	ns	0.10
E. crus-galli density/m^2 (E)						
25	99.2	7.4	8.3	37.9	1.14	2.5
50	103.2	7.1	7.9	34.1	1.03	2.4
75	107.5	6.8	7.7	33.1	0.97	2.3
100	112.5	6.4	7.6	31.2	0.89	2.1
125	114.3	5.6	7.1	28.2	0.84	2.0
150	118.3	5.0	6.6	26.4	0.78	1.9
175	120.8	3.6	6.1	22.1	0.75	1.6
LSD (p=0.05)	3.00	0.38	0.35	1.90	0.10	0.19
Y x E	NS	NS	NS	NS	NS	NS

Per unit more leaf surface area at 175/m^2 densities allows to intercept more sunlight for photosynthesis and assimilated higher biomass. Contrarily, at a lower density of *E. crus-galli*, per plant leaf number, length and width of the leaves are higher than at higher densities. At lower densities, *E. crus-galli* is more competitive and competitiveness increases with an increase in densities up to 100/m^2. However, it can produce more energy to support the taller plant stature and also support more seeds/ plants. Higher densities covered the canopy and gave shade which is detrimental to rice plants. Thus, self-shading rather than leaf angle per se is important for light interception and biomass gain (Falster and Westoby 2003). Contrarily, densities at >150/m^2, and self-shading makes plants weaker, resulting in comparatively less accumulation of plant biomass, thereby producing lesser tillers at this density onwards. Similarly, per unit caryopsis production and rachilla weight can be started reducing at densities >100/m^2, this might be due to intra-specific competition (**Table 4**).

Yield attributes of *Echinochloa crus-galli*

Yield attributes of *E. crus-galli* were affected significantly by the year of the study and its densities (**Table 4**). Yield attributes were obtained better during 2016 than in 2015. In 2016, inflorescence was longer by 11% and produced 8% more caryopsis/ inflorescence than in 2015. Moreover, inflorescence was 3% heavier in 2016 than in 2015 but was statistically ($p<0.05$) comparable.

Among the *E. crus-galli* densities, yield attributes of *E. crus-galli* were density-dependent and obtained better on densities at 25/m^2. Inflorescence was 7–52% longer, produced 12–86% more caryopsis/inflorescence and heavier inflorescence by 7–62% at 25/m^2. In general, per plant yield attributes were in decreasing trend with an increase in density of *E. crus-galli* and lowest with 175/m^2 (inflorescence of 8.6 cm length, 316.8 caryopsis/inflorescence and 0.8 g/inflorescence). However, for a better understanding, some of the parameters were computed per m^2 basis, in 2016, tillers/m^2 was higher by 6%, 13% more caryopsis/m^2, 10% heavier inflorescence and accumulated 24% higher plant biomass than in 2015.

Table 4. Effect of *Echinochloa crus-galli* density on yield parameters of *E. crus-galli*

Treatment	Inflorescence length (cm)	Caryopsis/ inflorescence	Weight (g/inflorescence)	Biomass (g/plant)	Tillers/m^2	Caryopsis/m^2	Inflorescence weight (g/m^2)	Biomass (g/m^2)
Years								
2015	10.3	423.8	1.1	1.9	523.2	208961	519.7	174.9
2016	11.4	459.8	1.1	2.3	555.2	236565	572.0	216.7
LSD (p=0.05)	0.69	9.8	0.02	0.1	25.35	7971.06	24.34	4.27
E. crus-galli density/m^2 (E)								
25	13.1	588.0	1.3	2.5	184.2	108860	242.2	62.5
50	12.2	525.0	1.2	2.4	355.0	186838	437.0	119.5
75	12.0	483.7	1.2	2.3	506.3	245344	586.8	169.5
100	10.6	435.7	1.1	2.1	638.3	278247	705.7	211.9
125	10.1	393.3	1.0	2.0	700.0	275269	688.2	247.3
150	9.8	350.0	0.9	1.9	755.0	263410	644.8	280.5
175	8.6	316.8	0.8	1.6	635.8	201373	516.2	279.4
LSD (p=0.05)	1.28	18.33	0.04	0.19	47.42	14912.5	45.53	8.00
Y x E	NS	25.92	NS	NS	NS	NS	NS	11.31

Densities of *E. crus-galli* from 50 to 175/m^2 increased the caryopsis/m^2 by 72–156%, heavier inflorescence by 80–191% and plant biomass by 91% to 350% higher over *E. crus-galli* at 25/m^2. It produced 278247 caryopsis/m^2 at the density of 100/m^2 and was higher by 156% over the density of 25/m^2. Besides an increase in density from 125 to 175/m^2 gradually decreased the caryopsis/m^2 by 3–71% more than that of 100/m^2. Higher caryopsis/m^2 in density at 100/m^2 could measure heavier inflorescence by 191% and it steadily decreased up to 175/m^2 (by 78%) over 25/m^2. Likewise, caryopsis/m^2 and inflorescence weight/m^2 gradually increased from 25 to 100/m^2 and later gradually decreased up to 175/m^2. Whereas plant biomass increased from 25 to 150/m^2 and it became lower at 175/m^2 over other densities of *E. crus-galli*. The fewer caryopsis, lighter inflorescence and plant biomass at a higher density of *E. crus-galli* were mainly due to intra-species competition which leads to a reduction of per plant capacity to produce caryopsis. Bagavathiannan *et al.* (2012) also reported that caryopsis production of *E. crus-galli* varies with crops, the timing of emergence, cropping system and climate. Likewise, due to fewer caryopsis, inflorescence became lighter and ultimately biomass accumulation was less. The interaction between years and *E. crus-galli* densities was found non-significant on yield attributes of *E. crus-galli* except caryopsis/inflorescence and biomass.

Among the *E. crus-galli* parameters, plant biomass per unit area of *E. crus-galli* and grain yield loss have followed a quadratic relationship with r=0.70 (**Figure 2a**). This elucidates that an increase in biomass of *E. crus-galli* offers more competition to rice plants for the resources resulting in plants becoming weaker and ultimately producing lesser grain yields. Likewise, an increase in the tiller density of *E. crus-galli* has produced more caryopsis/m2 and they followed a quadratic relationship with r=0.80 (**Figure 2b**). It was also noticed that with an increase in plant dry weight and inflorescence weight also gradually increased but linearly with r=0.76 (**Figure 2c**).

The experimental findings proved that there are significant (p<0.05) differences in the growth and yield parameters of rice with variable *E. crus-galli* densities at a fixed level of the rice. The data

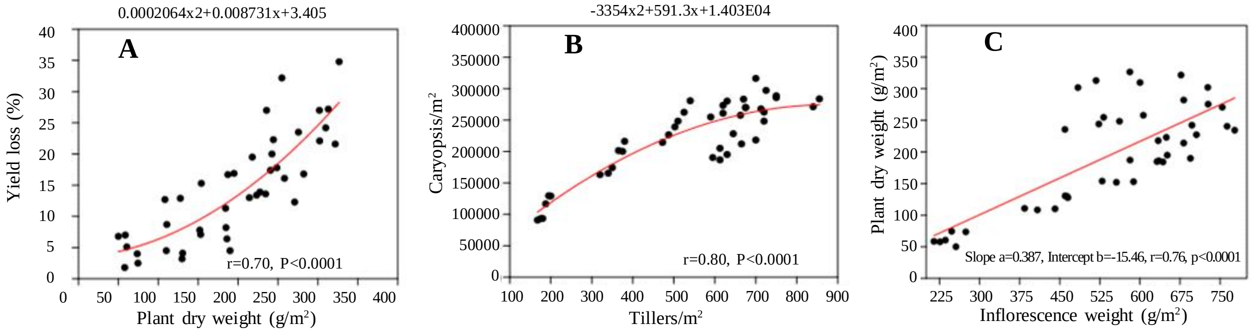

Figure 2. Relationship between a) plant dry weight and yield loss, b) tillers and caryopsis/m^2, c) inflorescence weight and plant dry weight irrespective of *E. crus-galli* densities

presented also support that the growth, development and yield parameters of rice were recorded as the highest without *E. crus-galli* and with an increase in the densities from 25 to 175/m^2 it gradually decreased. Contrarily, the inflorescence length of *E. crus-galli* was higher at 25/m^2, and it gradually decreased, while tiller production and biomass/plant increased up to 150/m^2, and the highest caryopsis production and inflorescence weight observed up to 100/m^2. An increase in the density of *E. crus-galli* from 25–175/m^2 reduced the grain yield up to 63.9%.

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RESEARCH ARTICLE

Weed removal and crop nutrient uptake as affected by tillage and herbicides in direct-seeded rice-yellow mustard cropping sequence

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ABSTRACT

A field experiment was conducted during rainy seasons of 2019 and 2020 to evaluate the impact of different tillage and herbicides on the nutrient removal by weeds and productivity of direct-seeded rice (DSR). The treatments consisted two tillage practices, *viz.* zero tillage (ZT) and conventional tillage (CT) in the main plot and six herbicide combinations [oxadiargyl followed by (*fb*) bispyribac-sodium, penoxsulam + cyhalofop-butyl, oxadiargyl *fb* penoxsulam + cyhalofop-butyl, fenoxaprop-p-ethyl + ethoxysulfuron, oxadiargyl *fb* fenoxaprop-p-ethyl + ethoxysulfuron and pendimethalin *fb* bispyribac-sodium] along with two control treatments (unweeded and weed free check) in the subplots of DSR. Total N, P and K removal by weed in unweeded control was 37.29, 47.12 and 35.86% higher under CT than under ZT. Oxadiargyl *fb* fenoxaprop-p-ethyl + ethoxysulfuron and oxadiargyl *fb* penoxsulam + cyhalofop-butyl registered the lowest total weed biomass, weed nutrient removal and higher nutrient uptake, crop yield and net return of DSR.

Keywords: Direct-seeded rice, Fenoxaprop-p-ethyl + ethoxysulfuron, Penoxsulam + cyhalofop-butyl, Nutrient uptake, Oxadiargyl, Tillage, Weed management

INTRODUCTION

Weeds of various species emerge along with the crop in direct-seeded rice (DSR), in different flushes and are difficult to control since they escape single weed control measure. Weeds have a higher competitive ability than crops and are more efficient in removing nutrients (Blackshaw *et al.* 2003). The removal of nutrients by weeds varies in different locations and this might be due to the type of species and the period of sample collection. Time of sampling is important to understand the total removal of nutrient by weeds since it depends on their biomass. Although, most weed species under DSR emerge at the same time, they do not mature simultaneously due to intra-specific competition and compete with the crop throughout the growing period. *Cyperus iria* (L.) emerges shortly after rice and flowers and produces seeds around a month later. *Ludwigia* sp. thrives in rice fields throughout the crop season. *Ludwigia* plants are initially slow in growth compared to rice, but later biomass increases and this may help *Ludwigia* sp. to compete with other species for light (Chauhan *et al*. 2011). This has wide ecological amplitude and is well-established weed in all the rice ecosystems. The probable reason for its wide ecological amplitude is the adaptation by developing special structure called periderm and pneumatophores like structures (Duary and Mukhopadhyay 1999, Duary *et al*. 2015).

Tillage has an impact on the emergence and growth of weeds. Zero tillage system gathers weed seeds on the soil surface and facilitates weed germination. Tilled soil provides a favourable condition for the establishment of weeds. Herbicides are the most effective and economic way to control the weeds in DSR. But, the application of a single herbicide on a regular basis may cause shift in weed flora. Sole application of single herbicide may not be effective against complex weed flora in DSR. Bispyribac-sodium - a widely used herbicide has already been found to be less effective against many weeds (Mahajan and Chauhan 2013, Chauhan *et al.* 2015, Menon 2019). Thus, combined or sequential application of herbicides is desirable for effective management of complex weed flora in DSR. However, limited information is available on the nutrient removal of various weed species under different tillage and herbicide combination in DSR. The objectives of the present study were to study the effect of combined/sequential application of herbicides on nutrient removal by weeds and crop and productivity of direct-seeded rice (DSR) under different tillage practices in this region of the west Bengal.

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MATERIALS AND METHODS

A field experiment was conducted at Agricultural Farm of Palli Siksha Bhavana (Institute of Agriculture), Visva-Bharati, Sriniketan, Birbhum, West Bengal during two consecutive rainy seasons of 2019 and 2020 in a fixed plot without disturbing the layout. The soil in the experimental field was sandy loam (*Ultisol*) with a pH of 5.80, 0.62% organic carbon, 253 kg/ha available N, 19 kg/ha P and 135 kg/ ha K. Zero tillage (ZT) and conventional tillage (CT) in main plot and eight weed management practices in sub-plots were assigned in a split-plot design replicated thrice. The weed management treatments consisted: pre-emergence application (PE) of oxadiargyl 90 g/ha followed by (*fb*) post-emergence application (PoE) of bispyribac-sodium at 25 g/ha, penoxsulam + cyhalofop-butyl (ready-mix) PoE 180 g/ha, oxadiargyl at 90 g/ha *fb* penoxsulam + cyhalofop-butyl (ready-mix) 180 g/ha, fenoxaprop-p-ethyl + ethoxysulfuron (tank-mix) PoE at 90 +15 g/ ha, oxadiargyl at 90 g/ha *fb* fenoxaprop-p-ethyl + ethoxysulfuron (tank-mix) at 90+15 g/ha, pendimethalin PE at 1000 g/ha *fb* bispyribac-sodium at 25 g/ha, weed free check and unweeded control. Glyphosate at 1.0 kg/ha was applied before sowing of crops under ZT. Before sowing rice with CT, the final land preparation was done using a rotavator. Rice cultivar *'MTU-1010'* was chosen for the study. The crop was fertilized with 80-40-40 kg/ha of N, P and K. Basal dose of nutrients was drilled through 10-26-26. Full quantity of P and K and 1/5th of N (16 kg/ha) was applied as basal on the day of sowing in DSR. Remaining quantity of N (64 kg/ha) was applied through urea in two equal splits at 25 and 50 DAS. The area of fresh green leaves for each treatment was measured by using leaf area meter (LICOR Model LI 3000CAP). Leaf area index (LAI) was computed using the formula as suggested by Evans (1972). Herbicides were applied with a battery-powered knapsack sprayer equipped with a flat-fan nozzle with 500 l/ha of water. Plant samples were collected at harvest for the estimation of nutrient, whereas weed samples were collected at their maturity [*Cyperus iria* (L.) at 30 DAS, *Digitaria sanguinalis* (L.) Scop., *Echinochloa colona* (L.) Link, *Fimbristylis miliacea* (L.) Vahl, *Spilanthes calva* DC., *Eclipta alba* (L.) and *Cyanotis axillaris* D. Don ex Sweet at 60 DAS and *Ludwigia parviflora* (Jacq.) Raven and *Alternanthera philoxeroides* (Mart.) Griseb. at 90 DAS]. Samples were dried in a hot air oven at 70 ^{0}C for 48 hours before chemical analysis. Total nitrogen was estimated using the Kjeldahl method from acid digestion, total phosphorus was estimated using the Vanado molybdate yellow colour method from diacid extract and total potassium was estimated using the flame photometric method from diacid extract as suggested by Jakson (1973). The uptake of N, P and K by crops and removal by weeds was estimated by multiplying crop yield with the corresponding % composition of N, P and K. Weed data were subjected to square root $\sqrt{x+0.5}$ transformation and the transformed data was used for analysis. Statistical analysis of the data was done as described by Gomez and Gomez (1984) at a 5% level of significance. The original data have been given in parentheses in each table along with the transformed values.

RESULT AND DISCUSSION

Weeds in direct-seeded rice and their nutrient uptake

Direct-seeded rice was infested with *Digitaria sanguinalis* (L.) Scop., *Echinochloa colona* (L.) Link, *Paspalum notatum* Flüggé among the grasses; *Eclipta alba* (L.), *Spilanthes calva* DC., *Ludwigia parviflora* (Jacq.) Raven, *Alternanthera philoxeroides* (Mart.) Griseb. and *Oldenlandia corymbosa* (L.) among broad-leaved; *Cyperus iria* (L.) and *Fimbristylis miliacea* (L.) Vahl among sedges and *Cyanotis axillaris* D. Don ex Sweet (monocot). Malik *et al.* (2021) also observed similar type of weed flora in DSR under lateritic soil of West Bengal. At maturity on a dry weight basis, *E. alba* (2.30%) recorded the highest N content (**Table 1**) followed by *S. calva* (2.18%). The phosphorus content was highest in *C. axillaris* (0.48%) and *E. alba* (0.47%). *Spilanthes calva* accumulated 5.48% K followed by *C. axillaris* (4.71%). Among weeds, the lowest N, P and K contents were obtained with *E. colona*.

Effect of tillage and herbicides on weed biomass and nutrient removal

The total biomass of all weed species at maturity was significantly lower in ZT (21.12 g/m^2) than in CT (31.79 g/m^2) in the first year (**Table 2**). However, in second year tillage had no effect on total weed biomass. Sequential application of oxadiargyl *fb* fexoxaprop-p-ethyl + ethoxysulfuron, oxadiargyl *fb* penoxsulam + cyhalofop-butyl, oxadiargyl *fb* bispyribac-sodium and pendimethalin *fb* bispyribac-sodium recorded the lowest total weed biomass. Penoxsulam + cyhalofop-butyl (ready-mix) and fenoxaprop-p-ethyl + ethoxysulfuron (tank-mix) significantly reduced the total weed biomass over unweeded control in first year. But, after one cropping cycle, sole application of penoxsulam + cyhalofop-butyl (ready-mix) recorded the highest total weed biomass, followed by unweeded control and fenoxaprop-p-ethyl + ethoxysulfuron (tank-mix) alone. The combination of cyhalofop-butyl and penoxsulam was poor against *L. perennis* as reported by Menon (2019). Pendimethalin *fb* bispyribac-sodium used in sequence was more effective than pendimethalin alone for controlling weeds (Patel *et al.* 2018).

During the second year, significant variation was not observed between tillage treatments in terms of the N, P and K removal by weeds in DSR (**Table 2**) as total weed biomass did not differ significantly between tillage practices in DSR. Although total nutrient removal was unaffected by tillage, interaction revealed that *D. sanguinalis* and *F. miliacea* removed N, P and K more efficiently under CT than under ZT (**Figure 1**). Total N, P and K removal was 37.29, 47.12, and 35.86% higher under CT than under ZT in the unweeded control (**Figure 1**). Among weed management treatments, highest N (32.22 kg/ha), P (9.02 kg/ha) and K (55.57 kg/ha) removal by weeds was in unweeded control during the first year (**Table 2**). However, following one cycle of the DSR-yellow mustard sequence, weeds under ready-mix penoxsulam + cyhalofop-butyl alone removed more nitrogen (60.72 vs. 38.56 kg/ha), phosphorus (12.18 vs. 6.50 kg/ha) and potassium (79.90 vs. 78.91 kg/ha) than the unweeded control due to the highest total weed biomass associated with it, followed by unweeded control and fexoxaprop-p-ethyl + ethoxysulfuron during second year (**Table 2**). When the weed biomass decreased, nutrient removal by weeds also decreased (Sangeetha *et al.* 2011). Within a very short period of life cycle, *Cyperus iria* removed 5.52 kg/ha of N, 0.68 kg/ha of P and 12.56 kg/ha of K in the unweeded control at 30 DAS (**Figure 2**). Poor control of *C. iria* with fenoxaprop-p-ethyl + ethoxysulfuron resulted in 4.03, 0.50 and 9.17 kg/ha N, P and K removal, respectively. Considerable removal of N (7.06 kg/ha), P (2.33 kg/ha), and K (12.17 kg/ha) by *Digitaria sanguinalis* was observed in unweeded control at 60 DAS (**Figure 3**). Penoxsulam + cyhalofop-butyl (ready-mix) applied alone, caused 3.07, 1.00 and 5.29 kg/ha of N, P and K removal , respectively by *D. sanguinalis*. In the second year penoxsulam + cyhalofop-butyl treated plot had the highest removal of N, P and K by *L. parviflora* at 90 DAS (**Figure 4**). *Ludwigia parviflora* removed 84.61, 86.12 and

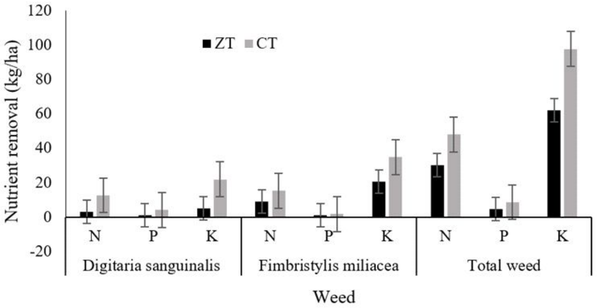
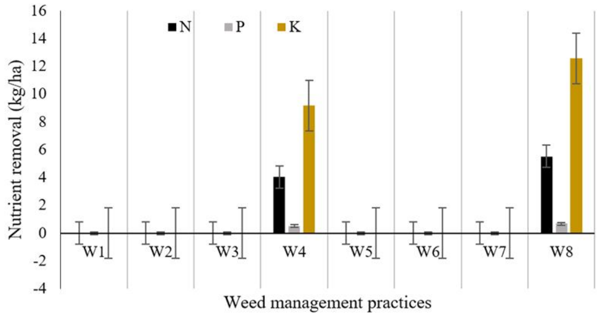
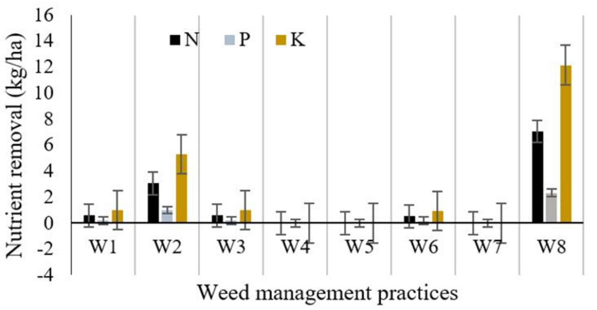


Figure 1. Removal of N, P and K by weeds in unweeded control under different tillage during 2020



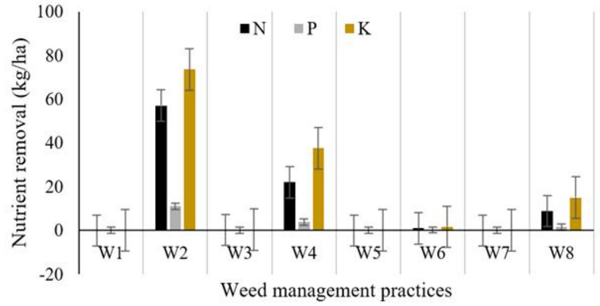
W1: Oxadiargyl *fb* bispyribac-sodium; W2: Penoxsulam + cyhalofop-butyl;W3: Oxadiargyl *fb* penoxsulam + cyhalofop-butyl;W4: Fenoxaprop-p-ethyl + ethoxysulfuron; W5: Oxadiargyl *fb* fenoxaprop-p-ethyl + ethoxysulfuron; W6: Pendimethalin *fb* bispyribac-sodium; W7: Weed free check; W8: Unweeded control

Figure 2. Effect of weed management practices on removal of N, P and K by *C. iria* during 2020



W1: Oxadiargyl *fb* bispyribac-sodium; W2: Penoxsulam + cyhalofop-butyl;W3: Oxadiargyl *fb* penoxsulam + cyhalofop-butyl;W4: Fenoxaprop-p-ethyl + ethoxysulfuron; W5: Oxadiargyl *fb* fenoxaprop-p-ethyl + ethoxysulfuron; W6: Pendimethalin *fb* bispyribac-sodium; W7: Weed free check; W8: Unweeded control

Figure 3. Effect of weed management practices on removal of N, P and K by *D. sanguinalis* during 2020



W1: Oxadiargyl *fb* bispyribac-sodium; W2: Penoxsulam + cyhalofop-butyl;W3: Oxadiargyl *fb* penoxsulam + cyhalofop-butyl;W4: Fenoxaprop-p-ethyl + ethoxysulfuron; W5: Oxadiargyl *fb* fenoxaprop-p-ethyl + ethoxysulfuron; W6: Pendimethalin *fb* bispyribac-sodium; W7: Weed free check; W8: Unweeded control

Figure 4. Effect of weed management practices on removal of N, P and K by *L. parviflora* during 2020

Table 1. Nutrient content of weeds in direct seeded rice at their maturity

Weed species	Nutrient content of weeds (%)		
	N	P	K
Digitaria sanguinalis	1.29	0.42	2.23
Cyperus iria	0.98	0.12	3.20
Fimbristylis miliacea	1.13	0.13	2.58
Spilanthes calva	2.18	0.16	5.48
Ludwigia parviflora	1.72	0.30	2.94
Echinochloa colona	0.78	0.10	1.59
Eclipta alba	2.30	0.47	3.79
Alternanthera philoxeroides	0.95	0.10	2.61
Cyanotis axillaris	2.13	0.48	4.71

79.61% more N, P and K in penoxsulam + cyhalofop-butyl treated plot than the unweeded control. *Ludwigia parviflora* removed higher N (21.99 kg/ha), P (3.84 kg/ha) and K (37.58 kg/ha) in fenoxaprop-p-ethyl + ethoxysulfuron due to its greater dominance in that treatment than in unweeded control. Among the different herbicide combinations, the lowest removal of N, P and K by weeds in DSR was recorded with sequential use of oxadiargyl *fb* fenoxaprop-p-ethyl + ethoxysulfuron, oxadiargyl *fb* penoxsulam + cyhalofop-butyl, oxadiargyl *fb* bispyribac-sodium and with pendimethalin *fb* bispyribac-sodium (**Table 2**). Similar results were previously reported by Hemalatha *et al.* (2017).

Effect of tillage and herbicides on crop growth, yield and nutrient uptake and economics

The leaf area index (LAI) and soil plant analysis development (SPAD) values of rice leaf in the DSR were unaffected by tillage (**Table 3**). Unweeded control recorded the lowest value of LAI (2.64) and SPAD (24.1 and 33.2 at 30 and 60 DAS, respectively). The sequential application of oxadiargyl *fb* fenoxaprop-p-ethyl + ethoxysulfuron recorded the highest LAI (4.43) and was at par with oxadiargyl *fb* penoxsulam + cyhalofop-butyl (4.39) and with oxadiargyl *fb* bispyribac-sodium (4.12). These findings are in accordance with those of Soni *et al.* (2020) and Pavithra *et al.* (2021). The SPAD value of rice leaf remained statistically comparable among herbicide treated plots (**Table 3**). Herbicide reduced weed competition for growth resources and increased rice LAI and chlorophyll content in rice leaves (Sanodiya and Singh 2017).

Tillage did not influence the grain yield of DSR (**Table 3**). Oxadiargyl *fb* fenoxaprop-p-ethyl + ethoxysulfuron recorded the highest grain yield of DSR (3.90-4.77 t/ha) and were closely followed by oxadiargyl *fb* penoxsulam + cyhalofop-butyl (3.93-4.37t/ha). Among herbicide treated plots, fenoxaprop-p-ethyl + ethoxysulfuron (tank-mix) and penoxsulam + cyhalofop-butyl (ready-mix) recorded the lowest grain yield (2.72-4.52 and 1.91-2.25 t/ha, respectively). Unweeded control recorded the lowest grain yield of DSR (0.37-0.78 t/ha) because of uncontrolled weed growth. Under weed free condition the growing environment provided favorable conditions for greater growth, which may have resulted in higher yield as also stated by Narolia *et al.* (2014).

Among tillage practices, no significant variation was recorded in N, P and K uptake by rice in DSR (**Table 4**). All the herbicide treated plots distinctly increased the N, P and K uptake by rice over unweeded control. As reported previously, there was higher uptake of nutrients in weed free conditions (Chakraborti *et al.* 2017).

Table 2. Nitrogen, phosphorus and potassium removal by weeds in DSR under different tillage and weed management practices

Treatment	Total weed biomass (g/m^2)		Nutrient removal (kg/ha) N		P		K	
	2019	2020	2019	2020	2019	2020	2019	2020
Tillage practice								
Zero tillage	4.65(21.1)	8.25(67.5)	2.02(3.60)	3.41(11.10)	1.21(0.97)	1.66(2.24)	2.49(5.71)	4.33(18.28)
Conventional tillage	5.68(31.8)	8.16(66.1)	2.34(4.98)	3.33(10.59)	1.38(1.40)	1.64(2.21)	2.94(8.17)	4.28(17.78)
LSD (p=0.05)	0.76	NS	NS	NS	0.15	NS	0.40	NS
Weed management practice								
Oxadiargyl *fb* bispyribac-sodium	3.94(15.0)	2.77(7.2)	1.61(2.10)	1.30(1.20)	1.07(0.65)	0.91(0.32)	2.02(3.58)	1.59(2.01)
Penoxsulam + cyhalofop-butyl	6.29(39.0)	19.89(394.9)	2.40(5.25)	7.82(60.72)	1.46(1.64)	3.56(12.18)	3.05(8.80)	8.97(79.90)
Oxadiargyl *fb* penoxsulam + cyhalofop-butyl	2.74(7.0)	3.64(12.7)	1.19(0.92)	1.70(2.40)	0.90(0.31)	1.03(0.56)	1.44(1.58)	2.12(4.01)
Fenoxaprop-p-ethyl + ethoxysulfuron	5.14(26.0)	13.68(186.6)	2.55(5.99)	5.51(29.84)	1.07(0.64)	2.28(4.68)	3.00(8.47)	7.51(55.91)
Oxadiargyl *fb* fenoxaprop-p-ethyl + ethoxysulfuron	1.67(2.29)	3.31(10.5)	1.01(0.53)	1.70(2.39)	0.77(0.10)	0.97(0.45)	1.19(0.93)	2.18(4.23)
Pendimethalin *fb* bispyribac-sodium	5.26(27.2)	4.27(17.7)	2.27(4.68)	1.95(3.31)	1.29(1.16)	1.10(0.72)	2.85(7.60)	2.46(5.55)
Weed free check	0.71(0.0)	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)
Unweeded control	15.58	17.37(301.4)	5.72(32.2)	6.25(38.56)	3.08(9.02)	2.64(6.50)	7.49(55.57)	8.91(78.91)
LSD (p=0.05)	0.80	0.67	0.29	0.27	0.14	0.11	0.37	0.32

*Figures within parentheses indicate original values and the data were transformed to $\sqrt{x+0.5}$ before analysis; NS: Nonsignificant

Table 3. Leaf area index (LAI), SPAD value, grain yield and economics of DSR under different tillage and weed management practices

Treatment	LAI (mean)	SPAD (mean)		Grain yield (t/ha)		Net return (× 1000 ₹/ha)	
	60 DAS	30 DAS	60 DAS	2019	2020	2019	2020
Tillage practice							
Zero tillage	4.03	33.3	40.3	3.32	2.92	27.76	26.37
Conventional tillage	3.92	33.0	39.0	3.57	3.06	29.84	26.67
LSD (p=0.05)	NS	NS	NS	NS	NS	NS	NS
Weed management practice							
Oxadiargyl *fb* bispyribac-sodium	4.12	33.5	40.1	3.15	3.25	25.31	34.53
Penoxsulam + cyhalofop-butyl	3.85	34.5	40.2	2.25	1.91	7.79	5.63
Oxadiargyl *fb* penoxsulam + cyhalofop-butyl	4.39	35.3	40.6	4.37	3.93	47.04	44.95
Fenoxaprop-p-ethyl + ethoxysulfuron	3.88	33.3	40.7	4.52	2.72	51.40	24.05
Oxadiargyl *fb* fenoxaprop-p-ethyl + ethoxysulfuron	4.43	34.9	41.2	4.77	3.90	54.48	45.18
Pendimethalin *fb* bispyribac-sodium	4.04	34.4	40.4	3.35	3.46	28.11	37.57
Weed free check	4.45	35.2	41.1	4.81	3.98	41.57	32.58
Unweeded control	2.64	24.1	33.2	0.37	0.78	-25.28	-12.33
LSD (p=0.05)	0.37	2.1	1.6	0.55	0.47	10.15	8.62

DSR: Direct-seeded rice; NS: Nonsignificant; SPAD: Soil Plant Analysis Development

Table 4. Nitrogen, phosphorus and potassium uptake by rice under different tillage and weed management practices

Treatment	Nutrient uptake by DSR (kg/ha)					
	N		P		K	
	2019	2020	2019	2020	2019	2020
Tillage practice						
Zero tillage	75.0	73.1	22.9	21.1	107.3	104.2
Conventional tillage	78.5	75.2	24.4	22.0	110.4	106.1
LSD (p=0.05)	NS	NS	NS	NS	NS	NS
Weed management practice						
Oxadiargyl *fb* bispyribac-sodium	72.4	83.1	21.9	23.7	105.0	108.8
Penoxsulam + cyhalofop-butyl	56.1	49.9	16.3	14.1	85.0	75.8
Oxadiargyl *fb* penoxsulam + cyhalofop-butyl	97.0	91.5	29.9	27.5	137.2	129.5
Fenoxaprop-p-ethyl + ethoxysulfuron	97.4	72.6	30.6	20.3	135.1	111.4
Oxadiargyl *fb* fenoxaprop-p-ethyl + ethoxysulfuron	101.0	91.8	32.0	27.4	138.4	114.9
Pendimethalin *fb* bispyribac-sodium	75.3	85.4	23.1	24.9	107.4	125.5
Weed free check	101.1	90.8	32.2	27.6	137.6	126.9
Unweeded control	13.9	27.9	3.3	6.8	24.9	48.6
LSD (p=0.05)	9.24	6.63	3.33	2.65	11.07	6.88

DSR: Direct-seeded rice; NS: Nonsignificant

No significant difference was observed in net return of DSR due to tillage practices (**Table 3**). There was net loss of 12,330-25,280 ₹/ha in unweeded control. In comparison to penoxsulam + cyhalofop-butyl (ready-mix) alone, oxadiargyl *fb* penoxsulam + cyhalofop-butyl fetched 6.03-7.98 times higher net return. Similarly, oxadiargyl *fb* fenoxaprop-p-ethyl + ethoxysulfuron fetched higher net return (by 5.99% in 2019 and 87.85% in 2020) as compared to fenoxaprop-p-ethyl + ethoxysulfuron (tank-mix) alone.

We observed that tillage had no effect on the total weed biomass and removal of N, P and K by weeds (at their maturity) after two cropping cycles of DSR-yellow mustard. *Digitaria sanguinalis* and *F. miliacea* together removed most of the applied N, P and K. Nutrient uptake by weeds was higher in CT than ZT under unweeded control. Herbicide application in sequence (pre-emergence *fb* post-emergence) not only reduced nutrient removal by weeds but also helped the crop absorbing more nutrients by providing almost a weed-free environment, resulting in a higher yield and return of DSR.

From the result, it can be stated that sequential application of pre-emergence oxadiargyl *fb* post-emergence fenoxaprop-p-ethyl + ethoxysulfuron or pre-emergence oxadiargyl *fb* post-emergence penoxsulam + cyhalofop-butyl will be an effective and economic approach for checking nutrient removal by weeds and managing complex weed flora both in zero and conventional tillage under DSR-yellow sarson sequence in lateritic soils of eastern India.

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RESEARCH ARTICLE

Halauxifen plus fluroxypyr pre-mix herbicide as a post-emergent against broad-leaf weeds in wheat

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ABSTRACT

Broad-leaf weeds are known to pose a severe challenge to wheat in the rice-wheat cropping system in North-West India. A field studies were conducted at Research Farm of Department of Agronomy, Punjab Agricultural University, Ludhiana during 2017-18 and 2018-19 in randomized complete block design replicated four times to evaluate the efficacy of herbicide with an alternative mechanism of action for the control of broad-leaf weeds in wheat. Treatments comprised of halauxifen-methyl 1.21% + fluroxypyr-methyl 38.9% EC at 160.4 (4.8+155.6), 200.6 (6.1+194.5) and 240.66 (7.3+233.4) g/ha, halauxifen 10.42% WG at 7.3 g/ha + PG 26-2 N surfactant at 750 ml/ha, fluroxypyr-methyl 48% EC at 233.4 g/ha, metsulfuron 20% WP at 4 g/ha+ surfactant, metsulfuron 10% + carfentrazone 40% DF at 25 g/ha + surfactant, weed free check and weedy check. The results indicated that post-emergence application of halauxifen + fluroxypyr at 200.6 and 240.66 g/ha effectively controlled broad-leaf weeds namely *Medicago denticulata, Rumex dentatus* and *Coronopus didymus* and gave wheat grain yield of 5.25 and 5.34 and 5.15 & 5.25 t/ha during 2017-18 and 2018-19, respectively. The current study demonstrated that halauxifen + fluroxypyr at 200.6-240.66 g/ha would be a suitable option for controlling broad-leaf weeds in wheat in Punjab.

Keywords: Broad-leaf weeds, Fluroxypyr, Halauxifen, Ready-mix, Weed management, Wheat

INTRODUCTION

Wheat is infested with diverse weed flora of grasses as broad-leaf weeds. In irrigated wheat, many broad-leaf weeds namely *Rumex dentatus* L., *Medicago denticulata* L., *Anagallis arvensis* L., *R. spinosus, Convolvulus arvensis* L., *Malva parviflora, Chenopodium album, Vicia sativa, Lathyrus aphaca, Circium arvense* (L.) Scop., *Melilotus alba, Coronopus didymus, Polygonum plebeium* and *Spergula arvensis* are of major concern in rice-wheat system in the North-Western part of India. Due to the continuous use of graminicides like clodinafop, fenoxaprop, pinoxaden *etc*., the weed spectrum started changing from grass to broad-leaved weeds and increased to the extent that weeds like *Rumex* and *Medicago* are alarmingly dominating the wheat fields. Thus, controlling broad-leaf weeds is essential for sustaining wheat productivity, as these are also becoming a major problem in conservation agriculture.

The wheat crop should be weed free during the critical period of 30-40 days of sowing otherwise, it may cause drastic yield reduction under heavy weed infestation. The yield losses depend on weed species, density, time of emergence, wheat variety, row spacing, soil, environmental factors and management factors *viz.* irrigation, fertilizer use, soil type, weed control practices and cropping sequences (Chhokar *et al*. 2007a,b). In wheat, 2,4-D, metsulfuron, carfentrazone and a pre-mix of metsulfuron plus carfentrazone are recommended to control broad-leaf weeds in Punjab. For control of broad-leaved weeds, 2,4-D is less preferred herbicide by the farmers due to its efficacy on limited broad-leaf weed species. After 2,4-D, metsulfuron was widely used herbicide but again is ineffective against weeds like *Malva parviflora* (Chhokar *et al*. 2002) and *S. nigrum* (Mukherjee *et al.* 2011) and provides poor control of *Rumex* due to resistance (Dhanda *et al.* 2020). Then, carfentrazone-ethyl was also recommended to control hardy weeds like *Malva* spp., *Solanum nigrum* and *Convolvulus arvensis* and other broad-leaf weeds. But, it does not control the subsequent weeds emerging after application due to lack of its residual activity (half-life of carfentrazone is 2-5 days) in soil (Lyon *et al.* 2007, Willis *et al.* 2007). Pre-mix of metsulfuron + carfentrazone has been recommended to control hardy and all other broad-leaf weeds, but its availability is a major challenge.

As many broad-leaf weeds germinate in flushes, the application stage is very important with respect to the herbicide used. All these herbicides are effective

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only at 2-4 leaf stage. Most of the times, farmers delay herbicide application due to foggy weather, field not coming to field capacity especially when heavily irrigated or in heavy textured soil. Therefore, if the weeds germinate after the spray window or sometimes weather prevents application at appropriate crop growth stage window, then the benefits of using herbicides which can control weeds at 4-8 leaf stage can serve as a useful tool for management of weeds.

Continuous dependence on a single herbicide, besides developing resistance in weeds, also causes a shift in weed flora. Hence, to address these problems, evaluating alternative herbicides with new mode of action becomes imperative. Halauxifen-methyl is the first active ingredient of the new arylpicolinate group (Epp *et al.* 2016) and belongs to the synthetic auxin mechanism of action. It is absorbed and translocated by the xylem and phloem, and accumulates in the meristematic tissue. Herbicide is rapidly degraded in soil and provides effective control of several important broad-leaf weeds (EFSA, 2014). Symptoms are similar to the herbicide 2,4-D, i.e., epinasty, deformation, necrosis, induces uncontrollable cell division and subsequent death (Epp *et al.* 2016). So, there is dire need to check the possibility of new mode of action herbicide halauxifen + fluroxypyr to control the broad-leaf weed flora in wheat.

MATERIALS AND METHODS

A field experiment was conducted to investigate the effect of new pre-mix halauxifen + fluroxypyr herbicide against broad-leaf weeds in wheat for two consecutive years 2017-18 and 2018-19 at Research Farm of Department of Agronomy, Punjab Agricultural University (PAU), Ludhiana, Punjab. The soil of the experimental site was sandy loam in texture, normal in reaction (pH 7.2) and electrical conductivity (0.11dS/m), low in organic carbon (0.42%) and available nitrogen (222.2 kg/ha) and high in available phosphorus (16.9 kg/ha) and potassium (201.43 kg/ha). The experiment was conducted in a randomized complete block design with four replications comprising nine treatments, which includes halauxifen 1.21% + fluroxypyr 38.9% EC at 160.4 (4.8+155.6), 200.6 (6.1+194.5) and 240.66 (7.3+233.4) g/ha, halauxifen 10.42% WG at 7.3 g/ha + PG 26-2 N surfactant at 750 ml/ha, fluroxypyr-methyl 48% EC at 233.4 g/ha, metsulfuron 20% WP at 4 g/ha + surfactant, metsulfuron 10% + carfentrazone 40% DF at 25 g/ha + surfactant, weed free check and weedy check. Herbicides were applied as post-emergence at 40 days after sowing (4-8 leaf stage) except metsulfuron and metsulfuron + carfentrazone, which were applied at 30 days after sowing (2-4 leaf stage). A knapsack sprayer (Aspee V-Dyut Delux VBD09) fitted with a flat-fan nozzle (FFPB/85/630) was used for herbicide application using 375 L/ha of water. A uniform spray of pinoxaden at 35 DAS at recommended rate was done to control *Phalaris minor* in the experiment.

Wheat varieties '*PBW 725*' and '*PBW 677*' were sown on 20 November, 2017 and 14 November, 2018 using 100 kg seed per hectare in 20 cm spaced rows with a seed cum fertilizer drill. The recommended doses of fertilizers were applied (125 kg N per ha, 50 kg P per ha and 30 kg K per ha) to the crop. The source of NPK used was urea, DAP and muriate of potash, respectively. Half of the recommended dose of N and whole of phosphorus and potassium were applied at the time of sowing and remaining half dose of N was applied as top dressing at the time of first irrigation. All the recommended plant protection measures were carried out as per the local recommendations of the state.

Data on weed density and biomass were recorded at 30 and 60 days after application (DAA) by placing quadrat (50 × 50 cm) at two representative spots in each plot. Weed samples were oven dried at 70 °C for constant dry biomass. Data were analyzed using analysis of variance (ANOVA) to evaluate the differences among treatments while the means were separated using the least significant difference (LSD) test at the 5% significance level. Weed density and biomass data were subjected to square root transformation.

RESULTS AND DISCUSSION

Predominant weed species in the experimental field consisted of *Rumex dentatus*, *Coronopus didymus*, *Medicago denticulata* among broad-leaf weeds. One broad-leaved weed *viz. Oenothera* spp., was also recorded but with very low densities (<2%), hence not included.

During both years, all the herbicide treatments recorded significantly lower weed density and weed biomass than weedy check. At 30 days after application (DAA), halauxifen + fluroxypyr at 200.6 and 240.66 g/ha recorded effective control of *Rumex dentatus*, *Medicago denticulata* and *Coronopus didymus*. Halauxifen 10.42% WG at 7.3 g/ha gave moderate control of *R. dentatus* and *Medicago denticulata* and poor control of *C. didymus* during both years. Fluroxypyr-methyl at 233.4 g/ha provided good control of *Coronopus didymus*, however significantly higher weed density of *M. denticulata* was recorded as compared to other herbicide treatments. Fluroxypyr gave poor control of *Medicago* as compared to other broad-leaf weeds (**Table 1**). At 60 DAA, all the three doses (240.66, 200.6 and 160.4 g/ha) of halauxifen + fluroxypyr were statistically at par for the control of *R. dentatus, C. didymus* and *M. denticulata* during both the years. Significantly more density of *C. didymus* was recorded in lower dose of halauxifen + fluroxypyr at 160.4 g/ha as compared to its higher doses. Metsulfuron + carfentrazone + surfactant at 25 g/ha provided good control of all broad-leaf weeds in both years. However, metsulfuron alone recorded *Rumex* and *Medicago* density in 2018-19 (**Table 2**).

All the herbicide treatments recorded significantly lower weed biomass as compared to weedy check during both years. The halauxifen + fluroxypyr at 240.66 g/ha recorded significantly lower weed biomass at 30 and 60 DAA (**Table 3**) during 2017-18 while during 2018-19, halauxifen + fluroxypyr at 200.6 and 240.66 were statistically at par with each other for biomass accumulation of weeds. Metsulfuron + carfentrazone provided good control of all weeds hence did not accumulate any weed biomass. Chhokar *et al.* (2007b) also reported effective control of *M. parviflora* with carfentrazone-ethyl. Moreover, it has also been reported that ready-mix combination of metsulfuron

Table 1. Effect of weed control treatments on weed density at 30 DAA in wheat

Treatment	Dose (g/ha)	Weed density (no./m^2)**							
		Rumex dentatus		*Medicago denticulata*		*Coronopus didymus*		Total	
		2017-18	2018-19	2017-18	2018-19	2017-18	2018-19	2017-18	2018-19
Halauxifen + fluroxypyr	160.4	1.24 (0.7)	1.00(0)	1.00(0)	1.67(2)	1.41(1)	2.37(5)	1.55(2)	2.78(7)
Halauxifen + fluroxypyr	200.6	1.00(0)	1.00(0)	1.00(0)	1.00(0)	1.00(0)	1.00(0)	1.00(0)	1.00(0)
Halauxifen + fluroxypyr	240.66	1.00(0)	1.00(0)	1.00(0)	1.00(0)	1.00(0)	1.00(0)	1.00(0)	1.00(0)
Halauxifen 10.42% WG +PG	7.3	1.55(2)	3.78(13)	2.37(5)	1.00(0)	4.93(23)	1.96(3)	5.57(30)	4.18(16)
Fluroxypyr-methyl 48% EC	233.4	2.38(5)	2.38(5)	2.88(7)	3.31 (10)	1.00(0)	1.00(0)	3.60(12)	3.95(15)
Metsulfuron 20% WP + surfactant	4	1.00(0)	1.90(3)	1.00(0)	1.41(1)	1.67(3)	1.00(0)	1.00 (0)	2.15(4)
Metsulfuron + carfentrazone + surfactant	25	1.00(0)	1.00(0)	1.00(0)	1.00(0)	1.00(0)	1.00(0)	1.67 (3)	1.00(0)
Weed free check	-	1.00(0)	1.00(0)	1.00(0)	1.00(0)	1.00(0)	1.00(0)	1.00(0)	1.00(0)
Weedy check	-	3.08(9)	4.70(21)	3.20(9)	3.78(13)	5.19(26)	4.03(15)	6.70(44)	7.13(49)
LSD (p=0.05)		0.68	0.44	0.29	0.75	0.80	0.59	0.94	0.79

*DAA- days after application; **Data subjected to square root transformations; figures in parenthesis are means of original values

Table 2. Effect of weed control treatments on weed density at 60 DAA in wheat

Treatment	Dose (g/ha)	Weed density (no./m^2)**							
		Rumex dentatus		*Medicago denticulata*		*Coronopus didymus*		Total	
		2017-18	2018-19	2017-18	2018-19	2017-18	2018-19	2017-18	2018-19
Halauxifen + fluroxypyr	160.4	1.00(0)	1.00(0)	1.00(0)	1.00(0)	1.41(1)	2.16(4)	1.41(1)	2.16(4)
Halauxifen + fluroxypyr	200.6	1.00(0)	1.00(0)	1.00(0)	1.00(0)	1.00(0)	1.00(0)	1.00(0)	1.00(0)
Halauxifen + fluroxypyr	240.66	1.00(0)	1.00(0)	1.00(0)	1.00(0)	1.00(0)	1.00(0)	1.00(0)	1.00(0)
Halauxifen 10.42% WG +PG	7.3	3.31(10)	4.28(17)	2.62(6)	1.24(0.7)	4.65(21)	2.88(7)	6.13(37)	5.13(25)
Fluroxypyr-methyl 48% EC	233.4	2.44(5)	2.64(6)	2.62(6)	3.85(14)	1.79(3)	2.85(7)	3.79(14)	5.31(27)
Metsulfuron 20% WP + surfactant	4	1.00(0)	2.57(6)	1.00(0)	2.93(8)	1.55(2)	1.00(0)	1.55(2)	3.77(14)
Metsulfuron + carfentrazone + surfactant	25	1.00(0)	1.00(0)	1.00(0)	1.00(0)	1.00(0)	1.00(0)	1.00(0)	1.00(0)
Weed free check	-	1.00(0)	1.00(0)	1.00(0)	1.00(0)	1.00(0)	1.00(0)	1.00(0)	1.00(0)
Weedy check	-	3.37(10)	5.44(29)	4.34(18)	4.03(15)	5.25(27)	4.58(20)	7.47(55)	8.06(64)
LSD(p=0.05)		0.23	0.25	0.43	0.45	0.93	0.35	0.92	0.36

*DAA- days after application; **Data subjected to square root transformations; figures in parentheses are means of original values

Table 3. Effect of weed control treatments on weed biomass at 30 and 60 DAA in wheat

Treatment	Dose (g/ha)	Weed biomass (g/m^2)**			
		30 DAA		60 DAA	
		2017-18	2018-19	2017-18	2018-19
Halauxifen + fluroxypyr	160.4	3.04 (8)	3.60 (12)	2.16 (6)	4.37 (18)
Halauxifen + fluroxypyr	200.6	1.00 (0)	1.00 (0)	1.00 (0)	1.00 (0)
Halauxifen + fluroxypyr	240.66	1.00 (0)	1.00 (0)	1.00 (0)	1.00 (0)
Halauxifen 10.42% WG +PG	7.3	6.25 (38)	6.26 (38)	7.03 (49)	7.38 (54)
Fluroxypyr-methyl 48% EC	233.4	5.15 (26)	4.74 (22)	4.00 (15)	6.57 (42)
Metsulfuron 20% WP + surfactant	4	2.08 (4)	3.14 (9)	2.98 (9)	3.92 (14)
Metsulfuron + carfentrazone + surfactant	25	1.00 (0)	1.00 (0)	1.00 (0)	1.00 (0)
Weed free check	-	1.00 (0)	1.00 (0)	1.00 (0)	1.00 (0)
Weedy check	-	11.45 (130)	12.47 (155)	13.76 (188)	15.99 (256)
LSD (p=0.05)		0.83	0.57	1.30	0.90

*DAA- days after application; **Data subjected to square root transformations; figures in parentheses are means of original values

+ carfentrazone is better against the diverse weed flora than sole metsulfuron (Singh *et al.* 2011, Chhokar *et al.* 2007b). Among all the herbicide treatments, halauxifen at 7.3 g/ha recorded the highest weed biomass from 2017-18 to 2018-19.

Effect on plant height of wheat was found to be non-significant under different herbicide treatments during both years. The highest grain yield was recorded with halauxifen + fluroxypyr at 240.66 g/ha, which was statistically at par with its lower dose at 200.6 g/ha during both years (**Table 4**). The halauxifen at 7.3 g/ha and fluroxypyr at 233.4 g/ha recorded less tillers and grain yield as compared to pre-mix halauxifen + fluroxypyr during both years. Compared to weedy check, all the weed control treatments resulted in significantly higher wheat grain yield due to effective control of broad-leaf weeds. The grain yield in pre-mix of halauxifen + fluroxypyr produced was significantly more than the sole application of halauxifen and fluroxypyr. This was mainly attributed to improved growth and yield attributes (height and tillers) due to effective weed control.

Correlation studies

There was positive correlation between wheat tillers with grain yield. However, weed density and weed biomass were negatively correlated during both years. Highest positive correlation was recorded between tillers and grain yield of wheat (0.990**) during 20017-18. Grain yield also had positive relationship with WCE (0.974**) at 30 days after application (DAA) and (0.971**) at 60 DAA, respectively during 2017-18. Correlation coefficient was negative between grain yield and weed density (-0.878** and -0.886** at 30 and 60 DAA) and weed biomass (-0.974** and -0.971** at 30 and 60 DAA), respectively during 2017-18. The highest positive correlation was recorded in grain yield with wheat tillers (0.970**) during 2018-19. Correlation coefficient was negative between grain yield and weed density (-0.976** and -0.947** at 30 and 60 DAA) and weed biomass (-0.977** and -0.979**at 30 and 60 DAA), respectively during 2018-19 (**Table 5**).

Correlation between grain yield of wheat and total biomass of weeds

The linear regression equation describes the relationship between the biomass of total weeds and wheat grain yield (**Figure 1** and **2**). There is linear close relationship between grain yield and biomass with R^2=0.948, 0.943, 0.963 and 0.962 at 30 and 60 DAA, respectively during 2017-18 and 2018-19. The results revealed significant response of weed control treatments to wheat grain yield and weed biomass. Maximum wheat grain yield (5.34 t/ha) was recorded in higher dose of halauxifen + fluroxypyr at 240.66 g/ha. The grain yield of wheat decreased as the biomass of weeds increased. The minimum grain yield (4.10 and 3.78 t/ha) was obtained in weedy check during 2017-18 and 2018-19.

Table 4. Effect of weed control treatments on yield attributes and yield of wheat

Treatment	Dose (g /ha)	Tiller count (no./m^2)		Plant height (cm)		Grain yield (t/ha)	
		2017-18	2018-19	2017-18	2018-19	2017-18	2018-19
Halauxifen + fluroxypyr	160.4	326.67	324.30	111.20	106.40	5.06	5.01
Halauxifen + fluroxypyr	200.6	333.17	326.13	109.27	108.13	5.25	5.15
Halauxifen + fluroxypyr	240.66	336.67	331.43	113.00	106.70	5.34	5.25
Halauxifen 10.42% WG +PG	7.3	326.23	324.30	109.13	108.07	4.98	4.89
Fluroxypyr-methyl 48% EC	233.4	326.40	321.57	111.40	108.60	5.05	4.89
Metsulfuron 20% WP + surfactant	4	337.63	322.97	110.20	107.20	5.16	5.14
Metsulfuron + carfentrazone + surfactant	25	330.77	323.33	111.27	105.60	5.25	5.11
Weed free check	-	337.57	333.13	109.53	106.93	5.33	5.43
Weedy check	-	283.33	249.17	111.47	106.27	4.14	3.78
LSD (p=0.05)		24.82	8.47	NS	NS	0.14	0.11

Table 5. Correlation coefficient between weed density, biomass, tillers and grain yield of wheat

	Grain yield	Weed density 30 DAA	Weed density 60 DAA	Weed biomass 30 DAA	Weed biomass 60DAA	Tillers	Grain yield	Weed density 30 DAA	Weed density 60 DAA	Weed biomass 30 DAA	Weed biomass 60 DAA	Tillers
	2017-18						2018-19					
Grain yield	1	-.878**	-.886**	-.974**	-.971**	.990**	1	-.976**	-.947**	-.977**	-.979**	.970**
Weed density 30 DAA	-.878**	1	.997**	.935**	.915**	-.863**	-.976**	1	.981**	.985**	.984**	-.938**
Weed density 60 DAA	-.886**	.997**	1	.938**	.921**	-.870**	-.947**	.981**	1	.951**	.952**	-.897**
Weed biomass 30 DAA	-.974**	.935**	.938**	1	.992**	-.980**	-.977**	.985**	.951**	1	.999**	-.974**
Weed biomass 60 DAA	-.971**	.915**	.921**	.992**	1	-.976**	-.979**	.984**	.952**	.999**	1	-.979**
Tillers	.990**	-.863**	-.870**	-.980**	-.976**	1	.970**	-.938**	-.897**	-.974**	-.979**	1

** Correlation significant at 0.01 level (2-tailed); DAA- Days after application

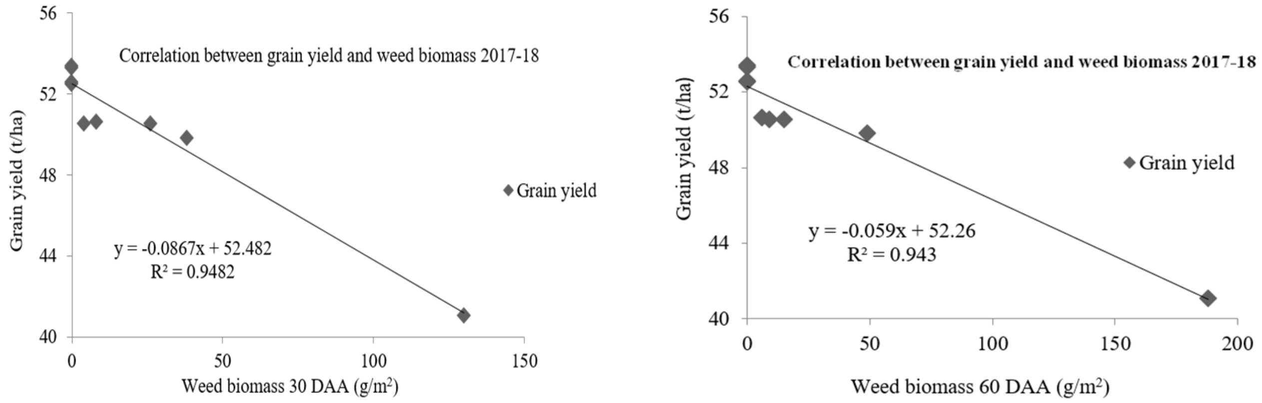

Figure 1. Correlation between grain yield and weed biomass at 30 and 60 DAA during 2017-18

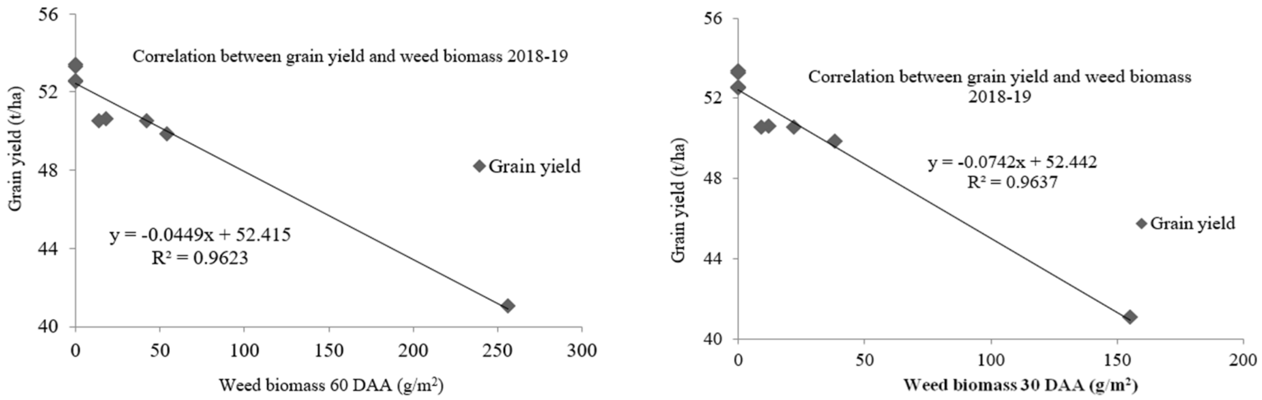

Figure 2. Correlation between grain yield and weed biomass at 30 and 60 DAA during 2018-19

Conclusion

The two-year study concluded that pre-mix of halauxifen + fluroxypyr at 200.6 to 240.66 g/ha may be used for management of broad-leaf weeds in wheat. The present study demonstrates that fields with diverse weed infestation require pre-mix herbicide combination. However, future studies need to be directed towards evaluating the compatibility of this pre-mix herbicide with recommended grass herbicides in wheat.

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RESEARCH ARTICLE

Effect of herbicide and straw mulch on weed growth, productivity and profitability of wheat under different tillage practices in Eastern India

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ABSTRACT

The purpose of this study was to evaluate the impact of straw mulch and herbicides on weed growth and productivity of wheat (*Triticum aestivum* L.) under different tillage practices. Two tillage practices in main plot [zero tillage (ZT) and conventional tillage (CT)], eight weed management practices in sub-plot [pendimethalin (PMT) at 0.75 kg/ha, clodinafop-propargyl + metsulfuron-methyl (CP + MSM) at 0.40 kg/ha, straw mulching (SM) at 4.0 t/ha, PMT at 0.75 kg/ha followed by (*fb*) CP + MSM at 0.40 kg/ha, PMT at 0.75 kg/ha *fb* SM 4 t/ha, SM 4 t/ha *fb* CP + MSM 0.40 kg/ha, three hand weeding and weedy check] were assigned in a split plot design replicated thrice. Zero tillage had lower density as well as biomass of *Digitaria sanguinalis* (L.) Scop., *Gnaphalium indicum* (L.), *Polygonum plebeium* R.Br., *Spilanthes calva* DC and total weed than CT. Pendimethalin *fb* CP + MSM recorded significantly lowest total weed density and biomass. Compared to pendimethalin *fb* CP + MSM, pendimethalin *fb* SM enhanced grain yield of wheat by 9.6, 5.5 and 7.5% in first year, second year and when pooled over the years, respectively. Zero tillage among tillage practices and PMT *fb* SM or PMT *fb* CP + MSM among weed management practices appeared to be effective for better weed management and higher productivity as well as profitability of wheat.

Keywords: Chemical control, Clodinafop-propargyl, Conventional tillage, Estern India, Metsulfuron- methyl, Rice straw mulch, Zero tillage

INTRODUCTION

Weeds are the major biotic constraint in the production of wheat (*Triticum aestivum* L.). Unchecked weed growth reduces crop yield to the extent of 24 to 65 % (Kumar *et al.* 2013a) in context of India, whereas, specifically in Eastern India, the yield loss is in the range of 32 to 46% (Duary *et al.* 2021). *Digitaria sanguinalis* (L.) Scop., is a common weed in the region, particularly in the rainy season. This weed's existence has been seen throughout the winter and post-winter seasons in recent years. The soil in this area is acidic and has a low water holding capacity, making it ideal for this weed to thrive. Bispyribac-sodium has been used as a common herbicide to manage weeds in rice for the last decade, however it has been proven ineffective against *D. sanguinalis* (Mahajan and Chauhan 2013). This could potentially be the cause for the establishment of the *D. sanguinalis* colony in winter as well. The weed germinates along with or before the emergence of the succeeding crop after rice harvest. The onset of winter in this region is late and short, allowing *D. sanguinalis* to survive the winter.

In Eastern India, due to late harvesting of rice, often there are delays in the sowing of wheat resulting in short vegetative growth period of wheat. Zero tillage (ZT) allows early sowing of wheat hence, reducing risks of terminal heat stress during the grain-filling phase, better nutrient management and saves water (Gathala *et al.* 2013), reduces the weed infestation and which may lead to increase in grain yield (5.9-11.9%) (Bhardwaj *et al.* 2004). It has been estimated that ZT requires less fuel consumption, facilitates lower cost of production and higher net income in comparison to conventional tillage (CT) (Stanzen *et al.* 2017).

Burning of paddy straw is a major source of air pollution, in the form of greenhouse gas emissions (CO_2, CH_4, NO_2) and particulate matter (Gupta *et al.* 2004) which deteriorates the soil health (Buttar *et al.* 2022). The straw ash also reduces the efficacy of different pre-emergence (PE) herbicides (Chhokar *et al.* 2009). Thus, instead of burning the residue, we can use it as mulching material to suppress the weed growth and density. Rice residue as mulch reduces the emergence and growth of *Echinochloa colona* (L.) Link., *Echinochloa crus-galli* (L.) Beauv and

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Dactyloctenium aegyptium (L.) Willd., in rice-wheat cropping system (Kumar *et al.* 2013b). Straw mulch not only suppresses the weed infestation but also enhances the soil water content and yield of wheat (Sidhu *et al.* 2007). Effective and season-long weed control cannot be achieved by sole application of herbicide and/or crop residue as mulch (Chauhan and Abugho 2013). However, integrated use of herbicides and mulch can suppress the weed growth to achieve the increment in crop yield in a sustainable manner (Fatima and Duary 2020, Fatima *et al.* 2021).

Little research data are available on the dynamics of major weeds under different tillage systems with integrated approach of herbicide and straw mulching. Keeping this background in view, the present investigation was undertaken to gather information on the population dynamics and growth of some major weed species and productivity and production economics of late sown wheat under different tillage practices with integration of herbicide and straw mulching in Eastern India.

MATERIALS AND METHODS

A field study was conducted at the Agriculture Farm of the Institute of Agriculture, Visva-Bharati University, West Bengal, India during the winter season (December-April 2016-17 and November-March 2017-18). The field is geographically located at about 23^{0}40.1052 N latitude and 87^{0}39.5212 E longitude with an average altitude of 56 m above the mean sea level of sub-humid red lateritic agro-ecological zone of the tropics. The soil of the experiment field was sandy loam (*Ultisol*) in texture, slightly acidic in reaction with pH 5.8, low in organic carbon (0.42%), low in available N (139.2 kg/ha), medium in available P (10.1 kg/ha) and low in available K (121.2 kg/ha).

The experiment was conducted in a split-plot design, with two tillage practices in the main plot and seven weed management practices and one control (weedy check) in the sub plot (**Table 1**), which were replicated thrice. Sowing was done with zero till ferti-cum-seed drill machine, which covers 11 rows. Row to row distance was maintained at 20 cm. Glyphosate was applied at 1.0 kg/ha in ZT before crop sowing. All the pre- and post-emergence herbicides were applied with a battery-operated knapsack sprayer equipped with a flat fan nozzle and a spray volume of 500 L/ha. The wheat variety *"HD 2824"* was sown at second week of December 2016 and fourth week of November 2017 in 2016-17 and 2017-18, respectively and harvested at first week of April 2017 and last week of March 2018 in 2016-17 and 2017-18, respectively. Seed rate for both ZT and CT was 100 kg/ha. The recommended dose of 120 kg nitrogen, 60 kg phosphorus and 60 kg potash/ha were applied to the crop.

Density and biomass of different weeds was taken by placing a quadrat of 50 × 50 cm (0.25 m^2) randomly in the sampling area. The weeds were uprooted, cleaned by washing, placed in sunlight for few hours and were kept in a hot air oven for drying at 70 ^{0}C for 72 hours or more till constant weights were recorded. Grain and straw yields were determined by middle 3×2 m^2 area of each plot.

Weed density and biomass data were subjected to square root ($\sqrt{x+0.5}$) transformation and the transformed data was used for analysis. Statistical analysis of the data was done using R-3.6.3 with a split plot design at a 5% level of significance. The original data have been given in parentheses in each table along with the transformed values.

RESULT AND DISCUSSION

The experimental field was infested with *Digitaria sanguinalis* (L.) Scop., and *Echinochloa colona* (L.) Link., among the grasses; *Eclipta alba* (L.), *Gnaphalium indicum* (L.), *Polygonum plebeium* R.Br., *Spilanthes calva* DC., *Solanum nigrum* (L.) and *Sphaeranthus indicus* (L.) among broad-leaf

Table 1. Details of the treatments

Treatment	Abbreviation	Rate of application	Application time (Day after sowing)
Tillage			
Zero tillage	ZT		
Conventional tillage	CT		
Weed management practice			
Pendimethalin (PE) (stomp 30 EC)	PMT	0.75 kg	1
Clodinafop-propargyl + metsulfuron-methyl (PoE)	CP + MSM	0.40 kg	30
Straw mulching alone	SM	4 t	20
Pendimethalin *fb* clodinafop-propargyl + metsulfuron-methyl	PMT *fb* CP + MSM	0.75 kg *fb* 0.40 kg	1 *fb* 35
Pendimethalin *fb* straw mulching	PMT *fb* SM	0.75 kg *fb* 4 t	1 *fb* 20
Straw mulching *fb* clodinafop-propargyl + metsulfuron-methyl	SM *fb* CP + MSM	4 t *fb* 0.40 kg	20 *fb* 30
Hand weeding		-	25 *fb* 35 *fb* 45
Weedy check		-	-

fb: followed by; PE: Pre-emergence; PoE: post-emergence weeds. Out of which, predominant weeds were *P. plebeium* (45.6-61.8% of total weed density), *D. sanguinalis* (12.1-25.2%), *S. calva* (11.5-17.8%) and *G. indicum* (10.8-14.0%).

In the first year of investigation, weed density was statistically equal between tillages (**Table 2**). However, in the second year, ZT recorded significantly lower density of *G. indicum*, *P. plebeium* and total weed (by 14.7%). There was reduction in total weed density with ZT by 10% even when pooled over the years. Glyphosate sprayed before to wheat sowing killed emerging weeds, resulting in a reduction in weed seed in the upper soil layer, which could be the cause for low weeds under ZT. Malik *et al.* (2000), Sen *et al.* (2010), Mishra *et al.* (2022) previously reported lower density of grassy weed (*Phalaris minor* Retz.), broad-leaf weed (*Solanum nigrum* L., *Chenopodium album* L., *Melilotus* sp., *Medicago denticulata* L.) and total weed density in ZT than CT. Tillage exposes weed seed on the upper layer of the soil and enable seedlings to emerge from deeper in the soil, which may account for a higher weed population than un-tilled soil (Singh *et al.* 2001, Franke *et al.* 2007, Chauhan 2012).

During both the seasons, pendimethalin alone provided excellent control of the grassy weed *D. sanguinalis* (0 no./m^2). Pendimethalin could control this weed very effectively as earlier documented by Mahajan and Chauhan (2013). *Spilanthes calva* emerged and grew vigorously in the pendimethalin treated plot (density 59-73 no./m^2), along with other broad-leaf weeds [*G. indicum* (density 5-16 no./m^2) and *P. plebeium* (density 0-3 no./m^2)] in the later stage (60 DAS) of wheat growth. It might be because pre-emergence herbicides lost their effectiveness after 15 days of application (Sudha *et al.* 2016). Ready-mix herbicide CP + MSM was found less effective against *D. sanguinalis* (only 5.0-36.5% reduction in density). Clodinafop-propargyl is an aryloxyphenoxypropionate herbicide. However, this herbicide poorly controls *Phalaris minor* Retz., a grassy weed of wheat as reported by Kaur *et al.* (2017). Aryloxyphenoxypropionate compounds are successfully used for post-emergence weed control in rice and wheat. However, they have no efficacy on problematic grass weeds including *D. sanguinalis* and *E. crus-galli* (Gao *et al.* 2022). In red and lateritic belt of West Bengal *D. sanguinalis* is one of the most problematic grass weeds in aerobic situations throughout the year. It has been observed that this weed is not controlled by cyhalofop-butyl and other herbicides like bispyribac-sodium in direct-seeded rice (Jaiswal 2022). However, it (CP + MSM) controlled *G. indicum*, *S. calva* and *P. plebeium* significantly and was found at par with three hand weeding. Broad-leaf such as *Melilotus alba*, *C. album* and *Anagallis arvensis* L. are susceptible to metsulfuron methyl as reported by Malik *et al.*

Table 2. Species wise and total weed density at 60 DAS of wheat under different tillage and weed management practices

Treatment	Weed density (no./m^2) at 60 DAS														
	D. sanguinalis			*G. indicum*			*P. plebeium*			*S. calva*			Total weed		
	2016-17	2017-18	Pooled	2016-17	2017-18	Pooled	2016-17	2017-18	Pooled	2016-17	2017-18	Pooled	2016-17	2017-18	Pooled
Tillage practice															
ZT	2.63 (11)a*	4.68 (38)a	3.65 (25)d	2.02 (8)a	2.34 (10)b	2.18 (9)c	3.82 (40)a	4.38 (45)b	4.10 (43)e	3.03 (15)a	3.91 (26)a	3.47 (21)b	6.55 (74)a	8.68 (121)b	7.61 (98)d
CT	3.01 (15)a	4.94 (43)a	3.97 (29)c	2.05 (8)a	2.71 (14)a	2.37 (11)d	3.52 (34)a	5.19 (55)a	4.36 (45)d	3.20 (17)a	4.15 (30)a	3.67 (24)e	6.66 (75)a	9.51 (142)a	8.08 (109)e
Weed management practice															
PMT	0.71 (0)d	0.71 (0)d	0.71 (0)d	2.33 (5)c	4.00 (16)c	3.17 (11)c	1.90 (3)c	0.71 (0)e	1.30 (2)e	7.71 (59)a	8.59 (73)b	8.15 (66)b	8.22 (67)c	9.47 (89)d	8.84 (78)d
CP + MSM	6.17 (38)a	8.84 (78)b	7.50 (58)b	0.71 (0)d	0.71 (0)d	0.71 (0)d	0.71 (0)d	6.95 (48)c	3.85 (24)c	0.71 (0)e	0.71 (0)e	0.71 (0)e	6.17 (38)d	11.24 (126)c	8.70 (82)c
SM	3.87 (14)b	8.49 (72)b	6.17 (43)b	3.54 (12)b	5.33 (28)b	4.43 (20)b	9.68 (93)b	10.84 (117)b	10.25 (106)b	4.53 (20)c	7.09 (50)c	5.81 (35)c	11.88 (141)b	16.35 (267)b	14.11 (205)b
PMT *fb* CP + MSM	0.71 (0)d	0.71 (0)d	0.71 (0)d	0.71 (0)d	0.71 (0)d	0.71 (0)d	0.71 (0)d	0.71 (0)e	0.71 (0)e	0.71 (0)e	0.71 (0)e	0.71 (0)e	0.71 (0)f	0.71 (0)g	0.71 (0)g
PMT *fb* SM	0.71 (0)d	0.71 (0)d	0.71 (0)d	0.71 (0)d	0.71 (0)d	0.71 (0)d	0.71 (0)d	0.71 (0)e	0.71 (0)e	3.71 (13)d	4.33 (18)d	4.01 (16)d	3.71 (13)e	4.33 (18)f	4.01 (16)f
SM *fb* CP + MSM	3.33 (11)c	7.19 (51)c	5.25 (31)c	0.71 (0)d	0.71 (0)d	0.71 (0)d	0.71 (0)d	2.72 (7)d	1.71 (0)d	0.71 (0)e	0.71 (0)e	0.71 (0)e	3.32 (11)e	7.89 (62)e	5.60 (36)e
Hand weeding	0.71 (0)d	0.71 (0)d	0.71 (0)d	0.71 (0)d	0.71 (0)d	0.71 (0)d	0.71 (0)d	0.71 (0)e	0.71 (0)e	0.71 (0)e	0.71 (0)e	0.71 (0)e	0.71 (0)f	0.71 (0)g	0.71 (0)g
Weedy check	6.39 (40)a	11.10 (123)a	8.74 (82)a	6.85 (46)a	7.33 (53)a	7.09 (50)a	14.24 (203)a	14.96 (223)a	14.60 (213)a	6.17 (38)b	9.38 (87)a	7.76 (63)a	18.12 (328)a	22.34 (488)a	20.10 (408)a

fb: followed by; original figures in parentheses were subjected to square-root transformation ($\sqrt{x+0.5}$) before statistical analysis; In a column, means followed by common letters are not significantly different at 5% level by Duncan's Multiple Range Test

(2013). *Digitaria sanguinalis*, *G. indicum*, *P. plebeium* and *S. calva* were absent in treatment PMT *fb* CP + MSM. Because pendimethalin was effective against *D. sanguinalis* and ready-mix CP + MSM effectively killed broad-leaf weeds (*G. indicum, P. plebeium* and *S. calva*) that emerged after two weeks of pendimethalin application. Straw mulch (SM) alone reduced the total density of weeds by 45.2, 57.0 and 49.7% in first year, second year and when pooled over the years, respectively over untreated control. We noticed that straw mulch alone reduced weeds in the inter-row zone (between two rows of crop) but not in the intra-row zone (in crop row). In comparison to PMT alone, the placement of straw mulch (SM) after PMT lowered the emergence of *G. indicum* (100%), *P. plebeium* (100%) and *S. calva* (65.7-79.3%). Mulching smothers weeds by blocking light and creating a physical barrier that prevents their germination and emergence (Kumar *et al.* 2013b; Bahadur *et al.* 2015).

Weed biomass

In unweeded control, *D. sanguinalis* contributed 33.1-42.6% of total weed biomass (**Table 3**). Among broad-leaf weeds, *P. plebeium* was found to be dominant in both the years (37.3-53.0% of total weed biomass). Lower biomass of *D. sanguinalis, G. indicum, P. plebeium, S. calva* and total weed (by 19.3%) was observed in ZT than in CT (**Table 3**). Tillage reduces soil surface resistance to root penetration (Verhulst *et al.* 2010). This explains why weed biomass in CT was higher. Our findings were similarly consistent with those of Sen *et al.* (2010), Mishra *et al.* (2022).

Among weed management practices, pendimethalin alone was seen to be ineffective against *S. calva* (biomass 6.4 g/m^2) and registered 12.5% higher biomass compared to weedy check (biomass 5.6 g/m^2). Ready-mix CP + MSM showed excellent control over *G. indicum* (by 100%), *S. calva* (100%) and *P. plebeium* (89.9%), but it lowered *D. sanguinalis* biomass by 40.4% only. However, sequential application of PMT *fb* CP + MSM resulted in complete reduction of weed biomass and was comparable to PMT *fb* SM (with 96.9% biomass reduction) and SM *fb* CP + MSM (with 86.2% biomass reduction). These findings were comparable with those of Kaur *et al.* (2017). Pendimethalin *fb* placement of straw mulch suppressed the growth and development of a wide range of weeds as previously reported by Fatima and Duary (2020).

Grain and straw yield

There was no significant effect of tillage on the grain and straw yield (**Table 4**). However, zero tillage recorded higher grain yield of wheat over CT by 4.8% possibly due to lower weed density and biomass under ZT. In current study, the grain yield of

Table 3. Species wise and total weed biomass at 60 DAS of wheat under different tillage and weed management practices

Treatment	Weed biomass (g/m^2) at 60 DAS														
	D. sanguinalis			*G. indicum*			*P. plebeium*			*S. calva*			Total weed		
	2016-17	2017-18	Pooled	2016-17	2017-18	Pooled	2016-17	2017-18	Pooled	2016-17	2017-18	Pooled	2016-17	2017-18	Pooled
Tillage practice															
ZT	1.75	2.45	2.10	1.00	1.16	1.08	1.68	1.82	1.74	1.26	1.34	1.30	2.73	3.41	3.06
	(4.0)[a*]	(8.8)[b]	(6.4)[e]	(0.7)[a]	(1.4)[b]	(1.1)[c]	(4.8)[a]	(5.4)[b]	(5.1)[e]	(1.5)[a]	(1.7)[b]	(1.6)[b]	(11.1)[a]	(17.4)[b]	(14.2)[e]
CT	1.83	2.73	2.28	0.93	1.30	1.11	1.73	2.04	1.89	1.27	1.66	1.47	2.87	4.02	3.42
	(4.4)[a]	(11.3)[a]	(7.9)[d]	(0.5)[a]	(1.9)[a]	(1.2)[d]	(5.6)[a]	(6.4)[a]	(6.0)[d]	(1.6)[a]	(3.3)[a]	(2.5)[e]	(12.3)[a]	(23.0)[a]	(17.6)[d]
Weed management practice															
PMT	0.71	0.71	0.71	0.91	1.33	1.11	0.96	0.71	0.83	2.75	2.45	2.60	2.94	2.70	2.79
	(0.0)[e]	(0.0)[e]	(0.00)[e]	(0.3)[c]	(1.3)[c]	(0.8)[c]	(0.4)[c]	(0.0)[e]	(0.2)[e]	(7.0)[a]	(5.5)[b]	(6.4)[b]	(7.9)[c]	(6.8)[e]	(7.5)[e]
CP + MSM	3.03	4.49	3.76	0.71	0.71	0.71	0.71	2.44	1.57	0.71	0.71	0.71	3.03	5.07	4.05
	(8.7)[b]	(19.7)[b]	(14.3)[b]	(0.0)[d]	(0.0)[d]	(0.0)[d]	(0.0)[d]	(5.5)[c]	(2.7)[c]	(0.0)[d]	(0.0)[e]	(0.0)[e]	(8.7)[c]	(25.2)[c]	(17.0)[c]
SM	2.65	4.01	3.33	1.33	2.28	1.80	4.02	3.65	3.83	1.36	2.09	1.72	5.04	6.14	5.59
	(6.5)[c]	(15.6)[c]	(11.1)[c]	(1.3)[b]	(4.7)[b]	(3.1)[b]	(15.7)[b]	(12.8)[b]	(14.3)[b]	(1.4)[c]	(3.9)[c]	(2.6)[c]	(24.9)[b]	(37.2)[b]	(31.3)[b]
PMT *fb* CP + MSM	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71
	(0.0)[e]	(0.0)[e]	(0.0)[e]	(0.0)[d]	(0.0)[d]	(0.0)[d]	(0.0)[d]	(0.0)[e]	(0.0)[e]	(0.0)[d]	(0.0)[e]	(0.0)[e]	(0.0)[f]	(0.0)[g]	(0.0)[g]
PMT *fb* SM	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	1.28	1.75	1.51	1.28	1.75	1.51
	(0.0)[e]	(0.0)[e]	(0.0)[e]	(0.0)[d]	(0.0)[d]	(0.0)[d]	(0.0)[d]	(0.0)[e]	(0.0)[e]	(1.1)[c]	(2.7)[d]	(1.8)[c]	(1.1)[e]	(2.6)[f]	(1.9)[f]
SM *fb* CP + MSM	1.72	3.71	2.71	0.71	0.71	0.71	0.71	1.20	0.95	0.71	0.71	0.71	1.72	3.85	2.78
	(2.5)[d]	(13.2)[d]	(7.9)[d]	(0.0)[d]	(0.0)[d]	(0.0)[d]	(0.0)[d]	(0.9)[d]	(0.6)[d]	(0.0)[d]	(0.0)[e]	(0.0)[e]	(2.5)[d]	(14.3)[d]	(8.5)[d]
Hand weeding	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71	0.71
	(0.0)[e]	(0.0)[e]	(0.0)[e]	(0.0)[d]	(0.0)[d]	(0.0)[d]	(0.0)[d]	(0.0)[e]	(0.0)[e]	(0.0)[d]	(0.0)[e]	(0.0)[e]	(0.0)[f]	(0.0)[g]	(0.0)[g]
Weedy check	4.08	5.68	4.87	1.95	2.70	2.32	5.13	5.32	5.22	1.91	2.90	2.40	7.01	8.66	7.83
	(16.1)[a]	(31.7)[a]	(24.0)[a]	(3.3)[a]	(6.8)[a]	(5.1)[a]	(25.8)[a]	(27.8)[a]	(26.85)[a]	(3.2)[b]	(7.9)[a]	(5.6)[a]	(48.6)[a]	(74.4)[a]	(61.6)[a]

fb: followed by; original figures in parentheses were subjected to square-root transformation ($\sqrt{x+0.5}$) before statistical analysis; In a column, means followed by common letters are not significantly different at 5% level by Duncan's Multiple Range Test.

Table 4. Grain and straw yield and economics of wheat under different tillage and weed management practices

Treatment	Grain yield (t/ha)			Straw yield (t/ha)			Net return (×10^3 ₹/ha)			Return per ₹ invested		
	2016-17	2017-18	Pooled	2016-17	2017-18	Pooled	2016-17	2017-18	Pooled	2016-17	2017-18	Pooled
Tillage practice												
ZT	3.44^{a}	3.14^{a}	3.29^{de}	5.03^{a}	4.61^{a}	4.82^{a}	37.29^{a}	35.55^{a}	36.42^{bc}	2.1^{a}	2.0^{a}	2.1^{ab}
CT	3.29^{a}	2.97^{a}	3.13^{cd}	4.90^{a}	4.39^{a}	4.64^{a}	30.78^{b}	27.39^{b}	29.08^{c}	1.8^{b}	1.7^{b}	1.8^{c}
Weed management practice												
PMT	2.90^{d}	3.06^{de}	2.98^{de}	4.32^{b}	4.70^{a}	4.51^{a}	29.05^{c}	36.78^{bc}	32.88^{bc}	2.0^{bcd}	2.2^{ab}	2.0^{ab}
CP + MSM	3.02^{cd}	2.66^{f}	2.84^{f}	4.69^{b}	4.05^{b}	4.37^{b}	32.13^{c}	27.72^{d}	29.92^{d}	2.1^{bc}	1.9^{c}	2.0^{c}
SM	3.35^{bc}	2.87^{e}	3.10^{e}	5.21^{a}	4.21^{b}	4.71^{b}	33.14^{c}	25.98^{d}	29.56^{d}	1.9^{cd}	1.7^{d}	1.8^{d}
PMT *fb* CP + MSM	3.66^{ab}	3.43^{bc}	3.55^{bc}	5.39^{a}	4.87^{a}	5.12^{a}	43.04^{ab}	41.92^{a}	42.48^{a}	2.3^{a}	2.3^{a}	2.3^{a}
PMT *fb* SM	4.05^{a}	3.63^{ab}	3.84^{ab}	5.52^{a}	5.06^{a}	5.29^{a}	43.81^{a}	40.17^{ab}	41.99^{ab}	2.1^{ab}	2.0^{b}	2.1^{b}
SM *fb* CP + MSM	3.59^{b}	3.24^{cd}	3.41^{cd}	5.30^{a}	5.03^{a}	5.16^{a}	35.64^{bc}	33.29^{c}	34.47^{c}	1.9^{bcd}	1.9^{c}	1.9^{c}
Hand weeding	4.06^{a}	3.65^{a}	3.85^{a}	5.51^{a}	5.07^{a}	5.28^{a}	36.15^{abc}	32.78^{c}	34.45^{d}	1.8^{de}	1.7^{d}	1.7^{d}
Weedy check	2.29^{e}	1.91^{g}	2.09^{g}	3.79^{c}	2.98^{c}	3.38^{c}	19.29^{d}	13.19^{e}	16.24^{e}	1.7^{e}	1.5^{e}	1.6^{e}

fb: followed by; In a column, means followed by common letters are not significantly different at 5% level by Duncan's Multiple Range Test

wheat was reduced by 43.6% in 2016-17, 47.7% in 2017-18 and 45.7% when pooled over the years due to weed competition. The highest grain yield (4.06 t/ha in 2016-17 and 3.65 t/ha in 2017-18) and straw yield (5.51 t/ha in 2016-17 and 5.07 t/ha in 2017-18) was recorded under the treatment hand weeding, which was at par with pendimethalin *fb* SM and PMT *fb* CP + MSM. As compared to pendimethalin (PMT) *fb* CP + MSM, SM and PMT, placement of SM after PMT enhanced grain yield by 7.5, 19.2 and 22.3%, respectively. The weed-free environment created by pendimethalin facilitated crop establishment at early stage, followed by SM, which suppressed growing weeds, conserved moisture and extended maturity time (5-6 days), leading to better yield. Straw mulch increases soil moisture storage (Ji and Unger 2001) and productivity (Verma and Acharya 2004). Higher soil water content improves wheat yield with rice straw mulch (Sidhu *et al.* 2007). The weed species *Spilanthes calva*, *G. indicum* and *P. plebeium* rendered 16.0% yield loss where pendimethalin was applied alone as compared to sequential application of PMT and CP + MSM. In comparison with sole application of CP + MSM, PMT *fb* CP + MSM increased the yield of wheat by 20%. This showed that effective and timely weed management through the integration of various weed management practices reduced the density and dry matter accumulation of various weed species throughout the crop's life cycle, as well as the competition for nutrients, moisture, light and space, resulting in higher grain and straw yields. Similar observations on integrated weed management were also reported by Singh (2014), Kaur and Singh (2019).

Economics

Significantly more net returns (17.4% higher in 2016-17 and 20.7% in 2017-18) and return per rupee invested (2.1 in 2016-17 and 2.0 in 2017-18) were recorded in ZT than in CT (**Table 4**). The results agreed with the findings of Stanzen *et al.* (2017). Pendimethalin *fb* SM fetched the highest net return (40,170-43,810 ₹/ha) and was at par with PMT *fb* CP + MSM (41,920-43,040 ₹/ha). Pooled analysis also showed that ZT, along with pendimethalin *fb* CP + MSM had higher net return over the years. In both years, pendimethalin *fb* CP + MSM fetched the highest return per rupee invested (2.3). The data when pooled over the years also proved that the sequential application of pendimethalin *fb* CP + MSM along with ZT had a higher return per rupee invested. Singh (2014) also reported that ZT along with herbicide increased profit.

It is evident from the results that zero tillage reduced total weed density and biomass. Pendimethalin effectively controlled *D. sanguinalis, G. indicum* and *P. plebeium*, but it was not able to control *S. calva*. Broad-leaf weeds *G. indicum*, *P. plebeium* and *S. calva* were effectively controlled by clodinafop-propargyl + metsulfuron-methyl, but the efficacy against *D. sanguinalis* was low. Straw mulch alone suppressed the growth of weeds but was not as effective as herbicides. Emergence of weeds such as *G. indicum, P. plebeium* and *S. calva* after the application of pendimethalin were controlled by sequential application of clodinafop-propargyl + metsulfuron methyl or straw mulch. Pre-emergence pendimethalin *fb* straw mulch and pendimethalin *fb* clodinafop-propargyl + metsulfuron-methyl recorded higher yield and economic return. In term of economics, significantly higher net returns and return per rupee invested were registered in zero tillage. Thus, zero tillage and pendimethalin *fb* straw mulch or pendimethalin *fb* clodinafop-propargyl + metsulfuron-methyl may be an effective weed management option for wheat in Eastern India.

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RESEARCH ARTICLE

Tillage and weed management influence on weed growth and yield of summer maize

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ABSTRACT

A field experiment was conducted at AICRP on Weed Management, MRS, Hebbal, Bengaluru during 2020 and 2021 (summer) to study the effect of different conservation tillage and weed management approaches on growth, yield and economics of cultivation of maize. The experiment was laid out in a split-plot design with five main plots of different tillage treatments and three subplots of different weed management practices replicated thrice. The main plot tillage treatments consisted of conventional tillage, zero tillage, minimum tillage, minimum tillage + zero tillage (combination), and permanent raised bed. Among tillage practices, permanent raised bed recorded the least total weed density (64.8 no./m^2) and weed dry weight (21.9 g/m^2) at 60 DAS, compared to other tillage practices and also high kernel yield, stover yield and B: C ratio 3.20 t/ha, 4.10 t/ha and 1.53, respectively due to less weed infestation, good root growth, adequate aeration, and nutrient availability compared to other tillage practices. The subplot weed management practices consisted of recommended herbicides (pendimethalin-750 g/ha (PE) *fb* tembotrione 120 g/ha + atrazine 500 g/ha), integrated weed management (pendimethalin-750 g/ha (PE) + hand weeding at 30 DAS) and unweeded check. Among weed management practices, integrated weed management (pendimethalin-750 g/ha (PE) + hand weeding at 30 DAS recorded the least total weed density and weed dry at 60 DAS compared to unweeded treatment and early 50% tasselling and silking, compared to unweeded treatment and also high kernel yield, stover yield and B: C, 2.94 and 3.49 t/ha, and 1.35 due to less weed infestation, compared to unweeded treatment 1.64 and 2.57 t/ha, and 0.91, respectively.

Keywords: Minimum tillage, Permanent raised bed, Silking, Summer maize, Tasselling, Weed management, Zero tillage

INTRODUCTION

Maize (*Zea mays* L.), popularly known as the queen of cereals, is considered the third most important cereal crop after wheat and rice in the world. India ranks fourth among the maize growing countries in the world with 9.72 mha area, 28.64 MT of production and average productivity of 2.94 t/ha (Anon. 2020). In Karnataka, it occupies 1.40 m ha area, with 3.96 m tonnes production, and average productivity of 2.84 t/ha (Anon. 2020). It contributes to more than half of the coarse cereal production of the country and is widely used as a dual-purpose crop for animal feed as well as industrial raw material in the developed countries, whereas, in the developing countries it is used as a general feed for a human being. In concern to the Indian agricultural scenario, the growth in maize area and production was steady since 1950 but the growth rate in both area and production of maize increased unprecedented in the country during the last ten years due to the adoption of improved production technologies, varieties/hybrids as well as expansion in non-traditional areas/states like Andhra Pradesh, Karnataka, Maharashtra, and Tamil Nadu, *etc.* In the years to come, there will be increased pressure on the lands of India's rainfed regions to produce more in order to meet the expanding demands of the human and livestock populations. If preventative actions are not taken, degradation could worsen. To maintain soil quality and increase agricultural output, especially in rainfed locations, it is essential to increase soil organic carbon stock (Srinivasa *et al.* 2011).

The fundamental principles of conservation agriculture are minimising the amount of tillage and increasing the amount of surface cover by keeping crop residues (FAO 2013). It has been widely reported that conservation agriculture (CA), which is viewed as an alternative strategy to maintain and possibly improve agricultural production, reduces soil erosion, improves infiltration, increases soil organic stocks, and improves soil quality in a variety of environments and crops while lowering the risk of soil degradation when grown in rainfed conditions (Vlek and Tamene 2010). Minimizing the intensity of tillage is one of the major conservation agricultural practices which needs to be evaluated under various

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crops and cropping systems for Indian conditions (Veeresh *et al.* 2016). The fundamental principle for all agro-technologies is to maximize the yield by utilizing the soil and other natural resources without making a negative impact on the environment. It is an important strategy for developing a sound long-term weed control program. Weeds tend to compete with crops for similar growth requirements as their own and cultural practices designed to contribute to the crop may also benefit the growth and development of weeds.

MATERIAL AND METHODS

A field experiment was carried out in the summers of 2020 and 2021 to examine the impact of various weed control and tillage practises on weed occurrence, growth characteristics, and yields of maize. The field study was carried out at the AICRP's Main Research Station in Hebbal, Bengaluru, which focuses on weed management. The soil at the experiment site was a sandy loam with a pH of 6.34 and a small amount of organic carbon (0.34%). Three subplots of various weed management practices were replicated three times, while five main plots of various tillage treatments were used in the field experiment. The main plot of tillage treatments consisted of zero tillage, minimum tillage, minimum tillage + zero tillage (combination) and permanent raised bed. The subplot weed management practices consisted of recommended herbicides (pendimethalin-750 g/ha (PE) *fb* tembotrione 120 g/ha + atrazine 500 g/ha), integrated weed management (pendimethalin-750 g/ha (PE) + hand weeding at 30 DAS) and unweeded treatment.

The maize (*MAH 14-5* hybrid) was sown at a spacing of 60 ³ 30 cm. Fertilizer level of 150 kg N, 75 kg P, and 40 kg K /ha was applied as per the recommendation and all the fertilizers were given as basal dose only. Irrigation was given at intervals of 10–15 days. The pre-emergence (one day after sowing) and post-emergence (20-25 days after sowing) herbicides were applied using a spray volume of 750 and 500 litters per hectare with a knapsack sprayer with nozzle, respectively. The data on species wise weed count in a quadrant of 50 x 50 cm were recorded at 60 DAS (days after sowing). Data were averaged for three replications. The weeds-wise density of sedges, grass and broad-leaf at 60 DAS was taken. In addition, total dry weight was also recorded at 60 DAS. The data on weeds density and dry weight were subjected to the transformation of square root ($\sqrt{x+0.5}$) depending on the variability and weed index calculated by using the formula suggested by Gill and Vijaykumar (1969). Leaf area index was calculated at 60 DAS by using the below formula given by Watson (1947).

$$LAI = \frac{\text{Leaf area of plant}}{\text{Ground area covered by plant}}$$

The data collected on different traits were statistically analyzed using the standard procedure and the results were tested at a five per cent level of significance as given by Gomez and Gomez (1984). The least significant differences were used to compare treatment means.

RESULTS AND DISCUSSION

Effect of conservation tillage and weed management practices on weeds

The tillage practices did not significantly influence the weed density and weed dry weight at 60 DAS. The interaction effect between tillage and weed management practices was also not significant. *Cyperus rotundus* and *Cynodon dactylon* were the major weeds, which come under sedge and grass.

Weed management practices significantly influenced the weed density and weed dry weight at 60 DAS (**Table 1**). At 60 DAS, integrated weed management practices of pre-emergence application of pendimethalin 750 g/ha followed by hand weeding at 30 DAS recorded significantly lowest total weed density (50.5 no./m^2) in comparison to unweeded control (77.3 no./m^2). Similar results were obtained by Singh *et al.* (2017) that the application of pendimethalin 1.0 kg/ha + two hoeing at 25 DAS and 45 DAS recorded lower weed density and weed dry weight at 60 DAS.

Integrated weed management practices of pre-emergence application of pendimethalin 750 g/ha followed by hand weeding at 30 DAS recorded significantly lower total weed dry weight (12.3 g/m^2) of sedges, grasses, and broad-leaf weeds compared to unweeded control (29.0 g/m^2). Similarly, Rajeshkumar *et al.* (2018) reported that the application of pendimethalin at 0.75 kg/ha followed by one rotary hoeing on 35 DAS recorded the highest weed control efficiency and reduced weed populations and weed dry matter production at 60 DAS. Sanodiya *et al.* (2013) reported that weed control efficiency (WCE) was maximum with pendimethalin 1.0 kg/ha followed by hand weeding at 30 DAS, but the lowest WCE was found with the pre-emergence application of atrazine 1.0 kg/ha alone in fodder maize.

Effect of conservation tillage and weed management practices on growth parameters of maize

The plots imposed with permanent raised bed and conventional tillage numerically recorded the highest leaf area index (2.18), compared to other tillage practices (**Table 3**). Among the weed management practices, the plots treated with pendimethalin 750 g/ha followed by hand weeding at 30 DAS recorded the highest leaf area index (1.85) compared to unweeded control (1.40). Unweeded control recorded the lowest leaf area index due to less effective control of weeds throughout the crop growth period, unweeded control lowered the leaf area as a result of the severe competition of weeds particularly broadleaf weeds and sedges.

Similar results were found by Singh *et al.* (2017). In a long term application of conservation tillage practices resulted in higher values of plant height, dry matter accumulation, LAI, crop growth rate (CGR) and relative growth rate (RGR) under the permanent bed with legume residue than no-residue, and this might be due to better soil health and micro-environment created by the continuous adoption of these resources conserving practice (Memon *et al.*

Table 1. Weed density at 60 DAS in summer maize as influenced by tillage and weed management practices

Treatment	Sedges			Grasses			BLW			Total		
	2020	2021	Pooled	2020	2021	Pooled	2020	2021	Pooled	2020	2021	Pooled
Tillage practice (T)												
Conventional tillage (CT)	-	-	-	-	-	-		-	-	-	-	-
Zero tillage (ZT)	6.23 (38.9)	6.88 (47.0)	6.56 (42.9)	3.57 (13.4)	3.24 (10.6)	3.41 (12.0)	4.82 (22.9)	5.14 (26.1)	4.98 (24.5)	14.6 (75.2)	15.2 (83.7)	14.9 (79.4)
Minimum tillage (MT)	6.75 (45.8)	7.05 (50.0)	6.90 (47.9)	4.02 (17.1)	3.69 (13.8)	3.86 (15.4)	4.36 (18.7)	4.93 (24.0)	4.65 (21.3)	15.1 (81.6)	15.6 (87.8)	15.4 (84.6)
Zero tillage (ZT) + minimum tillage (MT)	6.64 (44.3)	7.40 (54.7)	7.02 (49.5)	4.13 (18.4)	3.48 (12.0)	3.81 (15.2)	4.59 (20.7)	5.08 (25.4)	4.84 (23.0)	15.3 (83.4)	15.9 (92.1)	15.6 (87.7)
Permanent raised bed (PB)	6.18 (38.7)	6.07 (37.4)	6.13 (38.0)	3.44 (11.8)	3.35 (11.7)	3.40 (11.7)	3.19 (10.1)	4.52 (20.2)	3.86 (15.1)	12.8 (60.6)	13.9 (69.3)	13.3 (64.8)
LSD (p=0.05)	0.954	0.755	0.696	0.649	0.266	0.354	0.479	0.619	0.436	0.779	0.579	0.542
Weed management practice (W)												
Pendimethalin 750 g/ha (PE) *fb* tembotrione 120 g/ha + atrazine 500 g/ha	5.44 (37.5)	5.42 (36.9)	5.43 (37.2)	2.61 (8.20)	2.46 (7.20)	2.54 (7.70)	3.33 (14.3)	3.83 (18.1)	3.58 (16.2)	11.3 (60.0)	11.7 (62.2)	11.5 (61.1)
IWM – pendimethalin 750 g/ha PE + HW at 30 DAS	4.80 (28.9)	4.90 (29.8)	4.85 (29.3)	2.36 (6.60)	2.19 (5.73)	2.28 (6.17)	3.47 (15.2)	3.72 (17.1)	3.60 (15.1)	10.6 (50.7)	10.8 (52.6)	10.7 (50.5)
Unweeded control	5.23 (34.2)	6.12 (46.7)	5.68 (40.4)	4.12 (21.7)	3.60 (15.9)	3.86 (18.8)	3.36 (13.9)	4.25 (22.3)	3.81 (18.1)	12.7 (69.8)	13.9 (84.9)	13.3 (77.3)
LSD (p=0.05)	0.852	0.422	0.584	0.495	0.219	0.308	0.477	0.291	0.338	0.813	0.523	0.608
Interaction (T × W)												
LSD (p=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Note: (-) = Fallow. The data on weeds density and dry weight were subjected to the transformation of square root $\sqrt{x+0.5}$

Table 2. Weed dry weight (g/m^2) at 60 DAS in summer maize (2020 and 2021) as influenced by tillage and weed management practices

Treatment	Sedges			Grasses			BLW			Total		
	2020	2021	Pooled	2020	2021	Pooled	2020	2021	Pooled	2020	2021	Pooled
Tillage practice (T)												
Conventional tillage (CT)	-	-	-	-	-	-	-	-	-	-	-	-
Zero Tillage (ZT)	4.79 (24.3)	1.64 (2.30)	3.22 (13.3)	2.37 (5.21)	2.20 (5.09)	2.29 (5.15)	2.61 (6.35)	1.77 (2.73)	2.19 (4.54)	5.90 (35.86)	3.12 (10.1)	4.51 (22.9)
Minimum tillage (MT)	5.23 (28.3)	1.63 (2.22)	3.43 (15.2)	2.61 (6.56)	2.93 (8.42)	2.77 (7.49)	2.60 (6.26)	1.79 (2.74)	2.20 (4.50)	6.35 (41.2)	3.68 (13.3)	5.02 (27.1)
Zero tillage (ZT) + minimum tillage (MT)	5.08 (27.2)	1.66 (2.35)	3.37 (14.7)	2.78 (7.72)	2.79 (8.02)	2.79 (7.87)	2.60 (6.36)	1.96 (3.40)	2.28 (4.88)	6.30 (41.3)	3.68 (13.7)	4.99 (27.4)
Permanent bed (PB)	4.58 (20.6)	1.51 (1.83)	3.05 (11.2)	2.61 (6.47)	2.44 (6.24)	2.53 (6.35)	2.67 (6.67)	1.60 (2.12)	2.14 (4.39)	5.52 (33.7)	3.14 (10.1)	4.33 (21.9)
LSD (p=0.05)	0.472	0.107	0.208	0.433	0.145	0.212	0.119	0.193	0.094	0.576	0.147	0.272
Weed management practice (W)												
Pendimethalin-750 g/ha (PE) *fb* tembotrione 120 g/ha + atrazine 500 g/ha	3.91 (19.0)	1.18 (1.35)	2.55 (10.1)	2.09 (5.08)	2.0 (4.78)	2.05 (4.93)	2.01 (4.63)	1.34 (1.89)	1.68 (3.26)	4.76 (28.7)	2.57 (8.01)	3.67 (18.3)
IWM – pendimethalin 750 g/ha PE + Hand weeding at 30 DAS	3.09 (11.7)	1.09 (1.09)	2.09 (6.40)	1.71 (3.32)	1.36 (2.04)	1.54 (2.68)	2.01 (4.68)	1.32 (1.81)	1.67 (3.25)	3.87 (19.7)	2.04 (4.94)	2.96 (12.3)
Unweeded control	4.81 (29.5)	1.59 (2.78)	3.20 (16.1)	2.43 (7.17)	2.85 (9.84)	2.64 (8.50)	2.27 (6.07)	1.61 (2.89)	1.94 (4.48)	5.82 (42.7)	3.56 (15.5)	4.69 (29.0)
LSD (p=0.05)	0.613	0.076	0.304	0.242	0.225	0.194	0.120	0.131	0.089	0.479	0.192	0.290
Interaction (T × W)												
LSD (p=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Note: (-) = Fallow. The data on weeds density and dry weight were subjected to the transformation of square root $\sqrt{x+0.5}$

2014). Among weed management treatments, significantly higher number of days were taken for 50% tasseling and silking in unweeded when compared to two other treatments (**Table 3**). Similar results were found by Kommireddy (2018) who reported that among different treatments, the significantly higher number of days taken for 50 per cent tasseling and silking in unweeded control when compared to all other treatments.

Yield parameters and yield

The kernel and stover yields of maize were significantly influenced by different conservation tillage and weed management practices. Permanent raised beds had significantly higher kernel yield, stover yield, and harvest index of maize when compared to zero tillage among different tillage practices (**Table 5**). Significantly higher kernel yield in permanent raised beds was attributed to significantly higher yield parameters as compared to zero tillage (**Table 4**). Conservation tillage, which improves the physical and chemical qualities of the soil, that may greatly impact on root development, is likely to give similar or even higher crop yields than conventional tillage. These findings were in agreement with Sepat and Rana (2013), Choudhary *et al.* (2013) and Parihar *et al.* (2016).

Among the weed management practices, the plots treated with pendimethalin 750 g/ha followed by hand weeding at 30 DAS recorded the highest seed yield compared to the use of only recommended herbicide. Unweeded control recorded the lowest seed yield due to less effective control of weeds throughout the crop growth period. Unweeded control lowered the yield as a result of the severe competition of weeds particularly broadleaf weeds and sedges. Similar results were found by Rajeshkumar *et al.* (2018) when pendimethalin at 0.75 kg/ha was applied followed by one rotary hoeing on 35 DAS resulted. Similarly, a field experiment conducted at Ludhiana (India), found about 25% higher grain yield with a permanent bed planting of maize than flat sowing (Kaur and Mahey 2012) The highest yield in bed planting with the bed was due to increased number of cobs per plant and more grains per cob than flat sowing.

Table 3. Days to 50 per cent tasselling and silking in maize as influenced by different tillage and weed management practices

Treatment	Days to 50% tasseling			Days to 50% silking			leaf area index		
	2020	2021	Pooled	2020	2021	Pooled	2020	2021	Pooled
Tillage practice (T)									
Conventional tillage (CT)	-	-	-	-	-	-	-	-	-
Zero tillage (ZT)	51.4	52.0	51.7	58.2	58.6	58.4	2.08	2.03	2.05
Minimum tillage (MT)	51.8	52.3	52.0	58.5	59.2	58.9	2.04	1.99	2.02
Zero tillage (ZT) + minimum tillage (MT)	51.7	52.6	52.1	58.4	59.5	59.0	1.98	1.93	1.95
Permanent bed (PB)	50.0	50.5	50.2	56.9	57.9	57.4	2.20	2.15	2.18
LSD (p=0.05)	NS	NS	NS	NS	NS	NS	0.301	0.275	0.187
Weed management practice (W)									
Pendimethalin 750 g/ha (PE) *fb* tembotrione 120 g/ha + atrazine 500 g/ha	48.7	51.4	50.0	54.9	58.2	56.5	1.69	1.65	1.67
IWM – Pendimethalin 750 g/ha PE + hand weeding at 30 DAS	47.3	48.9	48.1	53.4	57.6	55.5	1.86	1.83	1.85
Unweeded control	51.3	51.1	51.3	57.3	57.1	57.2	1.42	1.38	1.40
LSD (p=0.05)	0.51	0.60	0.50	0.53	0.63	0.48	0.146	0.151	0.102
Interaction (T × W)									
LSD (p=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 4. Cob length, cob girth, number of rows per cob and number of kernels per row in maize (summer) as influenced by different tillage and weed management practices

Treatment	Cob length (cm)			Cob girth (cm)			No. of rows per cob			No. of kernels/row		
	2020	2021	Pooled	2020	2021	Pooled	2020	2021	Pooled	2020	2021	Pooled
Tillage practice (T)												
Conventional tillage (CT)	-	-	-	-	-	-	-	-	-	-	-	-
Zero tillage (ZT)	13.4	13.2	13.3	15.3	15.3	15.3	12.0	12.0	12.0	23.5	24.1	23.8
Minimum tillage (MT)	13.3	13.0	13.1	15.0	15.0	15.0	11.8	11.8	11.8	22.8	23.4	23.1
Zero tillage (ZT) + minimum tillage (MT)	12.9	12.7	12.8	14.0	14.2	14.1	11.6	11.3	11.4	21.9	22.5	22.2
Permanent bed	14.7	14.5	14.6	16.7	16.8	16.7	14.2	13.3	13.8	25.8	26.4	26.1
LSD (p=0.05)	1.39	1.48	0.93	1.57	1.66	1.05	1.68	1.52	1.04	2.42	2.70	1.66
Weed management practice (W)												
Pendimethalin-750 g/ha (PE) *fb* tembotrione 120 g/ha + atrazine 500 g/ha	10.9	10.7	10.8	12.2	12.2	12.2	9.7	9.6	9.7	19.3	19.7	19.5
IWM – pendimethalin 750 g/ha PE + hand weeding at 30 DAS	11.5	11.3	11.4	13.0	13.1	13.0	10.9	10.7	10.8	19.9	20.4	20.2
Unweeded control	10.3	10.1	10.2	11.4	11.5	11.4	9.1	8.8	8.9	17.2	17.7	17.4
LSD (p=0.05)	0.70	0.75	0.50	1.03	1.13	0.74	0.83	0.91	0.60	1.62	1.98	1.24
Interaction (T × W)												
LSD (p=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Table 5. Kernel yield, stover yield, and B:C ratio in summer maize as influenced by tillage and weed management practices

Treatment	Kernal yield (t/ha)			Stover yield (t/ha)			B: C ratio		
	2020	2021	Pooled	2020	2021	Pooled	2020	2021	Pooled
Tillage practice (T)									
Conventional tillage (CT)	-	-	-	-	-	-	-	-	-
Zero tillage (ZT)	2.89	2.88	2.89	3.74	3.79	3.77	1.45	1.36	1.41
Minimum tillage (MT)	2.91	2.92	2.92	3.65	3.90	3.78	1.49	1.38	1.42
Zero tillage (ZT) + minimum tillage (MT)	2.99	3.01	3.00	3.50	3.99	3.75	1.60	1.42	1.46
Permanent bed	3.21	3.18	3.20	4.04	4.16	4.10	1.62	1.45	1.53
LSD (p=0.05)	0.23	0.18	0.18	0.32	0.25	0.25			
Weed management (W)									
Pendimethalin 750 g/ha (PE) *fb* tembotrione 120 g/ha + atrazine 500 g/ha	2.61	2.62	2.62	3.01	3.36	3.19	1.27	1.17	1.22
IWM – pendimethalin 750 g/ha PE + hand weeding at 30 DAS	2.92	2.96	2.94	3.22	3.75	3.49	1.40	1.30	1.35
Unweeded control	1.67	1.61	1.64	2.74	2.39	2.57	0.92	0.90	0.91
LSD (p=0.05)	0.19	0.18	0.16	0.23	0.19	0.18			

Economics

The higher B: C ratio (1.53) was noticed in permanent raised bed, even though there was higher cost of cultivation, still it gave higher gross returns, net returns and B: C due to significantly higher grain and straw yields. The least was recorded in unweeded control (0.91) treatment (**Table 4**).

Conclusion

Permanent raised beds and integrated weed management practice in maize-greengram-maize cropping system under conservation agriculture, realised higher net returns and B: C ratios besides managing agro-ecosystem for improved and sustained productivity than other tillage and weed management practices. Integrated weed management is the most feasible method of weed management strategy for controlling weeds and for sustainable productivity of crops.

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RESEARCH ARTICLE

Effect of weed control measures on weeds and yield of *Rabi* (winter) maize

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ABSTRACT

A field study was carried out at AICRP-WM Farm, B. A. College of Agriculture, Anand Agricultural University, Anand, India during two consecutive *Rabi* (winter) seasons of 2019-20 and 2020-21 to assess the effect of weed control measures on weeds and yield of *Rabi* maize. The field experiment was laid out in randomized block design having ten treatments and replicated thrice. The pre-emergence application (PE) of either atrazine + pendimethalin (tank-mix) 500 + 250 g/ha) or early post-emergence application (EPoE) at 10-15 days after seeding (DAS) of topramezone 336 + atrazine 25.2 + 500 g/ha (tank-mix) or tembotrione + atrazine 120 + 500 g/ha (tank-mix) provided effective control of both monocot and dicot weeds with higher yield and benefit cost ratio in winter maize during both the years. However, the mechanical weed control treatments, inter-culturing (IC) + hand weeding (HW) at 20 and 40 DAS provided effective control of weeds with higher grain yield of maize and higher benefit cost ratio during both the study years.

Keywords: Herbicides, Maize, Tembotrione, Topramezone, Weed control efficiency, Weed index, Weed management

INTRODUCTION

Maize (*Zea mays* L.) is the third most important crop among the cereals in India and contributes to the nearly 9% of the national food basket (Jeet *et al*. 2017). Maize is the most versatile crop with highest genetic yield potential, wider adaptability to varied agroecological regions and diverse growing seasons. Maize serves as human food and animal feed and has wide industrial applications. Due to multiple uses, the demand for maize grain is constantly increasing in the global market. In India, maize is grown in an area of 9.18 million hectares with the average productivity of 2960 kg/ha with the production of about 27.23 million tonnes of maize kernels (DES-GOI 2020). Area under winter (*Rabi*) maize is increasing with the introduction of new hybrid varieties.

Due to ample irrigation provided to the winter maize, weeds flourish tremendously. The weed interference is a severe problem in maize, especially in the early stages of the crop growing season due to slow initial growth habit with wider row spacing. Severe competition between weeds and maize at critical growth stages could be reduced both the quality and quantity of maize as weeds compete with the crop for essential resources. Rani *et al*. (2020) observed that critical period of weed competition starts from 17 to 29 days after planting of corn, significantly affect the growth parameters and grain yield of maize. Whereas, Gharde *et al*. (2018) reported that potential yield loss in maize due to weeds ranged from 18-65%. Moreover, higher intensity of weeds increases the cost of cultivation, lowers value of land and curtails the net returns. In order to realize the yield potential of maize, weed management becomes indispensable. Thus, an experiment was conducted to study the effect of weed management treatments in *Rabi* maize in order to identify effective and economical weed management measure.

MATERIALS AND METHODS

A field experiment was conducted during two consecutive *Rabi* (winter) seasons of 2019-20 and 2020-21 at the farm of B. A. College of Agriculture, Anand Agricultural University, Anand. The soil of the experimental field was low in available nitrogen and medium in available phosphorous and high in potassium. Total ten weed management practices, *viz*. pre-emergence application (PE) of atrazine 1.0 kg/ha followed by (*fb*) inter-cultivation (IC) at 30 days after seeding (DAS), pendimethalin 1.0 kg/ha PE *fb* IC at 30 DAS, atrazine + pendimethalin 0.50 +0.250 kg/ha (tank-mix) PE, early post-emergence application (EPoE) of topramezone 25.2 g/ha *fb* IC + hand weeding (HW) at 40 DAS, topramezone + atrazine 25.2 + 500 g/ha (tank-mix) EPoE, tembotrione 120 g/ha EPoE *fb* IC *fb* HW at 40 DAS,

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tembotrione + atrazine 120 + 500 g/ha (tank-mix) EPoE, IC at 20 and 40 DAS, IC + HW at 20 and 40 DAS and weedy check tested. A randomized block design with three replications was used. Maize hybrid GAYMH 3 was sown on 11 and 30 November during 2019 and 2020, respectively keeping distance of 60 x 20 cm by using seed rate of 20 kg/ha. The crop was harvested on 20 and 26 March during 2020 and 2021, respectively. The crop was fertilized with recommended rate of fertilizer *i.e.* 150-60-00 NPK kg/ha wherein, entire quantity of phosphorous in the form of single super phosphate and 25% of recommended dose of nitogen (RDN) in the form of urea was applied at the time of sowing and remaining quantity of nitrogen was applied in three equal split at 4 leaf stage, 8 leaf stage and at tasseling stage during both the years of experimentation. The rest of the recommended package of practices was adopted to raise the crop. Herbicides were applied using knapsack sprayer fitted with flat fan nozzle using 500 litre water/ha as per the treatment. Weed dry weight (biomass) of monocot, dicot and sedges were recorded from randomly selected four spots by using 0.25 m^2 iron quadrat from net plot through destructive sampling method. Weed control efficiency (WCE) was calculated on the basis of dry weight of weeds as per the formula suggested by Maity and Mukherjee (2011). Other observations were also recorded from net plot area. Benefit cost ratio was workout based on the gross realization/total cost of cultivation.

RESULT AND DISCUSSION

Weed species

Fourteen weed species were observed in the experimental field, of which *Eleusine indica* (32.9%), *Dactyloctenium aegyptium* (8.55%), *Digitaria sanguinalis* (6.25%), *Setaria glauca* (4.11%), *Eragrostis major* (3.13%), *Asphodelus tenuifolius* (2.14%), *Commelina benghalensis* (1.32%) were monocot weeds and *Chenopodium album* (14.3%) *Chenopodium murale* (6.58%), *Digera arvensis* (6.58%), *Phyllanthus niruri* (4.44%), *Melilotus alba* (3.62%), *Boerhavia erecta* (1.81%) and *Oldenlandia umbellate* (1.64%) were dicot weeds. In general, monocot weeds were dominant with relative density of 59.9% followed by dicot weed with relative density of 40.1% in the control plot of experimental field.

Effect on weeds

The density and dry biomass of weeds were significantly affected by different weed management practices at 25 DAS during both the years (**Table 1**). IC + HW at 20 and 40 DAS recorded lower density and biomass of monocot, dicot and total weeds while IC alone showed poor control of weeds during both

Table 1. Density and dry biomass of monocot, dicot and total weeds as influenced by weed management practices in *rabi* maize at 25 DAS

Treatment	Weed density (no./m^2)						Weed biomass (g/m^2)					
	Monocot		Dicot		Total		Monocot		Dicot		Total	
	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21
Atrazine 1.0 kg /ha PE *fb* IC at 30 DAS	5.36 (28.0)	5.24 (26.7)	1.00 (0.00)	1.00 (0.00)	5.36 (28.0)	5.24 (26.7)	2.74 (6.53)	2.70 (6.36)	1.00 (0.00)	1.00 (0.00)	2.74 (6.53)	2.70 (6.36)
Pendimethalin 1.0 kg /ha PE *fb* IC at 30 DAS	1.63 (1.67)	1.52 (1.33)	3.58 (12.0)	4.57 (20.0)	3.80 (13.7)	4.71 (21.3)	1.20 (0.44)	1.15 (0.31)	1.96 (2.89)	2.13 (3.55)	2.07 (3.33)	2.20 (3.86)
Atrazine + pendimethalin 500 +250 g/ha PE (tank-mix)	1.52 (1.33)	1.41 (1.00)	1.00 (0.00)	1.00 (0.00)	1.52 (1.33)	1.41 (1.00)	1.14 (0.29)	1.11 (0.23)	1.00 (0.00)	1.00 (0.00)	1.14 (0.29)	1.11 (0.23)
Topramezone 25.2 g /ha EPoE *fb* IC + HW at 40 DAS	3.20 (9.33)	2.49 (5.33)	3.47 (12.0)	5.36 (28.0)	4.64 (21.3)	5.84 (33.3)	1.86 (2.47)	1.58 (1.53)	2.05 (3.24)	2.44 (5.01)	2.58 (5.71)	2.74 (6.54)
Topramezone + atrazine 25.2 + 500 g/ha) EPoE (tank-mix)	2.75 (6.67)	2.24 (4.00)	1.00 (0.00)	1.00 (0.00)	2.75 (6.67)	2.24 (4.00)	1.68 (1.84)	1.46 (1.13)	1.00 (0.00)	1.00 (0.00)	1.68 (1.84)	1.46 (1.13)
Tembotrione 120 g /ha EPoE *fb* IC + HW at 40 DAS	4.71 (21.3)	4.99 (24.0)	4.06 (16.0)	7.25 (52.0)	6.14 (37.3)	8.74 (76.0)	2.53 (5.42)	2.70 (6.34)	2.19 (3.85)	3.20 (9.31)	3.19 (9.26)	4.07 (15.6)
Tembotrione + atrazine 120 + 500 g/ha EPoE (tank-mix)	4.57 (20.0)	3.78 (13.3)	1.00 (0.00)	1.00 (0.00)	4.57 (20.0)	3.78 (13.3)	2.48 (5.17)	2.12 (3.49)	1.00 (0.00)	1.00 (0.00)	2.48 (5.17)	2.12 (3.49)
IC at 20 and 40 DAS	5.93 (34.7)	4.57 (20.0)	5.11 (25.3)	3.58 (12.0)	7.80 (60.0)	5.74 (32.0)	3.63 (12.3)	3.17 (9.07)	2.69 (6.31)	2.41 (4.84)	4.42 (18.6)	3.86 (13.9)
IC + HW at 20 and 40 DAS	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)	1.00 (0.00)
Weedy check	11.7 (136)	15.1 (228)	11.2 (124)	11.0 (120)	16.1 (260)	18.7 (348)	7.66 (57.9)	8.27 (67.6)	5.52 (29.6)	4.82 (22.3)	9.40 (87.5)	9.52 (89.9)
LSD (p=0.05)	0.98	1.01	0.98	0.83	1.18	0.85	0.48	0.41	0.39	0.30	0.53	0.46

Note: Data subjected to $(\sqrt{x+1})$ transformation. Figures in parentheses are means of original values; PE = pre-emergence application; EPOE = early post-emergence application; IC = inter cultivation, HW = hand weeding, DAS = days after seeding, *fb* = followed by the years. Among herbicidal treatments, significantly lower density and dry biomass of weeds was observed with atrazine + pendimethalin 500 +250 g/ha PE (tank-mix). Among pre-emergence herbicides, pendimethalin 1.0 kg/ha and atrazine 1.0 kg/ha showed poor control of dicot and monocot weeds, resulting in increased total density and dry biomass. Among post-emergence herbicide, the efficacy of topramezone and tembotrione was poor on monocot and dicot weed but complete control of dicot weed was achieved when applied as tank mix with atrazine. Triveni *et al*. (2017) also observed better weed control with pre-and post-emergence herbicides during critical period of crop weed competition.

At harvest, lower density of weeds was recorded with atrazine + pendimethalin 500 +250 g/ha (tank-mix) PE and it was at par with IC + HW at 20 and 40 DAS, pendimethalin 1.0 kg /ha PE *fb* IC at 30 DAS and tembotrione + atrazine 120 + 500 g/ha (tank-mix) EPoE during both the years of experimentation. Martin *et al.* (2011) also observed effective control of individual weed species, by 5 to 45%, with application of tank-mix of tembotrione with atrazine 31 + 370 g/ha at four to five-collar leaf stage of corn. Significantly lower dry biomass of monocot, dicot and total weeds was observed with atrazine + pendimethalin 500 +250 g /ha (tank mix) PE, pendimethalin 1.0 g/ha PE *fb* IC at 30 DAS, topramezone 25.2 g /ha EPoE *fb* IC + HW at 40 DAS, tembotrione 120 g/ha EPoE *fb* IC + HW at 40 DAS and IC + HW at 20 and 40 DAS during both the years (**Table 2**).The higher weed control might be due to the enhanced efficacy of tank-mix application which effectively controlled the dicot weeds. Atrazine + pendimethalin 500 + 250 g/ha (tank-mix) PE recorded 65.5 and 82.4% weed control efficiciency while IC + HW carried out at 20 and 40 DAS recorded 90.0 and 79.6%, during 2019-20 and 2020-2021, respectively. Triveni *et al.* (2017) also recorded higher weed control efficiency with tank-mix formulation of tembotrione 50 g/ha+ atrazine 0.5 kg/ha at 15-20 DAS followed by hand weeding twice at 20 and 40 DAS. As the weed control efficiency is directly related with the weed dry biomass observed under respective treatments wherein, lower weed dry biomass was recorded under above said treatment might have reflected in higher weed control efficiency. The effectiveness of tank mix application of herbicide in maize (Gharsiram 2022) was also documented.

Effect on crop

The grain and stover yield of maize were significantly affected due to different weed management practices during both the years (**Table 3**). Significantly higher grain yield (9.09 and 8.91 t/ha) was recorded under IC + HW at 20 and 40 DAS as well as topramezone 25.2 g/ha EPoE *fb* IC + HW at 40 DAS during 2019-20 and 2020-2021, respectively. The higher grain yield might be due to effective control of weeds during critical crop weed

Table 2. Density and dry biomass of monocot, dicot and total weeds as influenced by weed management practices in *Rabi* (winter) maize at harvest

Treatment	Weed density (no./m^2)						Weed biomass (g/m^2)						WCE (%)	
	Monocot		Dicot		Total		Monocot		Dicot		Total			
	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21
Atrazine 1000 g/ha PE *fb* IC at 30 DAS	4.71 (21.3)	5.11 (25.3)	5.08 (25.3)	3.20 (9.33)	6.86 (46.7)	5.95 (34.7)	7.92 (61.7)	7.08 (49.5)	7.83 (60.4)	5.02 (24.4)	11.1 (122)	8.63 (73.9)	58.4	59.2
Pendimethalin 1.0 kg/ha PE *fb* IC at 30 DAS	2.49 (5.33)	2.95 (8.00)	5.24 (26.7)	3.93 (14.7)	5.74 (32.0)	4.84 (22.7)	4.05 (15.5)	3.87 (14.5)	8.02 (64.4)	5.85 (34.0)	8.97 (79.9)	6.97 (48.5)	72.7	73.2
Atrazine + pendimethalin (500 +250 g./ha) PE (tank-mix)	2.95 (8.00)	2.49 (5.33)	4.96 (24.0)	3.20 (9.33)	5.70 (32.0)	3.95 (14.7)	5.97 (34.9)	3.39 (10.9)	8.16 (65.9)	4.67 (20.9)	10.1 (101)	5.71 (31.8)	65.5	82.4
Topramezone 25.2 g /ha EPoE *fb* IC + HW at 40 DAS	2.49 (5.33)	3.37 (10.7)	6.06 (36.0)	3.90 (14.7)	6.50 (41.3)	5.08 (25.3)	3.83 (13.8)	4.65 (21.4)	7.71 (58.5)	5.79 (32.7)	8.56 (72.3)	7.38 (54.1)	75.3	70.1
Topramezone + atrazine (25.2 + 500 g/ha) EPoE (tank-mix)	5.22 (26.7)	3.20 (9.33)	5.11 (25.3)	3.73 (13.3)	7.27 (52.0)	4.85 (22.7)	8.36 (69.1)	4.73 (21.5)	9.00 (80.1)	5.40 (28.9)	12.3 (149)	7.13 (50.4)	49.1	72.2
Tembotrione 120 g/ha EPoE *fb* IC + HW at 40 DAS	2.49 (5.33)	3.87 (14.7)	5.72 (32.0)	3.73 (13.3)	6.18 (37.3)	5.29 (28.0)	4.02 (15.2)	5.36 (29.5)	8.31 (68.4)	4.77 (21.9)	9.18 (83.6)	7.15 (51.3)	71.5	71.7
Tembotrione + atrazine (120 + 500 g/ha) EPoE (tank-mix)	3.75 (13.3)	3.78 (13.3)	4.24 (17.3)	3.58 (12.0)	5.60 (30.7)	5.12 (25.3)	9.07 (81.9)	4.98 (24.0)	9.31 (85.9)	5.13 (25.5)	13.0 (168)	7.08 (49.5)	42.7	72.7
IC at 20 and 40 DAS	5.26 (26.7)	4.43 (18.7)	5.91 (34.7)	3.90 (14.7)	7.86 (61.3)	5.83 (33.3)	10.1 (101)	7.08 (49.5)	9.64 (92.0)	6.50 (41.6)	13.9 (193)	9.60 (91.1)	34.1	49.7
IC + HW at 20 and 40 DAS	3.40 (10.7)	3.20 (9.33)	4.10 (16.0)	3.73 (13.3)	5.24 (26.7)	4.84 (22.7)	3.16 (8.97)	4.29 (17.6)	4.60 (20.2)	4.49 (19.5)	5.49 (29.2)	6.16 (37.0)	90.0	79.6
Weedy check	6.50 (41.3)	6.28 (38.7)	6.94 (48.0)	5.38 (28.0)	9.48 (89.3)	8.20 (66.7)	12.2 (149)	10.1 (102)	12.0 (144)	8.95 (79.2)	17.1 (293)	13.5 (181)	-	-
LSD (p=0.05)	0.89	0.96	1.20	1.01	1.07	1.08	1.3	1.58	1.16	1.08	1.37	1.48	-	-

Note: Data subjected to $(\sqrt{x+1})$ transformation. Figures in parentheses are means of original values., PE = pre-emergence application; EPOE = early post-emergence application; IC = inter cultivation, HW = hand weeding, DAS = days after seeding, *fb* = followed by

Table 3. Grain and stover yield as well as weed index of maize as influenced by weed management practices in *Rabi* maize

Treatment	Grain yield (t/ha)		Stover yield (t/ha)		Weed index (%)		B:C	
	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21	2019-20	2020-21
Atrazine 1.0 g/ha PE *fb* IC at 30 DAS	7.62	8.24	8.27	9.91	5.8	7.5	2.56	2.78
Pendimethalin 1.0 kg/ha PE *fb* IC at 30 DAS	7.85	8.03	8.60	9.93	3.0	9.9	2.63	2.70
Atrazine + pendimethalin (500 +250 g/ha) PE (tank- mix)	7.68	8.33	8.36	9.68	5.1	6.5	2.67	2.89
Topramezone 25.2 g/ha EPoE *fb* IC + HW at 40 DAS	7.94	8.91	8.91	9.86	1.9	-	2.42	2.70
Topramezone + atrazine (25.2 + 500 g/ha) EPoE (tank-mix)	7.34	8.90	8.19	9.82	9.3	0.1	2.38	2.85
Tembotrione 120 g/ha EPoE *fb* IC + HW at 40 DAS	7.89	8.78	8.87	9.80	2.5	1.5	2.41	2.67
Tembotrione + atrazine (120 + 500 g/ha) EPoE (tank-mix)	7.32	8.75	8.07	9.71	9.5	1.8	2.43	2.87
IC at 20 and 40 DAS	7.37	8.31	7.59	9.80	8.9	6.7	2.51	2.83
IC + HW at 20 and 40 DAS	8.09	8.69	9.29	10.48	-	2.5	2.43	2.60
Weedy check	6.73	6.76	7.82	8.59	16.8	24.1	2.44	2.46
LSD (p=0.05)	0.61	1.15	0.77	0.69	-	-	-	-

PE = pre-emergence application; EPoE = early post-emergence application; IC = inter cultivation, HW = hand weeding, DAS = days after seeding, *fb* = followed by

competition period which lead to increase the availability of resources which reflected in better growth of the crop thereby higher grain yield. Similar line of results was also observed by Saimaheswari *et al*. (2022). Whereas, significantly higher stover yield (9.29 and 10.48 t/ha) of *Rabi* maize was achieved under IC + HW at 20 and 40 DAS during both the years. Among all the weed management practices, significantly lower grain and stover yield was recorded under weedy check but it was at par with IC carried out at 20 and 40 DAS. The minimum yield reduction due to weeds was observed with topramezone 25.2 g /ha EPoE *fb* IC + HW at 40 DAS and topramezone + atrazine 25.2 + 500 g /ha (tank-mix) EPoE followed by tembotrione 120 g /ha EPoE *fb* IC + HW at 40 DAS during 2019-20 and 2020-2021, respectively. The highest yield reduction was observed under weedy check (16.8 and 24.1% during 2019-20 and 2020-2021, respectively).

Economics of different treatment indicated that maximum benefit cost ratio of 2.67 and 2.89 was observed with atrazine + pendimethalin 500 +250 g / ha (tank-mix) PE during 2019-20 and 2020-21, respectively. The higher B:C might be due to higher grain and stover yield achieved under these treatments as a result of better control of weeds. Barla *et al*. (2016) also observed that tank-mix application of atrazine + pendimethalin PE was cost effective weed control measure in maize. The results are in accordance with the results of Kakade *et al*. (2020).

It was concluded that tank mix application of atrazine + pendimethalin 500 +250 g /ha PE or early post-emergence (10-15 DAS) application of topramezone + atrazine 25.2 + 500 g /ha or tembotrione + atrazine 120 + 500 g /ha EPoE effectively controlled the weeds in winter maize.

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RESEARCH ARTICLE

Productivity and profitability of zero till winter maize as influenced by integrated weed management practices

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ABSTRACT

A field experiment was carried out during the winter season of 2016-17 and 2017-18 to evaluate the effect of integrated weed management in maize under zero tillage conditions on weed control efficiency, growth, yield and economics of maize. The experiment comprised ten integrated weed management treatments, *viz.* glyphosate 1.6 kg/ha 3 days before sowing (DBS); glyphosate 1.6 kg/ha 3 DBS followed by (*fb*) power weeder at 25 days after sowing (DAS); pre-emergence (PE) application of halosulfuron 67.5 g/ha; halosulfuron 67.5 g/ha PE *fb* power weeder at 25 DAS; atrazine 1.5 kg/ha PE; atrazine 1.5 kg/ha PE *fb* power weeder at 25 DAS; imazethapyr 100 g/ha PE; imazethapyr 100 g/ha PE + post-emergence (PoE) application of fenoxaprop 100 g/ha at 20-25 DAS; weed free (3 hand weeding at 20, 40, 60 DAS) and weedy check. The weed-free treatment as well as atrazine 1.5 kg/ha PE *fb* power weeder at 25 DAS recorded maximum weed control efficiency, maize growth and yield during both years. However, the highest net returns ₹ 99887 and ₹ 100333/ha and B: C ratio 2.66 and 2.78 were obtained with atrazine PE *fb* power weeder, respectively. Thus, integrated weed management using atrazine 1.5 kg/ha PE *fb* power weeder at 25 DAS improved the weed index, weed control efficiency, growth attributes, yield as well and profitability of winter maize under zero tillage conditions.

Keywords: Integrated weed management, Maize, Power weeder, Weed control efficiency, Zero tillage

INTRODUCTION

Maize is one of the most important cereal crops in the world agriculture economy as both food for humans and animals. It is the third most important cereal crop of India after rice and wheat and is cultivated in an area of 8.69 million ha with a production of 21.81 million tonnes and a productivity of 2509 kg/ha (Kumar *et al*. 2016). In the 2017-18 cropping season, winter maize in Bihar was grown in an area of 26 lakh hectares with annual production of about 64 lakh metric tonnes and productivity of 6135 kg/ha (Anonymous 2017) indicating the acceptance of winter maize technology by farmers of Bihar. However, weeds are the most severe constraints and pose major problems in maize production by diminishing the quantity as well as quality (Yakadri *et al*. 2015, Ramesh *et al*. 2017). Yield loss due to weed in maize varies from 28 to 93%, depending on the type of weed flora and intensity and duration of crop-weed competition. Pre- and post-emergence application of herbicides may lead to cost-effective control of the weeds right from the start which otherwise may not be possible by manual weeding. No-tillage maize production conserves soil and water and reduces capital investment in machinery for land preparation and intercultural operations, but most importantly to many producers, no-tillage can also improve maize yields (Singh *et al*. 2012). This practice also leaves crop residue on the surface after planting, which promotes infiltration of water (Kiran and Rao 2014). Hence, timely weed management plays an important role in increasing productivity of maize. Herbicides are being widely used to control weeds but sole dependency on herbicides may cause development of herbicide-resistant weeds along with contamination of herbicides in food chain and causing environmental hazards (Arvadiya *et al*. 2012). The integration of chemical and mechanical weed management strategies provides better weed control than herbicide alone (Mishra and Singh 2012). Therefore, emphasis should be given to increase maize yield through the adoption of technically effective and feasible, economically viable, socially acceptable and environmentally sound proper weed management practices. Hence, this study was undertaken to study the effect of integrated weed management on weed dynamics, growth, yield and economics of winter maize under zero tillage condition.

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MATERIALS AND METHODS

The experiment was carried out at Crop research farm of Borlaug Institute for South Asia (BISA), Pusa, Samastipur (Bihar), India during winter season of 2016-17 and 2017-18. BISA farm is located in the northern part of Samastipur district (25° 57' N latitude and 85° 40' E longitude). It is situated at an elevation of about 52 m above mean sea level. The soil of the experimental site was clay loam in texture with pH of 8.4, electrical conductivity of 0.26 (dS/m), medium in organic carbon (0.55%), low in available N (188 kg N/ha), high in available P (16.71 kg/ha) and medium in available K (121.25 kg/ha). The experiment was laid out in a randomised block design with 3 replications. The treatment details of the experimental plot consisted : glyphosate 1.6 kg/ha 3 days before sowing (DBS); glyphosate 1.6 kg/ha 3 DBS followed by (*fb*) power weeder at 25 DAS; pre-emergence (PE) application of halosulfuron 67.5 g/ha; halosulfuron 67.5 g/ha PE followed by (*fb*) power weeder at 25 days after sowing (DAS); atrazine 1.5 kg/ha PE; atrazine 1.5 kg/ha PE *fb* power weeder at 25 DAS; imazethapyr 100g/ha PE; imazethapyr 100g/ha PE + post-emergence (PoE) application of fenoxaprop 100g/ha (20-25 DAS); weed free (3 hand weedings at 20, 40 and 60 DAS) and weedy check.

Maize variety *Shaktiman-3* was sown on 18th November 2016 and 14th November of 2017 with row to row and plant to plant spacing of 60 and 20 cm, respectively. Seed rate of maize was 20 kg/ha and the net plot size was 4.6 × 2.4 m. The uniform dose of fertilizer used was 120:60:60 (N: P: K) kg/ha. The sources of fertilizer used for N, P and K were urea, diammonium phosphate and muriate of potash respectively. Full dose of P, K and 50% of N were applied as basal to maize. The rest of the nitrogen was top dressed in two splits *i.e.* first split of N was 30 kg/ha applied at 20 DAS and the remaining 30 kg/ha of N was given at 35 DAS. The khurpi (hand operated spade) is one of the most common tool which were used in the field for weeding. The power weeder being an efficient machine for intercultural operation in row crops that was used as per the treatment. Stock solution of respective quantity of each herbicide were prepared separately, by dissolving in half a litre of water and made up to required quantity of spray solution (spray volume) by adding water. The spray solution was dissolved in water as per requirement (600 L/ha) and applied with knapsack sprayer by using the flat fan nozzle. All the necessary cultural practices were carried out uniformly during the crop season. To record weed biomass, weeds were cut at ground level, washed with tap water, sun-dried in hot air oven at 70 °C for 48 hrs and then weighed. For the statistical analysis, weed density and biomass were converted to 1 m^2 and imposed square root transformation to normalize their distribution. Further weed control efficiency (WCE) was calculated by using the formulae given by Mani *et al.* (1973). The grain yield was taken from 1 m^2 area in the centre of each plot and expressed in t/ha at 14% moisture content. Economic analysis was done as per the prevailing cost of inputs and selling price of output in the concerned year. Statistical analysis was done by adopting appropriate method of Analysis of Variance (Gomez and Gomez 1984).

RESULTS AND DISCUSSION

Weed biomass, weed control efficiency and weed index in zero till winter maize

In both years, weed management treatments significantly reduced the weed biomass and increased the weed control efficiency. The lowest value of weed dry weight was recorded under weed free. Among the different herbicidal treatments, minimum weed dry weight was recorded under application of atrazine 1.5 kg/ha PE *fb* power weeder at 25 DAS and was found to be significantly more effective over all the other treatments in respect of suppressing weeds (**Table 1**) as reported earlier by Ram *et al.* (2017), Shantveerayya and Agasimani (2012) and Verma *et al.* (2009). The maximum weed control efficiency was registered under weed-free treatment followed by atrazine 1.5 kg/ha PE *fb* power weeder at 25 DAS during both years due to lower dry matter production of weeds. However, a reverse trend was recorded with the weed index. In case of weed index, it was found lowest with atrazine PE *fb* power weeder at 25 DAS during the years 2016-17 and 2017-18. The study further indicated that herbicides were more effective in reducing weed density and biomass next to 3-hand weeding as compared to weedy check. Lower weed index denoteed the less yield losses due to weeds as reported by Kakade *et al.* (2020), Dobariya *et al.* (2015), Stanzen *et al.* (2016) and Susha *et al.* (2014).

Crop growth and yield attributes

During both years, the integrated weed management practices significantly increased growth attributes in winter maize (**Table 2**). The maximum plant height was recorded under the weed free 205.94 and 206.87 cm whereas among herbicidal treatments, atrazine 1.5 kg/ha PE *fb* power weeder at 25 DAS recorded 23.98% and 24.21% taller plants over weedy check during 2016-17 and 2017-18, respectively. Plant height is an important vegetative character as it is an index of plant growth and vigour.

It is affected by various causes and effects medicated by herbicides and their application time. Treatment combinations, which exhibited better control of weeds, were also able to record more plant height than treatments having unacceptable weed control. Maize crop with better weed control attained greater plant height due to reduction in weed density. Increase in overall growth of crop at all stages of observation was mainly due to significant reduction in weed competition, which was a major factor affecting crop yield as reported by Barad *et al.* (2016) and Bibi *et al.* (2010). Dry matter accumulation was significantly influenced by the different herbicidal treatments at all the crop growth stages. Among the herbicidal treatments, maximum dry matter 364.3 g and 367.2 g/plant was observed with atrazine 1.5 kg/ha PE *fb* power weeder at 25 DAS during 2016-17 and 2017-18, respectively. However, weed free and atrazine PE *fb* power weeder recorded 54.77%, 56.55% and 43.03%, 44.62% higher dry matter as compared weedy check during both years, respectively. This might be due to less weeded environment at critical growth stages which improved growth and yield attributes of the crop. In general, the aforesaid improvements seem to be on account of direct impact of different weed management treatments through least crop-weed competition whereas, indirect effect might be least competition for plant growth inputs, *viz.* light, space, water, nutrients *etc*. (Gul and Khanday 2015). Uncontrolled weeds in weedy check plot created conditions similar to poor aeration and smothering effect on crop plants thus crop became vulnerable against different growth resources and this resulted in minimum dry matter accumulation conforming the previous findings of Rani *et al.* (2021), Dobariya *et al.* (2014), Mukundam *et al.* (2011) and Sarma and Gautam (2010).

The integrated weed management practices enhanced the yield attributes *viz*., number of cobs/m^2, number of grains/cob and 1000 grain weight. The grain yield is the function of interplay between yield attributes and growth characters. The higher number of cobs/m^2 (18 and 19) were recorded under weed free, which was found to be statistically at par with atrazine 1.5 kg/ha PE *fb* power weeder at 25 DAS

Table 1. Weed biomass, weed control efficiency and weed index of zero till winter maize as influenced by different weed management practices

Treatment	Weed biomass (g/m^2)		Weed control efficiency (%)		Weed index	
	2016-17	2017-18	2016-17	2017-18	2016-17	2017-18
Glyphosate 1.6 kg/ha 3 DBS	9.43	8.65	60.52	57.89	10.28	11.13
Glyphosate 1.6 kg/ha 3 DBS *fb* power weeder at 25 DAS	4.68	4.23	76.08	77.61	6.18	5.45
Halosulfuron 67.5 g/ha PE	9.67	9.16	54.71	54.71	21.01	20.62
Halosulfuron 67.5 g/ha PE *fb* power weeder at 25 DAS	5.36	4.78	74.89	75.88	8.29	5.71
Atrazine 1.5 kg/ha PE	6.21	5.96	70.91	70.91	9.86	7.69
Atrazine 1.5 kg/ha PE *fb* power weeder at 25 DAS	3.45	4.08	83.84	78.07	4.82	3.49
Imazethapyr 100 g/ha PE	16.07	15.48	24.73	26.22	31.55	29.03
Imazethapyr PE + fenoxaprop PoE 100 +100 g/ha (20-25 DAS)	14.62	14.16	31.52	31.52	29.14	26.73
Weed free (3 hand weeding at 20, 40 and 60 DAS)	2.06	1.67	90.39	90.39	0	0
Weedy check	21.36	21.12	-	-	48.50	44.00
LSD (p=0.05)	0.65	0.85	-	-	-	-

DBS: days before sowing; *fb*: followed by; DAS: days after sowing; PE: pre-emergence PoE: post-emergence

Table 2. Effect of integrated weed management on crop growth and yield attributes of winter maize under zero tillage conditions

Treatment	Plant height (cm)		Dry weight (g/plant)		No. of cobs/m^2		No. of grains/cob		1000 seed weight (g)	
	2016-17	2017-18	2016-17	2017-18	2016-17	2017-18	2016-17	2017-18	2016-17	2017-18
Glyphosate 1.6 kg/ha 3 DBS	191.3	192.2	321.6	324.8	12	14	479	483	312.6	315.2
Glyphosate 1.6 kg/ha 3 DBS *fb* power weeder at 25 DAS	200.9	201.8	339.9	338.5	14	16	515	524	363.3	364.0
Halosulfuron 67.5 g/ha PE	184.3	185.5	313.7	311.6	11	10	444	448	264.6	267.9
Halosulfuron 67.5 g/ha PE *fb* power weeder at 25 DAS	196.2	197.9	332.5	335.3	16	16	513	523	348.1	348.7
Atrazine 1.5 kg/ha PE	192.8	195.1	327.9	330.5	12	15	495	501	335.2	335.6
Atrazine 1.5 kg/ha PE *fb* power weeder at 25 DAS	201.7	204.2	364.3	367.2	16	17	523	528	363.6	365.4
Imazethapyr 100 g/ha PE	175.9	176.3	295.1	295.4	10	12	406	409	222.0	223.4
Imazethapyr PE + fenoxaprop PoE 100 +100 g/ha (20-25 DAS)	174.3	179.4	302.8	305.5	11	12	418	420	234.8	235.5
Weed free (3 hand weeding at 20, 40 and 60 DAS)	205.9	206.9	394.2	397.5	18	19	537	542	365.9	369.2
Weedy check	162.6	164.4	254.7	253.9	7	10	336	338	200.2	203.3
LSD (p=0.05)	14.9	14.5	16.98	17.02	3.24	3.39	5.04	5.38	4.77	4.72

DBS: days before sowing; *fb*: followed by; DAS: days after sowing; PE: pre-emergence PoE: post-emergence

Table 3. Effect of different weed management practices on yield and economics of winter maize under zero tillage condition

Treatment	Grain yield (t/ha)		Stover yield (t/ha)		Stone yield (t/ha)		Net returns (x10³ ₹/ha)		B:C ratio	
	2016-17	2017-18	2016-17	2017-18	2016-17	2017-18	2016-17	2017-18	2016-17	2017-18
Glyphosate 1.6 kg/ha 3 DBS	6.38	6.49	12.76	12.85	1.18	1.24	85.74	86.98	2.32	2.40
Glyphosate 1.6 kg/ha 3 DBS *fb* power weeder at 25 DAS	6.84	6.91	14.14	14.34	1.35	1.53	94.50	96.55	2.58	2.64
Halosulfuron 67.5 g/ha PE	5.57	5.80	12.08	12.12	1.08	1.11	74.61	75.66	2.01	2.12
Halosulfuron 67.5 g/ha PE *fb* power weeder at 25 DAS	6.55	6.89	13.84	13.99	1.38	1.46	93.49	95.71	2.58	2.66
Atrazine 1.5 kg/ha PE	6.73	6.74	13.57	13.75	1.19	1.39	92.12	93.37	2.52	2.61
Atrazine 1.5 kg/ha PE *fb* power weeder at 25 DAS	7.08	7.05	14.32	14.34	1.74	1.82	99.89	100.33	2.66	2.78
Imazethapyr 100 g/ha PE	5.03	5.18	10.10	10.26	1.04	1.09	60.99	62.99	1.68	1.76
Imazethapyr PE + fenoxaprop PoE 100 +100 g/ha (20-25 DAS)	5.12	5.35	10.86	11.19	1.07	1.10	62.95	64.65	1.55	1.68
Weed free (3 hand weeding at 20, 40 and 60 DAS)	7.23	7.30	16.43	16.63	1.85	1.93	89.99	91.79	1.60	1.72
Weedy check	4.05	4.09	8.81	8.96	0.84	0.86	42.86	45.46	1.24	1.33
LSD (p=0.05)	0.50	0.42	0.54	0.47	0.34	0.26	6.38	6.42	0.15	0.18

DBS: days before sowing; *fb*: followed by; DAS: days after sowing; PE: pre-emergence PoE: post-emergence

during the year 2016-17 and 2017-18 (**Table 3**). Among the herbicidal treatments, maximum number of grains/cob (523 and 528) was observed under weed free and with atrazine 1.5 kg/ha PE *fb* power weeder at 25 DAS during both years, respectively. Test weight is a general indicator of grain quality and higher test weight normally means higher quality grain. The maximum 1000 grain weight 365.93 g in 2016-17 and 369.2 g in 2017-18 was found with weed free check. Due to severe crop-weed competition throughout the growth period, weedy check recorded the least yield attributes confirming findings of Barkhtair *et al.* (2011), Hawaldar and Agasimani (2012) and Saman *et al.* (2015).

Yield and economics

Grain yield of winter maize was significantly affected by integrated weed management practices under zero tillage condition (**Table 3**). The highest grain yield of 7.2 and 7.3 t/ha was recorded with weed free treatment during 2016-17 and 2017-18, respectively. Among the herbicidal treatments, atrazine 1.5 kg/ha PE *fb* power weeder at 25 DAS showed 74.91% and 72.34% higher grain yield as compared to weedy check during the experimental year 2016-17 and 2017-18, respectively. Controlling weeds at the early growth as well as at later stages provided conducive atmosphere for better utilization of natural resources and external inputs by the crop as reported by Wasnik *et al.* (2022), Shekhar *et al.* (2014) and Mukundam *et al.* (2011). Stover yield also differed significantly due to the various treatments and similar trend was followed like grain yield. Weedy check scored 38.45% and 37.51% less stover yield as compared to the atrazine 1.5 kg/ha as PE *fb* power weeder at 25 DAS during 2016-17 and 2017-18 respectively (**Table 3**). Similar findings were reported by Chandrapala *et al.* (2010), Mathukia *et al.* (2014) and Sunitha *et al.* (2010).

Higher economic return is an important consideration in selection of weed management practices as farmers are mostly concerned with higher return per unit area, time and investment. The highest value of net return (₹ 99887 and ₹ 100333/ha) was scored atrazine 1.5 kg/ha PE *fb* power weeder at 25 DAS which was 10.99% and 9.30% higher as compared to weed free during 2016-17 and 2017-18, respectively. Benefit: cost ratio followed the similar trend. Higher net income recorded with atrazine under zero till conditions confirmed the findings of Barad *et al.* (2016), Parameswari (2013) and Reddy *et al.* (2012).

Weed free (3 hand weeding) and atrazine 1.5 kg/ha PE *fb* power weeder at 25 DAS recorded higher growth and yield of winter maize during both of years. However, from economic point of view, integrated weed management involving atrazine 1.5 kg/ha PE *fb* power weeder at 25 DAS was superior over all other treatments including weed free and hence is the most appropriate and adoptable integrated weed management strategy to achieve higher weed control efficiency, growth, yield and income of *winter* maize under zero tillage condition.

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RESEARCH ARTICLE

Integrated weed management in fodder maize crop in North-West India

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ABSTRACT

Field experiments were conducted in Punjab, India in 2020 and 2021 to study the integrated effects of row spacing, cultivars (variety) and weed control treatments on weed suppression and maize green fodder yield. The variety '*J-1007*' had higher maize equivalent fodder yield than the variety '*J-1006*' based on the averaged weed control treatments. Irrespective of the row spacing, the application of PoE herbicide tembotrione provided the highest maize equivalent fodder yield among all the weed control treatments and this treatment produced maize equivalent fodder yield of 43.28 and 47.97 t/ha for *J-1006* and *J-1007*, respectively in narrow 22.5 cm row spacing. Maize + cowpea intercropping provided similar level of weed control and yield as atrazine irrespective of the row spacing. The variety '*J-1007*' in 22.5 cm row spacing coupled with tembotrione accrued significantly lowest weed dry matter as compared to other treatment combinations. The study concluded that green fodder yield of maize cultivars could be improved by exploring their competitiveness through narrow row spacing and application of post-emergence herbicide tembotrione for weed control in maize fodder.

Keywords: Atrazine, Cultivar, Green fodder yield, Maize, Row spacing, Tembotrione, Weed control

INTRODUCTION

Maize (*Zea mays* L.) is one of the world's major cereal crops and is ranked third most important cereal crop after wheat and rice. During 2018-19 in India, maize area reached to 9.2 million hectare (DACNET 2020). A highly productive crop with diversified uses, maize is chiefly grown for human consumption in India, being a staple food of a large population (Milind and Isha 2013). Hence, it occupies a prominent place in the national food basket of the country. Besides its use in human diet, maize crop is extensively used as livestock feed for cattle, poultry and piggery in the form of green fodder and seed (Shah *et al*., 2016). Its use as green fodder has acquired immense importance because the quality of green fodder of maize is far excellent than other non-legume fodder crops (Kumar *et al*. 2017). It is the only non-legume fodder crop which produces better nutritional quality along with good quantity of biomass. It is commonly grown as a summer and rainy season fodder in the North-Western regions of the country, particularly in Punjab, Haryana and Western Uttar Pradesh. Its quality is much better than sorghum and pearl millet since both sorghum as well as pearl millet possesses anti-quality components such as hydrocyanic acid and oxalate (Hanif and Akhtar 2020).

Weed infestation in maize crop grown either for grain or fodder is one of the major causes behind heavy yield penalties. Particularly, in the early crop growing period, weed interference is a serious problem owing to its slow early crop growth rate. Also, coinciding rains especially during the rainy season help the weeds to grow faster and more luxuriantly. Weeds are notorious for competing successfully for resources mainly light, water and nutrients with the maize plants thus altering the maize crop morphology and phenology and ultimately reducing yield. Moreover, presence of weeds renders harvesting operations difficult and also mar the quality of the produce whether grain or green fodder (Ikram *et al*. 2018). The yield losses due to weeds generally depend on the composition of weed flora, duration of crop-weed competition and its intensity. Yield reductions of maize crop due to competition from weeds have been estimated to be around 37% (Oreke and Dehne 2004).

Currently, fodder producers are using pre-emergence (PE) herbicides chiefly atrazine for weed control in maize fodder which provides control of selected weed flora for first 3-4 weeks only. There is at present no post-emergence herbicide for weed control in fodder crop of maize. Now, atrazine, being a pre-emergence herbicide gives only selective weed

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control (Kumar *et al.* 2012) and weeds emerging in later flushes or which escape this herbicide continue to inflict heavy yield losses. Also, farmers sometimes skip the pre-emergent herbicide application and then they are left with no alternative in the absence of any recommendation for post-emergence herbicide application. Hence, it is pertinent to study the efficacy of post-emergence (PoE) herbicides in fodder maize. Recently introduced, a post-emergence herbicide labelled for use in grain crop of maize is tembotrione (Kaur *et al.* 2018). However, literature citing its use in fodder crop of maize is not available.

Although, the application of herbicides is inevitable and highly effective but the far-reaching consequence of heavy reliance on use of herbicides is mainly weed resistance (Mathers and Parker 2013). Crop competition can be employed as a potential valuable cultural weed control strategy in integrated weed management programme (Mohammadi *et al.* 2012) which would further contribute towards improving herbicide performance (Lodo *et al.* 2019). In maize, use of crop competition involves modification of row spacing, higher plant density, use of intercropping, use of competitive cultivars *etc.* (Ramesh *et al.* 2017, Mhlanga *et al.* 2016). These non-chemical weed control options can be used in conjunction with herbicides and weed control efficacy can be greatly enhanced. The present study aimed to find out the suitable row spacing to exploit the weed competitive ability of maize fodder cultivars along with suitable weed control treatments to reduce yield losses and weed infestation in maize fodder.

MATERIALS AND METHODS

The field experiments were conducted at the Fodder Research farm, Punjab Agricultural University, Ludhiana (30º54´N75º48´E), India, during the rainy seasons (June to October) of the year 2020 and 2021. The field had history of maize-oats (*Avena sativa*) rotation for fodder for the last 3 years. The climate at the site is semi-arid, with an average annual rainfall of 400 to 700 mm (75 to 80% of which falls from July to September), a minimum temperature of 0 to 4 ºC in January and a maximum temperature of 41 to 45 ºC in June. The soil at the experimental site was sandy loam with 0.3% organic matter and a pH of 7.2. During both years, same lands were prepared by ploughing twice using a cultivator followed by planking to make the soil well pulverized. Fodder maize was sown using 75 kg/ha seed rate at the seeding depth of 4-5 cm on 26 May, 2020 and 10 June, 2021 using a manual hand drill. The experiments were surface irrigated as and when required and depth of each irrigation was 5 cm. Nitrogen (120 kg/ha) as urea was applied (top-dressed) in two equivalent splits [(basal at sowing and 30 days after sowing (DAS)]. Recommended rates of chlorantraniliprole (9.25 g/ha) were used to control pests. The crop was harvested at 75-80 DAS on August 20 and August 30 during 2020 and 2021, respectively.

The experiment in each year was established in a factorial split-plot design with three replicates. The study included 16 treatments consisting of two row spacings (wide: 30-cm row spacing and narrow: 22.5-cm row spacing) and two cultivars (J-1006 and J-1007) in main plots and four weed control treatments (non-treated control, atrazine 625 g/ha, tembotrione 120 g/ha and maize + cowpea intercropping) in subplots. Atrazine (3 DAS) and tembotrione (20-25 DAS) were applied using a knapsack sprayer with a flood jet and flat-fan nozzle, respectively. For PE and PoE application of herbicides, the sprayer was calibrated to deliver 500 and 375 litres of spray solution per hectare, respectively. In maize + cowpea intercropping, one row of cowpea was sown between two maize rows using a seed rate of 15 kg/ha. The sowing of cowpea was done simultaneously with maize sowing. Two quadrats, 0.25 m^2, were placed at random in each plot to determine weed density and dry weight at 45 DAS and at harvest. For dry weight, weeds were cut close to the ground level, air-dried and then dried in an oven for 72 hours at 60ºC, and dry weight was recorded.

Five plants were selected randomly from each plot to measure plant height at regular intervals (30 DAS, 45 DAS and at harvest). Leaf area index of maize was recorded at regular intervals (30 DAS, 45 DAS and at harvest) using prescribed procedure (Sexsana and Singh, 1968).

The crop was harvested for taking green fodder yield at dough stage (75-80 DAS). The green fodder yield from each plot was immediately weighed in kg/plot and then expressed in t/ha. Both maize and intercrops were harvested separately from intercropping plots by using sickle. The green fodder yield of intercrop was converted into maize fodder equivalent yield by multiplying the prevailing market price of intercrop with its yield and then dividing price of sole maize fodder and expressed in t/ha.

Maize fodder equivalent yield (MEY) was calculated as:

$$\text{Maize fodder equivalent yield} = \frac{\text{Yield of cowpea} \times \text{price of cowpea/kg}}{\text{Price of maize/kg}}$$

Since the interaction of years with treatments were insignificant, the data were pooled for the two years for further analyses using the GLM procedure in SAS version 9.3 to evaluate the differences between treatments (SAS 9.3). Using square-root transformation, data on weed dry matter were transformed. Treatment means were separated using Fischer's protected least significant difference (LSD) at the 5% level of significance.

RESULTS AND DISCUSSION

Weeds density

The experimental field was dominated by *Digitaria sanguinalis*, *Dactyloctenium aegyptium*, *Echinochloa colona* under grasses; *Trianthema portulacastrum*, *Euphorbia hirta*, *Eclipta alba* under broadleaved weeds (BLWs); *Cyperus rotundus* under sedges. The different treatments significantly influenced the density of grasses, braod-leaved weeds (BLWs) and sedges at 45 DAS and at harvest (**Table 1**). Fodder maize cultivars had significant influence on density of weeds. Significantly higher density of grasses and BLWs were recorded in cultivar *J-1006* which could be due to shorter plant height and less leafiness of *J-1006* as compared to *J-1007*, which recorded lower weed density due to its more plant height and canopy coverage while the density of sedges was not affected by the cultivars. Between the two row spacings, significantly maximum density of grasses, BLWs and sedges was observed in wide 30 cm row spacing at both the stages. Among the weed control treatments, significantly lowest density of weeds was found in plots treated with PoE application of tembotrione. Maize + cowpea intercropping remained more or less similar in reducing density of weeds as PE application of atrazine. The interaction of the treatments was, however, non-significant with respect to weed density.

There was significant interaction among treatments with regard to weed dry weight at 45 DAS and at harvest (**Table 2** and **3**). As compared to weed density, weed dry matter is a better measure of weed growth because it combines weed density as well as size. At 45 DAS, total weed dry matter varied from 39.8 to 340.6 g/m^2 in different combinations of row spacing, cultivars and weed control treatments. The lowest weed dry matter was recorded in cultivar *J-1007* sown with narrow 22.5-cm row spacing coupled with PoE application of tembotrione. The highest total weed dry matter was found in the non-treated plots sown with cultivar *J-1006* with wide 30-cm row spacing. A similar response was observed at the harvest stage where total weed dry matter varied from 22.4 to 222.7 g/m^2 in different treatment combinations of row spacing, cultivars and weed control treatments. At 45 DAS, cultivar *J-1007* sown with narrow 22.5-cm row spacing and sprayed with PE application of atrazine produced total weed dry matter similar to that with either cultivar sown with wide 30-cm row spacing and sprayed with PoE application of tembotrione. These combinations were also at par with cultivar *J-1006* sown with narrow 22.5-cm row spacing and treated with PoE herbicide. Cultivar *J-1007* sown with narrow 22.5-cm row spacing and in intercropping with cowpea reduced total weed dry matter similar to when this cultivar was sown with wide 30-cm row spacing and sprayed with PoE application of tembotrione and when sown in 22.5 cm rows and treated with PE atrazine. These combinations were also at par with cultivar *J-1006* sown in wide 30 cm rows and sprayed with PoE herbicide or cultivar *J-1006* sown in 22.5 cm rows and sprayed with PE herbicide.

The cultivar *J-1006* sown in 22.5 cm rows exhibited more reduction in dry matter of total weeds

Table 1. Weed density in relation to different treatments at 45 DAS and at harvest (pooled data of two years)

Treatment	Weed density (no./m^2)					
	45 DAS			At harvest		
	Grasses	BLWs	Sedges	Grasses	BLWs	Sedges
Cultivar						
J-1006	7.1 (53.7)	6.5 (45.1)	7.0 (50.2)	6.2 (40.3)	5.6 (32.3)	6.2 (39.4)
J-1007	6.5 (46.3)	6.4 (42.6)	6.8 (47.7)	5.7 (34.2)	5.3 (29.4)	5.9 (36.1)
LSD (p=0.05)	0.2	NS	NS	0.4	0.2	
Row spacing (cm)						
30	7.6 (61.0)	6.9 (50.1)	7.3 (55.1)	6.5 (43.7)	5.6 (32.5)	6.7 (45.3)
22.5	6.0 (39.0)	6.0 (37.6)	6.5 (42.8)	5.4 (30.9)	5.3 (29.2)	5.4 (30.2)
LSD (p=0.05)	0.2	0.2	0.3	0.4	0.2	0.4
Weed control treatment						
Weedy check	9.8 (96.7)	9.1 (82.8)	9.0 (81.5)	8.1 (66.0)	7.4 (54.8)	7.8 (60.7)
Atrazine 625 g/ha	6.3 (39.6)	6.0 (35.9)	6.4 (40.0)	5.7 (31.5)	5.3 (26.9)	5.8 (33.2)
Tembotrione 120 g/ha	4.2 (17.4)	4.4 (18.6)	5.5 (29.2)	3.9 (15.2)	3.6 (11.9)	4.5 (19.8)
Maize + Cowpea intercropping	6.8 (46.3)	6.3 (38.2)	6.8 (45.0)	6.1 (36.5)	5.5 (29.7)	6.1 (37.4)
LSD (p=0.05)	0.7	0.4	0.4	0.4	0.3	0.3

Table 2. Total weed dry weight in relation to the integrated effect of treatments at 45 DAS in maize fodder (pooled data of 2 years)

Treatment	Total weed dry weight (g/m²)			
	30 cm row spacing		22.5 cm row spacing	
	J-1006	*J-1007*	*J-1006*	*J-1007*
Nontreated control	18.5 (340.6)	18.2 (329.0)	17.6 (307.9)	17.1 (289.8)
Atrazine	10.4 (106.5)	9.9 (97.8)	9.0 (80.6)	8.1 (64.7)
Tembotrione	8.8 (75.7)	8.0 (63.2)	7.9 (62.2)	6.4 (39.8)
Maize + cowpea intercropping	10.3 (104.2)	10.1 (101.0)	9.5 (90.2)	8.8 (77.4)
LSD (p=0.05)	0.8			

*Weed dry weight data were subjected to square-root transformation before analysis and original values are presented in parentheses

Table 3. Total weed dry weight in relation to the integrated effect of treatments at harvest in maize fodder (pooled data of 2 years)

Treatment	Total weed dry weight (g/m²)			
	30 cm row spacing		22.5 cm row spacing	
	J-1006	*J-1007*	*J-1006*	*J-1007*
Nontreated control	15.0 (222.7)	13.8 (190.0)	13.3 (176.9)	12.6 (157.4)
Atrazine	8.7 (75.1)	8.0 (63.5)	7.8 (59.2)	6.9 (46.7)
Tembotrione	7.7 (59.0)	7.4 (53.9)	7.0 (48.7)	4.8 (22.4)
Maize + cowpea intercropping	9.4 (87.9)	8.1 (65.0)	8.1 (65.6)	7.0 (48.6)
LSD (p=0.05)	0.5			

*Weed dry weight data were subjected to square-root transformation before analysis and original values are presented in parentheses

at both the stages when sprayed with PE herbicide as compared with PoE herbicide. Weed dry matter was lower in *J-1007* than *J-1006* in narrow 22.5 cm row spacing when treated with PE and PoE sprays. The PoE application of tembotrione resulted in the lowest total weed dry matter compared with other treatments at both stages. The cultivar *J-1006* in narrow 22.5 cm row spacing and in intercropping with cowpea resulted in total weed dry matter (at 45 DAS and at harvest) similar to that in wide 30-cm row spacing and sprayed with tembotrione. At 45 DAS, *J-1007* in 22.5 cm row spacing resulted in reduction in dry matter of total weeds from 329 to 289.8 g/m² compared with 30-cm row spacing in non-treated control plots. With PE spray of atrazine, dry matter of total weeds at 45 DAS in 22.5 cm row spacing decreased from 97.8 to 64.7 g/m² and 106.5 to 80.6 g/m² for *J-1006* and *J-1007*, respectively, compared with 30 cm row spacing. With PoE spray of tembotrione, dry matter of total weeds at 45 DAS at 22.5 cm row spacing decreased from 63.2 to 39.8 g/m² for *J-1007* compared with 30 cm row spacing, however, no such reduction was observed for *J-1006*. A similar response was observed at harvest stage. With PE application of atrazine, dry matter of total weeds at harvest in 22.5 cm row spacing reduced from 75.1 to 63.5 and from 59.2 to 46.7 g/m² for *J-1006* and *J-1007*, respectively compared with 30 cm row spacing. With PoE application of tembotrione, the dry matter of total weeds decreased from 48.7 to 22.4 g/m² for *J-1007* compared with 30 cm row spacing; however, no such reduction was noticed for *J-1006*. The correlation of weed dry matter at harvest with maize equivalent fodder yield was negative indicating that weeds accounted for 92% of the variation in green fodder yield (**Figure 1**). In maize crop, weeds seriously compete for different resources and cause significant reductions in yields (Bajwa *et al*., 2015).

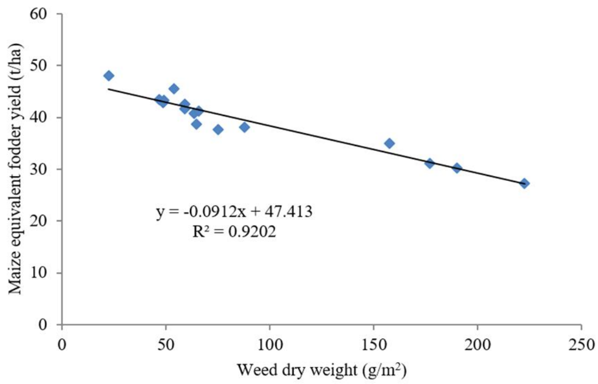

Figure 1. Relationship of weed dry weight and maize fodder equivalent yield at harvest

A practical management strategy to have a significant impact on weeds in crops is the manipulation of row spacing. The rate at which crop canopy closes *i.e.*, overlapping of leaves from the adjoining rows is highly determined by the row spacing which also affects the growth of weeds especially in the inter-row area. Significant yield losses occur when weeds out-compete the crops for essential nutrients. Reducing the row spacing of the crop reduces the time the crop takes to quickly cover the ground and close the canopy, hence providing rapid shading and suppressing weed growth and weeds' competitive abilities (Daramola *et al* 2021). Also, reduction in weed dry weight in narrower rows is attributed to increased LAI of the crop which restricts the solar radiation from reaching the weeds. Further, selecting a weed competitive cultivar confers suppression on weed infestation. A few studies have indicated that maize cultivars with greater leaf area index and more plant height have more suppressive effects on weeds (Lindquist and Mortensen 1998). In the present study, *J-1007* caused 9.0 and 18.5% reduction in weed dry weight at 45 DAS and at harvest, respectively over *J-1006*. The results of the present study thus corroborate the previous findings that changes in row spacing and selection of competitive cultivar influence weed growth. Among the herbicide options available for maize, atrazine has been the primary choice of farmers and it provides effective control of annual grasses and broadleaf weeds but for the complex weed flora and later emerging weeds, it is less effective. The new maize herbicide tembotrione is found to be very effective against a wide range of grass and broad-leaf weeds especially as post-emergence (Kaur *et al.* 2018). In the present study, the lowest weed dry matter was recorded with the application of PoE tembotrione in different combinations of row spacings and cultivars at both the stages. This could be due to the effective control of weeds emerging in the later flushes. Maize + cowpea intercropping caused reduction in weed dry weight which was comparable to the application of herbicide especially PE herbicide. Earlier also, it has been reported that maize + cowpea intercrops reduced weed dry weight as compared to sole crops due to the limited availability of resources to the weeds and also there was significant reduction in photo-synthetically active radiation reaching the ground by maize + cowpea intercrops (Eskandari and Kazemi 2011).

Plant height and leaf area index of the crop

There was no phyto-toxicity of either herbicide on maize fodder crop at the three observation stages (data not shown) which indicated that both PE and PoE herbicides are safe to the maize fodder crop. Plant height of the crop increased with successive stages up to harvest, however, the magnitude of the increase in plant height was found to get reduced beyond 45 DAS (**Table 4**). At each observation stage, plant height of the maize fodder was more at 22.5 cm row spacing. At harvest, the average plant height was 230.1 cm at 22.5 cm row spacing compared with 216.0 cm at 30-cm row spacing. At each observation stage, averaged over row spacings and weed control treatments, the plants of cultivar *J-1007* remained taller than the cultivar of *J-1006*. In weed control treatments, plants attained maximum height in the plots treated with the PoE application of tembotrione. The lowest plant height was recorded in the non-treated control plots at each stage.

Similar to plant height, leaf area index of the maize fodder was significantly affected by different treatments (**Table 5**). Leaf area index is a fair and reliable parameter of plant growth. It is an important indicator of radiation interception by each plant which affects plant growth and ultimately reflects in final dry matter yield. At 30 DAS, leaf area index of the crop in narrow 22.5 cm row spacing was 2.56 compared with 2.44 in wide 30 cm row spacing. At harvest, these values were 8.55 and 8.11 at 22.5 cm and 30 cm row spacing, respectively. The variety *J-1007* had higher leaf area index than *J-1006* at each stage. At harvest, the leaf area index of *J-1007* was 9.6% higher than that of *J-1006* plants. Among the weed control treatments, the leaf area index was highest with PoE application of tembotrione and lowest in non-treated control plots at each observation stage.

Plant height is an important component which determines the growth attained during the growing period and ultimately the green fodder yield in maize crop. In the present study, the maximum plant height was attained at narrow 22.5 cm row spacing. Increase in plant height due to closer row spacing might be attributed to better vegetative development resulting in increased mutual shading and inter-nodal extension. Also, as the number of plants increased, the competition among the plants for nutrients uptake and particularly sunlight interception increases which finally brings an increase in plant height.

Table 4. Plant height of maize fodder in relation to different treatments at different stages of plant growth (pooled data of two years)

Treatment	Plant height (cm)		
	30 DAS	45 DAS	At harvest
Cultivar			
J-1006	56.5	131.6	218.5
J-1007	58.9	141.0	227.5
LSD (p=0.05)	NS	3.1	5.4
Row spacing (cm)			
30	56.7	131.4	216.0
22.5	58.8	141.1	230.1
LSD (p=0.05)	NS	3.1	5.4
Weed control treatment			
Weedy check	54.4	123.0	203.9
Atrazine 625 g ai/ha	58.7	141.3	229.2
Tembotrione 120 g ai/ha	60.0	147.8	240.9
Maize + cowpea intercropping	57.7	133.0	218.2
LSD (p=0.05)	2.8	4.1	6.1

Table 5. Leaf area index of maize fodder in relation to different treatments at different stages of plant growth (pooled data of two years)

Treatment	Leaf area index		
	30 DAS	45 DAS	At harvest
Cultivar			
J-1006	2.41	4.65	7.95
J-1007	2.62	5.18	8.71
LSD (p=0.05)	0.073	0.28	0.26
Row spacing (cm)			
30	2.44	4.73	8.11
22.5	2.56	5.09	8.55
LSD (p=0.05)	0.073	0.28	0.26
Weed control treatment			
Weedy check	2.00	4.23	7.26
Atrazine 625 g/ha	2.66	5.16	8.68
Tembotrione 120 g/ha	2.93	5.52	9.34
Maize + cowpea intercropping	2.47	4.75	8.04
LSD (p=0.05)	0.13	0.29	0.52

Leaf area index is another important feature of maize fodder crop as the final green fodder yield is greatly determined by the leafiness of the crop per unit area. In our research, narrowing down the row spacing is observed to have an increase in LAI of the crop on account of more ground area covered by the green leafy canopy of plants per unit area. An increase in leaf area index helps capture more solar radiation and thus accumulation of more dry matter and ultimately more economic yield. The results of the present study are in close conformity with the results documented by Sharifi and Namvar (2016) who found that increase in plant density, increases the LAI in maize.

Among the important traits of cultivars conferring weed suppression, faster growth and development, improved plant height and presence of more light-intercepting leaf architecture are prominent. As compared to cereals such as wheat and rice, limited work pertaining to use of competitive cultivars has been done in maize. In a study by Lindquist and Mortensen (1998), the weed suppressive ability of maize cultivar was due to its greater leaf area index. Similarly, in our study, the cultivar *J-1007* had more competitive ability that *J-1006*. This response was accounted for by more plant height and leaf area index of *J-1007* which helped in early crop canopy closure and gave more smothering effect on weeds at both the stages of observation.

Maize fodder equivalent yield

Maize fodder equivalent yield was significantly influenced by row spacing, cultivars and weed control treatments (**Table 6**). Maize fodder equivalent yield varied from 27.25 to 47.97 t/ha in different combinations of row spacing, cultivars and weed control treatments. In the non-treated control plots, *J-1007* produced more green fodder yield over *J-1006* irrespective of row spacing and green fodder yield of *J-1007* further improved at 22.5 cm row spacing compared to 30 cm row spacing. In non-treated control plots, *J-1007* sown with 22.5 cm row spacing produced green fodder yield which was significantly highest as compared to other combinations of cultivars and row spacing with non-treated control. The green fodder yield of both the cultivars was similar in plots sprayed with PoE herbicide irrespective of row spacing. *J-1007* sown at 22.5 cm row spacing and sprayed with PE herbicide resulted in green fodder yield similar to that obtained with *J-1006* sown with either row spacing and sprayed with PoE herbicide. In intercropping with cowpea, row spacing had no influence on maize equivalent fodder yield between the cultivars. In either row spacing, maize + cowpea intercropping provided similar maize equivalent fodder yield in both cultivars. Additionally, maize + cowpea intercropping provided green fodder yield in both the cultivars similar to when sprayed with atrazine. With the application of atrazine, green fodder yield at 22.5 cm row spacing was 10.7 and 6.6% higher than in the 30-cm row spacing for *J-1006* and *J-1007*, respectively. With the application of tembotrione, green fodder yield increased by 5.5% at 22.5 cm row spacing for *J-1007* compared with 30 cm row spacing, however, no such increase was found for *J-1006*.

Table 6. Maize fodder equivalent yield in relation to interactive effect of row spacing, cultivars and weed control treatments (pooled data of two years)

Treatment	Maize fodder equivalent yield (t/ha)			
	30 cm row spacing		22.5 cm row spacing	
	J-1006	*J-1007*	*J-1006*	*J-1007*
Nontreated control	27.25	30.29	31.14	34.96
Atrazine	37.58	40.72	41.59	43.41
Tembotrione	42.63	45.49	43.28	47.97
Maize + cowpea intercropping	38.07	38.67	41.13	42.83
LSD (p=0.05)	2.56			

In conclusion, green fodder yield of maize could be enhanced by selecting the weed competitive cultivar in narrow rows coupled with PoE herbicide tembotrione or intercropping to achieve higher returns (**Table 7**). The total residue of herbicide tembotrione in maize grain and cob matrix were both below 0.02 mg/kg, lower than the max residue limit (MRL) recommended by European Food Safety Authority (EFSA), however, similar studies are required to determine the residues of tembotrione in maize green fodder.

Table 7. Economics of maize fodder in relation to different treatments at (pooled data of two years)

Treatment	Gross returns ($x10^3$ ₹/ha)	Net returns ($x10^3$ ₹/ha)	Benefit: cost ratio
Cultivar			
J-1006	93.96	56.15	2.48
J-1007	101.97	62.93	2.60
LSD (p=0.05)	4.37	4.37	0.11
Row spacing (cm)			
30	94.58	56.19	2.45
22.5	101.35	62.89	2.63
LSD (p=0.05)	4.37	4.37	0.11
Weed control treatment			
Weedy check	77.27	40.87	2.12
Atrazine 625 g/ha	102.06	64.34	2.70
Tembotrione 120 g/ha	112.10	71.53	2.76
Maize + cowpea intercropping	100.43	61.42	2.57
LSD (p=0.05)	2.81	2.81	0.07

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RESEARCH ARTICLE

Weed management effect on density, growth parameters and yield of cowpea

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ABSTRACT

Cowpea suffers badly due to weed invasion which cause wide range of yield reduction. Therefore, an experiment was planned to determine the effect of different pre- and post-emergence herbicides, stale seedbed techniques and hand weeding in cowpea (*Vigna unguiculata* L.) during summer season of 2019 and 2020. The average yield losses due to crop-weed competition in cowpea was estimated by 71.32%. The relative density of monocot, dicot and sedges observed in weedy plot were 55.1, 34.3 and 10.6 no./m^2, respectively. Plant height, branches/plant, pods/plant and seeds/pod were significantly higher under application of pendimethalin 30 EC 750 g/ha *fb* HW at 30 DAS, being at par with weed free (HW at 20 and 40 DAS) and pendimethalin 30 EC 750 g/ha *fb* imazethapyr 10 SL 60 g/ha at 30 DAS. This subsequently produced higher seed (1.37 t/ha) and stover yield (2.07 t/ha) and net return (₹ 65799/ha) of cowpea. Considering the labour shortage conditions and econiomics, pendimethalin 30 EC 750 g/ha PE *fb* imazethapyr 10 SL 60 g/ha at 30 DAS (₹ 64627/ha) was endorsed for weed management to produce comparable cowpea yield with highest B: C ratio (3.17).

Keywords: Cowpea, Imazethapyr, Pendimethalin, Sate Seedbed, Weed Indices

INTRODUCTION

Cowpea (*Vigna unguiculata*) is an important legume grown extensively under tropical and sub-tropical areas of the world and used as grain and vegetables. The pods are highly nutritive and good source of digestible protein, dietary fiber and vitamin A and C. In spite of the great economic prospective of cowpea as both domestic and commercial crop, a number of constraints *i.e.* insect, pests, diseases and weeds limit its production, impaired quality and crop yield. The growth of cowpea severely affected by weed competition, leads to significant yield losses. The initial slow development and wider spacing necessitate weed control in an earlier period of cowpea (Kandasamy 1999, Sinchana 2020). The critical period of crop weed competition (CWC) in cowpea was 20 to 40 days after sowing (DAS), which clearly points out the need of weed control during the first month of crop growth which would help to prevent an unacceptable yield loss. The season-long competition resulted in 53 to 76% yield reduction in cowpea (Gupta *et al*., 2016). Cowpea competes poorly with weeds in the growing stage having yield loss of 12 to 82% (Li *et al.* 2004, Tripathi and Singh 2001). The effects of weeds on crop yield depends on the duration of the interference and the time of the weed- crop system at which the interaction takes place (Knezevic *et al.* 2003). Delaying weed removal up to 14 DAE was not found good because it could reduce cowpea yield by 4 to 15% (Adigun *et al.*, 2014). Season-long weed competition resulted in 59% yield reduction in vegetable cowpea (Sinchana 2020) and, 56.7% seed yield reduction (Teli *et al.* 2020).

Considering different social, economic and environmental factors, choice of weed management needs to be applicable to crops as per requirements of the situation by including preventive and curative methods of weed management. At least two weeding are needed for cultivating cowpea (Mekonnen *et al.* 2017), and it was estimated that, for each weeding, at least 7 to 10 days work is required per hectare. Besides, manual hand weeding is labourious, intensive, tedious and does not ensure weed removal at critical stage of crop-weed competition (Patel *et al.* 2017). Hence, nowadays herbicidal weed control gains upper hand (Patel *et al.* 2023), which could replace approximately 10 labours/ha required for weed control (Gianessi and Reigner 2007). Chemical weed control seems to be cheaper and effective and generally adopted by growers except in area where the labour is cheap and easily available during peak period of farm operations. Under this situation, an integrated weed management (IWM) practice involving both chemical and other methods with agronomic manipulation may be an efficient tool. Keeping these facts in view, field study was planned with an objective to study the effect of weed management for cowpea crop.

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MATERIALS AND METHODS

The study was conducted during the summer season of 2019 and 2020 at College Farm, N. M. College of Agriculture, Navsari Agricultural University, Navsari. A field vacated by maize crop was selected having the history of the presence of diversified weed flora during summer season. The soil of the experimental field was clayey in texture, low, medium and high in available nitrogen (209 kg/ha), phosphorus (40.6 kg/ha) and potassium (384 kg/ha), respectively. The experiment was laid out in a randomized complete block design with four replications and nine treatments consisted weedy check (control), weed free by hand weeding (HW) at 20 and 40 DAS, pendimethalin 30 EC 750 g/ha pre-emergence (PE), imazethapyr 10 SL 60 g/ha post-emergence (PoE) at 20 DAS, quizalofop-ethyl 5 EC 40 g/ha PoE at 20 DAS, pendimethalin *fb* HW 750 g/ha PE + HW at 30 DAS, pendimethalin *fb* imazethapyr 750 *fb* 60 g/ha PE + PoE at 30 DAS, pendimethalin *fb* quizalofop-ethyl 750 *fb* 40 g/ha PE + PoE at 30 DAS, stale seed bed (destroying of one flush of weeds through glyphosate) 1000 g/ha before sowing.

Cross-harrowing was carried out twice to prepare the soil. Cowpea variety *GC-5* was sown at a planting distance of 45 x 15cm during second week of March of both years. The crop was thinned to one seedling per stand at 15 days after germination to have a population of approximately 108 plants/plot. Irrigation was started after sowing and suspended 15 days after the dry pods were first harvested. Cowpea crop was nourished by application of 20 kg N/ha and 40 kg P/ha through urea and SSP as basal. The fertilizers were applied by hand to the bottom of the sowing furrows, both under and to the side of the seeds. The crop was sprayed with imidacloprid 3.0 ml/10 liters of water for control of aphids and flubendiamide 39.35 SC to control pod borers to keep the crop free from pest during vegetative phase as well as at reproductive period.

In stale seed beds treatment, the weed seed bank was contrived by tillage during the month of February to expose and break the nut sedges tuber chain. These was followed by irrigation to stimulate sprouting of dormant tuber and other weed seed for two weeks. thereafter applied a non-selective herbicide (*e.g.* glyphosate) and destroyed germinated weeds entirely. Required quantity of solution of herbicides, *viz.* pendimethalin, imazethapyr and quizalofop-p-ethyl was prepared as per the treatments assigned to different plots. The herbicides were applied using knapsack sprayer fitted with a flatfan nozzle by usisng volume of 450 litres water/ha (30 pump of 15 liter) for pre-emergence and 510 litres of water/ha (32 pump of 15 liter) for post-emergence herbicide. Whereas, hand weeding was carried out with the help of hand operated small spade locally called "*khurpi*" as per treatments. Herbicide and hand weeding were not done in weedy check plot.

The species and category wise weed density and dry weight was recorded using quadrate of 50 × 50 cm during both the seasons. The monocot, dicot and sedges were separately counted at 20 and 40 DAS. The weed samples collected in paper bags were sun-dried initially followed by oven drying at 65 ^{0}C for 48 hours till they attain constant weight to determine biomass in g/m^2. The data were subjected to square root transformation ($\sqrt{x+0.5}$) to normalize their distribution. However, for better understanding, original values are given in parenthesis. Weed control efficiency (WCE) and weed index (WI) were calculated based on the weed biomass and cowpea seed yield, respectively. The Experimental data related to each character was then statistically analysed as per procedure of analysis of variance and significance tested by "F" test (Gomez and Gomez 1984).

Economics was computed using the prevailing market prices for inputs and outputs *viz.* cowpea seeds (₹ 60/kg) and stover (₹ 3/kg) and manual labour (₹ 287/ day); input price pendimethalin 30 EC (₹ 410/lit.); imazethapyr 10 SL (₹ 1300/lit.); quizalofop-ethyl 5 EC (₹ 1350/lit.); glyphosate 41 SL (₹ 350/lit.); nitrogen through urea (₹ 11.6/kg); phosphorus through single super phosphate (₹ 49.4/kg), *Rhizobium* (₹ 120/lit.); imidacloprid 17.8 SL (₹ 1100/lit.) and flubendiamide 39.35 SC (₹ 18000/lit.).

RESULTS AND DISCUSSION

Floristic composition

Floristic survey **(Table 1)** reflects diversified composition of weeds and total seventeen species were identified in the experimental area. The most dominating species were *Echinochloa crus-galli* L., *Cynodon dactylon* L., *Digitaria sanguinalis* L. *Dinebra retroflexa* L. and *Commelina benghalensis* L. amongst the grasses; *Convolvulus arvensis* L., *Digera arvensis* L. and *Trianthema portulacastrum* L. from broad-leaved weeds and *Cyperus rotundus* L. was only sedge observed in weedy cheek.

Relative density

The highest relative density 15.67% was recorded by *Cynodon dactylon* L. among grasses; 9.14% relative density for *Convolvulus arvensis* L. among the BLWs. The relative density of grasses, BLW's and sedges were given in **Figure 1**. Similar results were reported by Tripathi and Singh (2001).

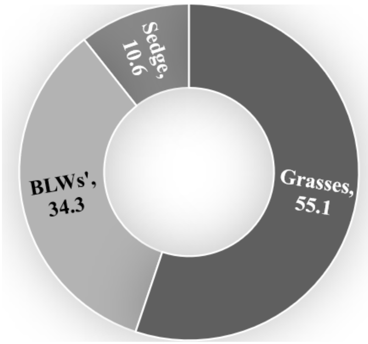

Figure 1. Relative density of weeds

Weed density

Application of pendimethalin as pre-emergence significantly reduced the density of monocot and dicot weeds at 20 DAS **(Table 1)**, while significantly the lowest density of sedges was noted under stale seedbed. Further at 40 DAS, significantly least number of monocot weeds was recorded under application of pendimethalin 30 EC 750 g/ha PE *fb* quizalofop-ethyl 5 EC 40 g/ha at 30 DAS and found statistically at par with treatments pendimethalin 30 EC 750 g/ha PE *fb* HW at 30 DAS, pendimethalin 30 EC 750 g/ha *fb* imazethapyr 10 SL 60 g/ha at 30 DAS and quizalofop-ethyl 5 EC 40 g/ha at 20 DAS. On account of dicots, significantly least number were recorded under application of pendimethalin 30 EC 750 g/ha PE *fb* HW at 30 DAS, which was at par with pendimethalin 30 EC 750 g/ha PE *fb* imazethapyr 10 SL 60 g/ha DAS. Application of pendimethalin 30 EC 750 g/ha PE *fb* HW at 30 DAS found to be effective against the sedges to reduce the density of sedges at lowest. Contrary to this, significantly the highest density of monocots, dicots and sedges under weedy check during both years of experimentation.

Weed dry weight

At 40 DAS **(Table 2)**, lowest weed dry weight was recorded under application of pendimethalin 30 EC 750 g/ha PE *fb* HW at 30 DAS. However, it was at par with pendimethalin 30 EC 750 g/ha PE *fb* imazethapyr 10 SL 60 g/ha at 30 DAS. The lowest dry weight of weeds was registered with pendimethalin 30 EC 750 g/ha PE *fb* HW at 30 DAS. Pre-emergence application of pendimethalin checked the germination of weed seed and controlled the weed establishment of annual broad-leaf weeds and grasses, whereas, HW at 30 DAS messed out the later emerged including sedges resulted lower dry weight of weeds. This trend was also in conformity of result repotted by Parmar *et al.* (2022).

At harvest, significantly the lowest dry weight of weeds was observed under HW at 20 and 40 DAS, followed by pendimethalin 30 EC 750 g/ha *fb* HW at 30 DAS or imazethapyr 10 SL 60 g/ha at 30 DAS. Lower dry weight of weeds in HW at 20 and 40 DAS was due to removal of first flush by hand weeding at 20 DAS and subsequent hand weeding done at 40 DAS controlled the second flush of weeds that emerged at later stages of crop growth and thus provided considerable weed free environment to the crop during the growing season. Further, significantly the highest weed dry weight was recorded with weedy check at 40 DAS and at harvest because weeds were freely allowed to grow in plot

Table 1. Weed flora observed in experimental field (mean of two years)

SN	Botanical name	English name	Local name	Family	Habitat	Density (no./m^2)	Relative (%)
[A]	Monocot weed						
1.	*Echinochloa crusgalli* L.	Sama grass	Banti	*Gramineae*	A,G,K	41	7.6
2.	*Cynodon dactylon* L.	Bermuda grass	Dharo	*Gramineae*	P,G,K	84	15.7
3.	*Digitaria sanguinalis* L.	Crabgrass	Arotaro	*Gramineae*	A,G,K	32	6.0
4.	*Commelina benghalensis* L.	Day flower	Shemul	*Commelinaceae*	A/P,H	61	11.4
5.	*Brachiaria spp*. L.	Para grass	Bharbhi	*Gramineae*	A,G,K	12	2.2
6.	*Sorghum halepense* L.	Johnson grass	Baru	*Gramineae*	P,G,K	17	3.2
7.	*Dinebra retroflexa* L.	Viper Grass	Panzer	*Gramineae*	A/P,G	48	9.0
				Total monocot weeds (A)		295	55.1
[B]	Dicot weed						
1.	*Amaranthus viridis* L.	Pigweed	Tandljo	*Amaranthaceae*	A,H,K	18	3.4
2.	*Convovulus arvensis* L.	Field bindweed	Chandan vel	*Convolvulaceae*	P,H	49	9.1
3.	*Digera arvensis* L.	Digera	Kanjaro	*Amaranthaceae*	A,H,K	32	6.0
4.	*Physalis minima* L.	Ground cherry	Popti	*Solanaceae*	A,H,K	7	1.3
5.	*Alternanthera sessilis* L.	Alligator weed	Khakhi weed	*Amaranthaceae*	A/P,H,K	15	2.8
6.	*Euphorbia hirta* L.	Garden spurge	Dudheli	*Euphorbiaceae*	A,H,K	24	4.5
7.	*Trianthema portulacastrum* L.	Carpet weed	Satodo	*Aizoaceae*	A,H,K	28	5.2
8.	*Abelmoschus esculentus* L.	White wild musk mellow	Jangli bhindi	*Malvaceae*	P,S,K,GL	8	1.5
9.	*Vernonia cinerea* L.	Little iron weed	Fulakia	*Compositeae*	A,H,K	3	0.6
				Total dicot weeds (B)		184	34.3
[C]	Sedge						
1.	*Cyperus rotundus* L.	Nut sedge	Chidho	*Cyperaceae*	P,K	57	10.6

A-annual, P-perennial, G-grass, K-kharif, S-sedges, H-herb throughout the crop growth period, ultimately population and dry weight of weeds increased progressively under this treatment with successive growth stages.

Weed control efficiency and weed index

Highest weed control efficiency (70.71%) was recorded under weed free through HW at 20 and 40 DAS, closely followed by pendimethalin 30 EC 750 g/ha PE *fb* HW at 30 DAS (65.9%) and pendimethalin 30 EC 750 g/ha PE *fb* imazethapyr 10 SL 60 g/ha at 30 DAS (63.3%). Two initial flushes of weeds through HW removal at 20 and 40 DAS reduced the weed growth more effectively during most of the crop growth period. Further, results indicated that application of pre-emergent pendimethalin 30 EC in addition to post-emergence imazethapyr 10 SL eventually provided weed free and congenial environment as the consequence of enhanced weed control efficiency of cowpea crop. On the other hand, inhibition of germination and growth of weeds following pre-emergence application of pendimethalin 30 EC might have reduced the weed growth through arresting different metabolic activities and thus causing mortality of weeds and HW done at 30 DAS controlled the second flush of weeds efficiently. These seem to be the most spectacular reason of accumulating lesser dry weight of weeds and consequently higher weed control efficiencies. Efficacy of different herbicidal application has been recounted by Mekonnen *et al.* (2016), Kumar and Singh (2017) and Parmar *et al.* (2022).

Weedy check treatment recorded maximum weed index as it allowed weeds to establish freely and caused 71.32% seed yield loss in cowpea followed by stale seedbed (60.09%), while pendimethalin 30 EC 750 g/ha PE *fb* HW at 30 DAS emerged out as best treatment with reference to weed index followed by weed free (HW at 20 and 40 DAS) and pendimethalin 30 EC 750 g/ha PE *fb* imazethapyr 10 SL 60 g/ha at 30 DAS (3.69%). The herbicide + hand weeding or sequential application of herbicides were found to be more effective in respect of reducing weed index addition with answer the labour shortage and reducing the drudgery of hand weeding. This may be attributed to better control of weeds under these treatments which provided comparatively stress-free environment to the crop. Their findings were in close proximity of that reported by Chattha *et al.* (2007).

Growth parameter and yield attributes

Significantly, the higher plant height and number of branches/plant at harvest was found under pendimethalin 30 EC 750 g/ha PE *fb* HW at 30 DAS treatment, being at par with weed free (HW at 20 and 40 DAS) and pendimethalin 30 EC 750 g/ha PE *fb* imazethapyr 10 SL 60 g/ha at 30 DAS. It might be due to aforesaid treatments' direct impact on reduction in density and periodical weed dry matter accumulation that caused reduction in crop–weed competition to the considerable extent. The lower values of plant height were recorded in weedy check, which might be due to severe crop-weed competition for resources, which made the plant inefficient to take up sufficient moisture and nutrients, consequently reducing the photosynthate production hence adversely affecting the crop growth (Mekonnen and Dessie 2017).

Weed-crop competition may pull down cowpea yield by suppressing one or more yield attributes. The yield attributes *viz*., pods/plant and seeds/pod increased significantly by all weed management treatments compared to weedy check. Significantly higher number of pods/plant and number of seeds/pods were recorded with application of pendimethalin 30 EC 750 g/ha PE *fb* HW at 30 DAS, being at par with weed free (HW at 20 and 40 DAS) and pendimethalin 30 EC 750 g/ha PE *fb* imazethapyr 10 SL 60 g/ha at 30 DAS (**Table 4**).

Seed and stover yield

Significantly, the higher seed yield (1354 and 1380 kg/ha) and stover (2047 and 2088 kg/ha) yield were recorded with application of pendimethalin 30 EC 750 g/ha PE *fb* HW at 30 DAS during 2019 and 2020 respectively (**Table 4)**. It was almost equal to yield obtained under the weed free *i.e.* HW at 20 and 40 DAS (seed yield – 1335 and 1360 kg/ha; stover yield – 2026 and 2067 kg/ha) and pendimethalin 30 EC 750 g/ha PE *fb* imazethapyr 10 SL 60 g/ha at 30 DAS (seed yield – 1305 and 1328 kg/ha; stover yield – 1969 and 2006 kg/ha) during 2019 and 2020, respectively. On the basis of pooled data, the magnitude of increase in seed yields was 3.49, 3.45 and 3.36 and stover yield was 253, 2.50 and 2.44 times more in pendimethalin 30 EC 750 g/ha PE *fb* HW at 30 DAS, 2 HW at 20 and 40 DAS and pendimethalin 30 EC 750 g/ha PE *fb* imazethapyr 10 SL 60 g/ha at 30 DAS, respectively over the weedy check.

The higher yield achieved under application of pendimethalin 30 EC 750 g/ha PE *fb* HW at 30 DAS might be due to application of pre-emergence herbicide and removal of weeds by hand weeding as evidenced by less number **(Table 2)** and dry weight of weeds **(Table 3)**, which resulted in less competition with plant nutrients and water, which increased the growth rate and biomass production which in turn increased the rate and supply of photosynthates to various metabolic sinks which have favoured yield. Moreover, pendimethalin herbicide found superior, because it persists in soil much longer time as half-life is greater than 42 days, even under extreme weather conditions, thus enabling longer protection for crop from weed competition, that reflected in growth and yield of cowpea. Improved yield under the weed free (HW at 20 and 40 DAS) and pendimethalin 30 EC 750 g/ha PE *fb* imazethapyr 10 SL 60 g/ha at 30 DAS was due to better control of weeds from the initial stage by periodical removal of weeds either by hand weeding or combined application of pre and/or post-emergence herbicide as evident by reduced crop-weed competition under these treatments saved a huge amount of nutrients for crop, which led to profuse growth enabled the crop to utilize more soil moisture and nutrients from deeper soil layers. These favourable effects in rhizosphere were apparent more in herbicides + HW, HW twice and pre- and post-emergence herbicides combination than application of herbicides alone because it improved the tilth by making soil more vulnerable for the plants to utilize water and air. In the presence of weeds, though the vegetative growth of the crop attained a level, but sink was not sufficient enough to accumulate the meaningful food assimilates translocation towards seed formation. Besides, the most severe crop-weed

Table 2. Weed density as influenced by weed management in cowpea (mean of two years)

Treatment	Dose (g/ha)	Weed density at 20 DAS (no./m^2) Monocot		Dicot		Sedge		Weed density at 40 DAS (no./m^2) Monocot		Dicot		Sedge	
Weedy check (control)	-	6.23	(38.0)	4.73	(21.5)	3.60	(12.0)	6.72	(44.2)	5.36	(27.7)	4.08	(15.7)
Weed free	-	6.11	(37.0)	4.67	(21.0)	3.11	(8.8)	3.93	(14.5)	3.27	(9.8)	3.04	(8.25)
Pendimethalin	750	2.78	(6.8)	2.16	(3.8)	3.43	(10.7)	3.93	(14.5)	3.57	(11.7)	3.87	(14.0)
Imazethapyr	60	6.02	(36.0)	4.71	(21.2)	3.34	(10.2)	2.98	(8.0)	3.45	(11.0)	3.77	(13.2)
Quizalofop-ethyl	40	5.79	(33.0)	4.67	(21.0)	3.42	(10.7)	2.15	(3.8)	5.15	(25.7)	3.74	(13.0)
Pendimethalin *fb* HW	750	2.68	(6.3)	2.06	(3.3)	3.20	(9.3)	1.93	(2.8)	2.45	(5.0)	2.33	(4.5)
Pendimethalin *fb* imazethapyr	750, 60	2.72	(6.5)	2.33	(4.5)	3.16	(9.0)	1.99	(3.0)	2.49	(5.3)	3.73	(13.0)
Pendimethalin *fb* quizalofop-ethyl	750, 40	2.77	(6.8)	2.11	(3.5)	3.31	(10.0)	1.87	(2.5)	3.42	(10.8)	3.84	(13.7)
Stale seed bed (glyphosate)	1000	2.63	(6.0)	2.59	(5.8)	2.24	(4.3)	5.06	(24.7)	4.71	(21.2)	3.80	(13.5)
LSD (p=0.05)		0.87		0.49		0.42		0.42		0.46		0.37	

Data in parentheses indicates actual value and outside parenthesis indicates ($\sqrt{x+1}$) transformed value

Table 3. Dry weight of weeds at 40 DAS and at harvest as influenced by weed management (mean of two years)

Treatment	Dose (g/ha)	Dry weight of weeds At 40 DAS (g/m^2)	At harvest (kg/ha)	WCE (%)	WI (%)
Weedy check (control)	--	122.54	851.7	--	71.32
Weed free	--	38.52	249.4	70.7	1.45
Pendimethalin	750	54.40	413.0	51.5	48.60
Imazethapyr	60	44.69	409.5	51.9	42.04
Quizalofop-ethyl	40	72.78	627.3	26.3	50.70
Pendimethalin *fb* HW	750	19.85	290.4	65.9	--
Pendimethalin *fb* imazethapyr	750, 60	33.84	312.7	63.3	3.69
Pendimethalin *fb* quizalofop-ethyl	750, 40	39.14	355.7	58.2	31.89
Stale seed bed (glyphosate)	1000	112.67	690.9	18.9	60.09
LSD (p=0.05)		9.69	61.8	--	--

WCE= Weed control efficiency and WI= Weed Index

Table 4. Growth and yield of cowpea as influenced by weed management (mean of two years)

Treatment	Dose	Plant height	Branches / plant	Pods/ plant	Seeds /pod	Yield (kg/ha) Seed			Stover			Net return	B: C ratio
	(g/ha)	(cm)	(No.)	(No.)	(No.)	2019	2020	Pooled	2019	2020	Pooled	(₹/ha)	
Weedy check (control)	--	58.75	13.30	6.65	7.40	404	380	392	829	802	816	8128	0.46
Weed free	--	71.75	19.00	11.25	10.95	1335	1360	1347	2026	2067	2046	62710	2.59
Pendimethalin	750	64.25	15.50	9.25	8.50	715	690	702	1602	1619	1610	27729	1.44
Imazethapyr	60	65.85	16.45	9.55	9.00	801	783	792	1711	1734	1722	33710	1.78
Quizalofop-ethyl	40	63.70	14.75	9.20	8.35	667	681	674	1484	1494	1489	25631	1.33
Pendimethalin *fb* HW	750	74.50	19.50	11.70	11.20	1354	1380	1367	2047	2088	2068	65799	2.93
Pendimethalin *fb* imazethapyr	750, 60	74.00	18.25	11.00	10.50	1305	1328	1317	1969	2006	1988	64627	3.17
Pendimethalin *fb* quizalofop-ethyl	750, 40	64.70	16.50	10.55	9.30	934	928	931	1767	1793	1780	40543	1.96
Stale seed bed (glyphosate)	1000	62.00	14.45	7.75	8.15	548	543	545	1121	1110	1115	17009	0.89
LSD (p=0.05)		8.01	2.56	1.27	1.41	137	150	99	238	251	167	--	--

competition throughout the season due to unrestricted weed growth under weedy check plots encouraged the depletion of nutrients and moisture by weeds, thus adversely affecting the crop growth. It might have also declined the translocation of photosynthates towards seed formation affecting yield attributes adversely, which reduced the yield to the lowest level. Higher crop weed competition due to poor growth and less uptake of nutrients in the weedy check was in close conformity with those reported by Chattha *et al.* (2007) and Oluwafemi and Abiodun (2016).

Economics

Amongst the treatments, pendimethalin 30 EC 750 g/ha PE *fb* HW at 30 DAS secured maximum net realization of ₹ 65799/ha with B: C ratio of 2.93 for cowpea crop followed by weed free treatment using HW at 20 and 40 DAS ₹ 62710 /ha and 2.59 and pendimethalin 30 EC 750 g/ha PE *fb* imazethapyr 10 SL 60 g/ha ₹ 64627 /ha and 3.17, respectively. The lowest seed and stover yields achieved under weedy check treatment was eventually reflected in the lowest net returns (₹ 8128/ha) and B: C ratio (0.46). The results were in conformity with the findings of Gupta *et al.* (2017).

Conclusion

It was inferred that application of pendimethalin 30 EC 750 g/ha (PE) *fb* HW at 30 DAS effectively managed the weeds, therefore recommended for securing higher and profitable yield of cowpea. Moreover, considering the labour scarcity and high wages, sequential application of pendimethalin 30 EC 750 g/ha (PE) *fb* imazethapyr 10 SL 60 g/ha at 30 DAS was proved more economical weed management.

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RESEARCH ARTICLE

Weed management with different herbicid combinations in winter groundnut under red sandy loam soils of Odisha, India

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ABSTRACT

A trial was conducted in red soils at the Research farm of AICRP on Groundnut, Odisha University of Agriculture and Technology, Bhubaneswar, Odisha, to study the effect of different weed control treatments on groundnut yield during two consecutive *Rabi* (winter) seasons of 2018-19 to 2019-20. Amongst the different herbicides, ready mix application of pendimethalin + imazethapyr along with manual weeding efficiently controlled weed density and weed dry matter of all types of weeds. It also incurred significantly higher yield attribute and yield of groundnut over all the other herbicidal treatments, *viz.* branch/plant (5 and 4.8), number of pods/plant (19.3 and 17.2), pod yield (2.63 and 2.35 t/ha) and haulm yield (4.10 and 3.93 t/ha), net returns of ₹ 82370 and 66740/ha and B: C (2.7 and 2.3) in 2018-19 and 2019-20, respectively. The lowest weed dry matter, weed density and weed index and WCE were recorded with this treatment at different stages of the crop growth period. The results obtained from the trial suggested that ready mix application of pendimethalin + imazethapyr along with manual weeding was the best measure to control all types of weeds effectively along with the highest pod yield.

Keywords: Groundnut, Manual weeding, Ready-mix herbicide, Weed control efficiency, Weed dry matter

INTRODUCTION

Groundnut (*Arachis hypogaea* L.), an important food and cash crop, has reserved its position because of its both domestic and export markets and nutritional value. India produced 10.1 million tons of groundnut from a 5.42 million ha area, with an average yield of 1.86 t/ha of groundnut (ANGRAU Groundnut Outlook Report, 2021-22) and contributes to 55% of the total oil seed production in the Country. One of the major constraints in groundnut production is weed menace. Weeds vigorously compete with the groundnut plant for resources (sunlight, space, moisture, and nutrients) during the growing season. The critical period of crop-weed control is 4-9 weeks after sowing for grasses and 3-6 weeks for broad-leaved weeds(Wesley *et al.* 2008). For a good yield, requires early management of weeds within 3–6 weeks after sowing for better groundnut production because the crop is not able to compete effectively with weeds, particularly before flowering and during pegging for essential resources. Compared to cultural methods, chemical control measures are quick, more effective, and time and labor-saving (Ahmad *et al.* 2004). Thus, the present study attempted to identify effective and economically viable methods of weed control for harnessing higher yield and productivity in groundnut crops.

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MATERIALS AND METHODS

A field experiment was conducted in the research block of AICRP on Groundnut (All India Co-Ordinated Research Project) Odisha University of Agriculture and Technology, Bhubaneswar, Odisha during the *Rabi* (winter) 2018-19 to 2020-21. The year-wise total rainfall received during the crop growth seasons 2018-19 to 2019-20 were 45.6 and 163.4 mm, with 5 and 15 rainy days, respectively. The soil of the experimental plot was sandy loam textured with a pH of 5.4 consisting 0.54% organic matter.The soil contains total nitrogen, available phosphorus and potassium 251,27 and 85 kg/ha, respectively. The result indicates a medium level of nitrogen and potassium and high phosphorus. The trial was carried out in randomized completely block design with ten treatments, *viz.* pendimethalin 1.0 kg/ha PE, pendimethalin + imazethapyr 1.0 kg/ha PE (ready mix), pendimethalin 1.0 kg/ha PE + quizalofop-p-ethyl 50 g/ha at 15 DAS, pendimethalin + imazethapyr 1.0 kg/ha PE (ready mix) + quizalofop-p-ethyl 50 g/ha at 15 DAS, pendimethalin 1.0 kg/ha PE + imazethapyr 75 g/ha at 15 DAS, pendimethalin 1.0 kg/ha PE + one manual weeding at 25 DAS, pendimethalin + imazethapyr 1.0 kg/ha PE (ready mix) + one manual weeding at 25 DAS, two manual weddings at 20 and 40 DAS, weed free and weedy check. The crop was fertilized with 20-40-40 N-P-K kg/ha. Groundnut variety 'Dharani' was sown at a spacing of 30 cm. PE of herbicides was applied as per the treatment immediately after the sowing. All other recommended package of practices was followed throughout the crop seasons. Weed count and dry weight of weeds per net plot, yield and yield attributes, were recorded at the time of crop harvest. In the case of the control plot, weeds were allowed to grow along with groundnut throughout the crop cycle, but in weed-free treatment, four times weeding was done manually to keep the plots free from weeds. The crop was raised under irrigated conditions asper as recommended package of practices. Densities and dry weight of weeds were recorded before and after post-emergence application and were subjected to log transformation before analysis. At the time of taking observation(40 and 70 days after sowing) for weed dry matter and density), a quadrant of 50 × 50 cm was placed at two places in each plot for collection of data. Weed dry weight was recorded after drying the weed samples at 70 °C for 48 hours in an oven. Weed control efficiency was calculated based on the data recorded at 40 and 70 DAS in groundnut as per the standard formula. Plant height (cm), branch no./ plant, was recorded just before harvesting. Pod and haulm yield (kg/ha), shelling%, and pod/plant were recorded after harvest of the crop. Data collected for various studies were subjected to the analysis of variance (ANOVA) appropriate to the design as given by Gomez and Gomez (1984). While the ANOVA indicated significant treatment effects, means were separated at $p<0.05$ and adjusted with Fisher's protected least significant difference (LSD) test. The significant differences between treatments were compared with the critical difference at a 5% level of probability. The economics of all the treatments were worked out. Weed control efficiency (WCE) denotes the magnitude of weed reduction due to weed control treatment. It was calculated by using the following formula suggested by Mani *et al.* (1973) WCE (%) =[(Weed dry weight (kg) in the un-weeded plot – Weed dry weight (kg) in the treated plot)x100]/ Weed dry weight (kg) in the un-weeded plot]

Weed index (WI) is defined as the magnitude of yield reduction due to the presence of weeds in comparison with weed-free checks. The weed index (WI) was calculated by using the following formula suggested by Gill and Vijayakumar,1969. WI (%) =[(Yield from weed-free plot – Yield from the treated plot) x 100]/Yield from the weed-free plot.

RESULT AND DISCUSSION

Effect of weed management in weed abundance in groundnut

The weed flora present in the experimental field consisted of seven species of broad-leaved weeds, five species of grasses and one species of sedge. The dominant broad-leaved weed flora were *Borreria hispida*, *Cleome rutidosperma*, *Cleome viscosa, Eclipta alba, Croton sparsiflorus, Celosia argentea, Phylanthus niruri*. Major grasses were *Digitaria sanguinalis, Digitaria ciliaris, Echinochloa colonum, Elusine indica, Dactyloctenium aegyptium* and the only dominant sedge was *Cyperus rotundus*.

The intensity of the broad-leaf, sedges and grasses differed with integrated weed management practices in Rabi groundnut. Higher biomass of total weeds occurred in the weedy check at 40 and 70 DAS in both years. Among various herbicidal treatments, pre-emergence application of pendimethalin + imazethapyr (ready-mix) *fb* manual weeding registered the lowest weed biomass in both years (**Table 1**) whereas, higher weed density and weed biomass was observed in pre-emergence application of Pendimethalin. The ready-mix combination of pendimethalin+ imazethapyr controlled up to 64% and 40% of weed population compared to weedy check and existing practice, respectively. This finding was in tune with (Solanki *et al.* 2005 and Kalhapure *et al.* 2013).

Effect of weed management on weed density, weed control efficiency and weed index in groundnut

The effect of different weed management strategies was significantly noticed in reducing weed density and dry matter under different treatments. The lowest weed density, weed dry matter and the highest weed control efficiency (WCE) were noticed under weed-free treatment. Among different herbicides used, ready mix application of pendimethalin and imazethapyr in combination with manual weeding significantly reduced weed dry matter (5.5 and 8.1, 52.2 and 38.7 g/m^2) and weed density (3.8 and 3.3, 3.9 and 5.5) at 40 and 70 DAS in 2018-19 and 2019-20, respectively but was at par with twice hand weedings at 20 and 40 DAS and pendimethalin *fb* manual weeding. It also recorded the highest WCE and WI at different intervals of crop growth periods. This might be due to a combination of both cultural and chemical methods found to be more effective in reducing the weed dry matter and weed density. These findings were with in tune Vora *et al.* 2019 and Bhatt *et al.* 2010.

Effect of weed management on plant growth attributes of winter groundnut

Different herbicides used in this weed management trial had significant positive impacts on plant growth parameters, yield attributes and yield of groundnut crops (**Table 3**). Significant lowest plant height and branch no. were recorded under weedy check and the highest values were observed in weed-free treatment. Two manual weedings registered significantly highest plant height of (45.6 cm and 41.5 cm in 2018-19 and 2019-20, respectively) over control. Ready-mix combination of pendimethalin and imazethapyr *fb* manual weeding registered highest no. branches/plant (5.0 and 4.8) in 2018-19 and 2019-20, respectively which was at par with twice manual weedings. Higher values of these parameters could be attributed to low crop-weed competition because of lesser weed density observed at the early crop stage and their consistent control over weeds at later stages under treatments. Similar findings were also reported by Yadav et *al.* (2014) and Singh and Giri (2001).

Effect of weed management on yield and yield attributes of groundnut

All herbicidal management practices along with twicehand weeding at 20 and 40DAS significantly resulted in higher pod and haulm yield over weedy check and weed-free treatment incurred the highest pod and haulm yield. The cumulative effect of the yield-attributing characters was reflected in terms of pod yield. The trend was similar in both the years. Amongst different herbicidal treatments, pendimethalin + imazethapyr (ready-mix) *fb* manual weeding incurred the highest pod (2.63 and 2.36 t/ha) and haulm yield(4.10 and 3.93 t/ha) in 2018-19 and 2019-20, respectively. The pod yield was (155% and 123% higher over weedy check in 2018-19 and 2019-20, respectively. It stands at par with the ready mix application of pendimethalin and imazethapyr

Table 1. Effect of different weed control methods on weed biomass and weed density in *Rabi* groundnut

Treatment	Weed density at 40 DAS (no./m^2)		Weed density at 70 DAS (no./m^2)		Weed biomass at 40 DAS (g/m^2)		Weed biomass at 70 DAS (g/m^2)	
	2018-19	2019-20	2018-19	2019-20	2018-19	2019-20	2018-19	2019-20
Pendimethalin 1.0 kg/ha PE	5.3(27.7)	4.2(17.7)	5.8(32.7)	6.5(41.3)	9.1	11.5	79.1	88.4
Pendimethalin imazethapyr 1.0 kg/ha PE ready mix (RM)	4.9(24.0)	4.0(15.7)	5.7(31.7)	7.2(51.3)	8.7	18.6	70.3	78.8
Pendimethalin 0.75/1.0 kg/ha PE + quizafop-p-ethyl 50 g/ha at 15DAS	4.9(23.7)	3.4(11.3)	5.6(30.7)	5.8(33.3)	8.8	3.6	67.5	56.3
Pendimethalin + imazethapyr 1.0 kg/ha PE RM + quizafop-p-ethyl 50 g/ha at 15DAS	4.1(16.0)	5.3(27.7)	5.0(24.3)	5.5(29.7)	7.3	14.9	63.7	54.7
Pendimethalin 1.0 kg/ha PE + imazethapyr 75 g/ha at 15 DAS	4.7(22.0)	4.1(16.7)	5.2(26.7)	5.4(29.0)	8.4	15.2	64.5	59.2
Pendimethalin 1.0 kg/ha PE + MW at 25 DAS	4.4(19.0)	6.4(40.3)	4.7(21.7)	7.2(51.0)	6.9	5.7	58.1	52.1
Pendimethalin + imazethapyr 1.0 kg/ha PE RM + MW at 25 DAS	3.8(13.7)	3.3(10.3)	3.9(14.7)	5.5(30.0)	5.5	8.1	52.2	38.7
Two manual weddings (MW) at 20 and 40 DAS	4.3(18.3)	4.7(21.7)	4.3(18.3)	4.9(23.7)	5.7	6.2	55.6	40.3
Weedy check	8.7(75.0)	15.4(236.3)	9.8(96.0)	24.6(603.7)	15.1	36.3	157.8	240.1
Weed free	0.7(0.0)	0.1(0.0)	0.7(0.0)	2.5(5.7)	0.0	1.2	6.6	2.6
LSD (p=0.05)	0.54	0.92	0.56	0.68	1.82	4.82	3.07	6.2

Table 2. Effect of different weed control methods on weed control efficiency and weed index in *Rabi* groundnut

Treatment	WCE (%) at 40 DAS		WCE (%) at 40DAS		Weed index (%)	
	2018-19	2019-20	2018-19	2019-20	2018-19	2019-20
Pendimethalin 1.0 kg/ha PE	39.7	68.3	49.9	63.2	53.0	48.2
Pendimethalin imazethapyr 1.0 kg/ha PE ready mix (RM)	42.4	48.8	55.4	67.2	46.7	42.9
Pendimethalin 0.75/1.0 kg/ha PE + quizafop-p-ethyl 50 g/ha at 15 DAS	41.7	90.1	57.2	76.6	42.7	34.6
Pendimethalin + imazethapyr 1.0 kg/ha PE RM + quizafop-p-ethyl 50 g/ha at 15 DAS	51.7	59.0	59.6	77.2	24.0	10.2
Pendimethalin 1.0 kg/ha PE + imazethapyr 75 g/ha at 15 DAS	44.4	58.1	59.1	75.3	38.3	33.0
Pendimethalin 1.0 kg/ha PE + MW at 25 DAS	54.3	84.3	63.2	78.3	33.7	28.1
Pendimethalin + imazethapyr 1.0 kg/ha PE RM + MW at 25 DAS	63.6	77.7	66.9	83.9	12.3	7.6
Two manual weddings (MW) at 20 and 40 DAS	62.3	82.9	64.8	83.2	28.5	18.0
Weedy check	-	-	-	-	65.7	58.7
Weed free	-	-	-	-	0.0	0.0

*Data in parentheses-original values

fb quizafop-p-ethyl as post-emergence applications with 2.28 and 2.29 t/ha pod yield in 2018-19 and 2019-20, respectively. The highest shelling % was incurred with twice manual weddings with 73.2 and 73.6% in 2018-19 and 2019-20, respectively, which was at par with a ready mix combination of pendimethalin and imazethapyr *fb* manual weeding over the other treatments. The higher yield might be due to higher shelling %, lesser weed density and dry matter observed at critical periods of crop-weed competition and reduced weed competition for limited resources which resulted increased number of sound mature pods per plant compared to other treatments (Olorunmaiye and Olorunmaiye 2009). Additional hand weeding at 20DAS after the pre-emergence application of pendimethalin + imazethapyr (ready-mix) could control the further flushes of weed flora which emerged early in case only pre-emergence herbicide application. The unweeded control treatment recorded significantly the lowest pod (1.03 and 1.05 t/ha in 2018-19 and 2019-20, respectively) and haulm (2.00 and 3.39 t/ha in 2018-19 and 2019-20, respectively) yield. Similar results were reported by Bhatt *et al.* (2010), Swetha *et al.* (2016), Vora *et al.* (2019).

Effect of weed management on economics and nutrient uptake in groundnut

Weed-free treatment registered the highest net return and the lowest was with a weedy check. Amongst different herbicidal treatments, the highest benefit and benefit–cost ratio was obtained from ready mix application of pendimethalin + imazethapyr in combination with manual weedings *fb* ready-mix application of same herbicididal combination with quizafop-p-ethyl at 15 DAS in both years (**Table 5**). This might be due to the increased cost of cultivation of groundnut crops under weed-free treatment due to the higher need of human labours and their higher wages. This cost was reduced in both the herbicidal treatments by using herbicides for effective control of weeds while minimizing human labours. Similar results were also reported by Sardana *et al.* (2006) and Rao *et al.* (2011).

The N, P and K uptake by the crop was significantly higher with weed-free treatment

Table 3. Effect of different weed control methods on Growth and yield attributes in *Rabi* groundnut

Treatment	Plant height (cm)		Branch/plant		Pod /plant	
	2018-19	2019-20	2018-19	2019-20	2018-19	2019-20
Pendimethalin 1.0 kg/ha PE	29.7	32.9	3.4	3.2	7.2	10.3
Pendimethalin imazethapyr 1.0 kg/ha PE ready mix (RM)	26.1	31.8	3.6	3.5	7.3	10.8
Pendimethalin 0.75/1.0 kg/ha PE + quizafop-p-ethyl 50 g/ha at 15 DAS	22.9	35.8	4.1	4.2	8.0	11.3
Pendimethalin + imazethapyr 1.0 kg/ha PE RM + quizafop-p-ethyl 50 g/ha at 15 DAS	28.7	33.9	4.6	4.4	13.2	15.2
Pendimethalin 1.0 kg/ha PE + imazethapyr 75 g/ha at 15 DAS	26.1	39.2	4.3	4.2	8.3	12.0
Pendimethalin 1.0 kg/ha PE + MW at 25 DAS	23.8	37.2	4.4	4.2	10.6	13.0
Pendimethalin + imazethapyr 1.0 kg/ha PE RM + MW at 25 DAS	37.1	40.3	5.0	4.8	19.3	17.2
Two manual weddings (MW) at 20 and 40 DAS	45.6	41.5	4.9	4.8	17.1	17.5
Weedy check	18.1	21.4	2.7	2.8	6.9	8.2
Weed free	34.3	34.8	8.0	6.0	20.3	18.4
LSD (p=0.05)	2.2	5.11	0.47	0.64	1.37	1.96

Table 4 Effect of different weed control methods on yield and yield attributes in winter groundnut

Treatment	Shelling (%)		Pod yield (kg/ha)		Haulm yield (kg/ha)	
	2018-19	2019-20	2018-19	2019-20	2018-19	2019-20
Pendimethalin 1.0 kg/ha PE	65.1	70.2	1410	1322	2607	2772
Pendimethalin imazethapyr 1.0 kg/ha PE ready mix (RM)	66.4	72.0	1600	1456	2810	3244
Pendimethalin 0.75/1.0 kg/ha PE + quizafop-p-ethyl 50 g/ha at 15 DAS	69.9	72.2	1720	1667	3001	3689
Pendimethalin + imazethapyr 1.0 kg/ha PE RM + quizafop-p-ethyl 50 g/ha at 15 DAS	70.1	75.2	2280	2289	3722	4611
Pendimethalin 1.0 kg/ha PE + imazethapyr 75 g/ha at 15 DAS	68.1	73.2	1850	1709	3049	3500
Pendimethalin 1.0 kg/ha PE + MW at 25 DAS	71.9	73.7	1990	1833	3250	3754
Pendimethalin + imazethapyr 1.0 kg/ha PE RM + MW at 25 DAS	71.7	76.1	2630	2355	4100	3933
Two manual weddings (MW) at 20 and 40 DAS	75.2	77.4	2145	2090	3520	4261
Weedy check	60.3	69.7	1030	1054	2000	3389
Weed free	75.6	77.6	3000	2550	4500	4033
LSD (p=0.05)	4.37	3.64	372.8	288.9	441.5	388.7

Table 5. Effect of different weed control methods on nutrient uptake and economics in winter groundnut

Treatment	Net Return		BCR		N (kg/ha)		P (kg/ha)		K (kg/ha)	
	2018-19	2019-20	2018-19	2019-20	2018-19	2019-20	2018-19	2019-20	2018-19	2019-20
Pendimethalin 1.0 kg/ha PE	25844	24825	1.6	1.4	40.1	40.8	11.2	12.0	33.5	33.2
Pendimethalin imazethapyr 1.0 kg/ha PE ready mix (RM)	34595	33673	1.8	1.5	42.9	41.3	10.8	10.6	30.2	31.5
Pendimethalin 0.75/1.0 kg/ha PE + quizafop-p-ethyl 50 g/ha at 15 DAS	37622	34457	1.8	1.7	75.3	75.1	9.4	8.9	33.7	35.3
Pendimethalin + imazethapyr 1.0 kg/ha PE RM + quizafop-p-ethyl 50 g/ha at 15 DAS	64792	65340	2.3	2.1	65.4	64.3	13.8	14.4	32.8	33.1
Pendimethalin 1.0 kg/ha PE + imazethapyr 75 g/ha at 15 DAS	44905	36704	1.9	1.8	72.9	73.5	10.2	10.7	42.1	43.0
Pendimethalin 1.0 kg/ha PE + MW at 25 DAS	52875	41564	2.1	1.8	54.4	54.2	13.3	12.8	50.8	50.6
Pendimethalin + imazethapyr 1.0 kg/ha PE RM + MW at 25 DAS	82370	66740	2.7	2.3	77.5	76.1	13.1	13.6	45.7	46.3
Two manual weddings (MW) at 20 and 40 DAS	56415	68531	2.1	1.9	78.6	81.3	14.5	14.2	38.4	40.8
Weedy check	9420	10619	1.2	1.3	55.7	52.4	8.7	8.4	24.1	26.5
Weed free	96700	74008	2.4	2.2	107.9	105.3	17.2	18.1	51.7	56.8
LSD (p=0.05)					-	-	-	-	-	-

followed by two manual weedings and ready mix application of pendimethalin and imazethapyr *fb* manual weeding (**Table 5**). In 2018-19, the nutrient uptake was higher in twice manual weeding with 78.6, 14.5 and 38.4 kg/ha N, P and K closely followed by ready-mix combination of pendimethalin and imazethapyr *fb* manual weeding. The higher nutrient uptake by crop might be due to decreased crop weed competition at critical stages, which simultaneously increased nutrient availability, better crop growth, and dry matter production coupled with more nutrient content (Samant and Mishra 2014, Singh *et al.* 2017).

Conclusion

Ready-mix application of pendimethalin + imazethapyr *fb* manual weedings at 25 DAS proved effective in controlling all types of weeds, increased yield and nutrient uptake. Alternatively, farmers can go for the post-emergence application of quizalofop-p-ethyl in combination with ready mix application of pendimethalin and imazethapyr under grassy weed situations for better yield, weed control efficiency and economics.

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RESEARCH ARTICLE

Elevated CO_2 and temperature influence on crop-weed interaction in soybean

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ABSTRACT

Soybean [*Glycine max* (L.) Merr.] is an important oilseed crop in central India. Climate change may have a positive or negative impact on crop-weed competition. Hence, an experiment was conducted in open-top chambers (OTC) to study the effect of ambient (A), elevated CO_2 (EC), elevated temperature (ET) and elevated CO_2+ elevated temperature (EC+ET). EC, ET and EC+ET have a significant encouraging effect on overall growth and yield attributes of weeds and soybean crop. The increase in the biomass of soybean at EC, ET and EC+ET ranged from 21-60% as compared to the ambient conditions. The biomass of *Echinochloa colona* (10-65%) and *Ischaemum rugosum* (16-37%) was found to be increased under EC, ET and EC+ET. EC and ET had a positive impact on plant height and leaf area of soybean, *E. colona* and *I. rugosum*. The seed yield of soybean was observed to be significantly higher at EC (13%) and EC+ET (46%), however at ET no significant increment over ambient was observed. A higher number of pods and nodules per plant were observed at EC and EC+ET. In the presence of *E. colona* and *I. rugosum*, the soybean yield was significantly reduced by 27, 59, 45 and 52% at A, EC, ET and EC+ET conditions, respectively as compared to the weed-free condition. The findings of the present study indicate that C_4 weeds may become more competitive with C_3 crops, thereby emphasizing the necessity of conducting future studies on C_3 and C_4 crop-weed competition under changing climatic conditions.

Keywords: Climate change, *Echinochloa colona*, Elevated CO_2, Elevated temperature, *Ischaemum rugosum*, Soybean

INTRODUCTION

Climate change, with measurable long-term shifts in climate patterns like rising temperatures, CO_2 levels, and precipitation, is likely to harm global agriculture (Korres *et al.* 2016). Future climate predictions include higher temperatures, altered rainfall patterns, and increased climate extremes, posing detrimental impacts on agriculture (IPCC 2014, FAO 2016, IPCC 2018). Temperatures have already risen by 0.1 to 0.3°C per decade globally since pre-industrial times, with a projected increase of 1.5°C by 2030-2052 (IPCC 2014, 2018). CO_2 concentrations have surged since the industrial revolution, currently at 419 µmol mol-1, nearly 50% higher than pre-industrial levels, and expected to exceed 700 µmol mol-1 by the century's end (NOAA Mauna Loa Atmospheric Baseline Observatory 2021, Long *et al.* 2004, Ainsworth *et al.* 2008, Salazar-Parra *et al.* 2018). These changes may seriously impact agriculture and threaten global food security (Ozdemir 2022).

C_3 and C_4 plants have distinct photosynthesis temperature responses. In C_3 plants, higher CO_2 levels favor ribulose-1,5-bisphosphate (RuBP) carboxylation, but temperatures above 25°C promote oxygenation, leading to photorespiration and hindering CO_2 assimilation (Jorden and Ogren 1984). Conversely, C_4 plants are minimally affected by temperature due to lower photorespiration and faster CO_2 fixation by PEP carboxylase in bundle sheath cells (Hatch, 1987, Hadi *et al.* 2020). Additionally, high CO_2 enhances dark respiration in soybean via metabolic reprogramming, while this effect is not observed in other species (Leakey *et al.* 2009). Due to these photosynthetic pathway differences, C_3 plants respond more robustly to increasing CO_2 levels, whereas C_4 plants are better suited for heat stress and drought, boasting higher water use efficiency (Osmond *et al.* 1982, Morgan *et al.* 2001).

Weeds are one of the important biotic constraints in agriculture, which may cause

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economic losses of ~USD 11 billion to 10 major crops in India and in soybean it may cause an economic loss of USD 1559 million (Gharde *et al.* 2018). In soybean, *E. colona, I. rugosum, Dinebra retroflexa, Commelina communis, Commelina benghalensis, Alternanthera paronychioides, Eclipta prostrata, Cucumis pubescens etc.* are major competitors, which sometimes cause meagre crop growth and seed yield (Shobha, 2001). *E. colona* and *I. rugosum* are dominant weed species causing significant yield loss and reduced seed quality in soybean (Alarcon Reverte *et al.* 2015, Reddy *et al.* 2013). Weeds have unique traits, *viz.* short life cycle, prolific seed producer, dispersal mechanisms, *etc.* which make them competitively superior to crops under climate change scenarios (Naidu and Murthy 2014).

The continuing rise in the concentration of atmospheric CO_2 would therefore have important consequences for crop-weed competition and crop yield reduction. Various studies have investigated the crop-weed interactions by evaluating the comparative growth and physiology of C_3 crops and C_4 weeds and reported that increased CO_2 concentrations typically promote C_3 plant species vegetative development over C_4 pathways (Patterson 1995). Although not all crops are C_3 based, and not all weeds are C_4 based (Ziska *et al.* 2010). Therefore, the above definition is applicable to cereals such as rice, which primarily compete with grassy C_4 and broad-leaved weeds; this is not a universal situation. There are several economically significant C_4 crops, such as maize, sugarcane and sorghum, which compete with critical C_3 weeds, such as *Chenopodium album* L. (Ziska 2000).

Predicting competition based on isolated species' responses cannot accurately represent weed competition with crops under varying CO_2 conditions, as weeds typically occur in mixtures (Ziska 2001). Evaluating weed competition in mixed environments is crucial since most studies focus on isolated CO_2 effects on crops and weeds. Few reports examine crop-weed response to CO_2 in competitive settings (Ziska 2001, 2004; Valerioa *et al.* 2013), and little attention is given to elevated CO_2 impact on weed distribution in managed ecosystems (McDonald *et al.* 2009). Climate change will likely increase weed competition, leading to higher yield reduction without proper control (Miri *et al.* 2012, Valerio *et al.* 2013). Climate-induced constraints on plant growth resources may alter crop-weed competition in different cropping systems. Detail study is required to identify problematic weeds in future climates to establish effective management strategies.

Soybean is a significant oilseed crop and food legume used for protein in animal feed (Pratap *et al.* 2011). India plays a crucial role in the global soy industry, producing various soy products (Tiwari 2022). Given its importance, studying the effects of climate change on soybean and associated weeds (*E. colona, I. rugosum, D. retroflexa, C. communis, C. benghalensis*) is vital. However, information on this topic is limited. To the best of our knowledge, the data in the present investigation are novel in being the first to demonstrate the implications of significant weeds on soybean growth under the regime of climate change. This study examines the impact of elevated CO_2 and temperature on soybean and associated weeds (*E. colona* and *I. rugosum*) using open-top chambers (OTCs). It was hypothesized that the effects of elevated CO_2, temperature, and weeds on soybean growth, physiological, and yield traits would differ.

MATERIALS AND METHODS

Soil, climate and experimental unit

The interactive effect of crop-weed interaction was studied in Open Top Chambers (OTCs) at ICAR-Directorate of Weed Research, Jabalpur research farm. The location of the experimental site was 23°13'58.63" N latitude and 79°58'05.02" E longitude. Climatic condition is humid subtropical, with summer set about the late march and lasting until June, and summer followed by south-west monsoon which lasts until early October and produces average annual rainfall of ~1386 mm. The soil of the experimental site was clay loam in texture with low organic carbon content having a pH of 7.6. The experiment was laid out in factorial complete randomized design. The levels of CO_2 were ambient (407.4 ppm) and elevated (550±50 ppm), and the temperature was ambient and elevated (ambient+2 ºC). The OTC was made off of polycarbonate sheets (6.0 mm thickness) with an open top and dimension of 2.9 m height with 1.35 m diameter and the total experimental area in each OTC is 5.72 m^2 area. Gaseous CO_2 was supplied continuously to OTCs through nozzles fitted to PVC fiber reinforced hose pipes connected to CO_2 cylinders. CO_2 concentration within the chambers was monitored and maintained through CO_2 analyzer fitted in the chamber and connected to computer system. Elevation in temperature was realized through infrared heaters.

Crop cultivation

Soybean crop, cv. *'RSK-2004-1'* was grown during the rainy seasons of 2018 and 2019. The crop was sown in the first week of July with 40 cm row-to-row and 15 cm plant-toplant spacing. The recommended dose of fertilizer (30–60–40 kg N, P and K/ha) was applied during sowing as basal along with vermicompost at 2.5 t/ha. The cultivable area in OTC was divided into 3 equal parts of 1.80 m^2 each and each OTC plot was marked and seeds of two grassy weeds, *viz. E. colona* and *I. rogosum* (collected from the weed cafeteria of the DWR farm) were broadcasted separately in each plot at the time of soybean crop sowing and one portion was kept weed free. After the emergence of crop and weed, the populations of both the weed species were maintained at 10 numbers/m^2 and other weed seedlings were removed at 5-7 days intervals. One plot was maintained weed-free by weeding 5-7 days intervals. The crop was protected from insect attack by spraying chlorpyrifos 25 EC and triazophos 40 EC 1.5 and 0.75 lit/ha respectively.

Observations

The plant growth parameter *viz*. plant height, above-ground biomass, number of root nodules yield attributes and yield were recorded in soybean. The number of root nodules was recorded at the anthesis stage. The plant height, dry biomass and the number of tillers were recorded in two weed species. Three plants each from crop and weeds were randomly selected for the observations from each treatment. Plant height and dry biomass were recorded at the maturity stage. Plant height was measured from ground level to the apical tip of the plant using a 5 m measuring scale. Dry biomass (above ground) was determined by drying in a hot air oven 60°C. The number of nodules and fresh weight were taken at the maximum flowering stage. The number of pods/plant and seed yield/5 plants were taken at harvest.

Statistical analysis

The recorded data on the selected parameters were analyzed using analysis of variance (ANOVA) as relevant for a completely randomized design. Treatment effects were determined by analysis of variance using the general linear model procedure of the SPSS package program version 16.0 (SPSS Inc., Chicago, IL, USA). Treatment means were separated with the use of Duncan's multiple range test at a 5% level of significance.

RESULTS AND DISCUSSION

Effect of elevated CO_2 and temperature on root nodules

The findings of the present study revealed that the number of root nodules was significantly increased under elevated CO_2 (EC) by 32.17% in comparison to ambient (A). However, elevated temperature (ET) had a negative effect on root nodules because the nodule count was decreased by 25.17% in comparison to A. Whereas, *E. colona* and *I. rugosum* weed interference severely impaired the root nodule number among all the treatments compared to weed-free soybean and higher reduction was observed under ET (**Figure 1**).

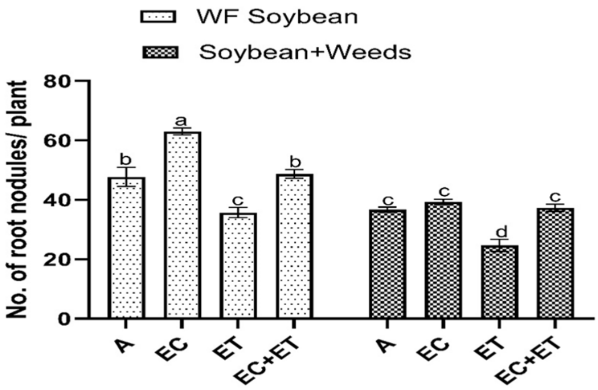

Figure 1. Effect of *E. colona* and *I. rugosum* on number of root nodules in soybean under different climatic conditions (pooled data of two years).

The data presented above are Mean ± SE (n = 3). *A*-Ambient; *EC*-Elevated CO_2; *ET*- Elevated temperature; *EC+ET* combined effect of EC and ET. Different lowercase letters on vertical error bars indicate significant difference at P = 0.05 level in Duncan's test.

Effect of elevated CO_2 and temperature on yield and yield attributes of soybean

Elevated CO_2: EC had a positive effect on yield and yield attributes under weed-free conditions. An increase in CO_2 concentration by 550 ppm significantly increased the plant height of soybean by 13% over the ambient condition. However, a slight increase (3.25%) in plant height was observed under weedy conditions. Similarly, plant dry weight was increased by 13.42% under EC in comparison with ambient. Likewise, a reduction in plant height (16.48%) was observed under weedy conditions. Under EC the number of pods/plants was increased by 7.88% and this was found to be significantly reduced by 42.42% under weedy conditions. EC had a positive effect on yield and it was significantly increased by 37.61%. However, weed interference reduced the yield by 31.12% in comparison to ambient (**Figure 2a, b, c, d**).

Elevated temperature: An increase in temperature by 2ºC decreased the plant height by 6.25% in weed-free soybean over the ambient condition. Whereas, the plant height of soybean was found to be significantly reduced by 49.47% due to weed interference. Similarly in weed-free soybean, the plant dry weight, the number of pods/plant and yield were impaired and it was observed to be reduced by 19.44%, 26.67 and 5.48, respectively. However, weed interference had a profound effect on yield and yield attributes of soybean and it was observed that the plant height, plant dry weight, the number of pods/plant and yield decreased by 47.80%, 95.42% and 56.40% respectively, over the ambient condition (**Figure 2a, b, c, d**).

The combined effect of elevated CO_2 and temperature

Negative effects of elevated temperature were slightly negated by elevated CO_2. Under the combined effect of elevated CO_2 and temperature, the soybean yield and yield attributes were severely impaired in both weed-free conditions and weedy conditions. The plant height, dry weight, number of pods/plant and yield was found to increase by 6.73%, 7.62%, 4.24% and 7.16%, respectively in weed-free soybean over the ambient conditions. However, weed interference had a negative effect under the combined effect of elevated CO_2 and temperature. It was observed that the plant height, dry weight, the number of pods/plant and yield was significantly decreased by 6.01%, 18.78%, 49.70% and 33.42% in comparison to weed-free ambient condition (**Figure 2a, b, c, d**).

Effect of elevated CO_2 and elevated temperature on weed growth

It was found that *E. colona* and *I. rugosum* biomass, growth traits like plant height, plant dry weight and the number of tillers responded positively under EC and ET and EC+ET as compared to the ambient condition. The plant height of *E. colona* was enhanced by 25.73%, 10.79% and 28.22% under EC, ET and EC+ET, respectively. Similarly, plant dry weight was increased by 62.63%, 64.92% and 9.65% under EC, ET and EC+ET, respectively. The number of tillers/plant increased by 85.92%, 146.48% and

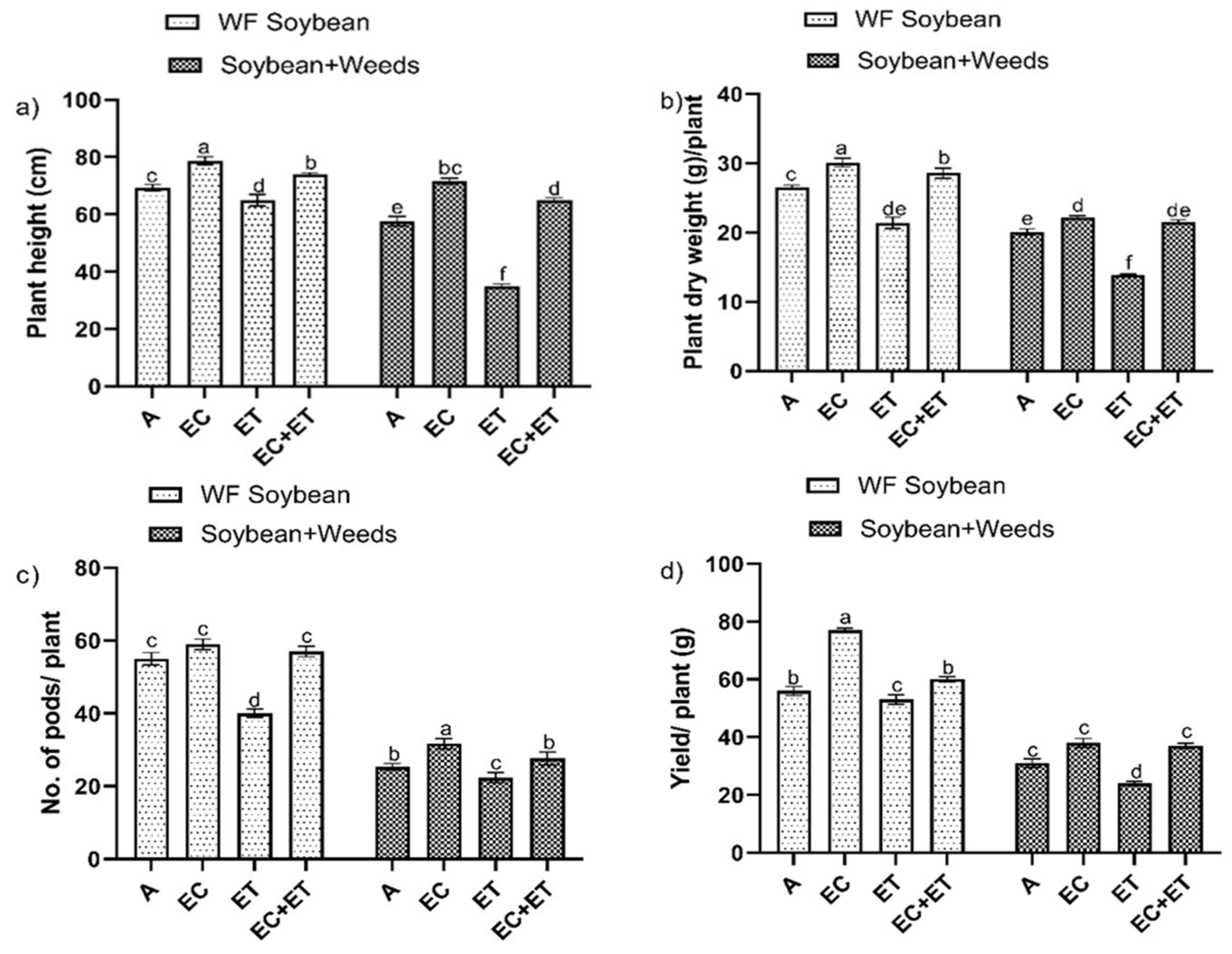

Figure 2. Effect of *E. colona* and *I. rugosum* on plant height (a), plant dry weight (b), number of pods/plant (c) and yield/ plant (d) in soybean under different climatic conditions. (pooled data of two years).

The data presented above are Mean ± SE (n = 3). *A* Ambient; *EC* Elevated CO_2; *ET* Elevated temperature; *EC+ET* combined effect of EC & ET. Different lowercase letters on vertical error bars indicate significant difference at P = 0.05 level in Duncan's test.

33.80% under EC, ET and EC+ET, respectively over ambient conditions (**Figure 3a**).

Similarly, in the case of *I. rugosum*, the plant height was found to be increased by 40.79%, 26.35% and 32.85% under EC, ET and EC+ET, respectively. The plant dry weight was increased by 16.21%, 37.15 and 27.83% under EC, ET and EC+ET, respectively. Likewise, the number of tillers/plant was found to be enhanced by 56.76%, 89.19% and 24.32% under EC, ET and EC+ET, respectively in comparison to ambient conditions (**Figure 3 b**).

EC, ET and EC+ET had a significant encouraging effect on the overall growth and yield attributes of weeds and soybean crop. Increased biomass by 13.42% and 7.62%, under EC and EC+ET, respectively was observed in weed-free soybean. Lenka *et al.* (2017) also reported a 47% increase in soybean biomass at harvest. Increase in biomass in soybean grown under elevated CO_2 was reported earlier (Tobert *et al.* 2004, Ziska 2000 Morgan *et al.* 2005 and Madhu and Hatfield 2016). In a study under EC+ET, Bhattacharyya and Roy (2013) found higher above-ground biomass in rice crops due to the higher rate of carboxylation and reduced rate of photorespiration. The biomass of *E. colona* was found to be increased by 62.63%, 64.92% and 9.65% under EC, ET and EC+ET, respectively. Whereas, the biomass of *I. rugosum* was observed to be increased by 16.21%, 37.15 and 27.83% under EC, ET and EC+ET, respectively. Ziska (2000) reported a significant increase in average biomass in *C. album* and no change in the average biomass of *Amaranthus retroflexus* at EC. However, Alberto *et al.* (1996) reported no significant biomass increase at EC in *Echinochloa glabrescens*. This indicates that *E. colona* is more responsive to EC and ET than *E. glabrescens*. Elevated CO_2 and temperature have increased the plant height of soybean, *E. colona* and *I. rugosum* significantly under OTC condition, which might be due to the increased rate of biochemical processes resulting in cell proliferation due to higher cell division and elongation (Wang *et al.* 1997, Pritchard *et al.* 1999, Geethalakshmi *et al.* 2017). Geethalakshmi *et al.* (2017) reported an encouraging effect of elevated CO_2 and temperature on plant height. However, leaf area, dry weight and grain yield were lower under changing climatic conditions which may be due to the higher temperature level (4 ºC) and higher CO_2 concentration (650 ppm).

The seed yield of soybean was significantly higher 37.61% and 7.6% at EC and EC+ET, respectively; however, at ET conditions there was no significant increment over the ambient conditions.

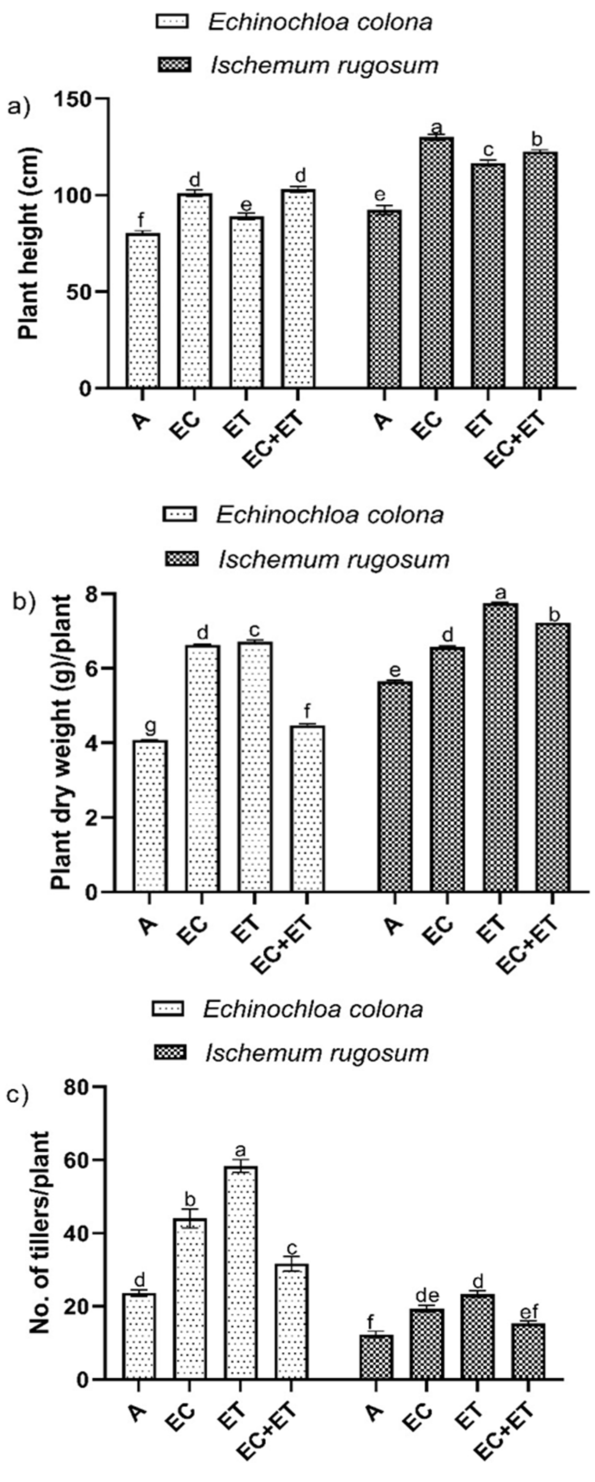

Figure 3. Effect of elevated CO_2 (EC) and elevated temperature (ET) on weed (*E. colona* and *I. rugosum*) growth and biomass (Pooled data of two years)

Plant height (a), Plant dry weight (c) and Number of tillers/ plant (c). The data presented above are Mean ± SE (n = 3). *A* Ambient; *EC* Elevated CO_2; *ET* Elevated temperature; *EC+ET* combined effect of EC & ET. Different lowercase letters on vertical error bars indicate significant difference at P = 0.05 level in Duncan's test.

Lenka *et al.* (2017) reported a yield increase at EC (51%), ET (30%) and EC+ET (65%) over the ambient condition. Bhattacharyya and Roy (2013) observed an increment of 24% in the grain yield of rice in EC. Due to floral sterility in rice at elevated temperatures, a 33.8% yield decrease was noticed; however, 69.6% higher grain yield was observed at EC conditions (Kim and Young 2010). In a pot experiment in a controlled environment of phytotron, Rakshit *et al.* (2012) reported an 11% increase in grain yield of wheat at EC (650 ppm), conversely significantly decreased (38%) the grain yield at ET conditions.

A higher number of pods and nodules per plant was observed at EC and EC+ET, hence this may be the possible reason for the higher seed yield of soybean under EC and EC+ET. Hikosaka *et al.* (2011) reported that legumes have enhanced capacity to fix nitrogen due to the presence of root nodules leading to higher seed weight and yield of soybean under EC and EC+ET conditions compared to the non-nitrogen fixing plants. In soybean growing under the weedy condition of *E. colona* and *I. rugosum*, compared to the weed-free condition, the yield was reduced by 31.12%, 56.40% and 33.42%, respectively at ambient, EC, ET and EC+ET conditions. Ziska (2000) reported that the soybean yield decreased by 28 and 45%, respectively by *C. album* and *A. retroflexus* under ambient conditions, whereas a 39 and 30% decrease was observed respectively by *C. album* and *A. retroflexus* under EC conditions. Similarly, Pawar (2022) observed that the impact of *Alternanthera paronychioides* was more under EC, ET, EC+ET conditions in rice. The data obtained from the current study are in general agreement with the study of Ziska (2000) and Treharbe (1989) that modern cultivars are less diverse than weeds as they possess more physiological plasticity.

It was concluded that the impact of EC, ET and EC+ET had a positive impact on the growth and development of weeds (*E.colona* and *I. rugosum*). This in turn enhanced the competitive strength of these weeds resulting in higher yield reduction of soybean under climate change scenarios. Therefore, both these C_4 weeds may become problematic weeds in soybean crops in futuristic climate change scenarios.

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RESEARCH ARTICLE

Dissipation kinetics and residues of pendimethalin in soil, straw and grain of rainy season greengram

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ABSTRACT

Pendimethalin [N-(1-ethylpropyl)-3, 4 dimethyl 2, 6 dinitrobenzenamine], is being used for control of majority of grasses and broad-leaf weeds in crops such as peas (*Pisum sativum* L.), rice (*Oryza sativa* L.), wheat (*Triticum aestivum* L.), soybean (*Glycine max* L. merr.), and vegetables. Dissipation pattern and the residues dynamics of the herbicide in the soil, greengram straw and grain was determined by conducting field and pot experiments during 2017-2019 utilizing the doses of 1000 g/ha for field study and 1 mg/20 g soil for pots. The residue level of pendimethalin in soil were 0.088, 0.080, 0.075, 0.065, 0.056 and 0.048 mg/g at 2, 5, 15, 25, 35 and 45 days, respectively after herbicide application (DAA) in field that had gone down to below detectable level at the time of harvest (65-70 days). However, greengram plants and seeds, at time of harvest, were found free from the pendimethalin residues. The dissipation of pendimethalin in field and in pots was found to operate as per first order kinetic equation [$dC_0/dt=K(C-C_0)$], therefore, based on dissipation rate constant (K) values, *viz.* 1.36 x 10^{-2} (field) and 1.11x10^{-2} (pot), the half-lives ($T_{1/2}$) of pendimethalin were calculated as 52 and 62 days in field conditions and pot culture, respectively. The effective period ($T_{eff.}$) with respect to weed control was worked out as 21 and 26 days for field and pot experiments, respectively by assuming the concentration of herbicide in field between 1000-750 g/ha. Therefore, this study suggests that the herbicide can only provide effective protection to crop against weed up to a maximum period of 20-25 days in sandy clay loam soil of taxonomical class *Typic Usrtochrept.*

Keywords: Dissipation kinetics, Greengram, Pendimethalin, Persistence, Residues

INTRODUCTION

Weeds are major constraints in getting maximum yield potentials of pulse crops. In India, yield losses due to weeds are being roughly estimated as 32–35% in crops such as cereals, pulses and oilseeds (DWSR 2018, Kaur *et al.* 2010). In the current scenario, relying on herbicides for an effective and timely weed management especially in crops like pulses is a practical and economical option as opined by Kraehmer (2012), Kraehmer *et al.* (2014). Among the herbicides used in pulse crops, pendimethalin [N-(1-ethylpropyl)-3, 4 dimethyl 2, 6 dinitrobenzenamine], is utilized extensively as a pre-emergence herbicide for control of a majority of grasses and broad-leaf weeds. Though, in one way, herbicides can be considered as an effective tool for weed management but on the other hand their residues were reported to cause numerous environmental problems (Kim *et al.* (2017, Sankhla *et al.* 2018). Herbicides may not only contaminate the surface and ground water but also remain on the soil surface and potentially affect the quality and yield of the succeeding crop. Presence of undesirable residues of herbicides in edible parts of plant also concerns a severe problem for human being (Bruggen *et al.* 2018).

Therefore, keeping in view of adverse impacts of herbicides, it is imperative to make an understanding of their dissipation and movement in fields prior to their recommendation for extensive use. Though, the pendimethalin is reported to possess moderate persistence and relatively immobile properties (Tsiropoulos and Miliadis 1998, Triantafyllidis *et al.* 2009), however based on various field experiments few report have also been published indicating appreciable persistence of this herbicide in various soils (Chopra *et al.* 2015, Sondhia 2012 and 2013b, Dennisc and Dale 2014). Pendimethalin persistence in soil is reported to depend largely on the environmental conditions, cultivation practices, soil

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type, soil temperature and moisture conditions as well as the photodecomposition (Maria and Andrzej 2012) besides a great portion of herbicide in field also got decayed by microbial action (Lee *et al*. 2004, Kocarek *et al.* 2016, Sondhia *et al.* 2016). Though the information regarding the persistence and residues situation of pendimethalin in field experiments and commodities of various agricultural crops is available in literature, but unfortunately, information on the persistence and residues of this herbicide in produces of pulse crops is lacking. Therefore, this study was undertaken at to determine terminal residues and degradation pattern of pendimethalin in soil, greengram grain, and straw by following its pre-emergence application to greengram crop in field. The information is vital for both *i.e.* the promotion of herbicidal weed control as well as the modeling of the fate and effects of these chemicals in the environment.

MATERIALS AND METHODS

Study design

The study was meticulously planned to determine the residues of pendimethalin in the soil, grain, and straw after its pre-emergence application in greengram crop. Field experiments were conducted for three years 2017-2019 at new research farm of Indian institute of Pulses Research, Kanpur, India. Soil physico-chemical characteristic of both of the IIPR farms are given in **Table 1**. The IIPR research farms are located at 26^o 27$^/$ N latitude, 80^o 14$^/$ E longitude at an altitude of approximately 152.4 m (508 ft) above mean sea level. Kanpur is located at the centre of Uttar Pradesh and falls in the agro climatic region of central Zone of the state with having tropical sub-humid climate. The region receives annual rainfall of 722 mm and mean annual maximum and minimum temperature of 33.0 and 20.0 ^{o}C, respectively. This agro climatic region is one of the most fertile tracts of Ganga and Jamuna basins and the soils of experimental site come under taxonomical class *Typic Usrtochrept* by containing sandy loam texture. Treatments comprised of pendimethalin 1000 g/ha, weedy check and weed free. The experiment was conducted under randomized block design with 3 replications. Greengram variety *'Samrat'* was used for the study, which has crop duration of approximately 60-65 days. Greengram was sown during 20-22 July in all the three years. Plant to plant distance was maintained approximately 10 cm with a row spacing of 30 cm. DAP was applied 60 kg/ha at the time of seedbed preparation. Pendimethalin was applied as pre-emergence within 24 hours of sowing using spray carrier volume 100 L/ha. Irrigation was not required due to sufficient rainfall during crop growth period. Plant protection measures were followed as per recommendations and need.

Sampling

From experimental plots, initial soil samples were collected at the time of sowing, thereafter samples were collected periodically by starting from just after 2 hrs of spray and second one at 5th day and thereafter a regular interval of 10 days, *viz.* 2 hrs, 5, 15, 25, 35, 45 and 55 days of herbicide spray and processed immediately for herbicide recovery. For the determination of terminal residues, soil samples were also collected at harvest (65-70 days). Approximately 0.5 kg of soil samples at depth of 15 cm were collected randomly from 10 to 15 different locations of pendimethalin treated and untreated plots by using a soil auger. Pebbles and other unwanted materials were screened out manually. The bulk soil samples from each one of the experimental plot were air dried under shade, powdered, and passed through a 3-mm sieve.

To determine the herbicide residue in greengram plants, approximately 0.5 kg of representative greengram plant samples were also collected randomly from the treated and untreated/control plots at the time of harvest. Grains were separated out from the plants samples and the remaining plant portions were cut into small pieces and air-dried

Table 1. Physicochemical characteristics of the experimental soil

Soil characteristic	Field location			
	IIPR main farm	IIPR, New research farm	Experimental field no. B 14 a	Soil filled in pots
Chemical properties				
pH	7.79	8.33	8.45	7.75
EC (dS/m)	0.131	0.154	0.23	0.130
Available N (kg/ha)	250.6	225	225.0	255.0
Available P (Kg/h)	17.4	14.3	13.41	18.0
Available K (kg/ha)	188.2	72.5	68.32	179.0
Organic carbon (%)	0.471	0.345	0.159	0.479
Physical properties				
Farm	Type	Sand (%)	Silt (%)	Clay (%)
Main farm	Sandy loam	46.6	26.6	26.8
NRF	Sandy soil	55.5	24.5	20.0

under shad. Greengram grains and straw samples were then ground to fine powder by using a mechanical grinder. For persistence and degradation studies, pot experiments were conducted under control conditions by externally adding the required amount of pendimethalin technical (1.0 mg/20 g soil). Pots were filled with 1.0 kg of soil collected from main research farm possessing soil physicochemical properties as described in **Table 1**. From treated pots, 10 g of soil samples were taken periodically, starting from just after 2 hrs of mixing of the technical and then after a regular interval of 10 days (10^{th}, 20^{th}, 30^{th}, 40^{th}, 50^{th} and finally at 70^{th} day).

Extraction and cleanup

Soil samples were air-dried, ground and stored at room temperature, however not kept them for more than three days. An amount of 10 g of subsamples was processed for extraction. Extraction was performed by shaking the samples for one hour with a mixture of 25 ml distilled water and 75 ml of acidified methanol which was obtained by mixing of 99 ml of methanol and 1 ml HCl and filtered. The soil deposited on filter paper was rinsed twice with the same extractants and filtered. From the obtained filtrates 25 ml was mixed with 25 ml of 0.1 N HCl and 50 ml of chloroform and then homogenized. The content was transferred to a separating funnel (500 ml) and shacked for some time. After proper shacking, the separating funnel was kept undisturbed for some time for settling the layers. The lower dichloromethane layer was collected, combined and dried on anhydrous Na_2SO_4, and passed through activated charcoal to remove coloring impurities. The solvent was evaporated completely to dryness at 45 ^{0}C temperature by using a rotary vacuum evaporator. Finally residues were dissolved in 5 ml of methanol and then subjected to cleanup. Extraction for greengram grain and straw was done by one hour shaking the 5 g samples with a mixture of 5 ml distilled water and 20 ml acetonitrile after adding 4 g $MgSO_4$ and 1 g NaCl. These samples were cleaned on a glass column (10 × 2 cm i.d.) packed with celite (1 g) and activated charcoal (0.25 g) between a layer of anhydrous sodium sulfate (2 g) at each end. The column was conditioned with methanol. The concentrated extract was added at the surface of the column and eluted with methanol and water (60 : 40 v/v). Elutes were collected, and the solvent was evaporated completely using a rotary vacuum evaporator. Residues were again dissolved in 5 ml of methanol and filtered through Pall Nylon 0.45-µm filter paper and again passed through MERCK, LiChrolut*RP-18, 1000mg columns prior to HPLC analysis.

Instrumentation

For detection purposes, pendimethalin residues were analyzed with a Shimadzu HPLC coupled with a diode array detector (DAD) at λ_{max} of 240 and 254 nm. A Phenomenex C-18 (ODS) column (250×4.6 mm) and methanol: water (70 : 30 v/v) as a mobile phase at a flow rate of 0.5 mL/min were used to separate out the pendimethalin residues. A 20-µL aliquot of the samples and standard were injected into the column with a micro syringe.

Method efficiency

In order to maintain the quality of the analytical data, quality control (QC) and quality assurance (QA) procedures were adopted since from the begging of collecting the soil samples and up to the stages of extraction and analysis. The extraction procedure adopted for recovery of pendimethalin residues from the samples of soil, straw and seed of greengram was found relatively simple and accurate. Since very few peaks was observed in chromatograms therefore the cleanup procedure adopted for purification of extracts was also found perfect to remove interfering substituent (**Figure 1**). For recovery check, the spiked samples (greengram grains, straw, and soil) were fortified by externally adding of the known concentration of pendimethalin standard solutions to ensure the herbicide concentrations in the samples in range of 0.01 to 1.0 µg/g. Thereafter, the extraction and cleanup processes as described above were adopted for calculation % recovery of the herbicide from the fortified samples. Calibration curve was obtained by taking known concentrations of pendimethalin pure technical, *viz.* 0.01, 0.05, 0.5, 1.0, and 5.0 µg/mL which were prepared in methanol by diluting a stock solution of 1000 µg/mL prepared from the same standard (**Table 2**). For this purpose certified standard of pendimethalin (Accu Standard, USA) was used. The concentration of pendimethalin was determined by comparing the peak area of the samples and calibration curves of five levels of standards and the % recovery was calculated as per formula *i.e.* % Recovery = Recovered Concentration/ Fortified Concentration × 100. A reporting limit of 0.01 µg/g was used for the calculation. The limit of determination (LOD) [estimated to be three times of the background noise] and the limit of quantification (LOQ) [estimated to be 10 times of the background noise] were found to be 0.001 and 0.01 µg/mL, respectively. Dissipation pattern in field and pots were determined by periodically taking soil samples and determining the residue levels. The value of degradation constant was determined by using the formula *i.e.* $C = C_0e^{-kt}$ Where: C – amount of pendimethalin recovered from soil at time t; C_0 – amount of pendimethalin recovered at t = 0 interval; k = degradation constant; t = time in days. Effective time (T_{eff}) *i.e.* the time period by which the concentrations of herbicide lies between 1000 g/ha (original concentration) to 750 g/ha in field was calculated by utilizing the same equation.

RESULTS AND DISCUSSION

Recoveries and detection limit

In order to ensure analysis credibility, certain analytical parameters, *viz*. accuracy, precision, linearity and limits of detection (LOD) and quantification (LOQ) were taken into consideration. The accuracy of the method in terms of extraction efficiency was determined by doing recovery tests of fortified samples of soil/greengram straw/ greengram seed at concentration levels of 0.5 and 1.0 µg/g. Linearity was determined by different known concentrations (0.01, 0.1, 1.0, 5.0, and 10.0 µg/mL) those prepared by diluting the stock solution of 1000 µg/mL (**Table 2**). The limit of quantification of pendimethalin in soil, greengram grain and straw was workout and found to be 0.5 µg/g along with a signal to noise ratio of 3:1. A good linear analytical calibration graphs was received by plotting peak areas on the y axis against concentrations*i.e.*10 to 0.01 µg/ mL of pendimethalin on the x axis and based on that a calibration equation was devised. At this concentration range, the correlation coefficient was found nearly to 0.95. On the instrumental conditions as explained under the head of materials and method section, the retention time of pendimethalin was found to be approximately 7.45 minutes. Pendimethalin recoveries from the fortified samples varied from 92–83%, 88–84%, and 84–85% respectively, for soil, greengram straw, and greengram grain, after their fortification with 0.05 and 1.0 µg/g of pendimethalin (**Table 3**). The recovery of pesticide from the fortified soil, greengram grain and straw samples were considered acceptable with these two fortified levels. Hence, these recovery rates of pendimethalin from various matrixes at different concentration levels were rated as satisfactory.

Periodical and terminal residues of pendimethalin

Field experiments, conducted to observe the residue level and persistence of pendimethalin applied to greengram crop in sandy clay loam soil of taxonomical class *Typic Usrtochrept*, at any point of time revealed residues far below then its prescribed maximum residue limit as set by WHO/ FAO (0.5 mg/ kg). The amount of herbicide residues extracted from the soil samples of the three years *i.e.* 2017-2019 at different sampling intervals is shown in **Table 4**. The residue level of the herbicide in soil of treated plots of greengram field as well as in pots, revealed a constant rate of dissipation since beginning to the end of the experiment. The average of the three years of residue level of pendimethalin in experimental field soil at different intervals was found as 0.088, 0.080, 0.075, 0.065, 0.056 and 0.048 mg/g of soil respectively at 2 hrs, 5th, 15th, 25th, 35th and 45th days (**Table 4**), whereas, in pots it was observed as 0.85, 0.76, 0.68, 0.62, 0.58, 0.51, 0.44 and 0.32 mg/g of soil respectively at 2 hrs, 10th, 20th, 30th, 40th, 50th, 60th and 70th day of herbicide applications (**Table 5**). Result clearly revealed that the initial deposits of pendimethalin when applied at the rate of 1000 g/ha goes down nearly to 50% within 45 days of application and further reached to below LOQ after 65 days of application or at harvest of greengram crop. The obtained results are in good agreement with findings of Sondhia (2012), Tandon (2015) where they reported below detectable limit of residues of this herbicide in maize cobs, maize plant and soil when applied at the rates of 1 and 2 kg/ha. Experiments separately kept in pots also revealed almost the same pattern of herbicide degradation. Initial concentration of pendimethalin in pot (applied 1 mg/20 g of soil) after 2 hours of pendimethalin application was measured as 0.85 mg/g of soil were reached down to the 0.32 mg/g of soil within a period of 70 days hence this shows >60% degradation of herbicide during this period. Though the degradation rate and pattern of herbicide in field and pots were showed almost similar trend however, in pots, it seems to persist for slight longer period and that may be described on the bases of different environmental

Table 2. Calibration of pendimethalin standard at concentration level of 0.01 to 10 µg/mL

Injected concentration of pendimethalin (µg/mL)	Av. Area (mabs)[a)]	Std. deviation
0.01	16108	±1815.21
0.1	89383	±5449.28
1	212758	±10416.49
5	925710	±12739.27
10	3883000	±13941.59

Table 3. Recovery of the pendimethalin from soil, grain and straw

Matrix	Fortification (µg/g)	Amount recovered (µg/g)	Recovery (%)
Soil	0.50	0.46±0.011	92
	1.00	0.83±0.015	83
Greengram straw	0.50	0.44±0.010	88
	1.00	0.84±0.013	84
Greengram seed	0.50	0.42±0.011	84
	1.00	0.85±0.017	85

conditions of pot and field. Since the pots were not exposed much to severe environmental conditions and the soil field in pots also found to retain different Physico-chemical soil properties (**Table 1**) moreover, the herbicide concentration in pots (1mg/20 g of soil) was much higher than the applied concentration (1000 g/ha) of field experiment. At the time of harvest, the grain and straw samples of greengram were found free from any kind of the herbicide residues. However, Sondhia (2012) reported a very low level of pendimethalin residues, *viz*. 0.025, 0.015, <0.001 µg/g and 0.015 to <0.001 µg/g in chickpea grain and straw after application of herbicide to the crop at 750, 350 and 185 g/ha, respectively. In case of field pea also a very low level of pendimethalin residues *i.e.* 0.004-BDL µg/g and 0.007- 0.001 µg/g, in grains of mature pea, and straw, respectively, was also reported by Sondhia (2013a) at 750-185 g/ha treatments. Since both of the crop are of winter season crop hence grown during winters where comparatively water stress conditions prevailed which may be the cause of getting minute pendimethalin residues in grains and plant parts however in contrary to that greengram crop under this trial was grown during full rainy season where frequent heavy rains along with enhanced microbial activities caused a faster removal of herbicide thereby no residue was detected in greengram grain and plant parts.

Persistence and dissipation pattern

The persistence or dissipation of an herbicide is mainly controlled by environmental conditions *viz*., climate, soil physicochemical properties and microbial activities in the soil *vis a vis* the crop management practices Maria and Andrzej (2012) Kaur and Bhullar (2017). In present experiments, the degradation of pendimethalin, under mentioned soil conditions was found to operate as per first order kinetic equation, *viz.* [$dC_0/dt=K(C-C_0)$]. Disappearance trends of initial deposits of pendimethalin residues on soil surfaces, dissipation coefficients (K), half-life

Table 4. Periodical and terminal residues of pendimethalin in greengram soil, grains, and straw at different times

Sampling at time	Residue level of pendimethalin herbicides (mg/g) at λ max 254									
	Soil (NRF farm)			Average of 3 years	Straw (NRF farm)			Grain (NRF farm)		
	2017	2018	2019		2017	2018	2019	2017	2018	2019
2 hrs	0.081	0.091	0.091	0.088	-	-	-	-	-	-
5 days	0.073	0.088	0.080	0.080	-	-	-	-	-	-
15	0.069	0.079	0.077	0.075	-	-	-	-	-	-
25	0.061	0.065	0.069	0.065	-	-	-	-	-	-
35	0.051	0.057	0.059	0.056	-	-	-	-	-	-
45	0.041	0.053	0.051	0.048	-	-	-	-	-	-
55 (terminal residue)	<LOQ	<LOQ	<LOQ		<LOQ	<LOQ	<LOQ	ND	ND	ND

(ND) not detected

Table 5. Dissipation pattern, persistence and effective time in field and pots experiments

Sampling (at DAS)	Decay pattern of pendimethalin in field (1000 g/ha) Dissipation pattern					Decay pattern of pendimethalin in pot (1 mg/20 g of soil) Dissipation pattern				
	Residue Level (field) (mg/g soil)	% dissipation	rate constant (K)	$T_{1/2}$ (days)	Effective time (T_{eff}.) & persistence (90%deg.)	Residue Level (Pot) (mg/g soil)	% dissipation	rate constant (K)	$T_{1/2}$ (days)	Effective time (T_{eff}.) & persistence (90%decay)
2 hrs	$8.8x10^{-2}$	0.00	0.00	0.00	Effective time of	$8.5X10^{-1}$	0.00	Average K=	Average	Effective time of
					herbicide calculated			$1.11x10^{-2}$	=62	herbicide calculated
5th	$8.0x10^{-2}$	10.0	$1.90x10^{-2}$	36	on the bases of	-	-	-	-	on the bases of
10th	-				concentrations.	$7.6x10^{-1}$	11.00	$1.12x10^{-2}$	62	concentrations.
15th	$7.5x10^{-2}$	15.0	$1.06x10^{-2}$	65	between 1000-750			-		between 1000-750
20th	-	-	-	-	g/ha by taking	$6.8x10^{-1}$	20.00	$1.12x10^{-2}$	62	g/ha by taking
25th	$6.5x10^{-2}$	26.0	$1.21x10^{-2}$	57	average K-1.36x10-	-	-	-	-	average K-1.11x10-
30th	-	-	-	-	2 is=21days &	$6.2x10^{-1}$	27.00	$1.05x10^{-2}$	66	2 is= 26 d &
35th	$5.6x10^{-2}$	36.0	$1.29x10^{-2}$	54	Persistence (90%	-	-	-	-	Persistence (90%
40th	-	-	-	-	decay) =169days	$5.8x10^{-1}$	32.00	$9.55x10^{-3}$	72	decay) =209 days
45th	$4.8x10^{-2}$	45.0	$1.34x10^{-2}$	52		-	-	-	-	
50th	-	-	Average k	Average		$5.1x10^{-1}$	40.00	$1.02x10^{-2}$	63	
			$1.36x10^{-2}$	= 52 days						
60th	-	-	-	-		$4.4x10^{-1}$	48.00	$1.09x10^{-2}$	63	
70th	-	-	-	-		$3.2x10^{-1}$	62.00	$1.39x10^{-2}$	50	

($T_{1/2}$), effective time (T_{eff}), and persistence (90% degradation) of field and pot experiments are given in **Table 5** and expressed *via* the logarithmic plots of herbicides residue *vs* time represented in **Figure 1** and **2**. The half-lives of pendimethalin as calculated by using first order kinetic equation were found to be of 52 (average K=1.36x10^{-2}) and 62 (average K=1.11x10^{-2}) days, respectively, for field and pot experiments. Since the field experiments were conducted at new research farm (NRF) of the institute where soil differs little in its physico-chemical properties by having comparatively lesser clay and organic matter content, more sand and silt particles and high pH (nearly 8.5) as compared to the soil packed in pots (**Table 1**) taken from main research farm, therefore, comparatively 10 days lowered half-life of the herbicide is received in field experiments. The combined effect of soil physico-chemical properties, *viz.* high organic carbon and temperature on its half-life was also reported by Raj *et al.* (1999). Since, application rate of the herbicide in soil also linked to contribute toward longer half life and persistence therefore; this may also be one of the causes of receiving longer half-life in pot experiment as pots contained comparatively more concentration and also not exposed much to severe environmental conditions. However, the half-lives of this herbicide approximately between 50-60 days as received by us in our experiments are in close agreement with previous findings of other workers. A maximum half life period of 53.8 days or very near to that for pendimethalin was not only reported by Tandon (2008) but also reported by Tsiropolos and Miliadis (1998), Nicholas *et al.* (1998), Kalpana *et al.* (1999), Raj and Chhonkar (2000) and Rathod *et al.* (2010). Though, dinitroanilines are reported to have short life in soil, even though pendimethalin can persist up to 50 weeks as reported by Wen-Ching Chen *et al.* (2018), Marin *et al.* (2019), Bharti *et al.* (2020). This, 50 week persistence period is enough to exert toxic effects on the succeeding crops Smith *et al.* (1995).

In our experiments, we calculated 90% degradation in the herbicide within 169 and 206 days in field and pot experiments, respectively. The persistence of pendimethalin in soil was also found concentration dependent *i.e.* the doses used for weed control therefore Neelam *et al.* (2014) reported a persistent period of 90 days at dose 0.75 kg/ha and 120 days at doses 1.50 and 3.00 kg/ha. In this respect, Sinha *et al.* (1996) also reported almost similar results. However, Yadav *et al.* (1995) reported a persistence period of 200 days of this herbicide in a sandy loam soil which is broadly resembled to our farm soil at application rates of 1 to 4 kg/ha that also caused phyto-toxicity to the succeeding sorghum crop at higher dose. The effective period (T_{eff}.) of the herbicide, for weed control points of view was workout by using first order kinetic equation and by utilizing rate constant (K) values *i.e.*1.36x10^{-2} and 1.11x10^{-2} for field and pot experiments, respectively. The time period by which the concentrations of herbicide lies between 1000 g/ha (original concentration) to 750 g/ha in field was considered as most effective period for weed control point of views. According to this, as per our experimental conditions the herbicide assume effective for 21 days in field whereas in pots it was found nearly to 26 days. The present result suggest that once spray, the herbicide can only provide effective protection to crop against weed up to a maximum period of 20-25 days in our soil *i.e.* sandy clay loam soil of taxonomical class *Typic Usrtochrept* and may differ slightly is soils of having different soil properties and environment. Finally, it can be concluded that soil with an alkaline pH and less adsorption capacity in totality may leads to less terminal pendimethalin residues. Since in our experiments at harvest, the soil of experiments was not only found to retain residues of the herbicide below detectable limit even after 45 days of application but seed and straw of the crop was also found free from residues, however, the maximum permissible residue limit in plant parts and seed as set by WHO/ FAO is 0.5 mg/kg for this herbicide. It indicates that the use of pendimethalin in greengram crop could be considered safe.

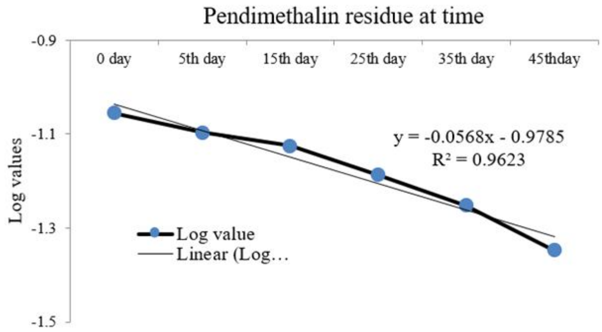

Figure 1. Degradation pattern of pendimethalin residues in the soil in field conditions

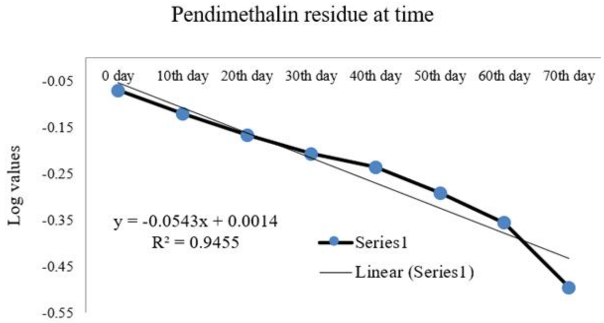

Figure 2. Degradation pattern of pendimethalin residues in the soil in pots

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RESEARCH ARTICLE

Simple detection method for paraquat dichloride in various matrices of cotton and sugarcane using liquid chromatography mass spectrometry

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ABSTRACT

Field trials were conducted to determine residues of paraquat dichloride in cotton and sugarcane at harvest time. Paraquat dichloride was sprayed on weeds at two to three leaves stage at doses of 480 and 960 g/ha. Samples collected at 87 and 102 days after herbicide application in cotton and 199 and 341 days after herbicide application in sugarcane were subjected to residue analysis by employing modified QuEChERS method. Recovery studies were conducted to determine the accuracy of method by spiking each matrix with a known concentration of paraquat dichloride. A satisfactory recovery rate of 70 to 120% and RSD < 20% were obtained in all the matrices. In harvest time samples of cotton (87 and 102 DAT) and sugarcane (199 and 341 DAT) matrices analysed, paraquat dichloride residues were less than the limit of quantification (0.05 mg/kg).

Keywords: Detection method, Herbicide residue**,** Paraquat dichloride, Cotton, Sugarcane

INTRODUCTION

Paraquat dichloride (1,10-dimethyl-4,40-bipyridinium dichloride), a contact herbicide is commonly used in agricultural fields to control broad-leaved and grassy weeds. It exerts a strong herbicidal effect on plants during photosynthesis by interfering with electron transport system by preventing NADP from being reduced to NADPH that resulting in the production of reactive oxygen species (ROS), which in turn reacts with unsaturated lipids found in cell membranes there by destroying plant organelles resulting in cell death.

Due to its crystalline structure, hygroscopicity, odour lessness and low vapour pressure, the chemical composition confers significant properties, such as ease of handling, high solubility in water, high binding capacity to soil, and stability in soil environment with a half-life of 1000 days (Vencill 2002). Apart from being used as herbicide in coffee, beans, soy, and citrus fields, it is also used as a desiccant on potatoes before harvest (Macbean 2012).

Concern about the residues left over by the widespread use of paraquat dichloride in agriculture have increased over the years due to its high toxicity to humans, farm and household pet animals, and particularly to aquatic animal species. Hence its usage is prohibited in several countries such as Sweden, Denmark, Austria, China, and Finland (Tingting 2015).

To determine paraquat dichloride residues in food crops, analytical methods such as capillary electrophoresis (Wigfield *et al.* 1993), gas chromatography with solid-phase extraction (SPE) (Almeida and Yonamine 2007), liquid chromatography (Ruan *et al.* 2014) and enzyme-linked immunosorbent assay (ELISA) (Garcia 2014) have been used. To increase the sensitivity of detection of paraquat dichloride residues in food and water samples, methods based on mass spectrometry, such as gas chromatography-mass spectrometry (GC–MS) and liquid chromatography-tandem mass spectrometry (LC-MS/MS), are critical (Vince 1998). However, when these methodologies are used, the presence of high buffer and ion-pairing concentrations compete with the analyte during ionisation, thereby reducing the sensitivity. Additionally, buffers containing high salt concentration also clog the analyte spray unit of MS equipments, necessitating frequent and thorough cleaning of the spray unit (Tingting 2015). To overcome these practical challenges associated with sensitive detection of paraquat residues, we have developed a method using a low salt concentration buffer and tested the sensitivity of the detection of paraquat residues in cotton and sugarcane.

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MATERIALS AND METHODS

Trials were conducted during two seasons in cotton and sugarcane to determine the residues of paraquat dichloride at harvest time in Kondaiyampalayam (10.9791° N, 76.8112° E) village in cotton and Panaimarathur (11.0046° N, 76.9298° E) village, Coimbatore district in sugarcane. The details of soil physiochemical properties and micronutrient status of the above region were collected from the Department of Soil Science and Agricultural Chemistry, Tamil Nadu Agricultural University, Coimbatore, India. The mean soil pH, 7.33 slightly acidic to alkaline nature; electrical conductivity, non - saline; mean Soil Organic Carbon, 5.4 g/kg (medium); available N, medium to high; available P, medium to high (47 kg/ha); available K, medium to high (352 kg/ha); Zn, 0.42 – 9.45; Fe, 5.62 – 30; Mn, 1.42 – 17; Cu, 0.59 – 9.76.

For this study, fields growing *Bollgard II* cotton variety and *Mandiya* sugarcane variety with recommended agronomic practices were selected. The paraquat dichloride 480 and 960 g/ha was applied twice with 15 days intervals in the interrow space, at 30 days after sowing (DAS)/planting (DAP) of cotton and sugarcane, or on weeds at 2 to 3 leaf stage. Throughout the study period, an untreated control area in the fields was marked and maintained without spraying the herbicide. Each treatment was replicated three times, in a 45 m^2 plot per replication. The herbicide was applied using 500 L/ha with a knapsack sprayer equipped with a flood jet nozzle with a hood to avoid drift of herbicide spray on to the main crop. Two season samples of cotton (87 and 102 DAT) and sugarcane (199 and 341 DAT) were collected during harvest.

Reagents used

Paraquat dichloride standard reference material was provided by M/s. Syngenta India Limited. Solvents such as acetonitrile (Lichrosolv and Chromosolv), ethyl-acetate, methanol, hexane, dichloromethane (M/s Merck Bangalore, India) (M/s. Fishers chemical Ltd., Chennai, India), acetone (M/s. Molychem, Mumbai, India) were purchased. Salts such as anhydrous sodium chloride, sodium sulfate AR grade (M/s Merck Bangalore, India), anhydrous Magnesium sulphate (M/s. Himedia Laboratory, Mumbai), sorbents such as Primary Secondary Amine (PSA, 40 ìm, Bondesil), Graphitized Carbon Black (GCB) (M/s. Agilent, USA) were also procured. The ultra-pure type I (18.2 MÙ) water was prepared using Merck (Direct - Q® 3) water purifier and filtered through 0.45 µm membrane filter paper using a millipore solvent filtration unit. The 0.45 and 0.20 µm membrane filter paper (Ultipor, M/s. Pal life Science, Mumbai) and LCMS grade formic acid (M/s. Sigma Aldrich, Bangalore) were also used in this study.

Standard preparation

A stock solution of 400 mg/kg of paraquat dichloride was prepared by dissolving 10 mg of Certified Reference Material (CRM) in a final volume of 25 ml of methanol in a clean Class A volumetric flask and stored at -20^{0}C for subsequent preparation of intermediate and working standards.

Instrument parameters

Chromatographic separations were performed using a Shimadzu Liquid Chromatography-Mass Spectrometry (LCMS-2020) system equipped with an electrospray ionization (ESI) interface. A concentration of 1.0 mg/kg paraquat dichloride was infused directly into the LCMS without using a column to determine the mass of the compound and to tune the conditions under which paraquat dichloride can be detected. Separation of paraquat dichloride was carried out in positive ionization mode (ESI+) at 185 m/z. The mobile phase ratio of water with 20 mM ammonium formate + 0.2% formic acid at 60% (solvent A): acetonitrile at 40% (solvent B) was used in a low-pressure gradient method using Agilent 5 TC-C18 (2) 250 x 4.6 mm column. The optimized instrument parameters were oven temperature 40^{0}C; interface temperature 350^{0}C; DL temperature 250^{0}C; heat block temperature 400^{0}C; nebulizing gas flow rate 1.5 L/min.; and dry gas flow rate 15 L/min.; flow rate 0.8 ml/min; injection volume 20 µl.

Validation

The linearity curve was established by injecting standard solution at concentrations of 0.05, 0.1, 0.25, 0.5, and 1 mg/kg in six replicates. The relative standard deviation (RSD) and coefficient of determination (R^2) was calculated using the analyte's mean response. The Limits of Detection (LOD) and Limits of Quantification (LOQ) were determined using three and ten levels of signal and noise intensity, respectively. The accuracy of the extraction method was determined using analyte concentrations of 0.05, 0.25, and 0.5 mg/kg. After spiking, the samples were mixed in a vortex and allowed for 30 minutes to equilibrate. The samples were then extracted using the procedure outlined below. To ensure the developed method's accuracy and precision, the percentage of analyte recovery and RSD were calculated with the appropriate matrix match standards.

Sampling

For sampling, two kilograms of cotton were collected on 87 DAT during season I and 102 DAT during season II from each treatment. A 200 g subsample of lint was ginned from each treatment to separate them from seeds. Another subsample of 500 g was taken for delinting seeds with 50 ml of concentrated H_2SO_4. Acid-treated seeds were continuously mixed with a wooden stick and then washed three to four times with water to remove residual acid. Two hundred grams of seeds were crushed in a mixer grinder and cotton oil was extracted in a Soxhlet apparatus using acetone as a solvent. To separate the oil and solvent, the mixture was evaporated at 30°C in a rotary vacuum. After separating oil from the seed, the seed cake was collected from the Soxhlet apparatus and subjected to residue analysis.

For sugarcane sampling, two kilograms of cane and 500 g of leaf from randomly selected plants in each treatment were collected on 199 DAT during season I and 341 DAT during season II. A 300 g subsample was taken from each cane sample and was finely chopped for analysing the residues in cane. The remaining canes were crushed and cane juice was extracted using a cane juice extractor. Leaf samples were cut and blended using blade homogenizer.

For harvest time soil sampling, the surface litter in the sampling site was removed and soil samples were collected at depth ranging from 0 to 15 cm. One kilogram sample from each replication was taken and thoroughly mixed with a conical trier. The samples were immediately transported to the laboratory for residue analysis. Soil samples were dried, powdered, and then quartered to get a sub sample of 250 g. Soil samples were sieved and stored in a polythene bag until analysis.

Extraction and cleanup

A representative sample of 5 g of cotton lint was taken for each treatment and soaked in 200 ml of acetonitrile for 24 hours. To remove excess moisture, the acetonitrile extract was filtered through Whatman filter paper No. 1 containing 10 g sodium sulphate and concentrated to near dryness using a rotary vacuum evaporator. The final residue was reconstituted in 1 ml methanol containing 0.2% formic acid for LC-MS analysis.

Representative samples of seed (5 g), cake (5 g), sugarcane leaves (5 g), and soil (10 g) were weighed in a 50 ml centrifuge tube and vortexed for 1 minute with 5 ml distilled water and 20 ml acetonitrile. Five-grams of chopped cane sample was added to a 250 ml conical flask containing 20 ml of ethyl acetate and extracted using a mechanical shaker at 250 rpm for 1 hour. The extract was filtered through a funnel with a cotton plug and the filtrate was transferred to a 50 ml centrifuge tube. A 10 ml representative sample of cane juice was added to a 50 ml centrifuge tube containing 10 ml of ethyl acetate and vortexed for 1 minute.

For all matrices, following clean-up steps were followed. Four grams anhydrous magnesium sulphate and one gram of sodium chloride were added to 50 ml centrifuge tubes, vortexed for one minute, and then centrifuged at 6,000 rpm for ten minutes. Nine millilitres of supernatant were transferred to a glass test tube containing 4 grams of anhydrous Na_2SO_4 and shaken for one minute, 6 ml of supernatant was transferred to a 15 ml centrifuge tube containing 100 mg PSA, 10 mg GCB, and 600 mg anhydrous $MgSO_4$. The mixture was vigorously shaken by hand for 1 minute and then centrifuged at 3000 rpm for 10 minutes. Four millilitres of supernatant were transferred to a turbovap tube and evaporated to near dryness; the residue was dissolved in 1 ml methanol containing 0.2% formic acid and used for subsequent LC-MS analysis.

Five grams of the oil was taken in a 125 ml separating funnel, 50 ml hexane was added, and the mixture was partitioned using acetonitrile saturated with hexane (3x50 ml) and vigorously shaken for one minute. Once the layers separated, acetonitrile layer was drained carefully into a 1 L separator funnel. Brine solution (600 ml) was added and partitioned twice using 150 ml (2 x 75 ml) of dichloromethane filtered through anhydrous sodium sulphate and treated for 2 hours at room temperature with 500 mg GCB. The clear extract was concentrated to near dryness using Whatman filter paper No. 1., 20 ml of acetonitrile was added to the dried residues and concentrated to dryness using a rotary vacuum at 30°C. The procedure was repeated twice to completely remove all traces of dichloromethane, and the final residue was dissolved in 1 ml methanol containing 0.2% formic acid and used for LC-MS analysis. In order to eliminate the effect of matrix on residue determination, all samples were compared with the matrix match standard.

RESULT AND DISCUSSION

Linearity, LOD and LOQ

The standard solutions prepared linearly in methanol and acetonitrile solvents resulted in an unacceptable coefficient of determination (R^2).

However, standard solutions prepared using methanol containing 0.2% formic acid resulted in enhanced paraquat dichloride ionization in LCMS as well as a high degree of linearity and R^2 value of 0.99 as coefficient of determination. The LOD and the LOQ were estimated at 0.01 and 0.05 mg/kg, respectively (**Figure 1**).

Recovery

Recovery studies on paraquat dichloride were performed to ascertain the accuracy of our method described in this article. The herbicide recovery was determined in a wide range of cotton matrices (lint, seed, seed cake, oil, and soil) and sugarcane matrices (leaf, juice, cane and soil) (**Table 1** and **2**). The mean recovery rate of paraquat dichloride in various cotton and sugarcane matrices ranged between 74.42 and 111.24%.

Degradation of paraquat dichloride in cotton and sugarcane

The present study's findings indicated that paraquat dichloride residues in cotton and sugarcane matrices at harvest were less than the limit of quantification (0.05 mg/kg). The method's accuracy was estimated in terms of the recovery experiment by following the modified QuEChERS method. In the present study, all the matrices showed a satisfactory recovery and RSD percentage (SANTE 2019). In combination with ammonium format, formic acid enhanced the ionization of the analyte. The lowest concentration that produced a response three times that of the noise peak was used as the LOD (0.01 mg/kg). The LOQ (0.05 mg/kg) is estimated to be 3.3 times the LOD.

The analysis of paraquat dichloride in various matrices was found to be complicated across all matrices with inconsistent recovery percentages and higher RSD. The problem could be rectified with the addition of 0.2% formic acid in methanol used finally to reconstitute the residues after evaporation and accuracy and precision were well within the acceptable limit (SANTE 2019). As a result, the developed method is deemed adequate for determining paraquat dichloride residues in cotton and sugarcane matrices.

The present study showed that paraquat dichloride residues were at less than the quantification limit of 0.05 mg/kg in cotton (lint, seed, seed cake, oil) and sugarcane (leaf, juice, cane) samples collected at harvest in both seasons. (**Figure 2**).

Paraquat dichloride is a contact herbicide that has not been shown to transfer to plant parts. Typically, paraquat dichloride disrupts the chloroplast's electron transport system (PS I). This inhibits oxygen and carbon dioxide fixation, forming the superoxide anion, which then reacts with the two hydrogen molecules to form hydrogen peroxide. Hydrogen peroxide decompose into free radicals in the presence of sunlight, and these free radicals cause cell death. Thus, once exposed to paraquat dichloride with sufficient sunlight, the plant will wilt or die. No

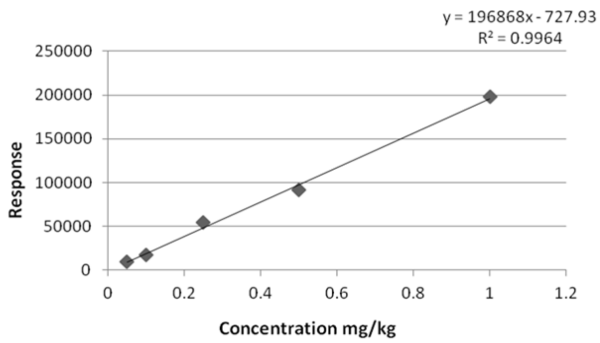

Figure 1. Mass spectrum and linearity curve of paraquat dichloride in LCMS

Table 1. Percent recovery of paraquat dichloride in cotton lint, seed, and oil

Fortification	Cotton lint		Cotton seed		Cotton oil		Cotton cake		Soil	
	Mean % recovery	RSD (%)	Mean % recovery	RSD (%)	Mean % recovery	RSD (%)	Mean % recovery	RSD (%)	Mean % recovery	RSD (%)
0.05 mg/kg	102.18	8.13	95.09	4.21	94.43	11.40	103.19	3.18	112.24	5.72
0.25 mg/kg	101.14	8.34	109.44	2.92	80.51	10.58	104.02	0.72	98.92	15.39
0.50 mg/kg	110.74	3.47	97.91	4.64	90.93	4.93	74.42	5.53	79.04	7.40

Table 2. Percent recovery of paraquat dichloride in sugarcane leaves, cane, juice and soil

Fortification	Leaves		Cane		Juice		Soil	
	Mean% recovery	RSD (%)	Mean% recovery	RSD (%)	Mean% recovery	RSD (%)	Mean% recovery	RSD (%)
0.05 mg/kg	91.87	2.77	102.68	5.52	104.54	9.51	92.88	9.82
0.25 mg/kg	90.04	10.62	103.07	6.19	95.13	7.67	83.18	5.47
0.50 mg/kg	89.31	8.41	85.40	1.94	110.28	3.57	82.10	8.38

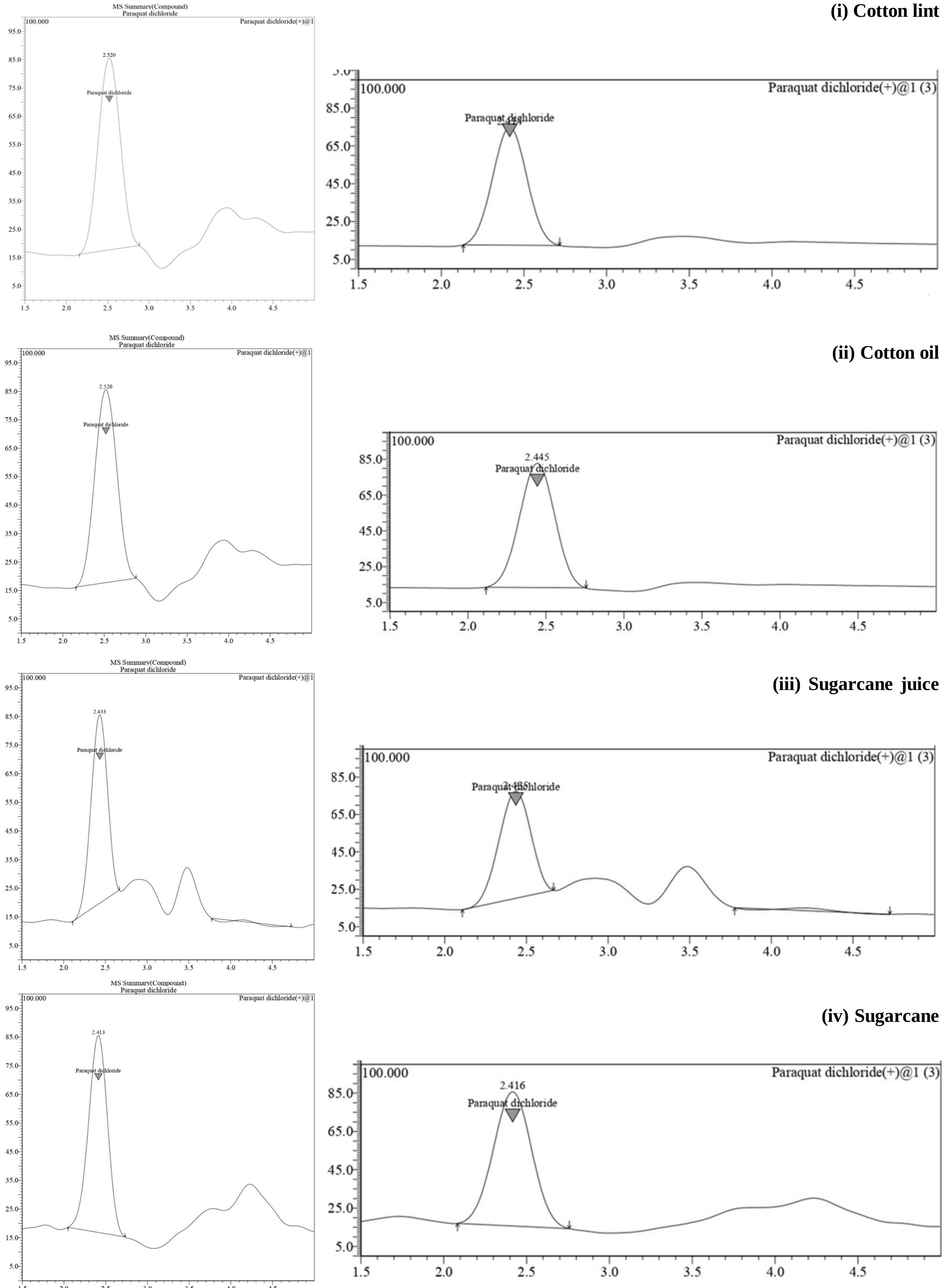

Figure 2. Chromatogram of matrix match standard (left) and recovery at LOQ level (right) for selected matrices in cotton and sugarcane by LCMS

such drying of crop plants was observed during the study period. Additionally, paraquat dichloride is highly soluble in water, it is typically trapped in soil or clay particles and degraded by microbial fauna (Alexander 1999 and Srinivasan 2004). No residues were reported in samples collected at 100 days after the application of paraquat dichloride 24% SL at a dose of 2 and 4 kg/ha in tea (Janaki and Chinnusamy 2016).

Cotton fiber is used to make natural textiles, cotton seed is used to make edible oil, and cotton meal is used to feed livestock. As a result, it is critical to maintain high-quality fiber, nutritional value and devoid of contaminants. Similarly, sugarcane juice is consumed fresh, and only very few studies were reported on pesticide residue in sugarcane juice. As a result, it is critical to investigate the fate of herbicides and their residue levels in these cropping ecosystems.

Thus, the study confirms the possibility of eliminating residues in plant and soil with an adequate gap between the last herbicide application and harvest. However, care should be taken to ensure that sound agricultural practices are followed to avoid residue deposition. Additionally, because of its high solubility and toxicity, indiscriminate use of paraquat dichloride may result in bioaccumulation in plants and animals, particularly in aquatic systems. The tolerance limits are established by CODEX Alimentarius and FSSAI for cotton seed (2 mg/kg) and cottonseed oil (0.05 mg/kg) by FSSAI. No MRL is available for paraquat dichloride in sugarcane. To ensure food safety, the MRL for paraquat dichloride need to be established for additional agricultural crops.

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RESEARCH NOTE

Comparing manual and mechanical weed management techniques for upland organic rice in acidic soil of Meghalaya: A on-farm study

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ABSTRACT

The on-farm trial was conducted at Kyrdemkulai village in Ri-Bhoi district of Meghalaya during *Kharif* (rainy) season of 2021. The objective of experiment was to compare the effectiveness of manual and mechanical methods of weed management in upland organic rice (*ArizeTej Gold*). Treatment includes, two-time manual weeding (25-30 days after sowing (DAS) and 45-50 DAS), three times manual weeding (25-30 DAS, 45-50 DAS and 60 DAS), two-time mechanical weeding with the help of manual operated star wheel weeder (23-25 DAS and 45-50 DAS), manual (25-30 DAS) followed by mechanical weeding (45-50 DAS), mechanical (23-25 DAS) followed by manual weeding (45-50 DAS) and two check, *viz.* weedy check and weed free check. These seven treatments were replicated thrice. Result showed that, three times manual weeding and weed free treatment recorded significantly higher grain yield (5–69%) and net returns (27270 ₹/ha and 27200 ₹/ha, respectively as well as lower weed population by 22-80 no./m^2 and 140-220 no./m^2, respectively over other treatments. The highest B: C ratio was recorded in mechanical weeding at 23-25 DAS followed by manual weeding at 45-50 DAS (1.50) and three-time manual weeding (1.48). It was concluded that three-time manual weeding will be best due to significantly higher yield (1.74 t/ha); while mechanical weeding *fb* manual weeding will be considered economic with B:C ratio of 1.50.

Keywords: *ArizeTej Gold*, *Heliotropium indicum*, Manual weeding, Mechanilcal weeding, Organic rice, Weed intensity

In Meghalaya, rice is staple food crop occupy first position with 13.6% area under occupation out of total agricultural land. Rice straw also contributes as a base material for mushroom production, fodder for cattle and also used in several small-scale cottage industries; hence is considered as a staple crop of peasant farmers in Meghalaya. The rice cultivation in state is known for organic production practices, acidic soil with high organic matter, increasing seed replacement ratio, promotion of traditional rice varieties and use of indigenous technical knowledge and its amalgamation with new technical knowledge (Kumar *et al.* 2016, Das *et al.* 2022). The major production constraints in organic upland rice in Meghalaya includes, soil acidity, termite infestation, blast infection, washing of manures due to runoff and soil relief and problem of weeds leading to low crop productivity (Munda *et al.* 2019). The rice production systems in Meghalaya are organic and are grown in both upland and lowland situation. The lowlands have puddling and standing water which have control over weed population; while upland organic rice production system have manual weeding as a single option for weed management. Besides that, the higher menace of weeds in upland rice (Saha *et al.* 2021, Chaudhary *et al.* (2022) and organic rice production system is reported in Gnanasoundari and Somasundaram (2014). The use of herbicides for weed control was not allowed in organic production system and hence weed management is a more time and energy taking in organic production system in absence of puddling and standing water in rice field. The weed management information in organic rice production system is restricted to cultural practices, brown manuring and manual and mechanical weeding; while they have varied adaptation due to cost and energy involved and their varied effectiveness. The biological methods have restriction of selective weed control of one or few species while composite weed flora cannot be addressed by biological methods. Hence, manual weeding or suitable substitute for manual weeding through mechanical weeding (to reduce drudgery) is considered as most important and potential option for weed management in organic production system. The substitution of manual weeding with mechanical tools is considered as an important intervention in both upland rice and organic production system (Saravanane 2020, Mohanty and Bhuyan 2020). Therefore, their economic and practical suitability in upland rice with organic production system need to

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be evaluated in on-farm condition. Besides the organic production system, introduction of new crop varieties also needs to be evaluated due to their varied response to weed management practices. Therefore, the study was conducted with hypothesis that mechanical weeding will reduce the cost involved over manual weeding and combination of both manual and mechanical weeding will be more economics than manual weeding besides knowing the impact of combinations and frequency of mechanical and manual weeding on productivity of organic rice variety (*ArizeTej Gold*).

The field trail was conducted at farmer's field at Kyrdemkulai village (25^0 751' N, 91^0 832' E) in Ri-Bhoi district of Meghalaya in *Kharif* (rainy) season of 2021. The climate of selected area is subtropical with average seasonal (June to September) and annual rainfall of 1424.1 mm and 2119.3 mm, respectively. The seasonal rainfall (28 May to 30 September) of 1328.9 mm received in 73 rainy days and highest and lowest relative humidity of 92.5% (27^{th} meteorological week) and 74.6% (35^{th} meteorological week) were recorded during year of experiment. The highest temperature of 34.4 ^{0}C and 33.4 ^{0}C was recorded in 41^{st} and 31^{st} meteorological week.

The experiment was conducted under organic production system and planned in randomized block design involving seven treatments. The treatments consisting of combination of time and frequency of manual and mechanical weeding and two controls (weedy check and weed free check) and all treatments were replicated thrice **(Table 1)**. The field was prepared by giving two passes of power tiller followed by preparation of field for sowing of crop by stubble collection (plots size- 5×3 m). Rice variety (hybrid) *ArizeTej Gold* was grown as direct seeded in upland condition on 2^{nd} July, 2021 with seed rate of 60 kg/ha and spacing of 20 cm row spacing followed by gap filling at 7 days after sowing (DAS). The crop was manured with poultry manure 120 kg/ha out of which 80 kg/ha was applied before sowing and remaining 40 kg/ha was applied in two equal split (after first and second weeding). The crop was grown as rainfed crop. In weed free plots, hand weeding was done 4 times (12-15 DAS, 25-30 DAS, 45-50 DAS and 60 DAS) and for manual weeding treatments weeds were removed by hand and also using 'khurpi'(hand operated small spade) as per the treatment details. For mechanical weeding, manual operated star wheel weeder was used.

For measurement of plant height five plants were randomly selected from each plot and for tiller measurement, tillers from one meter row length at three places from each plot were measured. For measurement of above ground shoot dry matter air dried plant samples were further dried in a hot air oven at 60±5 ^{0}C temperature till constant weight was obtained and expressed in g/m^2. Yield attributes (filled and unfilled spikelets) were measured from a sample of 10 panicles drawn at random from each plot at harvesting. The net plot (4 × 3 = 12 m^2) was harvested and sun dried for seven days followed by weighing the biological yield. Threshing was done manually and weighing of grain was done at 14% moisture content. Straw yield was measured by subtracting grain yield from biological yield. The fertility index was calculated by dividing filled spikelets with total spikelets and multiplied with 100. For measurement of weed count and weed dry matter accumulation, 30 × 30 cm quadrant was used and samples at three spots were taken at all observation. Weed dry matter accumulation and weed density data is transformed using square root transformation. The statistical significance among applied treatments were studied using the F-test and least significant difference (LSD) values (p=0.05).

Effect on weed density and dry matter accumulation

The weed density was highest at 30 DAS (381 – 409 no./m^2), decreased by 9.5 – 60.6 % and 33.6 – 68. % at 60 DAS and at harvest, respectively over 30 DAS (**Table 1**). The decrease in weed population in weed free check were 52.0% and 48.3% over two time weeding and three weeding, respectively at 60 DAS. The significant variation in weed free check and three-time manual weeding indicates that, the weed flushes are observed even after third weeding (60 DAS) and this leads to extension of period crop weed competition in directed-seeded rice. This also indicates the abundance of weed seed bank. The longer duration of crop weed competition in upland direct-seeded rice than transplanted rice was reported by Chaudhary *et al.* (2022); while role of weed seed bank in affecting the weed population was reported by Sharma *et al.* (2020). The major weed species were *Heliotropium indicum* (L.), *Chromolaena odorata* (L. R.M. king & H. Rob.), *Elephantopus scaber, Mimosa pudica* (L.), *Galinsoga Parviflora, Panicum repens, Cyperus iria* (L.), *Cyperus rotundus* (L.), *Fimbristylis aestivalis, Dactyloctenium aegyptium* (L.) Willd, *Paspalum conjugatum, Marsilea quadrifolia* (L) Linn., *Oxalis corniculata* (L.) and *Commelina diffusa* (L.). The weed dry matter accumulation at 60 DAS showed significant response to applied treatment with superiority of manual weeding over mechanical weeding in controlling weeds; while in case of combination, mechanical weeding followed by manual weeding was more promising than reverse trend. The major reason for variation in weed population was locations of field around the wild vegetation, no history of chemical measure control measure, variation in the relief as the field is not completely levelled and field was vacant during summer season occupied with wild vegetation. This resulted in higher weed population as well as variation in population density.

Effect on rice growth attributes

Both sequence and methods of weeding found to differ significantly for their effects on growth attributes of rice (**Table 1**). Manual weeding (three times) and weed free check remained at par with each other and had significantly higher tiller/m^2 than other treatments; while in case of sequence, mechanical weeding *fb* manual weeding was found significantly superior over manual *fb* mechanical weeding indicating higher weed population at 45–50 DAS (314.0 versus 351.3 no./m^2) and need of both inter and intra row weeding possible with manual weeding. The dry matter accumulation at 60 DAS was highest in manual weeding three times (209.0 g/m^2). The growth variations across weed management treatments arose due to higher weed dry matter accumulation and weed density (**Table 1**). The variation in plant growth due to mechanical weeding was also reported by Veeraputhiran *et al.* (2014).

Effect on yield attributes, yield and economics

All yield attributes were differed significantly among the treatments and two treatments, *viz*. three times manual weeding and weed free check had significantly higher values for all yield attributes studied (**Table 2**). The grain and straw yield in weedy check was lower than weed free check by 69.5 % and 61.9%, respectively indicating the volume of losses caused by weeds. Such variation in yield attributes and yield was also reported by Aske *et al.* (2018) in organic rice production system; while variation in rice yield due to different weed management practices in organic rice was reported by Gnanasoundari and Somasundaram (2014) and Rathod and Somasundaram (2019) in transplanted rice. The highest grain yield of 1.84 t/ha was recorded in weed free check which was at par with manual weeding three times (25-30, 45-50 and 60 DAS) (1.74 t/ha). The manual weeding two times (25-30 and 45-50 DAS) remaineded at par with combination of mechanical weeding (23-25 DAS) followed by manual weeding at 45-50 DAS, indicating the place of mechanization in upland rice. In term of economics, weed free check (90.28 × 10^3 ₹/ha and 27.65 × 10^3 ₹/ha) and manual weeding three times (85.46 × 10^3 ₹/ha and 27,72 × 10^3./ha) recorded highest gross and net returns; while mechanical weeding at 23-25 DAS *fb* manual weeding 45-50 DAS and manual weeding two times are other treatment found promising in economic

Table 1. Effect of mechanical and manual weeding on the weed and plant growth attributes in direct seeded upland rice

Treatment	Weed attribute					Plant attribute						
	Weed dry matter accumulation (g/m^2)		Weed density (no./m^2)			Plant height (cm)		Tiller/m^2			Dry matter accumulation (g/m^2)	
	30 DAS	60 DAS	30 DAS	60 DAS	At Harvest	60 DAS	At Harvest	30 DAS	60 DAS	At Harvest	30 DAS	60 DAS
Manual weeding at 25-30 DAS and 45-50 DAS	17.09 (292.0)	14.72 (216.7)	19.48 (379.3)	18.29 (313.3)	12.31 (151.7)	76.0	89.6	336.3	378.7	348.0	94.00	193.0
Manual weeding at 25-30 DAS, 45-50 DAS and 60 DAS	17.12 (296.7)	13.95 (194.7)	19.55 (382.3)	17.05 (290.7)	11.59 (134.3)	80.0	95.7	343.3	395.0	364.7	95.33	209.0
Mechanical weeding at 23-25 DAS and 45-50 DAS	16.91 (283.3)	15.28 (233.3)	19.87 (394.7)	18.63 (347.3)	14.35 (206.0)	71.0	72.7	334.0	351.0	332.7	96.60	180.8
Manual weeding at 25-30 DAS *fb* Mechanical weeding at 45-50 DAS	16.79 (282.0)	15.13 (229.0)	19.87 (395.0)	18.74 (351.3)	14.18 (201.0)	71.0	74.7	334.0	356.0	334.3	98.27	181.6
Mechanical weeding at 23-25 DAS *fb* manual weeding 45-50 DAS	16.86 (284.3)	14.73 (217.0)	19.58 (383.3)	18.72 (314.0)	12.50 (156.3)	75.0	87.3	338.0	377.7	347.0	99.13	196.3
Weed free	16.87 (284.7)	13.11 (172.0)	19.53 (381.3)	12.26 (150.3)	10.98 (121.7)	81.0	96.7	339.0	398.7	368.3	94.00	206.0
Control	17.40 (302.7)	16.82 (283.0)	20.23 (409.7)	19.25 (370.7)	16.49 (272.0)	62.7	75.00	338.0	333.0	308.0	97.37	102.6
LSD (p=0.05)	0.33	0.53	NS	0.88	1.04	3.51	3.81	10.0	9.41	8.78	4.10	4.98

DAS: days after sowing; Square root transformation was used for weed dry matter accumulation and weed density; The original values were mention in parentheses; *fb*: followed by

Table 2. Effect of mechanical and manual weeding on the yield attributes, yield and economics of rice in direct seeded upland condition

Treatment	Length of panicle (cm)	Weight of panicle (g)	Filled spikelets (no./ panicle)	Unfilled spikelets (no./ panicle)	Total spikelets (no.)	1000-grain weight (g)	Grain yield (t/ha)	Straw yield (t/ha)	Biological yield (t/ha)	Harvest index	Gross returns ($\times 10^3$ `/ha)	Cost of cultivation ($\times 10^3$ `/ha)	Net returns ($\times 10^3$ `/ha)	B: C
Manual weeding at 25-30 DAS and 45-50 DAS	20.0	2.22	95.3	25.3	120.7	21.8	139	4.02	5.41	25.7	67.63	47.93	19.69	1.41
Manual weeding at 25-30 DAS, 45-50 DAS and 60 DAS	21.4	2.45	106.0	20.0	126.0	22.3	174	5.23	6.98	25.0	85.46	57.73	27.72	1.48
Mechanical weeding at 23-25 DAS and 45-50DAS	18.2	2.06	86.0	25.3	111.3	22.1	102	2.78	3.80	27.0	49.33	38.13	11.19	1.29
Manual weeding at 25-30 DAS *fb* mechanical weeding at 45-50 DAS	18.5	2.13	85.0	26.3	111.3	21.9	106	2.82	3.88	27.4	50.90	43.03	7.87	1.18
Mechanical weeding at 23-25 DAS fb manual weeding 45-50 DAS	19.9	2.15	97.7	23.3	121.0	22.1	133	3.77	5.10	26.1	64.42	43.03	21.39	1.50
Weed Free	21.3	2.45	107.7	17.7	125.3	22.3	184	5.57	7.41	24.8	90.28	62.63	27.65	1.44
Control	16.3	1.08	34.0	44.7	78.7	21.3	0.56	0.22	1.79	21.0	28.78	28.33	0.45	1.02
LSD (p=0.05)	1.31	0.10	7.44	5.16	5.16	0.73	0.18	0.67	0.78	0.78	9.26	-	9.26	0.24

(DAS: days after sowing)

terms (**Table 2**). The manual weeding was costly considering its cost of cultivation (62.63 $\times 10^3$ /ha); while it was expected to have potential for marginal land holdings. Our on-farm evaluation of weed management in organic production system concluded that, combination of mechanical weeding (23-25 DAS) and manual weeding (45-50 DAS) is potential option to reduce cost involved in two- or three-time manual weeding.

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RESEARCH NOTE

Susceptibility of long-term unexposed population of *Phalaris minor* to isoproturon

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ABSTRACT

Phalaris minor populations (95 No.) were collected from 14 districts of Punjab. All these populations were not exposed to isoproturon for more than 15 years. Plants of each population/pot were planted and treated with the graded doses of isoproturon 75WP (234.5, 469, 938, 1876, 3752 g/ha) 30 days after sowing as per treatment. The mortality data was recorded and converted to morality percentage in relation to untreated control populations. Nonlinear regression analysis was used to determine the mean dose that caused mortality by 50% (GR50). Out of 95 *Phalaris minor* populations, isoproturon (IPU) at 938 g/ha provided more than 90% mortality in 39 populations and 70-90% mortality in 17 populations, respectively.

Keywords: GR50, Herbicides, Isoproturon, *Phalaris minor*, Reverse resistance, Wheat

In North-West India, *Phalaris minor* became the dominant weed in wheat fields under the rice-wheat production system. The broad-spectrum herbicides, *viz*. isoproturon (IPU), metoxuron, chlortoluron, and methabenzthiazuron were recommended for its control in wheat in the mid-1970s. Isoproturon (IPU) was readily adopted for weed control in early years of its recommendation (Gill *et al.* 1978). Owing to its flexible application method and broader application window, broad-spectrum weed control, IPU became the first choice of farmers during the 1980s-1990s till the onset of resistance in *P. minor* against IPU in the early 1990s (Malik and Singh 1993). Its continuous use in rice-wheat rotation for a longer period coupled with monoculture led to the evolution of resistance in *P. minor* against IPU (Walia *et al.* 1997). The evolution of isoproturon (IPU) resistance in *P. minor* in Haryana was the first case of herbicide resistance reported in India (Malik and Singh 1995) and it was the first report of weed resistance to isoproturon (IPU) in the world (Bhullar *et al.* 2017).

Alternate herbicides, *viz*. clodinafop-propargyl, sulfosulfuron, and fenoxaprop were introduced to control isoproturon (IPU) resistant *P. minor.* These herbicides provided excellent control for 6-7 years but they also met with the same fate due to their continuous use for killing *P. minor* (Yadav and Malik 2005). Subsequently, the GR50 values (dose of herbicide required for 50% growth reduction) of these herbicides increased for better weed control. Bhullar *et al.* (2014) reported that alternate herbicides like clodinafop, sulfosulfuron, and fenoxaprop lost their efficacy to control *P. minor* after 10-15 years of their continuous usage by the farmers even at double doses than the recommended dose of respective herbicide for their field use. Multiple resistance in *P. minor* to various modes of action herbicides is now well-established and confirmed by various scientists in northern India (Punia *et al.* 2017, Yadav *et al.* 2016). High levels of resistance to fenoxaprop, clodinafop-propargyl, and pinoxaden in the multiple herbicide-resistant populations of *P. minor* have been reported from Punjab (Bhullar *et al.* 2002, Bhullar *et al.* 2014, Kaur *et al.* 2015). During the extensive weed survey conducted in Punjab, it was also noticed that some farmers are getting good weed control with isoproturon. Keeping this in view, an experiment was carried out to study the response of *P. minor* populations, collected from different areas in Punjab to graded doses of isoproturon application.

A field survey of wheat fields of the rice-wheat system was conducted in March-April 2018 following reports of poor weed control across fourteen districts of Punjab *viz*. Amritsar (A1-A3),

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Barnala (B1-B8), Ferozepur (F1-F8), Gurdaspur (G1-G5), Hoshiarpur (H1-H4), Jalandhar (J1-J8), Kapurthala (K1-K6), Ludhiana (L1-L15), Moga (M1-M7), Patiala (P1-P2), Ropar (R1-R7), Sangrur (S1-S16), Tarantaran (T1-T4), Fatehgarh Sahib (FS1-FS2). Seeds of *P. minor*, which escaped herbicides, were collected from more than 100 different locations (wheat fields) in the state of Punjab. At these farmers' fields, farmers applied isoproturon (IPU) in the early 1980s, for control of *P. minor* and other weeds, which continued till late 1990s. After the evolution of resistance in *P. minor* to IPU, farmers abandoned its use in the early 2000s and as per personal communication with the farmers they had not used IPU in their fields since then. The farmers shifted to alternate herbicides, *viz*. clodinafop, sulfosulfuron, and fenoxaprop which worked well for a decade and after that, their efficacy decreased due to the evolution of resistance in *P. minor* to alternate herbicides. These results were confirmed by a farmers' field survey conducted by Bhullar *et al.* (2014). Thereafter, pinoxaden and ready-mix of mesosulfuron + iodosulfuron were introduced which were followed by ready-mixes of fenoxaprop and clodinafop with metribuzin for management of resistant *P. minor*. Isoproturon has not been used at most of these farmers' fields since the early 2000s.

Apart from resistant populations, *P. minor* seeds to be used as susceptible control were collected from the population that had not previously been exposed to any herbicide. Germination test of seeds of all populations was conducted during November 2018, using the Petri plate method where 10 seeds per plate were sown on moist filtered paper and the number of seeds germinated was counted after 10 days of sowing. *Phalaris minor* populations having more than 80% germination were selected. The pots were filled with soil from the field where no rice-wheat cropping system was followed for more than ten years to avoid *P. minor* soil seed bank. The soil was sieved to remove unwanted material and then filled in pots. About 15 g well-prepared vermicompost was added to every pot to provide the desired nutrition to the plants. Out of the selected populations, 48 populations were used for sowing in the first year (2018-19) and 49 populations were used for the second year (2019-20). The filled pots were arranged as per treatments in 6 blocks and 75 cm distance was maintained among blocks. Every block had three rows of 50 pots for planting 50 populations with three replications. The commercial formulation of photosystem II inhibitor isoproturon (Isoguard® 75 WP, Gharda Chemicals Pvt Ltd) was used for testing herbicide resistance and one block was kept as control (no herbicide spray) except water spray. All populations of *P. minor* per block were planted and replicated thrice for each dose of herbicide. The tagging of pots was done as per the layout. The populations were planted at 40 seeds per population per pot for each replicate in the first week of December during 2018 and 2019. Seeds were thoroughly mixed with soil and water was given to the pots as per need to avoid moisture stress. Pots were covered with black polythene sheets for a few days to give them the desired temperature and to save the seeds from bird damage. Water was applied uniformly to all pots. The number of seedlings per pot was counted four weeks after sowing from each pot. Plants of each population/pot were treated with the doses of isoproturon 75WP, *viz*. 234.5, 469, 938, 1876, 3752 g/ha 30 days after sowing as per treatment. Isoproturon at 938 g/ha was the recommended dose by Punjab Agricultural University, Ludhiana for the control of *Phalaris minor*. It was applied using a knapsack sprayer fitted with a flat fan nozzle, calibrated to deliver 375 liters of water per hectare and the spray lance was kept at knee-high height while spraying. Every precautionary measure was taken to avoid the spray drift from one block to another. As a precautionary measure, adjacent blocks on both sides were kept covered while spraying a block. The mortality of plants of each population was recorded 28 days after spray.

The mortality data was converted to morality percentage compared to untreated control populations. Nonlinear regression analysis was used to determine the mean dose that caused mortality by 50% (GR50). 'R' software was used to simultaneously fit multiple dose-response curves (Ritz and Streibig 2005) and to graph the distribution of data and regression lines. The effective herbicide doses that inhibited plant population by 50% (GR50) concerning the untreated control were estimated for each population by using this model. The resistance factor (RF), which is the ratio of the GR50 of the resistant *P. minor* population to GR50 of the susceptible population, was calculated based on mortality percentage, to compare resistance levels of evaluated populations.

Susceptibility of *Phalaris minor* isoproturon

The data about the control of *P. minor* populations by isoproturon (IPU) has been presented in **Figure 1.** The data revealed that at the recommended dose of 938 g/ha, IPU recorded more than 90% control of 39 populations, 70-90% control

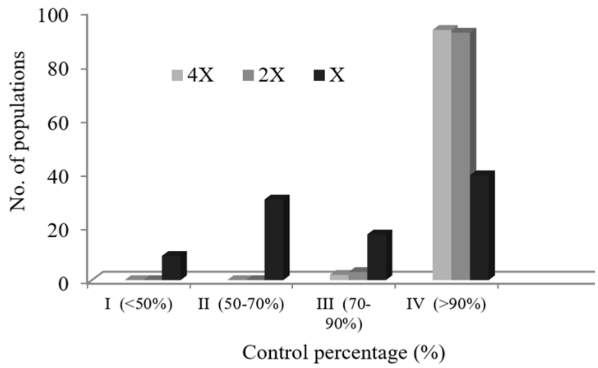

Figure 1. Percent control of *P. minor* populations in response to different doses of isoproturon (X represents the field dose of herbicide recommended by Punjab Agricultural University, Ludhiana)

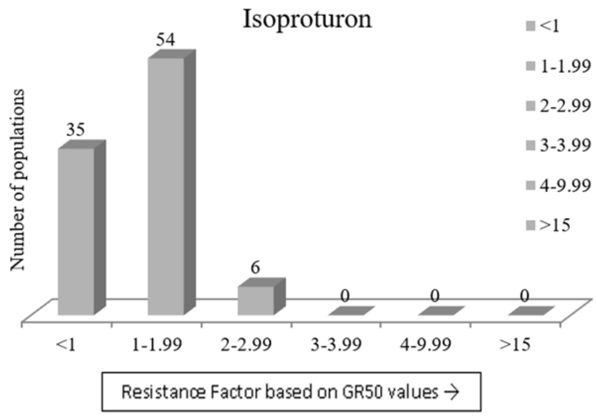

Figure 3. Categorization of *P. minor* populations from Punjab state based on resistance indices to isoproturon

of 17 populations, 50-70% control of 30 populations, and less than 50 % control of 9 populations of *P. minor*. At 1876 g/ha and 3752 g/ha, no population recorded less than 70% control. 92 populations showed more than 90% control whereas only 3 populations recorded 70-90 % control at 1876 g/ha. The respective figures were 93 and 2 at 3752 g/ha. Isoproturon (IPU) recorded remarkable control in most of the populations of *P. minor*.

GR50 and RF50 values for different *P. Minor* populations from 14 districts were calculated. A log-logistic model, with four parameters, was used using the dose-response curve graph the distribution of data, and regression lines, which has been presented in **Figure 2**. Out of 95 populations of *P. minor*, 37% had RF <1.0 at GR50, 57% had RF values between 1-2 and 6% of populations had RF >2.0 (**Figure 3**). Six populations of *P. minor, viz*. S4, R2, M6, T2, A2, and FS1 from districts Sangrur, Ropar, Moga, Tarntaran, Amritsar, and Fatehgarh Sahib, respectively, had RF between 2.0- 3.0. About 54 *P. minor* populations from Ferozepur, Gurdaspur, Kapurthala, Ludhiana, Hoshiarpur, Jalandhar, Patiala, and Bathinda districts were found susceptible to a low level (RF between 1 -2) of resistance to IPU. The effective control of *P. minor* populations with IPU indicates the evolution of reverse resistance in *P. minor* populations to IPU as these populations had not been exposed to IPU since the early 2000s.

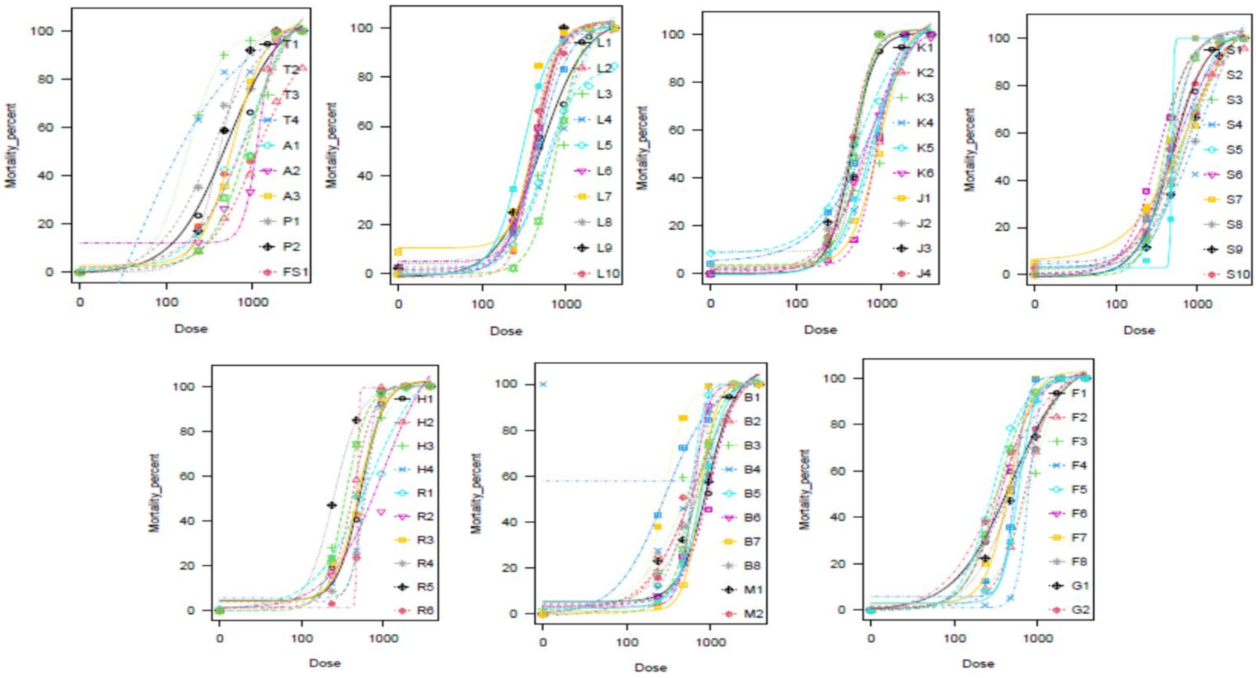

Figure 2. Estimated dose response curves for the *Phalaris minor* populations in response to different isoproturon concentrations

Conclusion

Out of 95 *Phalaris minor* populations, IPU at 938 g/ha provided more than 90% mortality in 39 populations and 70-90% mortality in 17 populations. The effective control of *P. minor* populations with isoproturon seems to be a fit case to investigate reverse resistance in *P. minor*.

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RESEARCH NOTE

Weed dynamics, growth and yield of maize as influenced by organic weed management practices

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ABSTRACT

Field experiment was conducted during winter of 2021-22 at Wetland farm of S.V. Agricultural College, Tirupati, Andhra Pradesh, India in a randomized block design with ten organic weed management practices and with three replications. Among all the organic weed management practices, lower weed density and dry weight with higher weed control efficiency was recorded with corn gluten meal 3.5 t/ha as pre-emergence (PE) *fb* hand weeding (HW) at 30 days after sowing (DAS), however, it was statistically comparable with HW twice at 15 and 30 DAS. Significantly higher growth parameters, yield attributes and kernel yield of maiz were recorded with corn gluten meal 3.5 t/ha as PE *fb* HW at 30 DAS over rest of the treatments. Mango leaves mulch 5 t/ha recorded significantly higher net returns; however, it was at par with HW twice at 15 and 30 DAS and groundnut shells mulch 12.5 t/ha. Higher benefit-cost ratio was realized with mango leaves mulch 5 t/ha, which was significantly superior over rest of the treatments. Significantly lower net returns and benefit-cost ratio was registered with corn gluten meal 3.5 t/ha as PE *fb* HW at 30 DAS, when compared to rest of the treatments. It was concluded that mango leaves mulch 5 t/ha is the most effective, sustainable and economical organic weed management practice in maize.

Keywords: Corn gluten meal, Maize, Mulch, Organic weed management

Maize (*Zea mays* L.) is considered as queen of the cereals and is the most important crop next to rice and wheat in global agriculture. Maize is grown on 194 million hactares area in more than 170 countries across the globe with 1148 million metric tons of production. In India, it is grown in 9.89 million hactares area with 31.65 million tons of production and with a productivity of 3199 kg/ha (www.indiastat.com, 2021). Corn being widely spaced gets infested with number of weeds and subjected to heavy weed competition, which often causes huge losses in yield ranging from 28 to 100% (Patel *et al*. 2006). Modern agriculture is productivity oriented and depends mainly on synthetic inputs namely herbicides to manage the weeds. Continuous non-judicious use of herbicides for weed management leads to loss of bio-diversity, environmental pollution and also developing of herbicide resistance in weeds. Weed persistence is more in organic farming due to the extensive usage of organic manures, which act as weed seed reservoirs. Mulching is an effective method of weed control without using chemicals. Mulch covers the soil surface and can prevent weed seed germination by blocking sunlight transmission. Mulch also acts as a physical barrier to impede weeds emergence (Choudhary and Kumar 2014). Live mulch involves growing a smother crop between the rows of the main crop. It is very important to kill and till in, or manage live mulch so that it does not compete with the actual crop. Allelopathy is an eco-friendly and organic weed management approach, which may be used as a tool in controlling weeds by using extracts of allelopathic plants as natural herbicides (Ankita and Chabbi 2012). However, in the current scenario of agriculture, evolving an eco-friendly, sustainable and economical approach of organic weed management is more advisable so as to protect our environmental resources such as soil flora and fauna including human being and animals in a holistic manner. Hence, the present study was undertaken to assess the performance of different organic weed management practices for broad-spectrum weed control and for higher productivity in maize.

A field experiment was conducted during winter season of 2021-22 at Wetland farm, S.V. Agricultural College, Tirupati, located at 13.5°N latitude and

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79.5°E longitude with an altitude of 182.9 m above mean sea level in the Southern Agro-Climatic Zone of Andhra Pradesh, India. The soil was sandy clay loam in texture, neutral in soil reaction, low in organic carbon (0.26) and available nitrogen (249 kg/ha), and medium in available phosphorus (37 kg/ha) and potassium (285 kg/ha). The total rainfall received during the crop growth period was 801.0 mm in 34 rainy days. The experiment was laid out in randomized block design with ten organic weed management practices with three replications. Treatments include hand weeding (HW) twice at 15 and 30 days after sowing (DAS), groundnut shells mulch 12.5 t/ha, saw dust mulch 5 t/ha, mango leaves mulch 5 t/ha, live mulching with 2 rows of cowpea, live mulching with 2 rows of sunhemp, eucalyptus leaf extract spray 15 L/ha at 15 and 30 DAS, sunflower extract spray 18 L/ha at 15 and 30 DAS, corn gluten meal 3.5 t/ha as pre- emergence (PE) *fb* HW at 30 DAS, and weedy check. Maize hybrid '*DHM-117'* was raised with recommended package of practices except for the weed management. The crop was fertilized with 240 kg N, 80 kg P and 80 kg K/ha. Nitrogen was applied in the form of urea in three equal splits, *viz.* 1/3 as basal, 1/3 at knee high stage and the remaining 1/3 at tasselling stage and entire dose of phosphorus as single super phosphate and potassium as muriate of potash was applied basally at the time of sowing. Weed management practices were imposed as per the treatments. Different organic mulches were applied on the day of sowing in between the rows of maize. Live mulches were grown up to 40 DAS and uprooted and spread on the soil surface. The required quantities of filtered concentrated plant water extracts were sprayed at 15 and 30 DAS. Weed population was counted with the help of 0.25 m^2 quadrat thrown randomly at two places in each plot and expressed as density (No./m^2). Different weed species collected for assessing the density of weeds were dried separately in a hot air oven at 65ºC till constant dry weight was reached and expressed as weed biomass (g/m^2). Due to large variation in values of weed density and biomass, the corresponding data was subjected to square root transformation $\left(\sqrt{x+0.5}\right)$ and the corresponding transformed values were used for statistical analysis as suggested by Gomez and Gomez (1984).

Five randomly selected plants were tagged in each treatment and from each replication in the net plot area and used for making observations on growth parameters and yield attributes at harvest of maize. Kernel and stover yield of maize were recorded based on the yield obtained from net plot. Net returns were calculated by subtracting the cost of cultivation from the gross returns. Benefit-cost ratio was calculated after dividing gross returns with cost of cultivation.

Weed dynamics in maize

The weed flora associated with maize belonged to thirteen different taxonomic families, of which the predominant weed species were *Dactyloctenium aegyptium* (L.) Willd (36%), *Cyperus rotundus* L. (22%), *Digitaria sanguinalis* (L.) Scop. (18%), *Boerhavia erecta* L. (11%), *Commelina benghalensis* L. (6%), *Euphorbia hirta* L. (3%) and others (4%). All the organic weed management practices significantly influenced weed density and biomass at harvest of maize (**Table 1**). Among the different organic weed management practices, lower density and biomass of grasses, sedges, broad-leaved weeds and total weeds and with higher weed control efficiency were recorded with corn gluten meal 3.5 t/ha as PE *fb* HW at 30 DAS, which was comparable with hand weeding twice at 15 and 30 DAS. The lower weed density in corn gluten meal treatment might be due to the pre-emergence herbicidal activity that efficiently reduced the germination of weed seeds (Yang and Lu 2010). Hand weeding performed at 15 and 30 DAS might effectively reduce the density of all categories of weeds as well as total weeds compared to rest of the treatments. Similar results were also reported by Ram *et al.* (2017). Among the different organic mulches and live mulches, lower weed density and biomass of total weeds coupled with higher weed control efficiency was recorded with groundnut shells mulch 12.5 t/ha, which was statistically at par with mango leaves mulch 5 t/ha, live mulching with 2 rows of cowpea and live mulching with 2 rows of sunhemp. Significantly higher density and biomass of all categories of weeds including the total weeds at harvest of maize was noticed with weedy check due to heavy weed infestation at all the stages of the crop growth as also reported by Saimaheswari *et al.* (2022).

Growth and yield of maize

The results revealed that different organic weed control measures significantly improved the growth, yield attributes and yield of maize. Growth parameters of maize, *viz.* plant height and dry matter production and yield attributes, *viz,* cob length, cob girth, number of kernels/cob, kernel weight/cob, kernel and stover yield were significantly higher with corn gluten meal 3.5 t/ha as PE *fb* HW at 30 DAS over rest of the treatments (**Table 2**). This ought to be due to pre-emergence herbicidal activity of corn gluten meal, that have controlled weeds in the initial stages of the crop growth and late emerged weeds were effectively removed by hand weeding performed at 30 DAS might have accelerated the plant growth and dry matter production that in turn reflected in the form of higher yield attributes and yield. The next best treatment was HW twice at 15 and 30 DAS, however it was at par with groundnut shells mulch 12.5 t/ha and mango leaves mulch 5 t/ha. This might be due to lower crop weed competition for growth resources throughout the crop growing period enabling the crop for maximum utilization of nutrients, moisture, light and space, which enhanced the vegetative and reproductive potential of the crop as reported by Stanzen *et al.* (2017).

Economics of maize

Highest net returns of maize were reported with mango leaves mulch 5 t/ha, which was followed by HW twice at 15 and 30 DAS and groundnut shells mulch 12.5 t/ha. This might be due to increased yields and reduced cost of cultivation in the above treatments. These findings were in close conformity with Mahto *et al.* (2020). Live mulching with 2 rows of cowpea or with 2 rows of sunhemp were the next best treatments in obtaining higher net returns, while it was lowest with corn gluten meal 3.5 t/ha as PE *fb*

Table 1. Weed dynamics at harvest of maize as influenced by organic weed management practices

Treatment	Weed density (no./m^2)				Weed biomass (g/m^2)				WCE (%)
	Grasses	Sedges	BLW	Total	Grasses	Sedges	BLW	Total	
Hand weeding twice at 15 and 30 DAS	3.53 (12.00)	4.33 (18.33)	3.58 (12.33)	6.57 (42.66)	2.79 (7.27)	3.87 (14.53)	2.76 (7.13)	5.42 (28.93)	81.70
Groundnut shells mulch (12.5 t/ha)	4.56 (20.33)	5.58 (30.67)	4.33 (18.33)	8.35 (69.33)	3.56 (12.07)	4.88 (23.30)	3.46 (11.53)	6.88 (46.90)	74.36
Saw dust mulch (5 t/ha)	8.23 (67.33)	8.71 (75.33)	5.72 (32.33)	13.23 (174.99)	6.23 (38.35)	6.76 (45.27)	4.69 (21.50)	10.27 (105.12)	39.99
Mango leaves mulch (5 t/ha)	4.81 (22.67)	5.95 (35.00)	4.38 (18.69)	8.76 (76.36)	3.61 (12.57)	4.96 (24.20)	3.55 (12.15)	7.02 (48.92)	73.21
Live mulching with 2 rows of cowpea	5.13 (25.83)	6.31 (39.33)	4.22 (17.33)	9.10 (82.49)	3.85 (14.36)	5.00 (24.53)	3.37 (10.90)	7.09 (49.79)	72.93
Live mulching with 2 rows of sunhemp	5.17 (26.33)	6.57 (42.67)	4.26 (17.67)	9.33 (86.67)	3.93 (15.02)	5.11 (25.67)	3.42 (11.25)	7.24 (51.94)	71.69
Eucalyptus leaf extract spray 15 L/ha at 15 and 30 DAS	7.75 (59.67)	7.92 (62.33)	5.40 (28.67)	12.27 (150.67)	5.73 (32.37)	6.55 (42.53)	4.26 (17.70)	9.65 (92.60)	47.14
Sunflower extract spray 18 L/ha at 15 and 30 DAS	8.11 (65.33)	8.29 (68.33)	5.55 (30.33)	12.81 (163.99)	5.82 (33.33)	6.67 (44.06)	4.51 (19.90)	9.88 (97.29)	44.46
Corn gluten meal 3.5 t/ha as pre-emergence *fb* HW at 30 DAS	3.39 (11.00)	4.02 (15.67)	3.39 (11.00)	6.17 (37.67)	2.46 (5.60)	3.56 (12.20)	2.61 (6.33)	5.12 (25.57)	85.40
Weedy check (control)	9.95 (98.67)	10.22 (104.00)	6.47 (41.33)	15.63 (244.00)	7.55 (56.55)	9.43 (88.50)	5.51 (29.83)	13.25 (175.18)	-
LSD (p=0.05)	0.76	1.05	0.59	1.52	0.61	0.55	0.47	1.01	-

Data in parentheses are original values, which were transformed to $\sqrt{x + 0.5}$ and analysed statistically. WCE: Weed control efficiency; DAS: Days after sowing

Table 2. Growth, yield attributes and yield of maize as influenced by different organic weed management practices

Treatment	Plant height (cm)	Dry matter production (t/ha)	Cob length (cm)	Cob girth (cm)	No. of kernels/ cob	Kernel weight/ cob (g)	Kernel yield (t/ha)	Stover yield (t/ha)	Net returns (₹/ha)	B:C ratio
Hand weeding 15 and 30 DAS	228	13.32	17.3	15.1	293	96.5	6.41	7.03	72616	2.66
Groundnut shells mulch (12.5 t/ha)	223	13.11	17.2	14.9	285	91.2	6.27	6.92	70952	2.69
Saw dust mulch (5 t/ha)	179	8.67	13.1	11.5	184	58.5	3.56	4.95	23344	1.56
Mango leaves mulch (5 t/ha)	222	13.01	16.9	14.8	278	88.3	6.22	6.85	73850	2.93
Live mulching with 2 rows of cowpea	204	11.32	15.4	13.6	248	76.1	4.92	6.21	50688	2.34
Live mulching with 2 rows of sunhemp	200	11.02	15.1	13.4	235	74.7	4.85	5.90	50346	2.36
Eucalyptus leaf extract spray 15 L/ha at 15 and 30 DAS	183	9.31	13.5	12.1	204	63.5	4.04	5.19	38254	2.11
Sunflower extract spray 18 L/ha at 15 and 30 DAS	180	9.04	13.4	11.8	195	61.8	3.95	5.10	36736	2.05
Corn gluten meal 3.5 t/ha as PE *fb* HW at 30 DAS	249	14.41	18.6	16.1	328	108.2	7.29	7.65	1408	1.01
Weedy check (control)	163	6.87	11.6	10.1	161	45.3	2.65	4.21	18206	1.55
LSD (p=0.05)	15	0.73	1.2	0.9	21	9.3	0.59	0.56	4634	0.21

HW at 30 DAS, this might be due to high cost of corn gluten meal. Significantly higher benefit-cost ratio was realized with mango leaves mulch 5 t/ha, which was statistically superior to rest of the treatments. This might be due to increased yields and reduced cost of cultivation. Groundnut shells mulch 12.5 t/ha was the next best, however it was comparable with hand weeding twice at 15 and 30 DAS. Corn gluten meal 3.5 t/ha as PE *fb* HW at 30 DAS recorded significantly lower net returns and benefit-cost ratio, when compared to rest of the treatments due to high cost of corn gluten meal.

The study revealed that mango leaves mulch 5 t/ha or groundnut shells mulch 12.5 t/ha was most effective, sustainable, chemical free and economical organic weed management practice to increase the productivity and to maximize the net returns in maize under organic farming.

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RESEARCH NOTE

Long term effect of soil nutrient management on composition and structure of weed community in a cashew plantation

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ABSTRACT

Shift from conventional (integrated) to organic system of nutrient management influences the weed spectrum and species richness. Weed communities in conventionally and organically managed cashew plots were studied to assess phytosociological parameters and community diversity indices. The weed spectrum was found to have widened considerably in both systems in comparison to weed species recorded thirty years back, and was dominated by broad-leaved and grass species. Species richness was slightly lower in the organically managed plots. In both systems, broad-leaved weeds dominated, accounting for more than 78% of the population. The major broad-leaved species were *Synedrella nodiflora*, *Borreria hispida* and *Pouzolzia zeylanica*, while the major grass species were *Oplismenus burmannii*, *Brachiaria* sp. and *Panicum* sp. Community diversity indices, *viz.* Simpson's diversity index and evenness index, did not vary greatly between the two systems, indicating the uniformity of distribution of species, and lack of any major dominant species due to introduction in any one system alone.

Keywords: Cashew plantations, Diversity indices, Soil composition, Weed density, Weed spectrum

The composition and distribution of weed species in a cropping system largely depends on climate soil and agricultural practices. Crop rotation increases the species diversity, while use of herbicides is known to reduce it. Pronounced changes in the ecosystem have been observed on transition from conventional to organic system of cultivation. A reduction in the incidence of problematic weeds and increased species richness has been noted in organic production systems as observed by Liebman and Davis (2000) in sweet corn and potato. In a perennial plantation crop like cashew which covers large areas with similar abiotic characteristics, management practices would largely be responsible for the variation in weed species composition. Cashew (*Anacardium occidentale*) is an important foreign exchange earning crop of India. Planted at a spacing of 7 to 10 m, the wide interspaces between the trees are covered by a dense undergrowth of weeds, if left uncontrolled. The humid tropical climate of Kerala in the southern-most state of India, is conducive for the luxuriant growth of a wide diversity of weed species. Although weeds may offer competition to young cashew plants for water and nutrients, later on their roots occupy different niches and competition for natural resources with cashew is unlikely. The cashew is a surface feeder with about 50% of the root activity being confined to the top 15 cm of the soil, and about 72% cent of the roots within a 200 cm radius from the tree trunk (Wahid *et al*. 1989). However, luxuriant weed growth poses problems in intercultural operations and harvesting, and serves as alternate hosts for several cashew pests. Vanitha *et al*. (2014) have reported that fourteen weed species belonging to eleven families serve as alternate hosts to the most serious cashew pest, the tea mosquito bug.

Conventional system of nutrient management in the Cashew Research Station, Madakkathara, under the Kerala Agricultural University involves both organic and inorganic sources of nutrients. Herbicides are not usually applied, and mechanical weeding using slasher-fitted tractors or brush cutters are the common methods adopted for reducing weed growth in the plantation. The current study focused on organic agriculture necessitates the replacement of the integrated nutrient supply with organic sources of nutrients. Such a shift to organic system is expected to affect the weed spectrum and richness. While several studies have been conducted in annual crops to assess the magnitude and type of change, such studies are lacking in perennial crops like cashew and an investigation was, therefore conducted to assess the effect of transition from conventional to organic system of nutrient management on weed species composition, abundance and density.

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MATERIALS AND METHODS

Weed sampling was conducted in August-September of 2022 in the Cashew Research Station, Madakkathara, Thrissur under the Kerala Agricultural University. The area comes under the midland laterite zone and is located geographically at a location between 10°15' and 40°35' N latitude and between 75°15' and 76°25' E longitude, and at an elevation of 30 m above MSL. Humid tropical climate prevails in the region and the annual rainfall received in the area is around 2900 mm. The soil type is laterite with acidic pH. The experiment was carried out in 13-year-old cashew trees, consisting of several high yielding varieties, planted at a spacing of 7 x 7 m. The farm followed the conventional system of cultivation, with nutrients applied in an integrated manner as per the package of practices of the Kerala Agricultural University (KAU 2016). An organic system of cultivation was initiated in 2009 and continued up to 2021 (for 12 years) in about 30 cents area (1214m^2) of the farm with solely organic nutrient sources including farmyard manure, vermicompost, cashew leaf litter and green leaf manure. An equal area (30 cents) under the conventional system was also marked out for the purpose of the study. Weed growth was restricted in both types of cultivation by operating tractors equipped with slashers twice a year. Quadrats of 0.5 x 0.5 m were placed randomly in fifteen locations each in both conventional and organic plots. The quadrats were placed approximately at the centre, equidistant from four cashew trees. All the weed species as well as their number in each quadrat were recorded. Phytosociological measures indicating weed abundance were worked out for each species as per the standard methods proposed by Odum (1971) and Raju (1977).

Analytical characters and community diversity indices of the surveyed areas were then calculated. All parameters were recorded separately for the conventional and organic plots. The analytical characters included frequency (F, number of individual species in an area in percentage), abundance (A, number of individuals of different species in the community per unit area of their occurrence), density (D, the numerical strength of a species per unit area), relative density (RD, the numerical strength of a species in relation to total number of individuals of all species in the quadrat), relative frequency (RF, the frequency of a species in terms of its dispersion relative to that of all the rest of the species), relative abundance (RA, the abundance of a species in terms of its occurrence relative to that of all the rest of the species), important value index (IVI, the sum of relative density, relative frequency and relative dominance, which is the area covered or occupied by different species in percentage), and summed dominance ratio (SDR, the ratio of the IVI of the given species to the number of parameters used to work out the IVI). The derived or synthetic characters, *viz*. species richness (R: total number of species in a given area), Shannon-Wiener diversity index (H'), Simpson's diversity index (C) and Evenness index (J) were worked out using following equations:

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

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

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

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

The organic carbon content in the conventional plot was 0.40%, while in the organic plot it was 0.32%. Available N, P and K in the conventionally manured plots were 242, 18 and 90 kg/ha, while the corresponding figures in the organically manured plots were 232, 17 and 155 kg/ha, respectively. Soil pH was slightly higher in the organically manured plots (5.06) than in the conventionally manured plots (4.99).

Weed spectrum and occurrence

The weed species present in the Cashew Research Station, Madakkathara were compared with species documented almost 30 years ago by Salam *et al*. (1993). At that period of time, five grass species were identified, *viz*. *Pennisetum pedicellatum, P. polystachyon, Paspalum* sp., *Brachiaria* sp. and *Ischaemum indicum*. The fourteen major broad-leaved weeds recorded were *Chromolaena odorata, Mimosa pudica, Synedrella nodiflora, Elephantopus scaber, Desmodium triflorum, Glycosmis arborea, Hemidesmus indicus, Ichinocarpus frutescens, Passiflora foetida, Cyclea peltata, Tragia involucrata, Triumfetta rhomboidea, Ziziphus* sp. and *Naregamia alata.*

The list of weed species observed in the plantation after a period of thirty years revealed that the diversity had widened considerably (**Tables 1** and **2**). The current weed spectrum in the plantation was composed of broad-leaf weeds (BLWs) and grasses, with the former dominating. In the present study, under conventional nutrient management, nine grass species (22%) and 22 broad-leaved (78%) weed species were recorded. Of the grasses documented 30 years ago, only one species namely *Brachiaria* sp., persisted, while four new grasses were identified. Only *Synedrella nodiflora* and *Desmodium triflorum* of the original BLW population were identified, while many new species, particularly

Borreria hispida and *Pouzolzia zeylanica*, were abundant. Broad-leaved species were dominant in the weed community, with *Synedrella nodiflora*, *Borreria hispida*, and *Pouzolzia zeylanica* recording the highest density (**Figure 1a**), frequency, relative density and relative frequency. *Borreria hispida* and *Pouzolzia zeylanica* also recorded the highest abundance and relative abundance. These three weeds also recorded the highest importance value index and summed dominance ratio (**Table 1**). Among grasses, the dominant ones were *Brachiaria* sp., *Oplismenus burmannii* and *Panicum maximum* (**Figure 1b**). From the ecological point of view, the most important species was *Borreria hispida* (IVI of 43.15 and SDR of 11.38%), followed by *Pouzolzia zeylanica* (IVI of 29.10 and SDR of 9.71%) and *Synedrella nodiflora* (IVI of 28.70 and SDR of 9.57%). Among grasses, the major species was *Brachiaria* sp. (IVI of 18.4 and SDR of 6.15%).

The number of weed species was slightly lower in the plots applied with organic manures in which four grasses (21%) and 17 BLWs (79%) were identified. Highest densities were recorded of *Pouzolzia zeylanica, Synedrella nodiflora* and *Borreria hispida* (**Figure 2a**), the same as those in the conventionally manured plots. *Pouzolzia zeylanica* was the most dominant, recording an IVI of 45.88 and SDR of 15.29%, followed by *Synedrella nodiflora* (IVI of 39.21 and SDR of 13.07%) and *Borreria hispida* (IVI of 34.45 and SDR of 11.48%). The dominant grass weed was *Oplismenus burmannii* with an IVI of 30.33 and a SDR of 10.11%, *fb Panicum repens* (IVI of 14.67 and SDR of 4.89%) (**Table 2** and **Figure 2b**).

In arable systems, organic agricultural methods have been reported to increase the abundance of many weed species and organism groups compared with conventional methods. However, in some cases, reduction of species richness has been observed. Suppression of weeds by the addition of organic manures was reported by Jabran (2017) and was explained by the possible phytotoxic allelochemicals released after the addition of concentrated organic manures which effectively inhibited weed seed germination or caused weed seed mortality. Similar results were reported by Ghosh *et al.* (2022) in rice. However, in perennial plantations, such effects may not occur as frequent and regular soil disturbances are absent and more or less similar soil and weather conditions prevail throughout. Organic agriculture has been observed to have a stronger effect on biodiversity in arable systems (for example, in cereals) than in grassland systems (Tuck *et al.* 2014).

Composition, diversity and density of weeds are strongly influenced by the source, and dose of added nutrients like nitrogen (Ghosh *et al.* 2018). Availability of sunlight could also alter the species composition. Increased nitrogen availability in conventionally fertilized plots could have promoted the growth of

Table 1. Distribution of weed species in conventionally manured plots

Sl. no.	Weed species	Density (no./m^2)	Frequency (%)	Abundance (no./m^2)	RD (%)	RF (%)	RA (%)	IVI	SDR (%)
1.	*Ageratum conyzoides* L.	0.67	11.1	6.00	1.88	1.23	6.01	9.12	3.04
2.	*Oplismenus burmannii*	1.78	33.3	5.33	5.00	3.70	5.34	14.0	4.68
3.	*Alternanthera bettzickiana*	1.67	55.6	3.00	4.69	6.17	3.00	13.86	4.62
4.	*Asystasia gangetica*	1.22	33.3	3.67	3.44	3.70	3.67	10.8	3.60
5.	*Biophytum sensitivum*	0.89	33.3	2.67	2.50	3.70	2.67	8.87	2.96
6.	*Borreria hispida*	6.22	77.8	8.00	17.5	8.64	8.01	34.15	11.38
7.	*Brachiaria* sp.	2.67	44.4	6.00	7.50	4.94	6.01	18.4	6.15
8.	*Centrosema pubescens*	0.78	33.3	2.33	2.19	3.70	2.34	8.23	2.74
9.	*Cleome burmannii*	0.22	11.1	2.00	0.63	1.23	2.00	3.86	1.29
10.	*Commelina diffusa*	0.56	22.2	2.50	1.56	2.47	2.50	6.53	2.18
11.	*Dactyloctenium aegyptium*	0.11	11.1	1.00	0.31	1.23	1.00	2.55	0.85
12.	*Desmodium triflorum*	1.33	22.2	6.00	3.75	2.47	6.01	12.2	4.08
13.	*Digitaria sanguinalis*	0.56	11.1	5.00	1.56	1.23	5.01	7.80	2.60
14.	*Eleusine indica*	0.56	22.2	2.50	1.56	2.47	2.50	6.53	2.18
15.	*Hemidesmus indicus*	0.22	11.1	2.00	0.63	1.23	2.00	3.86	1.29
16.	*Ichnocarpus frutescens*	1.00	44.4	2.25	2.81	4.94	2.25	10.00	3.33
17.	*Ischaemum* sp.	0.22	11.1	2.00	0.63	1.23	2.00	3.86	1.29
18.	*Ludwigia parviflora*	0.33	11.1	3.00	0.94	1.23	3.00	5.18	1.73
19.	*Merremia* sp.	0.11	11.1	1.00	0.31	1.23	1.00	2.55	0.85
20.	*Merremia vitifolia*	0.44	33.3	1.33	1.25	3.70	1.33	6.29	2.10
21.	*Mikania micrantha*	0.22	11.1	2.00	0.63	1.23	2.00	3.86	1.29
22.	*Mimosa pudica*	0.56	22.2	2.50	1.56	2.47	2.50	6.53	2.18
23.	*Panicum maximum*	1.22	22.2	5.50	3.44	2.47	5.51	11.41	3.80
24.	*Paspalum conjugatum*	0.44	22.2	2.00	1.25	2.47	2.00	5.72	1.91
25.	*Phyllanthus niruri*	0.33	22.2	1.50	0.94	2.47	1.50	4.91	1.64
26.	*Pouzolzia zeylanica*	5.00	77.8	6.43	14.1	8.64	6.44	29.1	9.71
27.	*Rungia repens*	0.56	33.3	1.67	1.56	3.70	1.67	6.93	2.31
28.	*Sida rhombifolia*	0.22	11.1	2.00	0.63	1.23	2.00	3.86	1.29
29.	*Synedrella nodiflora*	4.78	88.9	5.38	13.4	9.88	5.38	28.70	9.57
30.	*Triumfetta rhomboidea*	0.44	33.3	1.33	1.25	3.70	1.33	6.29	2.10

specific weed species, as compared to organically manured plots where nutrients were only slowly available in smaller quantities from the manure and did not directly affect the weeds (Stevenson *et al.* 1997). Weed species dominating arable fields under conventional farming tended to be more nitrophilous than those species characteristic in organic farming (Rydberg and Milberg 2000). Efthimiadou *et al*. (2012) observed that N availability had a significant on weed density and biomass in sweet maize, with highest weed biomass recorded in fertilizer treatments and a similar effect was obtained with organic amendments only when double the dose was applied. The increased abundance of dicotyledonous weeds and some grasses in the present study could be related to increased N availability, tolerance to acidic soil conditions and tolerance to partial shade. Dominance of the same weeds in both systems of nutrient management could be related to the similar contents of major nutrients in the soil. Nitrogen fertilization was seen to increase growth and fresh and dry matter production of *Synedrella nodiflora* as compared to organic manure application (Suwignyo *et al*. 2020). However, in the present study, both systems had similar soil nitrogen contents leading to *S. nodiflora* being equally abundant. The high density and frequency of *Borreria hispida* in both conventionally and organically manured plots could be linked to the acidic nature of the soil as *B. hispida* is an acidophile (Rao 2000). Decreased light availability in older cashew plantations could be a factor favouring the growth of dicotyledonous weeds. Hence, cashew plantations with partial sunlight penetration are ecologically suited to *Pouzolzia zeylanica,* another dominant weed in both situations. This observation is supported by the findings of Shukla (2009), who reported that grasslands were dominated in partial or full shade by *Pouzolzia zeylanica* and *Oplismenus burmannii*, the latter grass also being an important constituent of the weed spectrum in the plantation. Shade tolerance of *Pouzolzia zeylanica* was also reported by Yang *et al.* (2019). The spread of *O. burmannii* due to partial weed slashing in shaded coffee plantations has been reported by Milberg (2003), while *Brachiaria* sp. and *Panicum* sp., which were also prominent grasses in both the systems, had been rated as medium tolerant to shade by Shelton *et al.* (1987).

Habitat analysis

Habitat analysis of the conventionally and organically manured plots revealed that all diversity indices were slightly higher in the former (**Table 3**). Higher species richness and biodiversity was recorded on integrated application of nutrients as compared to organic manures alone. It was seen that BLWs dominated in both conventionally manured and organically manured plots and hence the Simpson's diversity index was almost the same (0.91 and 0.86). Almost similar values of evenness index (0.82 and 0.79) indicated the uniformity of distribution of the species in the two systems, probably due to lack of significant variation in soil fertility. Thus, the species richness or evenness of the weed communities was not significantly affected by organic nutrient sources as compared to inorganic sources in the present study. This indicated that there was no major dominant species due to introduction, and the soil weed seed bank was not greatly influenced by organic amendments (Cordeau *et al.* 2021).

Table 2. Distribution of weed species in organically manured plots

Sl. no.	Weed species	Density (no./m^2)	Frequency (%)	Abundance (no./m^2)	RD (%)	RF (%)	RA (%)	IVI	SDR (%)
1.	*Achyranthes aspera*	0.83	33.3	2.5	3.03	4.26	4.33	11.62	3.87
2.	*Alternanthera bettzickiana*	0.67	16.7	4.0	2.42	2.13	6.93	11.48	3.83
3.	*Asystasia gangetica*	1.00	33.3	3.0	3.64	4.26	5.20	13.09	4.36
4.	*Borreria hispida*	4.17	83.3	5.0	15.15	10.64	8.66	34.45	11.48
5.	*Brachiaria* sp.	0.83	16.7	5.0	3.03	2.13	8.66	13.82	4.61
6.	*Cyclea peltata*	0.17	16.7	1.0	0.61	2.13	1.73	4.47	1.49
7.	*Elephantopus scaber*	0.17	16.7	1.0	0.61	2.13	1.73	4.47	1.49
8.	*Euphorbia geniculata*	0.33	16.7	2.0	1.21	2.13	3.46	6.80	2.27
9.	*Ficus hispida*	0.33	16.7	2.0	1.21	2.13	3.46	6.80	2.27
10.	*Ichnocarpus frutescens*	0.33	33.3	1.0	1.21	4.26	1.73	7.20	2.40
11.	*Macaranga peltata*	0.33	16.7	2.0	1.21	2.13	3.46	6.80	2.27
12.	*Merremia* sp.	0.83	66.7	1.3	3.03	8.51	2.17	13.71	4.57
13.	*Panicum maximum*	0.33	16.7	2.0	1.21	2.13	3.46	6.80	2.27
14.	*Panicum* sp.	1.17	50.0	2.3	4.24	6.38	4.04	14.67	4.89
15.	*Phyllanthus niruri*	0.17	16.7	1.0	0.61	2.13	1.73	4.47	1.49
16.	*Pouzolzia zeylanica*	6.17	83.3	7.4	22.42	10.64	12.82	45.88	15.29
17.	*Oplismenus burmannii*	3.50	66.7	5.3	12.73	8.51	9.09	30.33	10.11
18.	*Sida rhombifolia*	0.33	16.7	2.0	1.21	2.13	3.46	6.80	2.27
19.	*Synedrella nodiflora*	5.00	83.3	6.0	18.18	10.64	10.39	39.21	13.07
20.	*Triumfetta rhomboidea*	0.17	16.7	1.0	0.61	2.13	1.73	4.47	1.49
21.	*Urena lobata*	0.67	66.7	1.0	2.42	8.51	1.73	12.67	4.22

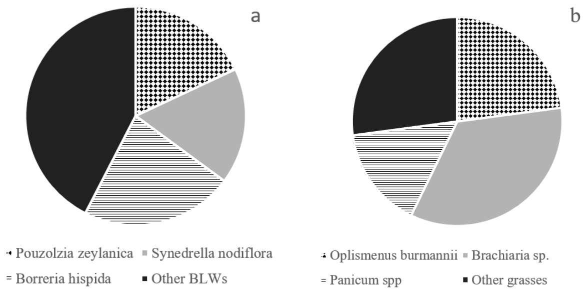

Figure 1. Major broad-leaved (a) and grass weeds (b) in conventionally manured cashew plots

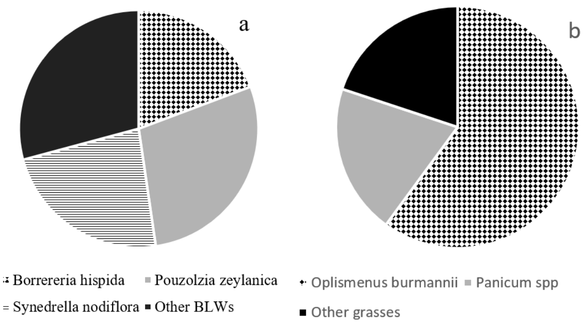

Figure 2. Major broad-leaved (a) and grass weeds (b) in organically manured cashew plots

Table 3. Diversity indices of conventionally and organically managed cashew plots

Diversity indices	Conventional management	Organic management
Species richness	31	21
Shannon-Wiener diversity index (H')	2.84	2.37
Simpson's diversity index (C)	0.91	0.86
Evenness index (J')	0.82	0.79

Conclusion

The weed community in a cashew plantation underwent a significant change in composition, species richness and abundance over a thirty-year period. A few broad-leaved species, namely *Pouzolzia zeylanica, Synedrella nodiflora* and *Borreria hispida,* dominated in the weed community. Conventional plots recorded more number of weed species than the organically managed plots. However, the evenness of the weed communities in organically and inorganically manured plots did not vary greatly, probably due to similar environmental parameters. As the quantity of N supplied was the same in both treatments, domination of specialist nitrophilic species did not occur. Ecologically safe weed management strategies through nutrient management could be developed based on these results.

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RESEARCH NOTE

Evaluation of dose and application time of topramezone for weed management in chickpea

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ABSTRACT

Application of a broad-spectrum post-emergence herbicide is a promising weed management option for chickpea (*Cicer arietinum* L.). So, the goal of this experiment was to find out how much and when to use topramezone to control weeds in chickpea. The experiment was designed in RBD of ten treatments, *viz.* two different doses of topramezone 20.6 and 25.7 g/ha were applied at 14, 21, and 28 days after sowing (DAS) and quizalofop-p-ethyl 100 g/ha at 25 DAS applied as post-emergence (PoE). The ready-mix of pendimethalin 30% + imazethapyr 2% 1000 g/ha applied as pre-emergence (PE) *fb* one HW at 30 DAS, weed free check, (WFC) and weedy check (WC). Among different application times of topramezone sprayed, early-PoE application (14 DAS) caused some phytotoxicity on crop (rating 4), and late-PoE application (28 DAS) was less effective on weeds, but the application of topramezone at 21 DAS controlled all broad and narrow leaf weeds without crop injury. In all the topramezone sprayed plots, topramezone 25.7 g/ha (21 DAS) had the lowest narrow and broad-leaf weeds density, and total weed dry weight than other doses and application times. Among all PoE herbicide treatments, topramezone 25.7 g/ha (21 DAS) yielded the highest seed yield (1.31 t/ha), while quizalofop-p-ethyl 100 g/ha (25 DAS) yielded the lowest (0.79 t/ha). It produced 7-65% higher seed yield as compared to other doses and time of application of all PoE applied herbicides. It gave 81% and 116% higher net return than topramezone 25.7 and 20.6 g/ha sprayed at 28 DAS (late-PoE), and 159% and 259% higher than topramezone 25.7 and 20.6 g/ha sprayed at 14 DAS (early-PoE), respectively. Hence, topramezone application of 25.7 g/ha (21 DAS) can be safely used for proper weed management in the chickpea crop.

Keywords: Chickpea, Chemical control, Early-PoE and Late-PoE, Imazethapyr, Phytotoxicity, Topramezone, Weed management

Chickpea is the major pulse crop in India. The cultivated area of chickpea in India has been constantly increasing though, the productivity has not substantially increased during this period (Samriti *et al.* 2020). It is a well-known fact that productivity of chickpea is affected by various biotic and abiotic factors. Poor weed management is one of the factors of the reduction in chickpea productivity (Rathod *et al*. 2017) and affects its productivity adversely. Chickpea is a poor weed competitor due to its slow initial growth rate, on the contrary, weeds grow fast and compete with crop for nutrients, space, and water (Chaudhary *et al.* 2005, Rao, 2000), hence, reduced chickpea yield up to 70–80%. The initial 30-60 days of the crop growth period are very important for crop weed competition in chickpea (Kumar and Singh 2010). Farmers generally manage weeds in chickpea by pre-emergence herbicides and/or hand weeding (Kumar *et al.* 2015), but due to scarcity and the higher cost of labour, manual weeding is difficult and less economic. Application of pre-emergence (PE) herbicides does not control the second flushes and many weeds. Post-emergence (PoE) herbicide like quizalofop-p-ethyl at 100 g/ha is recommended for narrow-leaf weeds, but dominated broad-leaf weeds caused crop yield loss (Nath *et al.* 2018). Therefore, weed control by herbicides is inevitable, and farmers need a broad-spectrum herbicide for effective weed management in chickpea. Topramezone is a new highly selective pyrazole-structured herbicide known to control broad-spectrum weeds in maize but their selectivity and efficacy not well established in chickpea. Topramezone treatment results in strong photo-bleaching symptoms on the shoots, followed by (*fb*) sensitive weed plant death. 4-HPPD activities are strongly inhibited by topramezone and targeted plant bleach after exposure to sunshine, and perish as a result. So, it requires studying the proper dose and time of application of topramezone in chickpea. If this herbicide found selective, it would be helpful for controlling all broad- and narrow-leaf weeds in chickpea. Taking all these things into consideration, the current experiment was done to find the best dose and time to apply topramezone to control weeds in chickpea.

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A field experiment was carried out at an agronomical research farm, TCA, Dholi, Muzaffarpur (Bihar) during *Rabi* (winter) season of 2020-21. It is situated in the mid Indo-Gangetic area and lies at 25° 99' North latitude, 85° 60'East longitude, and an altitude of 52.18 m above mean sea level. The soil in the field was sandy-loam with organic carbon (0.45%), available nitrogen (239 kg/ha), phosphorus (17.6 kg/ha), potassium (128 kg/ha), EC 1.13 dS/m, and pH 7.84. The experiment was designed in randomized block consisted of 10 treatments, *viz*. topramezone 20.6 g/ha at 14 days after sowing (DAS) (as early-PoE), 21 DAS (as PoE) and 28 DAS (late-PoE), topramezone 25.7 g/ha at 14 DAS (early-PoE), 21 DAS (PoE) and 28 DAS (late-PoE), and quizalofop-p-ethyl 100 g/ha at 25 DAS applied as post-emergence (PoE). The ready-mix pendimethalin 30% + imazethapyr 2% at 1000 g/ha was applied as pre-emergence (PE) *fb* one HW at 30 DAS, weed free check (two hand weeding at 30 and 50 DAS), (WFC) and weedy check (WC). The variety of chickpea was *GNG-2299* (*Awadh*)**.** At the time of field preparation, the entire recommended dose of N, P, K and Zn (20, 40, 20 and 25 kg/ha, respectively) was applied as a basal dose. Before sowing, seeds were treated with *Rhizobium* culture, phosphate solubilizing bacteria (PSB) culture (200 g/10 kg seed) and thiram (2.5 g/kg seed). The crop was sown on November 10th, 2020 at 30 × 10 cm spacing (R × P) and harvested on April 3rd, 2021. The calculated dose of herbicides, as per treatment, was mixed with water and sprayed over the plot by a knapsack sprayer. One day after sowing, PE herbicide ready-mix of pendimethalin 30% + imazethapyr 2% was sprayed, PoE herbicides were applied as per schedule, and two-hand weeding (HW) were done at 30 and 50 DAS. The only pod borer major pest was seen in field, which was kept in check by the spraying chlorpyrifos insecticide. Weeds were counted using a quadrate of 0.25 square meter (0.5 × 0.5 m), and data obtained were expressed as density (no./m^2) at 60 and 90 DAS. These weeds species were identified and divided in groups of sedges, narrow leaf weeds and broad leaf weeds. To record weed biomass, weeds within each square was trimmed close to the ground, washed with tap water, and after sun drying, the samples were placed in an oven at 70 °C until a constant weight was achieved. Subsequently, the dried samples were measured in grams (g) and the dry weight was converted to grams per square meter (g/m^2). The grain yield was taken from each plot and expressed in kg/ha at 12% moisture content. Economic analysis was done as per the prevailing cost of inputs and selling price of output as per the concerning year. Visual scoring for phytotoxicity (*like*-chlorosis, burning, and death) was undertaken of PoE applied herbicides up to 15 days after application on a 0-10 scale for crop. For chickpea, 0 meant no phytotoxicity and 10 meant complete death of the plant, and a score of <3 was considered acceptable. For the statistical analysis weed density and biomass were converted to 1 m^2 and imposed square root transformation by using formula ($\sqrt{x + 0.5}$) before analysis. The grain yield was taken by 1 m^2 area from the centre of each plot and expressed in kg/ha. Economic analysis was done as per the prevailing cost of inputs and selling price of output as per the concerning year. Statistical analysis was done by adopting appropriate method of Analysis of Variance (Gomez and Gomez 1984). For each species and category, weed density and dry weight necessitate square-root transformation. Treatment means were compared using a protected least significant difference test at p=0.05.

Effect on weeds

Narrow-leaf or grassy weeds (*Cynodon dactylon, Echinochloa colona,* and *Avena fatua*), broad-leaf weeds (*Cannabis sativa*, *Chenopodium album, Melilotus albus,* and *Anagallis arvensis*), and sedges (*Cyprus rotundus*) were the most common in the experimental field. All weed management practices reduced the total weed density and weed dry weight over the weedy check. The application of ready mix of pendimethalin 30% + imazethapyr 2% + single HW had the lowest total weed density and dry matter (**Table 1** and **2**), which was significantly lower than all herbicide treatments except topramezone 25.7 g/ha applied at 21 DAS. It is due to the ready-mix of pendimethalin 30% + imazethapyr 2% herbicide persist in the soil, suppressed germination of weeds, and at 30 DAS, weeds are removed manually, leading to the lowest weed density. Topramezone 25.7 g/ha (21 DAS) suppressed all narrow-leaf weeds (NLWs) and broad- leaf weeds (BLWs), and had lowest total weed density and weed dry matter than other topramezone applied treatments. It reduced total weed density and weed dry weight by 77-83% and by 78-81%, respectively as compared to weedy control treatment. It also recorded significantly lower weed dry weight than other doses and time of applications of topramezone. Similarly, Mahto *et al.* (2020) reported, 25.2 g/ha dose of topramezone recorded lowest weed density and weed dry weight as compared to other doses.

Species wise weed density and dry weight

With a relative density (RD) of 69%, the BLWs were the most common plants in the experimental research control plot. The narrow-leaf weeds (NLW) and sedges came in second and third, with RDs of 10% and 21%, respectively. Among all PoE applied herbicides, either dose or time of application did not affect the sedges The lowest NLW density recorded under quizalofop-p-ethyl treatment and it was significantly over by other PoE applied herbicides but at par with topramezone 21 DAS treatment. Topramezone 25.7 g/ha (21 DAS) had lowest NLW density than other topramezone treatments. It decreased NLWs density by 39-52% and 44-57% as compared to early and early-PoE applications of topramezone (14 and 28 DAS) at 60 to 90 DAS. respectively.

Effect on BLW weeds

All practices of weed management significantly reduced BLW density as compared to unweeded treatment except quizalofop-p-ethyl 100 g/ha sprayed at 25 DAS. Among different doses and time of applications of topramezone, 25.7 g/ha at 21 DAS reduced BLWs density by 59-66% and 60-69% at 60 and 90 DAS, respectively than other doses and application times.

Weed control efficiency and weed index

Application of ready-mix of pendimethalin 30% + imazethapyr 2% 1000 g/ha as PE + HW at 30 DAS significantly reduced the weeds growth and resulted in the highest WCE (89.6%) and the lowest value of weed index (4.3%). Topramezone 25.7 g/ha (21 DAS) recorded the highest WCE, both at 60 and 90 DAS (81.0 and 77.7%, respectively), lowest WI (17.3%) compared with other PoE applied herbicides (**Table 2**).

Herbicide phytotoxicity

Herbicide phytotoxicity observations were recorded at 1, 3, 5, 8, 11 and 15 days after herbicide spraying, chlorosis and necrosis like symptoms were observed on crop plants in early-PoE application (**Table 3**). Topramezone acts by inhibiting 4-hydroxy-phenyl-pyruvate dioxygenase (HPPD) enzyme and preventing carotenoid biosynthesis, which lead to photo-oxidation of chlorophyll molecules (Wang *et al*., 2018). Crop phytotoxicity of topramezone after herbicide application varied with dose and time of application. Spray of topramezone 25.7 g/ha at 14 and 21 DAS, both controlled weed properly but early-PoE (14 DAS) dose caused some phytotoxic effects on the crop (rating 3-4), as well as weeds also emerged at later stage, due to slow early growth of crop. When topramezone applied as late-PoE (28 DAS), it was unable to control weeds due to weeds at later stage becomes hardy in nature and topramezone not effective against weeds at this stage. So, topramezone 25.7 g/ha PoE (21 DAS) application was safe for crop and also controlled all narrow and broad-leaf weeds.

Yield and economics

The highest seed yield (kg/ha) was observed in two hand weeded treatment, which yielded 221% more, than the weedy check treatment, despite the weedy check decreased crop yield by 56%. Similarly, Yadav *et al.* (2019) reported weeds infestation reduced 69% chickpea yield. Among all herbicidal treatments, pre-emergence spray of ready mix of pendimethalin 30% + imazethapyr 2% 1000 g/ha + single hand weeding produced the highest seed yield (1504 kg/ha), which was significantly higher than other herbicidal treatments and recorded 209% more seed yield, also generated 4.95 times more net return, than the weedy check. Among PoE herbicide applications, highest seed yield was obtained from topramezone 25.7 g/ha (21 DAS) treatment, it produced 82% higher seed yield over weedy check

Table 1. Effect of herbicide application on weed density (no./m²)

Treatment	Sedge		NLW		BLW		Total weed density	
	60 DAS	90 DAS	60 DAS	90 DAS	60 DAS	90 DAS	60 DAS	90 DAS
Topramezone 20.6 g/ha at 14 DAS (early-PoE)	4.11(16.6)	2.95(8.2)	3.93(15.0)	3.73(13.5)	7.38(54.2)	6.81(46.1)	9.27(85.8)	8.25(67.8)
Topramezone 20.6 g/ha at 21 DAS (PoE)	3.88(14.6)	2.96(8.3)	3.35(10.8)	3.21(9.8)	5.36(28.3)	4.68(21.5)	7.36(53.7)	6.32(39.6)
Topramezone 20.6 g/ha at 28 DAS (late-PoE)	3.81(14.1)	2.75(7.1)	3.64(12.9)	3.49(11.8)	7.39(54.3)	6.73(45.0)	9.02(81.2)	8.01(63.9)
Topramezone 25.7 g/ha at 14 DAS (early-PoE)	4.15(16.9)	3.14(9.4)	4.10(16.3)	3.95(15.2)	8.03(64.1)	7.29(52.9)	9.88(97.3)	8.81(77.5)
Topramezone 25.7 g/ha at 21 DAS (PoE)	3.68(13.2)	3.01(8.6)	3.08(9.1)	2.64(6.5)	4.69(21.6)	4.09(16.3)	6.65(44.0)	5.65(31.4)
Topramezone 25.7 g/ha at 28 DAS (late-PoE)	3.96(15.3)	2.77(7.2)	3.53(12.0)	3.37(10.9)	7.25(52.4)	6.44(41.2)	8.95(79.7)	7.72(59.3)
Quizalofop-p-ethyl 100 g/ha at 25 DAS (PoE)	3.59(12.5)	3.31(10.5)	2.98(8.4)	2.94(8.2)	11.2(125.7)	10.2(103.3)	12.12(146.5)	11.0(122.0)
Ready mix of pendimethalin 30% + imazethapyr 2% 1000 g/ha (PE) + HW at 30 DAS	2.86(7.8)	1.90(3.1)	2.73(7.0)	2.12(4.0)	4.31(18.2)	3.46(11.5)	5.76(33.0)	4.36(18.6)
Two HW at 30 DAS and 50 DAS (WFC)	1.68(2.3)	1.38(1.4)	2.04(3.7)	2.00(3.5)	3.13(9.3)	2.98(8.4)	3.98(15.3)	3.71(13.3)
Weedy check (WC)	4.54(20.2)	3.92(14.9)	6.42(41.0)	5.72(32.4)	11.5(132.7)	10.7(114.8)	13.9(193.9)	12.7(162.1)
LSD (p=0.05)	0.68	0.22	0.61	0.48	0.89	0.86	0.93	1.01

DAS = Days after sowing, NLW = Narrow-leaved weed, BLW = Broad-leaf weed; Transformed value = $\sqrt{(x+0.5)}$). Original values are given in the parentheses

Table 2. Effect of herbicide application on total weed density, total weed dry weight, WCE and WI

Treatment	Total weed dry weight (g/m^2)		WCE (%)		WI (%)	Seed yield (kg/ha)	Net return (₹/ha)	BCR
	60 DAS	90 DAS	60 DAS	90 DAS				
Topramezone 20.6 g/ha at 14 DAS (early-PoE)	6.97$^{\#}$ (48.1)	16.7 (280)	54.7	42.5	44.0	886	12769	1.40
Topramezone 20.6 g/ha at 21 DAS (PoE)	5.17 (26.3)	11.8 (139)	75.3	71.4	22.8	1222	29573	1.93
Topramezone 20.6 g/ha at 28 DAS (late-PoE)	6.60 (43.1)	15.5 (239)	59.4	50.7	40.7	938	15322	1.48
Topramezone 25.7 g/ha at 14 DAS (early-PoE)	7.05 (49.2)	17.9 (321)	53.6	33.9	47.4	832	9219	1.28
Topramezone 25.7 g/ha at 21 DAS (PoE)	4.55 (20.2)	10.4 (108)	81.0	77.7	17.3	1308	33085	2.01
Topramezone 25.7 g/ha at 28 DAS (late-PoE)	6.23 (38.4)	13.8 (190)	64.0	60.9	36.0	1012	18282	1.56
Quizalofop-p-ethyl 100 g/ha at 25 DAS (PoE)	7.37 (53.8)	20.6 (423)	49.5	13.2	49.8	794	10461	1.35
Ready mix of pendimethalin 30% + imazethapyr 2% 1000 g/ha (PE) + HW at 30 DAS	3.40 (11.1)	8.1 (65)	89.6	86.7	4.3	1504	40670	2.17
Two HW at 30 DAS and 50 DAS (WFC)	1.54 (1.9)	5.2 (27)	98.2	94.5	0.0	1582	39204	1.98
Weedy check (WC)	10.35 (106.8)	22.1 (488)	0.0	0.0	54.7	717	8216	1.29
LSD (p=0.05)	0.36	0.71	-	-	-	287.19	14363.33	0.43

Transformed value = $\sqrt{(x+0.5)}$). Original values are given in the parentheses

Table 3. Effect of herbicides applications on crop phytotoxicity

Treatment	Phytotoxicity rating
Topramezone 20.6 g/ha at 14 DAS	3
Topramezone 20.6 g/ha at 21 DAS	2
Topramezone 20.6 g/ha at 28 DAS	1
Topramezone 25.7 g/ha at 14 DAS	4
Topramezone 25.7 g/ha at 21 DAS	3
Topramezone 25.7 g/ha at 28 DAS	2

treatment and also giving 7-57% higher seed yield as compared to other doses and time of application of topramezone treatments. It gave maximum net return than topramezone 20.6 and 25.7 g/ha early- late-PoE application (14 and 28 DAS). It was recorded the highest B: C ratio than all other PoE herbicidal treatments (**Table 2**). It could be due to higher uptake of plant nutrients and soil moisture in comparison to other plots, resulting in more photosynthates translocated from source to sink. Tiwari *et al.* (2018) reported in maize, higher dose of topramezone (25.2 g/ha) was found significantly superior over lower dose of topramezone (13.4 g/ha). Whereas, topramezone 20.6 and 25.7 g/ha (early-PoE) controlled weeds effectively but new weeds emerged at later stage due to slow initial growth of chickpea. However, other two doses of topramezone 25.7 and 20.6 g/ha (late-PoE) gave lower weed control efficiency, because at later stage weeds becomes hardy in nature and then tolerant to herbicide, and finally decreased crop yield.

Conclusion

Topramezone 25.7 g/ha (21 DAS) was best option for controlling all narrow- and broad-leaved weeds in chickpea as compared to other early and late post-emergence herbicdes applications. It recorded the highest WCE, lowest total weed density and weed dry matter, maximum seed yield than other topramezone treatments. Hence, it can be effectively utilized in future for its selectivity, and future research should conduct for its doses and application time optimization.

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RESEARCH NOTE

Production potential and economics of integrated weed control measures in ginger

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ABSTRACT

A field experiment was carried out in 2014 and 2015 to evaluate the effect of integrated weed management on growth, yield, weed control efficiency and economics of ginger. The experiment was laid out in a randomized block design with nine integrated weed management treatments and three replications. The results revealed that hand weeding twice at 30 and 60 days after planting (DAP) recorded the lowest weed population 6.20 and 7.38/m^2, dry weight 11.80 and 10.23 g/m^2 at 75 DAP and the highest weed control efficiency (WCE) 85.0 and 86.6% in 2014 and 2015, respectively, which was followed by application of glyphosate 0.80 kg/ha + pendimethalin 1.5 kg/ha and glyphosate 0.80 kg/ha + oxyfluorfen 0.2 kg/ha before the emergence of sprouts of ginger in both years. However, glyphosate 0.80 kg/ha + pendimethalin 1.5 kg/ha (25 DAP) and glyphosate 0.80 kg/ha + oxyfluorfen 0.20 kg/ha (25 DAP) significantly improved the rhizome yield to the tune of 86.9, 81.5 and 91.8, 93.9% over the control during the years, respectively. The highest B: C (2.07) was obtained with glyphosate 0.80 kg/ha + oxyfluorfen 0.20 kg/ha (25 DAP) followed by unweeded control. Hence, it was concluded that for better ginger productivity and weed management two-hand weeding at 30 and 60 DAP; or application of glyphosate 0.80 kg/ha + oxyfluorfen 0.2 kg/ha is the most potential and viable practice.

Keywords: Economics, Ginger, Glyphosate + oxyfluorfen, Hand weeding, Yield, Weed control efficiency

Tropical and subtropical regions cultivate ginger (*Zingiber officinale* Roscoe) for its culinary and therapeutic uses. Ginger has been grown since ancient times and India is currently one of the world's top producers. This crop produces a good yield, and since it is a cash crop, its profitability is better than that of other crops growing at that time (Choudhary *et al*. 2015). Due to its guaranteed better yield, demand, and market availability, ginger farming has recently got a boost in the area (Kushwaha *et al*. 2013). Ginger is highly vulnerable to weed infestation, due to its slow emergence and long growing season. Weed causes yield losses and requires much monetary investment to save the crop (Rahaman *et al.* 2009).

In Bihar state of India, weeds are typically controlled manually, which is a time-consuming and an expensive process. Occasionally owing to a labour shortage and unexpected rains, hand weeding and mechanical operations are frequently either postponed or abandoned that frequently results in crop loss. Herbicides are also less effective due to the heavy rains, Moreover, continuous and intensive use of herbicide over a period of time leads to the development of resistant biotypes within the weed community (Singh *et al.* 2023). Organic mulching is also not standardized for this area, although it is an excellent way to control weeds in ginger (Chatterjee *et al*. 2011). Therefore, timely weed control is essential for optimizing the yield of ginger. Furthermore, the integration of different weed management practices holds great promise for effective, timely and economical weed management. Thus, the present study was carried out to quantify the efficacy of the integration of different weed management practices and herbicides used either alone or in combination with other herbicides at different times to manage weeds and improve ginger yield.

A field study was conducted during two successive years (2014 and 2015) at the Agricultural Research Farm of Tirhut College of Agriculture, Dholi, Dr. RPCAU, Pusa. The experiment was laid out in a randomized block design with 3 replications. The experiment was comprised of nine weed management treatments follows: pendimethalin 1.5 kg/ha (after planting but before mulching (20 days after planting, DAP)); oxyfluorfen 0.20 kg/ha (after

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planting but before mulching (20 DAP)); pendimethalin 1.5 kg/ha *fb* hand weeding (after planting but before mulching (20 DAP) *fb* 30-35 DAP); oxyfluorfen 0.20 kg/ha *fb* hand weeding (after planting but before mulching (20 DAP)) *fb* 30-35 DAP); glyphosate 0.80 kg/ha (just before emergence of sprouts of ginger (25 DAP); glyphosate 0.80 kg/ha + pendimethalin 1.5 kg/ha (just before emergence of sprouts of ginger (25 DAP)); glyphosate 0.80 kg/ha + oxyfluorfen 0.20 kg/ha (just before emergence of sprouts of ginger (25 DAP); hand weeding (twice at 30 and 60 DAP); unweeded control. The soil of the experimental plot was sandy loam in texture, alkaline in reaction (pH 8.52), low in organic carbon (0.44 %), available N (272 kg/ha), P (18.05 kg/ha) and K (144.6 kg/ha). The ginger variety "Nadia" (a variety with 270–300 days maturity, slender rhizome with less fibre) was planted in an individual plot of 20 m^2 at the spacing of 25 x 20 cm. The uniform dose of fertilizer used was 80:50:100 (N-P-K kg/ha). A stock solution of the respective quantity of each herbicide was prepared separately, by dissolving in half a liter of water and made up to the required quantity of spray solution (spray volume) by adding water. The spray solution of 600 L/ha was applied with a knapsack sprayer by using a flat fan nozzle. Mulching was done by using leaf biomass 5 t/ha. The crop was raised as a rainfed crop. All the necessary cultural practices were carried out uniformly to bring the crop to maturity. Weeds were counted at 75 DAP using a quadrat of 0.25 square meters (0.5 x 0.5 m), and the data obtained were expressed as density (no./m^2). The percent composition of weed flora was estimated from a weedy check plot. To record weed biomass weeds were cut at ground level, sun-dried in a hot air oven at 70 °C for 48 hrs and then weighed. Plant height (cm) was determined by randomly picking ten plants from each plot at 180 DAP and averaged. The number of effective tillers was obtained by counting them inside a 1 m^2 quadrate from four distinct sites within each plot at 180 DAP and taking the average. Similarly, number of leaves per plant were measured at 180 DAP. For the statistical analysis weed density and biomass were converted to 1 m^2 and imposed square root transformation by using a formula before analysis. Economic analysis was carried out by including all the variable costs (rhizome, manure, chemicals, labour, mulch materials, *etc*.) and their respective units used during the experiment. The prevalent market price of the produce was considered to calculate gross and net returns and finally, the benefit-cost ratio, an indicative of gross return per rupee investment, was calculated as follows: B: C ratio = gross return/cost of cultivation.

Statistical analysis was done by adopting the appropriate method of analysis of variance (Gomez and Gomez 1984) and mean comparisons were performed based on the least significant difference (LSD) at 0.05 probability.

Effect on weeds

All the integrated weed management treatments reduced the weed density and weed dry weight as compared to unweeded control in both the years at 75 DAP (**Table 1**). Unweeded control recorded significantly the highest number of weeds and dry

Table 1. Weed density, weed dry weight and weed control efficiency at 75 DAP of ginger as influenced by integrated weed management practices

Treatment	Weed density (no./m^2)		Weed dry weight (g/m^2)		Weed control efficiency (%)	
	2014	2015	2014	2015	2014	2015
Pendimethalin 1.5 kg/ha after planting but before mulching (20 DAP)	29.20	31.57	52.70	53.52	32.9	30.0
Oxyfluorfen 0.20 kg/ha after planting but before mulching (20 DAP)	30.60	32.35	55.40	56.48	29.4	26.1
Pendimethalin 1.5 kg/ha *fb* hand weeding (after planting but before mulching (20 DAP) *fb* 30-35 DAP)	20.40	18.89	37.60	38.62	52.1	49.5
Oxyfluorfen 0.20 kg/ha *fb* hand weeding (after planting but before mulching (20 DAP) *fb* 30-35 DAP)	20.70	19.73	38.80	39.37	50.6	48.5
Glyphosate 0.80 kg/ha (just before emergence of sprouts of ginger 25 DAP)	25.80	27.21	45.40	44.48	42.2	41.8
Glyphosate 0.80 kg/ha + pendimethalin 1.5 kg/ha (just before emergence of sprouts of ginger 25 DAP)	12.60	13.21	22.80	23.05	71.0	69.8
Glyphosate 0.80 kg/ha + oxyfluorfen 0.20 kg/ha (just before emergence of sprouts of ginger (\25 DAP)	11.40	12.46	21.40	22.12	72.7	71.1
Hand weeding (twice at 30 and 60 DAP)	6.20	7.38	11.80	10.23	85.0	86.6
Unweeded control	42.40	45.15	78.50	76.46	-	-
LSD (p=0.05)	4.20	2.62	5.26	3.22	-	-

DAP: Days after planting

matter of weeds than all other treatments. Hand weeding twice at 30 and 60 DAP recorded the lowest weed density 6.20 and 7.38/m^2 and dry weight of weeds 11.80 and 10.23 g/m^2, which was statistically at par with glyphosate 0.80 kg/ha + pendimethalin 1.5 kg/ha (just before emergence of sprouts of ginger (25 DAP) and glyphosate 0.80 kg/ha + oxyfluorfen 0.20 kg/ha (just before emergence of sprouts of ginger 25 DAP) and significantly superior over rest of the treatments in both the, respectively. The weed dry matter was 72.8% and 71.1% in 2014 and 2015, respectively which was lower in both years with the application of glyphosate 0.80 kg/ha + oxyfluorofen 0.2 kg/ha (before emegence of sprouts of ginger) than the unweeded control. This might be due to the application of pre-emergence herbicide, which effectively hindered the germination of weed seeds or hand weeding at 30 and 60 DAP and effectively controlled the latter emerged weeds. Moreover, Sathya Priya *et al.* (2013) recorded lesser weed density and dry weight with pre-emergence application of oxyfluorfen 200 g/ha in onion.

Weed control efficiency (WCE) denotes the magnitude of increase in yield due to weed control. In both years, the highest WCE (85.0%, 86.6%) were recorded in the plots receiving 2 hand weeding (30 and 60 DAP) which was closely followed by glyphosate 0.80 kg/ha + pendimethalin 1.5 kg/ha (just before emergence of sprouts of ginger (25 DAP)) (71.0%, 69.9%) and glyphosate 0.80 kg/ha + oxyfluorfen 0.20 kg/ha (just before emergence of sprouts of ginger 25 DAP) (72.7%, 71.1%), respectively. The lowest WCE was recorded in weedy check plots. The results confirmed the findings of Channappagouder and Biradar (2007) and Sampat *et al.* (2014).

Effect on ginger

The main growth contributing factors, *viz.* plant height, number of leaves per plant and number of tilers per plant were significantly influenced by different weed control treatments (**Table 2**). Among the treatments, unweeded control recorded significantly lower plant height, number of tilers per plant, and number of leaves per plant due to weed competition. Hand weeding twice at 30 and 60 DAP showed maximum plant height 56.5 and 57.5 cm and number leaves per plant 23.5 and 24.2, which was statistically at par with glyphosate 0.80 kg/ha + pendimethalin 1.5 kg/ha (just before emergence of sprouts of ginger 25 DAP) and glyphosate 0.80 kg/ha + oxyfluorfen 0.20 kg/ha (just before emergence of sprouts of ginger 25 DAP) and significantly superior over rest of the treatments in both the years (2014 and 2015), respectively. A similar trend was followed in number of tillers per plant. In 2014 and 2015 in both years, the number of tillers/plant was recorded 45.0 and 57.4%, respectively which was higher over the application of glyphosate 0.80 kg/ha + oxyfluorfen 0.2 kg/ha (before emegence of sprouts of ginger) than the unweeded control. This was attributed to timely and effective control of weeds, which might have increased the availability of moisture, nutrients, and solar radiation to the ginger.

However, All the weed control treatments differed in influencing fresh rhizome yield of ginger. Hand weeding twice at 30 and 60 DAP recorded significantly higher rhizome yield 21.32 and 22.43 t/

Table 2. Effects of integrated weed management practices on growth attributes and yield of ginger

Treatment	Plant height (cm)		No. of tillers per plant		No. of leaves per plant		Rhizome yield (t/ha)	
	2014	2015	2014	2015	2014	2015	2014	2015
Pendimethalin 1.5 kg/ha after planting but before mulching (20 DAP)	51.7	52.0	24.2	24.0	19.2	20.2	15.75	16.89
Oxyfluorfen 0.20 kg/ha after planting but before mulching (20 DAP)	51.2	51.7	23.8	22.9	18.8	19.1	15.12	16.05
Pendimethalin 1.5 kg/ha *fb* hand weeding (after planting but before mulching (20 DAP) *fb* 30-35 DAP)	54.4	54.0	26.3	26.1	20.7	21.0	18.88	19.12
Oxyfluorfen 0.20 kg/ha *fb* hand weeding (after planting but before mulching (20 DAP) *fb* 30-35 DAP)	53.8	53.5	25.7	26.1	20.2	20.9	18.23	18.46
Glyphosate 0.80 kg/ha (just before emergence of sprouts of ginger 25 DAP)	53.2	53.0	24.7	24.1	19.6	20.1	16.92	17.08
Glyphosate 0.80 kg/ha + pendimethalin 1.5 kg/ha (just before emergence of sprouts of ginger 25 DAP)	55.9	55.7	29.6	30.1	22.1	23.0	20.32	19.95
Glyphosate 0.80 kg/ha + oxyfluorfen 0.20 kg/ha (just before emergence of sprouts of ginger 25 DAP)	56.1	56.1	30.2	31.3	22.8	23.5	20.85	21.32
Hand weeding (twice at 30 and 60 DAP)	56.5	57.5	31.5	32.5	23.5	24.2	21.32	22.43
Unweeded control	48.3	47.1	20.9	19.9	16.4	15.8	10.87	10.99
LSD (p=0.05)	3.3	3.4	2.6	3.1	3.1	3.1	3.18	3.67

DAP: Days after planting

ha, respectively. It was statistically at par with the remaining other weed control treatments (**Table 2**) during both years. Two hand weeding treatments provided the season-long weed-free conditions hence resulted in appreciably higher yield than other treatments. Moreover, the application of glyphosate 0.80 kg/ha + pendimethalin 1.5 kg/ha and glyphosate 0.80 kg/ha + oxyfluorfen 0.2 kg/ha both before emegence of sprouts of ginger was the next superior treatment with respect to rhizome yield, as they improved the rhizome yield to the tune of 86.9, 81.5 and 91.8, 93.9% over the control in both years in 2014 and 2015, respectively. These treatments kept the crop almost weed free up to 75 days which markedly reduced the competition for nutrients and other resources by weeds which ultimately reduced weed dry matter production and nutrient depletion. However, improved growth parameters might have helped the plant to produce more photosynthates and translocation towards the sink *i.e.* rhizome. This accumulation of photosynthates helped the plant to develop more mother, primary and secondary rhizomes which ultimatey led to higher rhizome yield. The results were in agreement with those of Barooah *et al.* (2010) and Eshetu and Addisu (2015) who also obtained better crop growth and higher yield of ginger through effective weed control.

The rhizome yield of ginger was negatively associated with weed population (r = -0.986, -0.979) and weed dry weight (r = - 0.988, -0.973); during the year 2014 and 2015 respectively. Irrespective of species, with every one weed/m^2 increase in population of weeds, ginger rhizome yield would be expected to fall by 0.293, 0.275 t/ha (Y= 24.073 – 0.293x, R^2= 0.973, Y= 24.401 – 0.275x, R^2= 0.958). Similarly, every g/m^2 increase in biomass of weeds would result in 0.161, 0.162 t/ha loss in rhizome yield of ginger (Y= 24.112 – 0.161x, R^2= 0.977, Y= 24.577 – 0.162x, R^2= 0.948). Weed control efficiency of ginger followed the linear relationship with rhizome yield during both years respectively (R^2 = 0.9662 and 0.9514, **Figure 1a and b**).

Economics

The economic parameters largely depend on the economic yield of crop and production cos. The hand weeding twice at 30 and 60 DAP recorded the highest gross returns (₹ 2,24,320) and net returns of ₹ 1,12,230, which was followed by pendimethalin 1.5

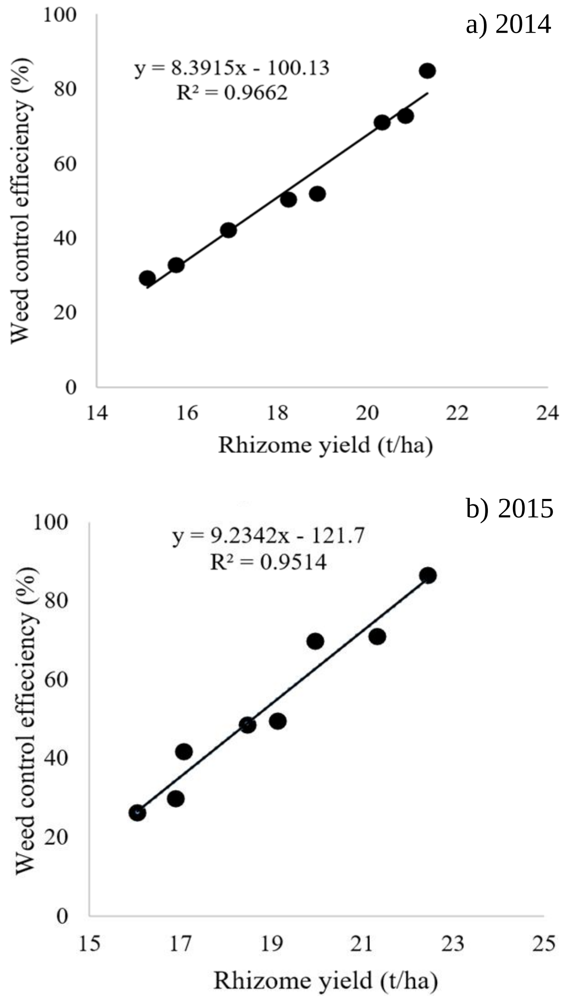

Figure 1. The relationship between weed control efficiency and rhizome yield of ginger as influenced by integrated weed management practices

Table 3. Economics as influenced by integrated weed management practices in ginger

Treatment	Gross returns (x10^3 ₹/ha)	Net returns (x10^3 ₹/ha)	B:C
Pendimethalin 1.5 kg/ha after planting but before mulching (20 DAP)	168.90	66.46	1.65
Oxyfluorfen 0.20 kg/ha after planting but before mulching (20 DAP)	160.50	58.50	1.57
Pendimethalin 1.5 kg/ha *fb* hand weeding (after planting but before mulching (20 DAP) *fb* 30-35 DAP)	191.20	82.76	1.76
Oxyfluorfen 0.20 kg/ha *fb* hand weeding (after planting but before mulching (20 DAP) *fb* 30-35 DAP)	184.60	76.60	1.71
Glyphosate 0.80 kg/ha (just before emergence of sprouts of ginger 25 DAP)	170.80	70.00	1.69
Glyphosate 0.80 kg/ha + pendimethalin 1.5 kg/ha (just before emergence of sprouts of ginger 25 DAP)	199.50	96.26	1.93
Glyphosate 0.80 kg/ha + oxyfluorfen 0.20 kg/ha (just before emergence of sprouts of ginger 25 DAP)	213.20	110.40	2.07
Hand weeding (twice at 30 and 60 DAP)	224.32	112.32	2.00
Unweeded control	109.93	9.93	1.10
LSD (p=0.05)	36.32	36.32	-

kg/ha *fb* hand weeding (after planting but before mulching (20 DAP) *fb* 30-35 DAP), glyphosate 0.80 kg/ha + oxyfluorfen 0.20 kg/ha (just before emergence of sprouts of ginger 25 DAP) and the lowest net returns obtained with unweeded control with net loss of ₹ 1,02,387 after two years of experiment. The net returns with the combined application of glyphosate 0.80 kg/ha + oxyfluorfen 0.2 kg/ha as 88.71% and 57.71% was higher as compared to application of oxyfluorfen 0.20 kg/ha after planting but before mulching and glyphosate 0.80 kg/ha before emergence of sprouts of ginger respectively (**Table 3**). But B:C was significantly higher (2.07) with application of glyphosate 0.80 kg/ha + oxyfluorfen 0.2 kg/ha. In hand weeded plots, the cost of cultivation increased remarkably due to higher labour wages. It increased the cost of manual weeding corresponding to total output cost. Higher profit due to chemical control in ginger have been supported by Barooah *et al.* (2010) and Sachdeva *et al*. (2015). The study demonstrated that two hand weeding at 30 and 60 DAP or application of glyphosate 0.80 kg/ha + oxyfluorfen 0.2 kg/ha is better options to manage weeds and improve rhizome productivity of ginger under rainfed ecosystem of middle Indo-Gangetic plains.

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RESEARCH NOTE

Assessing the compatibility of pre- and post-emergence herbicides with plant growth promoting rhizobacteria on performance of soybean

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ABSTRACT

The study was conducted to know the compatibility of different herbicides recommended for soybean with plant growth promoting rhizobacteria (PGPR) including the native strain of *Rhizobium* so that the tolerant microbes could be used as a potential herbicide tolerant microbial culture to support the soybean crop nutritionally and on the growth performance of the soybean (*Glycine max* L. Merill). In this study, the soybean crop was inoculated by cultures of *Bradyrhizobium daqingense, Paenibacillus polymyxa* and *Bradyrhizobium japonicum*. As recommended herbicides for soybean, pre-emergence herbicides diclosulam and pendimethalin were sprayed to the soybean plant 52 ppm/ha and 6 ppm/ha, respectively at 5 days after sowing. Post-emergence herbicides propaquizafop and imazethapyr were sprayed to the soybean plant 1.2 ppm/ha and 2 ppm/ha, respectively and their cocktail mix 4 ppm/ha at 18 days after sowing. The experiment was laid out in a completely randomized design with eighteen treatments repeated three times on a soybean crop (cv: *JS-9560*). The results of the investigation revealed that pendimethalin was comparatively more compatible with PGPRs than diclosulam under pre-emergence herbicide category. In case of post-emergence herbicides, propaquizafop was comparatively more compatible with PGPRs, than imazethapyr and cocktail mix of propaquizafop + imazethapyr. The propaquizafop was found safe herbicide to produce maximum biomass yield of soybean at 50 days after herbicide application (DAHA). The nodulation behavior was found significantly less affected by all the herbicidal application in presence of *Bradyrhizobium daqingense*.

Keywords: *Bradyrhizobium*, Diclosulam, Imazethapyr, *Paenibacillus polymyxa*, Pendimethalin, Propaquizafop, Soybean

Soybean (*Glycine max* L. Merill) belongs to family "Legumenaceae or Papilionaceae" has been called "Goldan bean" or "Miracle crop" of twentieth century consisting 40-42% protein and 18-22% oil (Masciarelli *et al*. 2014). Soybean produces 2-3 times more high-quality protein yield per hectare than other pulses and cholesterol free oil (Kumari *et al*. 2002). It is cultivated as the world's sixteenth most significant crop. (Foley *et al*. 2011). Soybean is mostly grown in *Kharif* (rainy) season and suffers from severe weed crop competition due to continuous rain, which do not permit hand weeding operation timely resulting in yield loss to the tune of 30–80% (Yaduraju 2002). Weeds are the major biotic factor responsible for poor soybean yield. Malik *et al.* (2006). have reported 55% soybean yield reduction with broad-leaved weeds (80%), grasses and sedges (20%) infestation throughout the crop season. Major broad-leaved weeds of soybean are *Celosia argentia, Digera arvensis, Commelina benghalensis, and Amaranthus viridis* (Singh Pratap and Rajkumar 2008). Pre-emergence herbicides are recommended in soybean production systems for management of weed species with extended emergence window (Norsworthy *et al*. 2012). Due to the widespread prevalence of glyphosate-resistant weeds and limited effective post-emergence herbicide options in soybean, the use of pre-emergence herbicides has become a standard recommendation for weed management. Benefits of incorporating pre-emergence into weed management programms include reduced early season weed competition and delayed critical time for weed removal, thus optimizing weed control strategies and minimizing potential crop yield loss (Oliveira *et al.* 2017, Knezevic *et al*. 2019). The availability of pre-emergence herbicides such as chlorimuron-ethyl, cloransulam-methyl, metribuzin, sulfentrazone, flumioxazin, saflufenacil, acetochlor, S-metolachlor, dimethenamid-P, pyroxasulfone, diclosulam and pendimethalin *etc*. and post-emergence herbicides such as imazethapyr, propaquizafop, acifluorfen, fomesafen, sethoxydim and fluazifop-p-butyl *etc*. for soybean crop has been noticed in recent years in Indian herbicide market. The ideal bio-fertilizers for soybean are *Rhizobium* and phosphate solubilizing bacteria. These crop beneficial microorganisms

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supplement substantial amount of nitrogen and phosphorus to crop which increase the productivity and simultaneously reduce the input cost of cultivation. Generally, the large farmers have initiated use of the above bio-fertilizers under the new techniques of cultivation but the small and marginal farmers are far behind. When we apply different herbicides to the soil for controlling the weeds, it may cause some effect on the applied bio-inoculant. Hence, an experiment was framed to assess the compatibility of different soybean herbicides with plant growth promoting rhizobacteria (PGPR) including the native strain of *Rhizobium* so that the tolerant microbes could be used as a potential herbicide tolerant microbial culture to support the soybean crop nutritionally.

The experiment was conducted under the open microcosm conditions in the Department of Agricultural Microbiology, Indira Gandhi Krishi Vishwavidyalaya, Raipur (Chhattisgarh) during 2021-22 with Soybean (*Glycine max*), Variety: *JS-9560*. The study area receives average annual rainfall of 1200-1400 mm, with temperature ranged from 12 °C in December to 45 °C in May. Polybags were used for conducting the experiment. A random collection of surface soil was done from 15 cm (6-inch) depth from the fields of real agricultural land near the College of Agriculture, Raipur and was thoroughly blended with compost samples. This soil was sieved and processed from a 2 mm sieve. Well-mixed sample of 8 kg soil, sand and compost in the ratio 3:1:1 was filled for facilitating proper drainage of water. The surface of the seeds was sterilized with 95% ethanol and 0.1 per cent mercuric chloride. The seeds were then rinsed 7 times with sterilized water and then placed on the Petri-plates to undergo seed treatments. A five per cent sugar solution was applied to each Petri-plate to help in adhesion.

Hundred micro-litre of each bacterial cultures, such as *Bradyrhizobium daqingense*, *Paenibacillus polymyxa* and *Bradyrhizobium japonicum* for thirty seeds were introduced by using a micropipette in aseptic surrounding. The treated seeds were sown in the holes made aseptically by the glass rod. Ten seeds were sown in each polybag. At 7 days after sowing (DAS), the seedlings were thinned and three seedlings were maintained in each pot. The nutrients such as nitrogen, phosphorus and potassium were added after seven days of sowing with the recommended dose of 20:80:40 NPK, kg/ha. The experiment was laid out in a completely randomized design with eighteen treatments. The details of the treatments and their scheduling are given in **Table 1**. The soybean crop was inoculated by cultures *of Bradyrhizobium daqingense, Paenibacillus polymyxa* and *Bradyrhizobium japonicum*. The required amount of pre-emergence herbicides diclosulam and pendimethalin were sprayed to the soybean plant 52 ppm/ha and 6 ppm/ha, respectively at 5 DAS. Post-emergence herbicides propaquizafop and imazethapyr were sprayed to the soybean plant 1.2 ppm/ha and 2 ppm/ha, respectively and also the cocktail mix of propaquizafop and imazethapyr was sprayed 4 ppm/ha, each at 18 DAS. The plants height (cm) was measured at 15, 30 and 50 days after pre- and post-emergence herbicide application, the number of weed population (area of 12.36 square inch) were measured at 10 days after pre- and post-emergence herbicide application, the number of nodules (nodules/plant), fresh and dry weight of nodules (g/plant), fresh and dry weight (g/plant) of shoot and root were recorded at 50 DAHA (days after herbicide application). All observations from this experimental study have been systematically tabulated. For their respective number of replications used, values were given as a means. For complete randomized design, the data were statistically analysed using ANOVA. The significant difference was tested at signifying level by F-test at 5 per cent. If F-test found significant in comparing treatment means then standard error of mean (SEm ±) and CD was calculated, (Panse and Shukhatme 1978).

The plants height: The Data on plant height of soybean was recorded at three different growth stages of the crop which was tabulated in **Table 1** and **Plate 1**. The data recorded at 15, 30 and 50 DAHA revealed that pre-emergence herbicides diclosulam and pendimethalin significantly reduced the plant height at all the stages in comparison to untreated check. Data recorded at different growth stages of crop growth indicated that among different PGPRs, highest plant growth was recorded due to *Bradyrhizobium daqingense* (33.9 cm) followed by *Bradyrhizobium japonicum* (31.4 cm) and *Paenibacillus polymyxa* (30.1 cm) at 30 DAHA. *Paenibacillus polymyxa* was least affected by pre-emergence herbicide diclosulam among the three PGPRs whereas local isolate *Bradyrhizobium japonicum* was severely affected by diclosulam application among the three PGPRs. In case of pendimethalin, the trend of plant growth inhibition was similar to that of diclosulam. Post- emergence herbicide propaquizafop did not inhibit the plant growth at all the growth stages of crop in presence of *Bradyrhizobium daqingense* and *Paenibacillus polymyxa*. However, in case of *Bradyrhizobium japonicum,* the propaquizafop found detrimental to reduce the plant height at 30 and 50 DAHA.

Growth performance of the crop PE (diclosulam) at 50 DAHA

Growth performance of the crop PE (pendimethalin) at 50 DAHA

Growth performance of the crop PoE (propaquizafop) at 50 DAHA

Growth performance of the crop PoE (imazethapyr) at 50 DAHA

Growth performance of the crop (cocktail mix of propaquizafop + imazethapyr) at 50 DAHA

Plate 1. Growth performance of the crop at 50 DAHA (days after herbicide application)

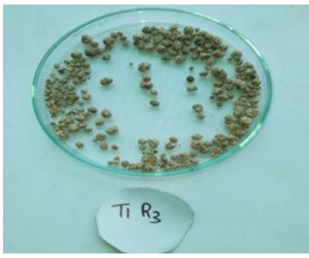
Bradyrhizobium daqingense + pendimethalin PE

Bradyrhizobium daqingense + diclosulam PE

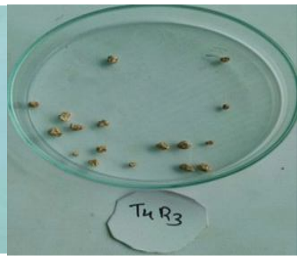
Bradyrhizobium daqingense + propaquizafop PoE

Bradyrhizobium daqingense + imazethapyr PoE

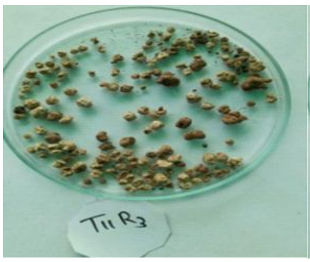
Plate 2. Biomass of soybean crop at 50 days as influenced by pre- and post -emergence herbicides



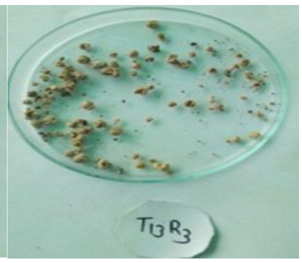
Bradyrhizobium daqingense + pendimethalin PE



Bradyrhizobium daqingense + diclosulam PE



Bradyrhizobium daqingense + propaquizafop PoE



Bradyrhizobium daqingense + imazethapyr PoE

Plate 3. Soybean nodulation behavior at 50 days after pre- and post- emergence herbicide application

Application of post- emergence herbicide imazethapyr alone and its cocktail mixture with propaquizafop significantly affected the plant growth at all the three stages over individual application of PGPRs, without treatment of herbicides. Thus, it was concluded that in case of pre-emergence herbicides, pendimethalin was comparatively more compatible with PGPRs, than diclosulam. Similar results were obtained by ESFA (2014) and it was revealed that the residues of pendimethalin were not detected at harvest in soil, soybean oil, defatted cake and straw from treated fields. Pendimethalin residues were below MRL in soybean. In our case, we found that post-emergence herbicides propaquizafop was comparatively more compatible with PGPRs, than imazethapyr and cocktail mix of propaquizafop + imazethapyr. Above observations were in close agreement with Renjith and Sharma (2014) as they reported that among herbicidal treatments, plants treated with propaquizafop 50 g/ha at 3 weeks after sowing (WAS) gave better performance.

Weed population: The data of weed population as affected by herbicide application are presented in **Figure 1**. It is apparent from the data that the weed population was significantly reduced in the treatments where herbicides were applied. Among pre-emergence herbicides, application of diclosulam did not allow the growth of any weed in the poly-bag having an area of 12.36 square inch. Similarly, application of pendimethalin also reduced the weed population to the extent of zero level in the treatment containing *Paenibacillus polymyxa*. Among post-emergence herbicides, propaquizafop was found better than imazethapyr for reduction of weed population. Minimum weed population (0.7/bag) was recorded in treatment received propaquizafop in presence of *Paenibacillus polymyxa*. In case of imazethapyr, the minimum weed population was 1.3/bag recorded in treatment where *Paenibacillus polymyxa* was applied. Cocktail mix of post-emergence herbicides although significantly reduced the weed population but did not find more effective to reduce the population as comparison to the single application of post-emergence herbicides. Higher population of weeds was observed in pots treated with PGPRs compared to untreated check. Highest population of weeds was recorded in *Bradyrhizobium daqingense* (4.3/bag) treatment and minimum in *Paenibacillus polymyxa* (3.7/bag). Thus, it was concluded that in case of pre-emergence herbicides, diclosulam had comparatively more weed control efficiency as compared to other herbicidal treatments. Similar results were obtained by Singh *et al.* (2009), who revealed that diclosulam applied at 22 and 26 g/ha showed higher weed control efficiency as compared to other herbicidal treatments at all the stages of crop growth. It also provided higher value for all the characters of yield attributes and grain yield. In case of post-emergence herbicides, propaquizafop had comparatively more weed control efficiency as compared to imazethapyr & cocktail mix of propaquizafop + imazethapyr.

Plant biomass: The data on the effect of inoculation with different PGPRs, with and without application of herbicides on plant fresh and dry matter at 50 DAHA is presented in **Figure 1** and **Plate 2**. Data

Table 1. Effect of pre- and post-emergence herbicides on plant height (cm) of soybean

Treatment	Plant height (cm)		
	15 DAHA	30 DAHA	50 DAHA
Bradyrhizobium daqingense (control- I)	11.53	33.90	36.90
Paenibacillus polymyxa (control- II)	10.60	30.10	35.23
Bradyrhizobium japonicum (local strain – control -III)	10.80	31.40	35.80
Bradyrhizobium daqingense + diclosulam	8.83	19.53	24.43
Paenibacillus polymyxa + diclosulam	8.70	17.93	24.96
Bradyrhizobium japonicum + diclosulam	8.00	13.30	18.30
Bradyrhizobium daqingense + pendimethalin	9.03	21.20	26.40
Paenibacillus polymyxa + pendimethalin	9.10	21.40	28.30
Bradyrhizobium japonicum + pendimethalin	8.200	13.60	23.20
Bradyrhizobium daqingense + propaquizafop	10.43	32.90	34.80
Paenibacillus polymyxa + propaquizafop	11.00	32.73	36.30
Bradyrhizobium japonicum + propaquizafop	10.10	24.30	31.20
Bradyrhizobium daqingense + imazethapyr	8.50	17.43	26.56
Paenibacillus polymyxa + imazethapyr	8.20	13.93	24.23
Bradyrhizobium japonicum + imazethapyr	8.50	17.66	26.93
Bradyrhizobium daqingense + (propaquizafop + imazethapyr)	8.40	23.66	30.80
Paenibacillus polymyxa + (propaquizafop + imazethapyr)	8.30	23.33	30.60
Bradyrhizobium japonicum + (propaquizafop + imazethapyr)	8.00	20.76	28.43
LSD (p=0.05)	1.19	2.82	3.80

showed that application of pre-emergence herbicides significantly reduced the fresh and dry biomass of shoot but the root biomass was not affected except in the treatment received pendimethalin and treated with *Bradyrhizobium daqingense.* Among pre-emergence herbicides, diclosulam was found more effective to reduce the fresh and dry biomass of soybean than pendimethalin. Among post-emergence herbicides, the biomass yield of soybean was not affected by propaquizafop but significantly reduced due to application of imazethapyr. Among tested PGPRs, *Bradyrhizobium daqingense* was least affected due to application of imazethapyr whereas in case of propaquizafop along with *Paenibacillus polymyxa* performed best. Cocktail mix of post-emergence herbicides, imazethapyr significantly reduced the biomass yield of soybean at 50 DAHA. Data clearly indicated that combined effect of both the post-emergence herbicides reduced the shoot biomass in comparison to their individual application but the shoot dry biomass reduction due to cocktail application of post-emergence herbicides was significant than individual application. The results clearly elucidated that *Bradyrhizobium japonicum* was least affected by cocktail mix of propaquizafop and imazethapyr followed by *Bradyrhizobium daqingense*. Fresh and dry biomass of soybean root was unaffected by application of cocktail combination of post-emergence herbicides except the case in which *Bradyrhizobium daqingense* was applied**.** Similar results were obtained by Shaner and Singh (1992), who revealed that the reductions in fresh and dry matter content of maize and soybean seedlings in response to treatment with the different herbicides appeared as a result of concomitant alterations in certain metabolic processes. Protein and carbohydrate metabolism in several plant species can be affected by many herbicides with a reduced production of plant materials and, consequently, growth cessation.

Nodulation behavior: The data on the effect of different herbicides on number of nodules and their biomass are presented in **Table 2** and **Plate 3**. The number of nodules recorded at 50 days after herbicide application (DAHA) revealed that both pre- and post-emergence herbicides including cocktail mix of post-emergence herbicides significantly reduced the nodule number and their biomass. In case of pre-emergence herbicides, diclosulam affected the nodulation more than pendimethalin. Among pre-emergence herbicides, comparatively higher nodules were recorded in treatment of pendimethalin over diclosulam. Higher number of nodules was recorded 41 per plant) in the treatments of *B. daqingense*; in case of pendimethalin. It was reduced to (8.33 per plant) in treatment of *B. daqingense*, due to the treatment of diclosulam. Similar results were obtained by Praharaj and Dhingra (1995) who revealed that application of pendimethalin 0.5 kg/ha neither had any adverse effect on the nodulation and nitrogenase activity nor it influenced the efficiency of rhizobial inoculants in terms of BNF (biological nitrogen fixation) in soybean. Among PGPRs, *Bradyrhizobium*

Table 2. Effect of pre- and post-emergence herbicides on nodulation behavior of soybean at 50 DAHA

Treatment	Nodulation		
	No. of nodules/ plant	Fresh weight of nodules (g/plant)	Dry weight of nodules (g/plant)
Bradyrhizobium daqingense (control-I)	221.66	3.26	1.22
Paenibacillus polymyxa (control-II)	164.32	2.59	0.92
Bradyrhizobium japonicum (local strain – control-III)	101.43	2.04	0.70
Bradyrhizobium daqingense + diclosulam	8.33	0.14	0.04
Paenibacillus polymyxa + diclosulam	7.66	0.11	0.03
Bradyrhizobium japonicum + diclosulam	4.66	0.06	0.01
Bradyrhizobium daqingense + pendimethalin	41.00	0.52	0.21
Paenibacillus polymyxa + pendimethalin	39.33	0.82	0.26
Bradyrhizobium japonicum + pendimethalin	28.00	0.34	0.11
Bradyrhizobium daqingense + propaquizafop	85.00	1.63	0.53
Paenibacillus polymyxa + propaquizafop	106.00	1.48	0.49
Bradyrhizobium japonicum + propaquizafop	88.7	1.42	0.47
Bradyrhizobium daqingense + imazethapyr	75.67	0.76	0.24
Paenibacillus polymyxa + imazethapyr	33.00	0.48	0.20
Bradyrhizobium japonicum + imazethapyr	58.00	0.96	0.32
Bradyrhizobium daqingense + (propaquizafop + imazethapyr)	61.00	0.76	0.26
Paenibacillus polymyxa + (propaquizafop + imazethapyr)	33.67	0.77	0.28
Bradyrhizobium japonicum + (propaquizafop + imazethapyr)	41.33	0.52	0.16
LSD (p=0.05)	11.73	0.16	0.06

japonicum was severely affected by pre-emergence herbicides followed by *Paenibacillus polymyxa* to produce nodules. In case of nodule biomass, diclosulam significantly affected the fresh and dry biomass of nodules in comparison to pendimethalin. Among PGPRs, *Paenibacillus polymyxa* was least affected by pendimethalin followed by *Bradyrhizobium daqingense*. However, *Bradyrhizobium daqingense* was least affected by diclosulam followed by *Paenibacillus polymyxa* in both the cases of fresh and dry biomass of nodules. The study on the effect of post-emergence herbicides alone and combination revealed that number of nodules and their biomass was less affected by propaquizafop in comparison to imazethapyr. Among different PGPRs, *Paenibacillus polymyxa* found resistant over others and produced maximum number of nodules (106 per plant) and their biomass yield (1.48g/plant). However, in case of imazethapyr, *Bradyrhizobium daqingense* produced the maximum number of nodules (75 per plant) followed by Bradyrhizobium japonicum (58/plant). In case of biomass yield of nodules, the maximum yield was attributed with *Bradyrhizobium japonicum* (0.96 g/plant) followed by *Bradyrhizobium daqingense* (0.76 g/plant). Combined application of post-emergence herbicides

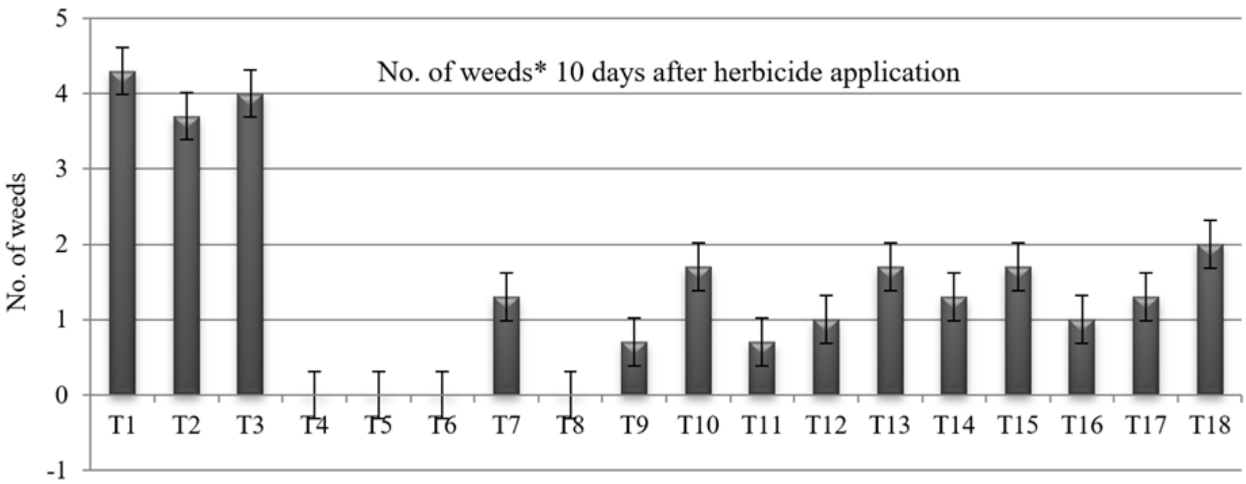


Figure 1. Effect of pre- and post-emergence herbicides on weed population

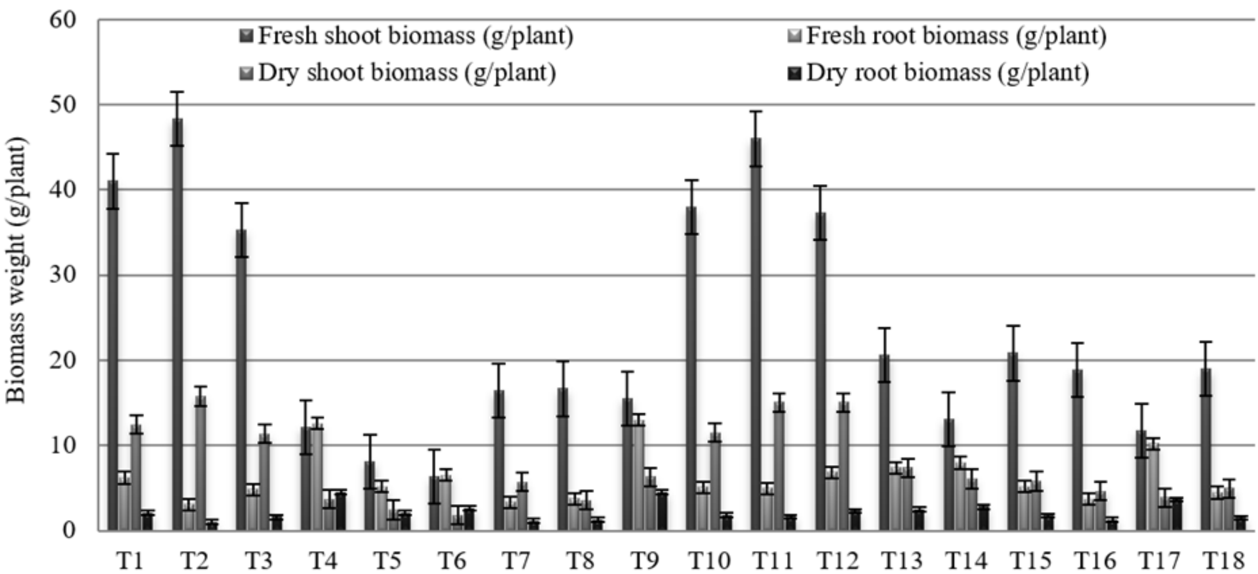


Figure 2. Effect of pre- and post-emergence herbicides on plant biomass of soybean at (50 DAHA)

T_1: *Bradyrhizobium daqingense* (control- I); **T_2:** *Paenibacillus polymyxa* (control- II); **T_3:** *Bradyrhizobium japonicum* (local strain – control -ÉÉÉ); **T_4:** *Bradyrhizobium daqingense* + diclosulam; **T_5:** *Paenibacillus polymyxa* + diclosulam; **T_6:** *Bradyrhizobium japonicum* + diclosulam; **T_7:** *Bradyrhizobium daqingense* + pendimethalin; **T_8:** *Paenibacillus polymyxa* + pendimethalin; **T_9:** *Bradyrhizobium japonicum* + pendimethalin; **T_{10}:** *Bradyrhizobium daqingense* + propaquizafop; **T_{11}:** *Paenibacillus polymyxa* + propaquizafop; **T_{12}:** *Bradyrhizobium japonicum* + propaquizafop; **T_{13}:** *Bradyrhizobium daqingense* + imazethapyr; **T_{14}:** *Paenibacillus polymyxa* + imazethapyr; **T_{15}:** *Bradyrhizobium japonicum* + imazethapyr; **T_{16}:** *Bradyrhizobium daqingense* + (propaquizafop + imazethapyr); **T_{17}:** *Paenibacillus polymyxa* + (propaquizafop + imazethapyr); **T_{18}:** *Bradyrhizobium japonicum* + (propaquizafop + imazethapyr) and *Bradyrhizobium daqingense* (61/lant) produced the maximum nodulation followed by *Bradyrhizobium japonicum* (41/per plant) However, the biomass yield of soybean nodules was found maximum with *Paenibacillus polymyxa* (0.77 g/ plant) followed by *Bradyrhizobium daqingense* (0.76 g/plant). In this study, it was proved that in case of pre-emergence herbicides, pendimethalin was comparatively more compatible with PGPRs than diclosulam to produce nodules. In case of post-emergence herbicides, propaquizafop was comparatively more compatible with PGPRs than imazethapyr and cocktail mix of propaquizafop + imazethapyr to produce nodules. Above observations were in close agreement with Sawicka and Selwet (1998), who claimed that both imazethapyr and linuron can cause decrease of root– nodule and bacterial nitrogenase activity. They also can stimulate development of bacteria and inhibitory growth of fungi.

From the above findings, it may be concluded that pendimethalin was comparatively more compatible with PGPRs than diclosulam under pre-emergence herbicides category. The same chemical was found suitable to produce maximum biomass yield of soybean at 50 DAHA. In case of post-emergence herbicides, propaquizafop was comparatively more compatible with PGPRs than imazethapyr and cocktail mix of propaquizafop + imazethapyr. Propaquizafop was found safe herbicide to produce maximum biomass yield of soybean at 50 DAHA. Among pre- and post-emergence herbicides, application of propaquizafop was found comparatively better molecule to produce maximum soybean biomass yield.

The salient findings of this investigation are (i) the nodulation behavior of soybean was least affected by all the herbicidal application in presence of *Bradyrhizobium daqingense*. Hence, it is proved that *Bradyrhizobium daqingense* is highly tolerant to different pre-and post-emergence herbicides. However the plant biomass was found to be less affected by pre-emergence herbicides in presence of *Bradyrhizobium daqingense* and post-emergence herbicides in presence of *Paenibacillus polymyxa* (ii) the rhizobial population in soil was comparatively less affected by application of pre-emergence and post-emergence herbicides up to 20 DAHA due to inoculation of *Bradyrhizobium daqingense*, but after 20 DAHA, the performance of local strain *Bradyrhizobium japonicum* was the best to accelerate the population.

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RESEARCH NOTE

Impact of weed management practices on weed growth, crop yield and soil microbes in groundnut

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ABSTRACT

A field experiment was conducted in a randomized block design with different organic weed management treatments including water extracts of sorghum, sunflower, Parthenium, Lantana and purplenut sedge plants, each 15 L/ha applied at 15 and 30 days after seeding (DAS) alongwith paddy straw mulch 5 t/ha. The predominant weed species were *Cyperus rotundus* L. (45%), *Digitaria sanguinalis* (L.) Scop. (15%), *Borreria hispida* (L.) K. Schum. (7%). Application of paddy straw mulch 5 t/ha proved to be best in controlling weeds and promoting yield components and yield of groundnut as well as realizing higher returns followed by sunflower water extract spray 15 L/ha. The efficacy of Parthenium water extract and purple nutsedge water extracts were poor in controlling weeds and enhancing yield of groundnut. The reduction in groundnut pod yield due to unchecked weed growth was 52.53% and 37.18% compared to pendimethalin 1.0 kg/ha + hand weeding (HW) at 30 DAS and paddy straw mulch 5 t/ha, respectively. Pre-emergence application of pendimethalin1.0 kg/ ha followed by HW recorded significantly higher number of effective Rhizobium nodules/ plant whereas paddy straw mulch 5 t/ha recorded significantly higher count of soil microorganisms.

Keywords: Groundnut, Organic weed management, Plant water extracts, Soil microbes, Pod yield

Groundnut (*Arachis hypogaea* L.) is grown throughout the year during rainy (*Kharif*), winter (*Rabi*) and summer seasons in one or other parts of the India due to diversified climate. Groundnut is grown under tropical climate with hot and humid weather and hence confronted by repeated flushes of various grasses and broad-leaved weeds throughout its growing period. Though, groundnut is a hardy crop, it is highly susceptible to weed preponderance due to lower height of canopy and slow initial growth. The critical period of crop weed competition in groundnut was around 4-9 weeks after sowing in sandy loam soils (Wesley *et al*. 2008). In groundnut, weeds compete with crop plants for nutrients and remove more than 50% of applied nutrients under un-weeded conditions resulting in significant yield reduction (Naveen Kumar *et al*. 2021). Improvisation in methods of weed management is the need of the day for effective weed control to meet the labour shortage during peak period of demand and increased cost of weeding. Weed control with herbicides is expensive and pose detrimental effect on the environment. The toxic herbicides are polluting the surface and ground water for livestock as well as human beings while their residues released from the plants as well as from the soil move into the nutrition cycle and ultimately become perilous for descendants (Judith *et al*. 2001). In recent years, the increased emphasis is placed on sustainable agriculture and concerns about the adverse effect of extensive use of farm chemicals and on reducing the dependence upon synthetic herbicides and finding alternative strategies for weed management in general and in organic and sustainable agricultural systems in particular. There is an exigency to develop natural and ecological strategies for controlling weeds due to the consumer preference on organic products in recent years. Allelopathy is utilizing natural allelochemicals for weed management. Unlike synthetic herbicides, such compounds are produced naturally in the plants and used directly as herbicides. A number of secondary metabolites/allelomones produced by some of the plants act as potential natural herbicides with considerable crop selectivity, which could be directly used in the form of aqueous plant water extracts for weed management in organic and sustainable agriculture systems (Ray *et al*. 2022). The application of allelopathic water extract of sorghum 25 L/ha twice at 15 and 30 DAS resulted in less weed density as compared to all other plant aqueous extracts in cotton grown on clay loam soils of Peshawar,

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Pakistan (Kandhro *et al.* 2015). In this context, the present field experiment was conducted to study the efficacy of different plant water extracts for control of mixed weed flora associated with groundnut in sandy loam soils and compare them with efficacy of commonly used herbicides.

A field experiment was conducted during winter (*Rabi*), 2017-18 at wetland farm of Sri Venkateswra Agricultural College, Tirupati campus of Acharya N.G. Ranga Agricultural University, Andhra Pradesh, India which is geographically situated at 13.5°N and 79.5°E with an altitude of 182.9 m above the mean sea level. The experimental soil was sandy loam in texture with soil p^H 7.7, organic carbon (0.23 %), available N (128 kg/ha), P 12 kg /ha, potassium (225 kg/ha) and EC of 0.65 dS/m. The experiment was laid out in randomized block design with ten treatments replicated thrice. The treatments consisting of five plant water extracts *viz*., sorghum, sunflower, Parthenium, rice, Lantana and purplenut sedge each at 15 L/ha applied at 15 and 30 days after seeding (DAS) and paddy straw mulch 5 t/ha each, pre-emergence application (PE) of pendimethalin 1.0 kg/ha followed by (*fb*) hand weeding (HW) at 30 DAS, post-emergence application (PoE) of imazethapyr 75 g/ha and unweeded check. The entire plant of sorghum (*Sorghum bicolor* L.), sunflower (*Helianthus annus* L.), rice (*Oryza sativus* L.), carrot grass (*Parthenium hysterophorus* L.), Lantana (*Lantana camara* L.) and tubers of purple nutsegde (*Cyperus rotundus* L.) were harvested at flowering and then shade dried. The dried plant material was chopped with power operated fodder chaff cutter into 2 cm pieces, separately. The chopped plant material was soaked in distilled water for 24 hours at room temperature of 21^0C at a ratio of 1:10 (w/v) and the same was filtered through 10 and 60 mesh sieves according to procedure laid down by Cheema *et al.* (2003). The initial volume of distilled water for soaking was 10 litres for every one kilogram of chopped material and after filtration the final volume of filtrate was seven litres. These plant water extracts separately boiled at 100 ^{0}C to concentrate up to 20 times for easy handling, storage and application convenience as per the treatments. Healthy and matured seeds of groundnut variety, *Dharani (TCGS-1043)* were treated with mancozeb 3 g/kg of seed. The sowing was carried out on 22nd December, 2017 with seed rate of 180 kg/ha at a spacing of 22.5 cm between the rows and 10 cm between the plants. The required quantities of plant water extracts were applied at 15 and 30 DAS and pendimethalin was applied at one DAS and imazethapyr was applied at 15 DAS by using spray fluid of 500 L/ha with the help of knapsack sprayer fitted with flat fan nozzle. Paddy straw mulch 5 t/ha was applied at 5 DAS after emergence of the crop. The groundnut crop was applied with recommended dose of fertilizer *i.e.* 30 kg N, 40 kg P and 50 kg K/ha using urea, single super phosphate and muriate of potash, respectively to all the plots. Two third of nitrogen and entire dose of phosphorous and potassium were applied as basal at the time of sowing. The remaining one third of nitrogen was top dressed at 25 DAS. Weed density and weed dry weight was recorded by adopting standard procedures and weed control efficiency (WCE) was calculated as per the formula suggested by Mani *et al.* (1973) at 60 DAS. Yield attributes and yield of groundnut were recorded from net plot area at harvest. The weather during the crop period was most congenial for better performance and did not deviate much from the normal values of decennial mean of the experimental area. Groundnut plants were uprooted at 40 DAS and at harvest for recording number of effective rhizobium nodules/plant. The nodules which release pink colour liquid by pressing were considered as effective nodules. Microbial analysis of soil in all the treatments was carried out at 40 DAS and at harvest for estimation of microbial load in the soil *viz.*, bacteria, fungi and actinomycetes by serial dilution plate count technique as per the method suggested by Pramer and Schemidt (1965). The soil samples were cultured with suitable media *i.e* nutrient agar for bacteria, potato dextrose agar for fungi and actinomycetes agar for actinomycetes. The initial bacteria, fungi and actinomycetes population were 14.67 x 10^6, 9.0 x 10^3 and 6.0 x 10^4 cfu/g soil, respectively.

Effect on Weeds

The major weed flora associated with groundnut were *Cyperus rotundus* (45%), *Digitaria sanguinalis* (15%), *Borreria hispida* (7%), *Digera arvensis* (6%), *Boerhavia erecta* (5%), *Cleome viscose* (3%), *Dactyloctenium aegyptium* (4%), *Trichodesma indicum* (4%), *Phyllanthus niruri* (4%) and other weed species consist of 7% in unweeded check. The dominance of purple nutsedge continued in the present experiment was due to its perennial nature coupled with excellent persistence mechanism under irrigated dry conditions. All the weed management practices registered significantly lesser density and dry weight of weeds than unweeded check (**Table 1**). Among, all the organic weed management treatments tested, paddy straw mulch 5 t/ha recorded significantly lower density and biomass of weeds as paddy straw mulch might have increased the albedo and decreased the solar energy flux to the soil, which in-turn reduce germination and growth of weeds. Further, paddy straw mulch might have released allelomones, *viz.* momilactone B, p- hydroxyl benzoic acid, vanillic acid, p- coumaric and ferulic acids which were identified as natural herbicides to control weeds. The weed smothering efficiency of paddy straw was also reported by Khan *et al.* (2014). Among the plant water extracts, sunflower water extract 15 L/ha twice at 15 and 30 DAS resulted in lesser density and biomass of weeds, which was in parity with sorghum water extract, but all the above organic weed management practices were inferior in reducing the density and biomass of weeds than pre-emergence application of pendimethalin 1.0 kg/ha PE. The herbicides showed their superiority in controlling weeds more effectively than plant water extracts and paddy straw mulch. The inhibitory effect of sunflower water extracts on weed growth was possibly due to their readily available and solubilized form of allelomones, which might have affected the water and nutrient uptake, chlorophyll biosynthesis, hormone biosynthesis, membrane permeability and protein metabolism (Rice 1984). The inhibitory effect of sunflower water extracts on weed growth due to presence of higher concentrations of annuinones A, B, annuolide E, leptocarpin, Heliannuols, Isochlorogenic acid and Scopolin, which are considered as natural herbicides. Among the organic weed management practices, the maximum weed control efficiency was computed with application of paddy straw 5 t/ha (74.50 %) followed by sunflower (62.97 %) and sorghum (57.83 %) plant water extracts, but these organic weed management practices registered lesser weed control efficiency than chemical weed management of pendimethalin (86.21 %) as PE and imazethapyr (76.65%) asPoE. Application of plant water extracts of Parthenium and purple nutsedge were found to be less effective in controlling weeds than rest of the plant water extracts. Similar results were also reported by Khaliq *et al* (2012) in their field experiment in wheat as the maximum density of weeds was recorded with Parthenium water extract, which was at par with unweeded check.

Effect on crop growth and yield

All the weed management practices significantly influenced the dry matter production and yield component of groundnut (**Table 1**). Significantly higher dry matter production and yield components, *viz.* number of filled pods/plant, hundred pod weight and hundred kernel weight were recorded with pendimethalin 1.0 kg/ha PE *fb* HW at 40 DAS. Among the organic weed management practices, the highest values of the above said parameters were registered with paddy straw mulch 5.0 t/ha followed by sunflower water extract 15 L/ha twice at 15 and 30 DAS. This might be due to maintenance of better source-sink relations owing to adequate availability of growth resources as a result of less weed competition, which in-turn enhanced the translocation of photosynthates from source to developing kernel lead to increased hundred pod and kernel weight. The positive effect of paddy straw mulch on growth and yield attributes in groundnut was also reported by Mahita *et al.* (2014). The values of the above yield parameters were at their lowest with Parthenium water extract spray, which were in parity with purple nutsedge water extract spray due to their poor performance in controlling all the categories of weeds as reported by Parthasarathi *et al.* (2012).

All the organic weed management practices significantly influenced the pod and haulm yield as well as harvest index of groundnut (**Table 1**), but all the organic weed management practices recorded

Table 1. Weed growth, yield components and yield of *Rabi* (winter) groundnut as influenced by different organic weed management practices

Weed management practices	Weed density (no./m^2)	Weed biomass (g/m^2)	WCE (%)	DMP (t/ha)	No. of filled pods/ plant	100-pod weight (g)	100-kernel weight (g)	Pod yield (t/ha)	Haulm yield (t/ha)	Harvest index (%)	B:C
Sorghum water extract 15 L/ha 15 and 30 DAS	83.7(9.17)	47.4(6.92)	57.83	5.17	11.40	129.08	53.87	1.85	2.49	42.60	2.08
Sunflower water extract 15 L/ha 15 and 30 DAS	67.7(8.29)	41.4(6.47)	62.97	5.22	11.67	138.29	54.63	1.90	2.51	43.12	2.23
Rice straw water extract 15 L/ha 15 and 30 DAS	101.3(10.09)	64.5(8.09)	43.05	5.07	10.73	123.95	52.57	1.61	2.46	39.60	1.83
Parthenium water extract 15 L/ha 15 and 30 DAS	111.9(10.61)	71.2(8.47)	36.65	4.66	10.00	118.89	46.87	1.39	2.38	36.95	1.57
Lantana water extract 15 L/ha 15 and 30 DAS	92.3(9.63)	62.3(7.96)	53.42	5.05	10.93	126.46	52.67	1.72	2.48	40.85	1.92
Purple nutsedge water extract 15 L/ha 15 and 30 DAS	111.4(10.60)	69.7(8.38)	37.99	4.93	10.33	122.58	51.53	1.42	2.39	37.29	1.58
Paddy straw mulch 5 t/ha 7 DAS	40.0(6.36)	28.6(5.40)	74.50	5.34	12.53	143.94	55.87	2.09	2.58	44.48	2.15
Pendimethalin 1000 g/ha PE *fb* HW 1 and 30 DAS	21.0(4.64)	15.5(4.00)	86.21	5.64	13.33	146.15	59.37	2.77	2.65	51.10	3.04
Imazethapyr 75g/ha PoE 15 DAS	34.7(5.93)	26.2(5.17)	76.65	5.40	11.80	144.01	56.87	2.55	2.60	49.53	2.85
Unweeded check (control)	226.0(15.05)	112.4(10.62)	-	4.08	8.93	108.53	42.20	1.32	2.17	37.68	1.56
LSD (p=0.05)	1.68	0.98		0.13	0.49	5.60	2.25	0.16	0.11	1.79	0.12

Data in parentheses indicate the square root transformed values.; PE = pre-emergence application; PoE = post-emergence application *fb* = followed by; HW= hand weeding; DAS = days after seeding significantly lesser yields than chemical weed management practices. Application of paddy straw mulch 5.0 t/ha produced significantly higher pod and haulm yield as well as harvest index due to better weed control. The next best organic weed management practice in producing higher pod yield was sunflower water extract spray 15 L/ha twice at 15 and 30 DAS, which was at par with sorghum water extract spray 15 L/ha due to maintenance of weed free environment at early stages of crop growth, which might have increased the growth and yield contributing parameters and finally recorded higher pod yield. The reduction in pod yield of groundnut due to unchecked weed growth was 52.53, 37.18 and 38.84% compared to pendimethalin 1.0 kg /ha PE *fb* hand weeding at 30 DAS, paddy straw mulch 5.0 t/ha and sunflower water extract 15 L/ha, respectively. Similar results were also reported by Naeem *et al* (2016) with sorghum and sunflower water extracts sprays each 15 L/ha in combination applied at 20 DAS in maize. Among the organic weed management practices, sunflower water extract spray realized the highest benefit-cost ratio, which was statistically similar to paddy straw mulch 5.0 t/ha which in-turn at par with sorghum water extract spray 15 L/ha due to increased pod yield with reduced cost of cultivation. The sustainability of any weed management practices ultimately lies in its economic returns and the cost involved and also its impact on the environment.

Effect on soil microorganisms

There was a significant influence of different weed management practices on number of effective rhizobium nodules/plant and soil microbial population at 40 DAS and at harvest (**Table 2**). *Rhizobium* nodules/plant was maximum at 40 DAS due to better growth and development of crop and then declined towards harvesting due to senescence. Pendimethalin 1.0 kg/ha PE *fb* HW at 30 DAS recorded significantly higher number of effective *Rhizobium* nodules/plant which was comparable with paddy straw mulch 5.0 t/ha as reported by Sharma *et al* (2017) since pendimethalin created better environment for growth and development of the crop due to effective weed control, which in turn increased the number of effective *Rhizobium* nodules/plant. Application of paddy straw mulch 5.0 t/ha might have increased the rhizosphere bacterial population due to favourable environment and increased organic matter content of the soil.

Soil microorganisms *viz*., bacteria, fungi and actinomycetes colonies were tends to increase from 40 DAS to harvest. Paddy straw mulch 5.0 t/ha recorded significantly higher count of bacteria, fungi and actinomycetes followed by sunflower water extract at 40 DAS and at harvest. The increase in microbial colonies may be due to paddy straw mulching as it modifies hydrothermal regime, recycles plant nutrients and add organic matter to soil. The present findings are in-line with Bhagat *et al.* (2016) and they reported that higher population of plant growth promoting rhizobacteria and fungal population were noticed with paddy straw mulch 6 .0 t/ha. The lowest soil microbial count was registered with chemical weed management practices *i.e.* imazethapyr 75 g/ha PoE, which might have showed the inhibitory effect on growth and proliferation of bacterial population. Among the plant water extracts, the lowest number of effective *Rhizobium* nodules/ plant, bacterial and fungal counts were observed with Parthenium water extract, which was however comparable with purple nutsedge water extract spray confirming findings of Raut and Pukale (2010). However, lower actinomycetes population in soil was noticed with sunflower water extract spray followed by sorghum water extract spray as the allelomones present in these water extracts might have showed inhibitory effect on actinomycetes growth and development.

Table 2. Effect of different herbicides and plant water extracts on soil microbial population in groundnut

Weed management practices	Rhizobium nodules/plant		Bacteria ($x10^6$) cfu/g soil		Fungi ($x10^3$) cfu/g soil		Actinomycetes (x 10^4) cfu/g soil	
	40 DAS	At harvest	40 DAS	At harvest	40 DAS	At harvest	40 DAS	At harvest
Sorghum water extract 15 L/ha 15 & 30 DAS	58.40	5.53	34.67	47.33	21.33	24.33	12.67	16.33
Sunflower water extract 15 L/ha 15 & 30 DAS	58.53	5.60	36.67	52.33	22.67	26.33	11.67	15.00
Rice straw water extract 15 L/ha 15 & 30 DAS	58.07	5.33	35.00	48.67	19.00	23.00	14.67	14.33
Parthenium water extract 15 L/ha 15 & 30 DAS	57.53	5.07	36.33	47.67	21.33	21.33	14.67	15.00
Lantana water extract 15 L/ha 15 & 30 DAS	58.40	5.47	34.33	48.67	20.67	22.00	13.67	18.67
Purple nutsedge water extract 15 L/ha 15 & 30 DAS	57.67	5.20	31.67	44.33	19.67	22.33	13.67	15.67
Paddy straw mulch 5 t/ha 7 DAS	59.40	5.73	41.00	52.67	26.00	27.67	19.00	20.67
Pendimethalin 1000 g/ha PE *fb* HW 1 & 30 DAS	60.27	5.80	30.00	42.33	14.67	27.00	9.67	14.00
Imazethapyr 75g/ha PoE 15 DAS	59.00	5.60	27.67	36.33	14.67	28.33	9.33	15.33
Unweeded check (control)	58.00	4.80	33.33	45.00	20.61	43.67	13.33	16.67
LSD (p=0.05)	0.48	0.33	2.14	2.56	2.32	2.40	1.36	NS

It was concluded that the paddy straw mulch 5.0 t/ha followed by sunflower water extract 15 L/ha applied at 15 and 30 DAS caused significantly lower density and biomass of all the categories weeds in groundnut; highest values of groundnut yield components and pod yield. However, benefit-cost ratio was comparable with each other among the organic weed management practices. Pre-emergence application of pendimethalin1.0 kg/ha + HW at 30 DAS recorded significantly higher number of effective *Rhizobium* nodules/ plant whereas paddy straw mulch 5/0 t/ha recorded significantly higher count of soil microorganisms *viz*., bacteria, fungi and actinomycetes, at 40 DAS and at harvest.

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RESEARCH NOTE

Efficacy of pre-and post-emergence herbicides on weed dynamics, growth and yield of soybean

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ABSTRACT

A field investigation was conducted at AICRP on Weed Management Farm, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola. The experiment was laid out in a randomized block design with three replications and twelve treatments. Among the herbicidal treatments, diclosulam 84% WDG 0.026 kg/ha and sulfentrazone 28% + clomazone 30% WP 0.725 kg/ha (ready mix) as pre-emergence were found effective in controlling sedges, monocot and dicot weeds across the crop growth period along with lowest weed dry matter accumulation, maximum weed control efficiency, lowest weed index and higher seed yield and economics in soybean. Mulching with wheat straw 5t/ha recorded statistically comparable yield over the application of post-emergence herbicide treatments.

Keywords: Diclosulam, Flumioxazin, Soybean, Sulfentrazone + Clomazone, Weed management

Soybean (*Glycine max* L.) often designated as a miracle crop of the twenty-first century, contains about 20% of oil, 40% high-quality proteins, 23% carbohydrates and reasonable amounts of minerals, vitamins, and dietary fibers. Since the yield per unit for many conventional crops has perhaps come to a plateau, the search for unconventional sources of protein-rich food and edible oil supply is a necessity and soybean seems the only crop at present, that has the potential to meet the present and future needs of the world for protein and edible oil. Among the various factors responsible for the low productivity of soybeans, weed infestation during the early stages of growth is a major concern. The losses caused by weeds exceed the losses from any other category of biotic factors like insects, nematodes, rodents, *etc*. In *Kharif* (rainy) season, there is high rainfall which does not permit hand-weeding operations timely resulting in yield loss of up to 30-80% (Yaduraju 2002). Thus, intense weed competition is one of the main constraints for increasing soybean productivity. Soybean crop grows slowly during the initial period, which results in vigorous growth and proliferation of weeds. Pre- and post-emergence weed control method is becoming popular and regarded potentially as one of the most labour-saving innovations in modern agriculture. Spraying of pre-emergence herbicides helps to minimize the crop weed competition during initial critical growth stages resulting in higher crop yields. Several herbicides used in soybean reported *viz.* broad-spectrum pre-plant incorporation (PPI); pendimethalin (Malik *et al.* 2006), pre-emergence (PE); diclosulam, flumioxazin, (Hosmath *et al.* 2009) and post-emergence (PoE); herbicides imazethapyr, quizalofop-ethyl, sodium acifluorfen. These herbicides could be used in fields with the least risk of crop yield loss. However, in many instances weeds flourish even after a critical period of crop-weed competition and it is difficult to control these weeds through cultural operation due to unfavorable conditions. Hence, it is imperative to give season-long weed control in soybeans.

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A field investigation was conducted at AICRP on Weed Management Farm, Department of Agronomy, Dr. Panjabrao Deshmukh Krishi Vidyapeeth, Akola to study the relative performance of different herbicides on weed flora in Soybean. The soil of the experimental field was characterized as clayey in texture, having slightly alkaline pH (7.80), moderate organic carbon status (0.46%), low nitrogen content (178 kg/ha), medium available phosphorus content (17.05 kg/ha) and high potassium status (384 kg/ha). Soybean cv '*PDKV Yellow Gold*' was sown on broad-bed and furrow on 18 June 2021 with row-to-row spacing of 45 cm and fertilizer use of 30:60:30 NPK kg/ha as basal and the crop was harvested on 7 October 2021. The total rainfall received during the crop growth period was 850 mm. The experiment was laid out in a randomized block design with three replications with 12 treatments. The treatments comprised of flumioxazin 50% SC 0.125 kg/ha, diclosulam 84% WDG 0.026 kg/ha, pendimethalin

38.7% CS 0.677 kg/ha, pendimethalin 30% + imazethapyr 2% EC 0.960 kg/ha (ready mix), sulfentrazone 28% + clomazone 30% WP 0.725 kg/ha (ready mix), pendimethalin 30% EC + diclosulam 84% WDG 0.750 + 0.0252 kg/ha (tank mix), sodium acifluorfen 16.5% + clodinafop-propargyl 8% EC 0.245 kg/ha as PoE (ready mix), quizalofop-ethyl 10% EC + chlorimuron-ethyl 25% WP 0.037+0.009 + 0.2% surfactant kg/ha as PoE at (ready mix), fomesafen 12% + quizalofop-ethyl 3% SC 0.225 kg/ha as PoE at (ready mix), mulching (wheat straw) 5 t/ha, farmer's practice (two hand weeding at 15 and 30 DAS and one hoeing 20 DAS) and weedy check. All the pre-emergence herbicides were applied on the same day after sowing of crop seed and post-emergence herbicides were applied at the 2-3 leaf stage (25 DAS). The data on weed density (no./m^2) and weed biomass were assessed on the intensity and growth of the weeds at 20, 40 and 60 DAS. The number of weeds in a quadrate of 0.25 m^2 at two random spots in each plot was counted from net plot area and converted into one m^2. The entire weeds inside the quadrate were uprooted and cut close to the transition of root and shoot in each plot and collected for dry matter accumulation. The samples were first dried in the sun and kept in an oven at 70 ºC for 48 hours. The dried samples were weighed and expressed as dry biomass (g/m^2). Square root transformation was done for weed density and weed biomass by using the formula. Weed control efficiency (WCE) refers to the efficiency of treatment expressed in percent for controlling weeds in comparison to weedy check. Weed index refers to the reduction in the yield due to the presence of weeds in comparison with weed-free check.

Weed Flora: The density of dicot weeds was much higher than that of monocot weeds throughout the crop-growing season. Among dicot, the density of *Euphorbia* sp., *Parthenium hysterophorus*, *Phyllanthus niruri, Acalypha indica, Digeria arvensis* and with respect to monocot *Commelina benghalensis*, *Cynodon dactylon, Digiteria sanguinalis, Euphorbia geniculate, Rottboelia cochinchinensis, Eleusine indica, Dinebra retroflexa* and among sedges, *Cyperus rotundus* were predominant weeds in the experimental plots. Similar findings were recorded in several previous studies reports by Shashidhar *et al*. (2020) regarding weed flora existence in the experimental plots.

Weed density: Weed density at 60 DAS was higher as compared to those recorded at 20 and 40 DAS irrespective of the species. The weed intensity of all species was significantly reduced by the application of herbicides either applied pre- or post-emergence at all stages (20, 40 and 60 DAS) of crop growth over the weedy check (**Table 1**). The results showed that hand weeding at 15 and 30 DAS and one hoeing at 20 DAS was significantly better concerning control of different weed species. Diclosulam was most effective in controlling the broad spectrum of weed flora. It was observed that the application of sulfentrazone 28% + clomazone 30% WP 0.725 kg/ha (RM) as pre-emergence effectively controlled the sedge density. Herbicides initially inhibited the germination of weeds but later these dissipated and deactivated in the soil increasing the next flush of weeds subsequently. These results conformed with the findings of Mansoori *et al.* (2015). Many researchers (Krauz and Young 2003, Andhale and Kathmale 2019) have reported lower sedge densities in soybean with the use of herbicides like sulfentrazone 28% + clomazone 30% WP 0.725 kg/ha. Poornima *et al.* (2018) reported that the application of diclosulam 84% WDG 0.026 kg/ha as pre-emergence effectively controlled both monocot and dicot weeds.

Weed dry matter: The dry matter accumulation of weeds (g/m^2) increased with the increasing weed density as well as the variation of weed species and their growth. The highest weed dry matter was achieved under weedy check at 20, 40 and 60 DAS (**Table 2**) and the lowest weed dry matter was recorded in farmer's practice. Among herbicidal treatments, diclosulam 84% WDG 0.026 kg/ha as pre-emergence resulted in maximum weed dry matter reduction of monocot and dicot. However, the application of sulfentrazone 28% + clomazone 30% WP 0.725 kg/ha (RM) as pre-emergence effectively reduced the dry matter accumulation of sedges. The effect of herbicides applied as pre-emergence was subdued at this belated stage, which might be on account of a longer period after application and restricted effective residual period. These results conform with Gupta *et al.* (2017).

Weed indices: The highest weed control efficiency (%) and minimum weed index (%) were achieved by the application of diclosulam 84% WDG 0.026 kg/ha as pre-emergence which was followed by sulfentrazone 28% + clomazone 30% WP 0.725 kg/ha (RM) (**Table 3**). Higher weed control efficiency and lower weed index in these treatments might be due to the lower dry weight of weeds and higher seed yield, respectively. Weed competition was significantly reduced by pre-emergence use of diclosulam, which was significantly superior to the remaining treatments suggesting that diclosulam offers greater reduction of grasses, sedges and broad-leaved weeds and there is a positive effect of herbicide application on crop yield. It confirms the findings of Singh *et al.* (2019).

Seed yield: Data related to the seed yield of soybeans was significantly influenced by various weed control

Table 1. Weed density (no./m^2) as influenced by different weed control treatments

Treatment	Sedges			Monocots			Dicots			Total		
	20 DAS	40 DAS	60 DAS	20 DAS	40 DAS	60 DAS	20 DAS	40 DAS	60 DAS	20 DAS	40 DAS	60 DAS
Flumioxazin 0.125 kg/ha	3.24 (10.00)	5.59 (30.70)	5.37 (28.33)	3.24 (9.99)	3.63 (12.67)	5.18 (26.33)	1.35 (1.33)	3.24 (10.0)	2.92 (8.00)	4.67 (21.33)	7.34 (53.38)	7.95 (62.66)
Diclosulam 0.026 kg/ha	2.34 (5.00)	1.55 (1.90)	2.04 (3.67)	2.34 (4.97)	3.54 (12.02)	4.88 (23.31)	0.71 (0.00)	3.85 (14.3)	3.44 (11.33)	3.24 (9.98)	5.36 (28.23)	6.66 (43.81)
Pendimethalin 0.677 kg/ha	4.53 (20.00)	7.31 (33.00)	5.40 (28.67)	4.53 (20.02)	4.1 (16.31)	5.02 (24.70)	3.14 (9.33)	3.54 (12.0)	5.02 (24.67)	7.06 (49.35)	9.04 (81.31)	8.86 (78.04)
Pendimethalin + imazethapyr 0.960 kg/ha (RM)	2.55 (6.00)	1.67 (2.30)	1.78 (2.67)	2.55 (6.00)	5.46 (29.31)	1.58 (1.99)	1.78 (2.67)	4.02 (15.67)	5.05 (25.00)	3.90 (14.67)	6.91 (47.28)	5.24 (27.00)
Sulfentrazone + clomazone 0.725 kg/ha (RM)	2.12 (4.00)	0.83 (0.70)	0.71 (0.00)	2.12 (3.99)	4.3 (17.99)	4.67 (21.30)	0.71 (0.00)	4.06 (16.00)	4.80 (22.50)	2.91 (7.99)	5.93 (34.69)	6.23 (38.81)
Pendimethalin + diclosulam 0.750 + 0.0252 kg/ha (TM)	2.27 (4.67)	1.58 (2.00)	1.47 (1.67)	2.29 (4.74)	4.88 23.31	4.78 (22.34)	0.71 (0.00)	3.44 (11.33)	4.53 (20.00)	3.15 (9.41)	6.09 (36.64)	6.67 (44.02)
Sodium acifluorfen + clodinafop-propargyl 0.245 kg/ha as PoE (RM)	4.30 (18.00)	4.60 (20.70)	5.58 (30.67)	4.53 (20.02)	3.24 (9.99)	3.81 (14.01)	4.81 (22.67)	3.67 (13.00)	5.15 (26.00)	7.82 (60.69)	6.65 (43.70)	8.44 (70.69)
Quizalofop-ethyl + chlorimuron-ethyl WP 0.037+0.009 + 0.2% surfactant kg/ha as PoE at (RM)	4.22 (17.33)	3.35 (10.70)	4.10 (16.33)	4.22 (17.30)	4.3 (17.99)	3.85 (14.32)	5.58 (30.67)	4.95 (24.00)	5.93 (34.67)	8.11 (65.31)	7.29 (52.69)	8.11 (65.32)
Fomesafen + quizalofop-ethyl 0.225 kg/ha as PoE at (RM)	4.60 (20.67)	3.85 (14.33)	4.30 (18.00)	4.6 (20.66)	4.56 (20.29)	4.74 (21.96)	5.58 (30.67)	3.54 (12.00)	5.08 (25.33)	8.51 (72.00)	6.86 (46.62)	8.11 (65.30)
Mulching (wheat straw) 5 t/ha	3.03 (8.67)	2.41 (5.30)	5.12 (25.67)	3.03 (8.68)	4.22 (17.30)	1.96 (3.34)	2.92 (8.00)	4.95 (24.00)	5.37 (28.33)	5.08 (25.35)	6.86 (46.61)	7.61 (57.34)
Farmer's practice (2 HW at 15 and 30 DAS and hoeing 20 DAS)	1.47 (1.67)	1.34 (1.30)	1.70 (2.40)	1.45 (1.60)	1.58 (1.99)	1.78 (2.66)	1.35 (1.33)	1.82 (2.80)	1.70 (2.40)	2.26 (4.60)	2.57 (6.10)	2.82 (7.47)
Weedy check	5.46 (29.33)	6.26 (38.70)	6.10 (36.67)	5.46 (29.31)	5.73 (32.33)	6.10 (36.71)	6.15 (37.33)	7.60 (57.33)	6.79 (45.67)	9.82 (95.97)	11.35 (128.3)	10.93 (119.0)
LSD (p=0.05)	1.45	1.58	0.60	1.16	1.79	1.57	1.83	1.47	2.00	0.44	0.60	0.62

*Data subjected to $\sqrt{x+0.5}$ transformation and figure in parentheses are the original value.

Table 2. Weed dry weight (g/m^2) as influenced by different weed control treatments

Treatment	Sedges			Monocots			Dicots			Total		
	20 DAS	40 DAS	60 DAS	20 DAS	40 DAS	60 DAS	20 DAS	40 DAS	60 DAS	20 DAS	40 DAS	60 DAS
Flumioxazin 0.125 kg/ha	2.20 (4.33)	4.22 (17.30)	4.93 (23.81)	3.03 (8.67)	2.90 (7.90)	3.43 (11.26)	0.84 (0.20)	2.39 (5.20)	3.07 (8.95)	3.70 (13.20)	5.56 (30.40)	6.67 (44.02)
Diclosulam 0.026 kg/ha	1.94 (3.27)	2.15 (4.11)	2.85 (7.64)	1.97 (3.40)	1.96 (3.33)	3.05 (8.83)	0.71 (0.00)	1.69 (2.34)	2.91 (7.97)	2.68 (6.67)	3.21 (9.78)	4.99 (24.44)
Pendimethalin 0.677 kg/ha	3.68 (13.03)	5.58 (30.61)	5.17 (26.22)	3.13 (9.30)	1.81 (2.79)	3.41 (11.15)	2.61 (6.30)	2.80 (7.34)	3.95 (15.08)	5.40 (28.63)	6.42 (40.74)	7.28 (52.45)
Pendimethalin + imazethapyr 0.960 kg/ha (RM)	1.97 (3.38)	2.19 (4.29)	3.56 (12.14)	2.15 (4.12)	2.17 (4.23)	3.33 (10.60)	1.36 (1.35)	2.76 (7.12)	4.14 (16.60)	3.06 (8.85)	4.02 (15.64)	6.31 (39.34)
Sulfentrazone + clomazone 0.725 kg/ha (RM)	1.82 (2.82)	1.99 (3.45)	0.71 (0.00)	2.50 (5.75)	2.66 (6.59)	4.29 (17.89)	0.71 (0.00)	1.61 (2.09)	4.37 (18.56)	3.01 (8.57)	3.55 (12.13)	6.08 (36.45)
Pendimethalin + diclosulam 0.750 + 0.0252 kg/ha (TM)	2.84 (7.58)	2.51 (5.82)	4.05 (15.92)	2.26 (4.61)	2.68 (6.66)	3.69 (13.14)	0.71 (0.00)	2.00 (3.49)	4.16 (16.80)	3.56 (12.19)	4.06 (15.97)	6.81 (45.86)
Sodium acifluorfen + clodinafop-propargyl 0.245 kg/ha as PoE (RM)	4.14 (16.60)	4.25 (17.60)	5.78 (32.89)	2.48 (5.64)	2.35 (5.04)	2.57 (6.10)	3.35 (10.73)	2.60 (6.25)	2.94 (8.12)	5.79 (32.98)	5.42 (28.89)	6.90 (47.11)
Quizalofop-ethyl + chlorimuron-ethyl WP 0.037+0.009 + 0.2% surfactant kg/ha as PoE at (RM)	3.50 (11.77)	1.70 (2.41)	3.07 (8.90)	2.71 (6.87)	1.08 (0.67)	2.91 (7.96)	3.04 (8.75)	4.32 (18.13)	5.01 (24.58)	5.28 (27.39)	4.66 (21.21)	6.48 (41.44)
Fomesafen + quizalofop-ethyl 0.225 kg/ha as PoE at (RM)	3.86 (14.40)	3.23 (9.93)	3.66 (12.89)	2.43 (5.39)	3.66 (12.88)	3.80 (13.94)	3.04 (8.75)	2.19 (4.31)	2.76 (7.11)	5.39 (28.53)	5.26 (27.13)	5.87 (33.94)
Mulching (wheat straw) 5 t/ha	2.48 (5.65)	2.97 (8.29)	3.92 (14.89)	3.08 (8.98)	3.35 (10.70)	3.46 (11.50)	2.31 (4.84)	1.95 (3.31)	2.75 (7.09)	4.47 (19.47)	4.78 (22.30)	5.83 (33.48)
Farmer's practice (2 HW at 15 and 30 DAS and hoeing 20 DAS)	2.06 (3.67)	3.22 (9.85)	4.75 (22.04)	0.71 (0.00)	0.89 (0.30)	2.56 (6.05)	1.86 (2.95)	1.14 (0.81)	2.78 (7.23)	2.69 (6.71)	3.39 (10.96)	5.98 (35.32)
Weedy check	5.14 (25.90)	5.42 (28.90)	5.63 (31.23)	4.89 (23.44)	5.22 (26.77)	5.79 (32.98)	5.33 (27.89)	5.43 (29.00)	5.86 (33.82)	8.82 (77.23)	9.23 (84.67)	9.93 (98.03)
LSD (p=0.05)	0.39	1.83	2.67	1.07	1.74	1.85	1.11	1.37	1.99	0.36	0.58	0.59

treatments (**Table 3**). Pre-emergence herbicide application of diclosulam 84% WDG 0.026 kg/ha recorded higher seed yield and was found at par with all pre-emergence herbicides namely, sulfentrazone 28% + clomazone 30% WP 0.725 kg/ha (RM), pendimethalin 30% + imazethapyr 2% EC 0.960 kg/ha (RM), flumioxazin 50% SC 0.125 kg/ha and pendimethalin 30% EC + diclosulam 84% WDG 0.750 + 0.0252 kg/ha (TM) excluding pendimethalin 38.7% CS 0.677 kg/ha. However, among pre-emergence herbicide application of quizalofop-ethyl 10% EC + chlorimuron-ethyl 25% WP 0.037+0.009

Table 3. Weed control efficiency (WCE) and weed index, seed yield and economics of different weed control treatments

Treatment	Weed control efficiency (%) 20 DAS	Weed control efficiency (%) 40 DAS	Weed index (%)	Seed yield (t/ha)	Cost of cultivation (x10^3 `/ha)	Net monetary returns (x10^3 `/ha)	B:C
Flumioxazin 0.125 kg/ha	82.91	64.10	12.19	2.53	41.64	64.83	2.56
Diclosulam 0.026 kg/ha	91.36	88.45	0.00	2.88	41.70	79.37	2.90
Pendimethalin 0.677 kg/ha	62.93	51.88	16.71	2.40	40.00	60.91	2.52
Pendimethalin + imazethapyr 0.960 kg/ha (RM)	88.54	81.53	8.02	2.65	41.87	69.45	2.66
Sulfentrazone + clomazone 0.725 kg/ha (RM)	88.90	85.67	3.16	2.79	45.42	71.56	2.58
Pendimethalin + diclosulam 0.750 + 0.0252 kg/ha (TM)	84.21	81.14	12.99	2.51	41.48	63.77	2.54
Sodium acifluorfen + clodinafop-propargyl 0.245 kg/ha as PoE (RM)	57.30	65.88	17.33	2.31	40.49	59.71	2.47
Quizalofop-ethyl + chlorimuron-ethyl WP 0.037+0.009 + 0.2% surfactant kg/ha as PoE at (RM)	64.53	74.95	19.94	2.38	39.97	56.97	2.43
Fomesafen + quizalofop-ethyl 0.225 kg/ha as PoE at (RM)	63.05	67.96	18.62	2.34	40.58	58.09	2.43
Mulching (wheat straw) 5 t/ha	74.79	73.66	20.67	2.28	47.16	48.90	2.04
Farmer's practice (2 HW at 15 and 30 DAS and hoeing 20 DAS)	91.31	87.06	30.29	2.01	48.73	36.18	1.74
Weedy check	0.00	0.00	44.66	1.59	35.08	33.19	1.95
LSD (p=0.05)	--	--	--	0.38	--	15.36	--

+ 0.2% surfactant kg/ha (RM) recorded the highest seed yield. The lowest seed yield was recorded in the weedy check. The enhancement in the seed yield due to various weed control measures was because they helped to keep the field comparatively free from weeds. This consequently led to the production of more vigorous and healthy plants having more pod-bearing capacity, more seed per pod and 100-seed weight. The cumulative effect of all these resulted in higher seed yield, making it amply clear that these weed control measures exerted a profound influence in curtailing the weed population and thereby reducing the weed biomass at important growth stages of crop. The results corroborate the findings of Pandya *et al.* (2005).

Economics: Application of diclosulam 84% WDG 0.026 kg/ha as pre-emergence recorded significantly higher net monetary returns followed by sulfentrazone 28% + clomazone 0.725 kg/ha (RM), pendimethalin 30% + imazethapyr 0.960 kg/ha (RM), flumioxazin 0.125 kg/ha, pendimethalin + diclosulam 0.750 + 0.0252 kg/ha (TM) and pendimethalin 0.677 kg/ha (**Table 3**). Among post-emergence herbicides, the maximum net monetary return was recorded with quizalofop-ethyl + chlorimuron-ethyl 0.037+0.009 + 0.2% surfactant kg/ha, followed by fomesafen 12% + quizalofop-ethyl 0.225 kg/ha and sodium acifluorfen 16.5% + clodinafop-propargyl 0.245 kg/ha. The lowest net monetary returns were recorded in a weedy check. The higher net monetary return was mainly due to the lower cost of cultivation especially for labour wages engaged in spraying. Similar results were reported by Shruthi *et al.* (2015).

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RESEARCH NOTE

Weed management in finger millet (*Eleusine coracana* L.) intercropped in coconut garden

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ABSTRACT

A field experiment was laid out in randomized block design at Coconut Research Station, Balaramapuram consisted 12 weed management treatments replicated thrice to determine the cost-effective weed management practice for finger millet intercropped in coconut. There was significant reduction in the absolute density of grasses and broad-leaed weeds in finger millet due to weed management. Manual weeding at 15 and 30 DAS resulted in the lowest weed biomass at 40 DAS, however at 60 DAS, pre-emergence (PE) pyrazosulfuron-ethyl 20 g/ha *fb* wheel hoe weeding (WHW) at 25 DAS recorded the lowest weed biomass (32.40 g/m^2). Weed control efficiency also followed the same trend as that of weed biomass. Pre-emergence application of pyrazosulfuron-ethyl 20 g/ha *fb* WHW at 25 DAS resulted in the highest weed control efficiency (91.8 %). Uncontrolled weed growth resulted in a yield loss of 53.88%. The lowest weed index was noted in PE pyrazosulfuron-ethyl 20 g/ha *fb* WHW at 25 DAS. Among the treatments, PE pyrazosulfuron-ethyl 20 g/ha *fb* WHW at 25 DAS recorded the highest productive tillers (93.3 no./m^2), fingers per ear head (13.3 no.) and ear head weight (12.8 g). This treatment also resulted in the highest grain yield (2072.2 kg/ha) which was statistically at par with PE pyrazosulfuron 20 g/ha *fb* penoxsulam + cyhalofop-butyl 125 g/ha at 25 DAS (1931.5 kg/ha). The net return (40974 ₹ /ha) and B: C ratio (1.98) were also highest in PE pyrazosulfuron 20 g/ha *fb* WHW at 25 DAS.

Keywords: Chemical control, Coconut, Finger millet, Intercrop, Weed management, Wheel hoe weeding

Finger millet locally known as ragi or madua in South India is a low-cost cereal and a staple food for the people of dryland regions of the world. It is estimated that finger millet accounts for about 10% of global millet production (Dida *et al.* 2008). In India, it ranked third in area and production among millets. Fingers millet has higher nutraceutical value because of higher calcium content (0.38%), dietary fibre (18%) and phenolic compound (0.3-3%) (Devi *et al.* 2014). The grains are rich in amino acids, which are lacking in the diets of the poor who eat mostly starchy foods. It was intensively grown in rainfed areas due to its high plasticity in terms of soil type, fertility status, and low water requirement.

Weed infestation was the serious problem in finger millet due to slow initial growth. Only when it reaches the mid-growth phase, finger millet plants achieve sufficient canopy cover to shade and restrict the growth of weeds (Mishra *et al.* 2015). Kujur *et al.* (2019) pointed out that severe crop weed competition resulted in 72% reduction in grain yield in direct sown finger millet. Mahapatra (2021) observed that among the various biotic stresses, weed infestation alone caused 70 per cent yield loss in finger millet.

Herbicidal method of weed control was considered to be the easiest and most viable way of weed management. Kumar *et al.* (2015) noticed lower weed density and weed biomass by using pre-emergence application of bensulfuron-methyl + pretilachlor 10 kg/ha compared to weedy check in drill sown finger millet. Prithvi *et al.* (2015) reported bispyribac-sodium 25g/ha alone at 15 DAT and bispyribac-sodium 25 g/ha at 15 DAT *fb* inter cultivation at 30 DAT resulted in a WCE of 45 and 63%, respectively in transplanted finger millet. Pre-emergence application of oxyfluorfen 50 g/ha resulted in higher grain yield (2720 kg/ha) and straw yield (4924 kg/ha) in finger millet (Shanmugapriya *et al.* 2019).

Mechanical weed control is one of the most traditional and widely used techniques for controlling weeds in millets. Naik *et al.* (2001) found that hoeing at 35 DAS was beneficial in managing the weed

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competition and resulted in the destruction of 40-50% of weeds compared to weedy check in direct sown finger millet. With this background, the present study was carried out with an aim to determine the cost-effective integrated weed management practice for finger millet intercropped in coconut.

Field experiment was laid out at Coconut Research Station, Balaramapuram in randomized block design with 12 treatments replicated thrice during Summer 2021. The treatments adopted for the study were PE application of bensulfuron-methyl + pretilachlor 495 g/ha *fb* wheel hoe weeding (WHW) at 25 DAS, PE application of bensulfuron-methyl + pretilachlor 495 g/ha *fb* bispyribac-sodium 20 g/ha at 25 DAS, PE application of bensulfuron-methyl + pretilachlor 495 g/ha *fb* penoxsulam + cyhalofop-butyl 125 g/ha at 25 DAS, PE application of pyrazosulfuron-ethyl 20 g/ha *fb* WHW at 25 DAS, PE application of pyrazosulfuron-ethyl 20 g/ha *fb* bispyribac-sodium 20 g/ha at 25 DAS, PE application of pyrazosulfuron-ethyl 20 g/ha *fb* penoxsulam + cyhalofop-butyl 125 g/ha at 25 DAS, PE application of oxyfluorfen 50 g/ha *fb* WHW at 25 DAS, PE application of oxyfluorfen 50 g/ha *fb* bispyribac-sodium 20 g/ha at 25 DAS, PE application of oxyfluorfen 50 g/ha *fb* penoxsulam + cyhalofop-butyl 125 g/ha at 25 DAS, WHW at 15 and 30 DAS, hand weeding (HW) at 15 and 30 DAS) and weedy check. The variety used for the study was '*PPR 2700* (*Vakula*)', a high yielding blast resistant variety released from Agricultural Research Station, Perumalapalli, Andhra Pradesh. The crop was raised in the inter-row spaces of coconut in the Coconut Research Station Farm, Balaramapuram, where coconut was planted at a spacing of 7.6 x 7.6 m which received 70% light intensity. Previously the inter-row spaces of coconut were utilized for banana cultivation. The soil was acidic in reaction and texture of the experimental area was sandy loam. The soil was low in available N, medium in available P and high in available K. Rainfall received during the crop season was 129.8 mm. Garden tiller was used to plough the field. The entire experimental site was laid out into 36 treatment plots. Gross plot size of the experimental plots was 4 x 3.6 m and the net plot size was 3x 3 m. Treatment plots were separated with bunds of 30 cm height and width. The seeds were sown at the rate of 5 kg/ha using seed cum fertilizer drill at a spacing of 25 x 15 cm. Fertilizer recommendation followed was 45:22.5:22.5 NPK kg/ha. (KAU, 2016). Farm yard manure (5 t/ha) and lime (250 kg/ha) were uniformly applied to plot at the time of final land preparation. Spray solution used for the study was 500 L/ha. Pre-emergence herbicides were applied on the day of sowing as per the treatments and post-emergence (PoE) herbicides as per the treatments were applied with the help of a crop protective herbicide applicator.

Absolute density of grasses and broad- leaf weeds (BLW) were calculated by randomly placing the quadrant 0.25 x 0.25 m at two places in each treatment plot and weeds present within the quadrant area were counted and expressed as no./m^2. Weed biomass was determined by uprooting the weeds from the same area where the quadrant was placed for recording the absolute density of weeds, later collected weeds were shade dried to reduce the moisture content and then oven dried at 65 °C until a constant weight was attained, average was worked out and expressed as g/m^2. Weed control efficiency was worked out by the formula put forth by Mani and Gautham (1973) and the weed index was worked out by the formula explained by Gill and Vijayakumar (1969). For calculating the weed index the treatment which recorded the highest grain yield was taken as the control treatment.

The number of fingers in the ear head and the ear head weight were recorded from the ten observation plants and the mean value was worked out. Productive tillers per m^2 were recorded by placing quadrate (0.25 x 0.25 m) at two places in each treatment plot and expressed as no./m^2. Grain yield from the net plot area was dried under sun to a constant moisture content of 12% and expressed in kg/ha. Economics was computed by considering the market price of finger millet grain and input costs. Statistical analysis was conducted using Grapes Agri.1, a collection of shiny apps for agricultural research data analysis in R software (Gopinath *et al.* 2021).

Effect on weed flora

Grasses and broad-leaved weeds (BLW) were the major weeds in the experimental site. Among the two, grasses were the predominant one. *Panicum maximum* Jacq., *Setaria barbata* (Lam.) Kunth, and *Digitaria sanguinalis* (L.) Scop. were the three prominent grasses present in the experimental filed. The major BLW present in the experimental plots were *Mimosa pudica* L., *Phyllanthus niruri* L., *Boerhavia diffusa* L. and *Synedrella nodiflora* (L.) Gaertn. Sedges were absent in the experimental field.

Effect on the absolute density of grasses and BLW

Among the weed management practices, PE oxyfluorfen (50 g/ha *fb* WHW at 25 DAS, 50 g/ha *fb* bispyribac-sodium 20 g/ha at 25 DAS and 50 g/ha *fb* penoxsulam+ cyhalofop-butyl 125 g/ha at 25 DAS) resulted in the lowest absolute density of grasses compared to other two PE herbicides tested (bensulfuron-methyl + pretilachlor and pyrazosulfuron-ethyl). Abraham *et al*. (2010) revealed that PE application of oxyfluorfen 150-200 g/ha on four days after transplanting significantly reduced the BLW, grassy weeds and sedges in rice. Data on absolute density of grasses at 40 DAS revealed that, though a reduction in density of grassy weeds were noted in all weed management treatments, the treatments with WHW resulted in lower density of grasses compared to PoE bispyribac-sodium or penoxsulam + cyhalofop-butyl (**Table 1**). This was because of the fact that WHW at 25 DAS effectively uprooted *Panicum maximum* along with the roots, the major grass weed present in the experimental area. Data on absolute density of weeds revealed that, the density of BLW was found to be lesser in PE application of bensulfuron-methyl + pretilachlor and pyrazosulfuron-ethyl treated plots at 40 DAS compared to oxyfluorfen. The result was in agreement with the observations of Yathisha *et al.* (2020) who observed that PE application of bensulfuron-methyl + pretilachlor 198 g/ha effectively controlled the BLW compared to other PE herbicides like atrazine, oxadiargyl, pendimethalin and isoproturon in direct-seeded finger millet. Pal *et al.* (2012) reported that pyrazosulfuron-ethyl was more effective against BLW than sedges and grasses.

Effect on weed biomass and weed control efficiency

Weed management caused significant reduction in weed biomass compared to weedy check (**Table 1**). The percentage reduction in weed biomass in weed management treatments in comparison to weedy check ranged from 82.0 to 98.9% at 40 DAS and 18.6 to 91.8% at 60 DAS, respectively. Patil and Reddy (2014) and Pandey *et al.* (2018) also came to similar conclusion that uncontrolled weed growth in weedy check resulted in higher weed biomass. At 40 DAS, treatment HW at 15 and 30 DAS resulted in the lowest weed biomass and it was followed by PE pyrazosulfuron-ethyl 20 g/ha *fb* penoxsulam + cyhalofop-butyl 125 g/ha. The treatment PE pyrazosulfuron-ethyl 20 g/ha *fb* penoxsulam + cyhalofop-butyl 125 g/ha was statistically at par with PE pyrazosulfuron-ethyl 20 g/ha *fb* WHW at 25 DAS and PE oxyfluorfen 50 g/ha *fb* WHW at 25 DAS. At 60 DAS, PE pyrazosulfuron-ethyl 20 g/ha *fb* WHW at 25 DAS resulted in the lowest weed biomass and it

Table 1. Absolute density of grasses, broad leaf weeds, weed biomass and weed control efficiency as influenced by weed management practices in finger millet

Treatment	Absolute density grasses (no./m^2)		Absolute density BLW (no./ m^2)		Weed biomass (g/m^2)		Weed control efficiency (%)	
	40 DAS	60 DAS	40 DAS	60 DAS	40 DAS	60 DAS	40 DAS	60 DAS
Pretilachlor + bensulfuron-methyl 495 g/ha PE *fb* WHW at 25 DAS	3.32 (10.67)	3.20 (9.33)	1.49 (1.33)	1.90 (2.67)	3.39 (10.51)	8.55 (72.68)	88.3	81.5
Pretilachlor + bensulfuron-methyl 495 g/ha PE *fb* bispyribac-sodium 20 g/ha at 25 DAS	4.43 (18.67)	2.95 (8.00)	1.00 (0.00)	1.00 (0.00)	4.09 (15.98)	14.35 (205.33)	82.3	47.9
Pretilachlor + bensulfuron-methyl 495 g/ha *fb* penoxsulam + cyhalofop-butyl 125 g/ha at 25 DAS	3.95 (14.67)	4.86 (22.67)	1.00 (0.00)	1.52 (1.33)	4.15 (16.24)	13.16 (172.67)	82.0	56.2
Pyrazosulfuron-ethyl 20 g/ha PE *fb* WHW at 25 DAS	3.40 (10.67)	3.78 (13.33)	3.78 (13.33)	1.00 (0.00)	1.58 (1.51)	5.78 (32.40)	98.3	91.8
Pyrazosulfuron-ethyl 20 g/ha PE *fb* bispyribac-sodium 20 g/ha at 25 DAS	4.43 (18.67)	3.20 (9.33)	1.00 (0.00)	1.41 (1.33)	2.21 (3.90)	7.26 (51.87)	95.7	86.8
Pyrazosulfuron-ethyl 20 g/ha PE *fb* penoxsulam + cyhalofop-butyl 125 g/ha at 25 DAS	4.66 (21.33)	3.00 (8.00)	1.90 (2.67)	1.00 (0.00)	1.57 (1.48)	6.14 (36.69)	98.4	90.7
Oxyfluorfen 50 g/ha PE *fb* WHW at 25 DAS	2.24 (4.00)	3.78 (13.33)	3.95 (14.67)	1.91 (2.67)	1.65 (1.71)	10.07 (100.93)	98.1	74.4
Oxyfluorfen 50 g/ha PE *fb* bispyribac-sodium 20 g/ha at 25 DAS	2.75 (6.67)	3.61 (12.00)	3.11 (8.67)	1.000 (0.00)	2.24 (4.02)	12.62 (158.67)	95.5	59.7
Oxyfluorfen 50 g/ha PE *fb* penoxsulam+ cyhalofop-butyl 125 g/ha at 25 DAS	3.40 (10.67)	3.75 (13.33)	1.90 (2.67)	1.000 (0.00)	2.78 (6.72)	11.62 (134.13)	92.5	65.9
WHW at 15 and 30 DAS	3.20 (9.33)	3.78 (13.33)	2.24 (4.00)	1.000 (0.00)	2.00 (3.03)	7.45 (55.33)	96.6	85.9
HW at 15 and 30 DAS	3.57 (12.00)	3.61 (12.00)	3.00 (8.00)	3.000 (8.00)	1.41 (0.97)	17.89 (320.53)	98.9	18.6
Weedy check	6.70 (44.00)	5.97 (34.67)	4.72 (21.33)	3.211 (9.33)	9.55 (90.13)	19.81 (393.73)	0	0
LSD (p=0.05)	0.835	0.612	0.376	0.390	0.134	1.665	-	

PE-Pre-emergence; WHW-wheel hoe weeding; HW-hand weeding; values in parentheses are original values, values are subjected to square root transformation ($\sqrt{x+1}$)

was comparable with PE pyrazosulfuron-ethyl 20 g/ha *fb* penoxsulam + cyhalofop-butyl 125 g/ha and PE application of pyrazosulfuron-ethyl *fb* bispyribac-sodium 20 g/ha. Reduction in the density of grasses and BLW in the weed management treatments favoured crop growth and enabled the crop to suppress the weeds effectively. Shanmughapriya *et al*. (2019) reported that PE application of bensulfuron-methyl + pretilachlor 660 g/ha *fb* PoE bispyribac-sodium 25 g/ha significantly reduced the weed biomass in transplanted finger millet. Ramadevi *et al.* 2021) also revealed the superiority of PE application of pyrazosulfuron-ethyl 15 g/ha in reducing the weed biomass in transplanted finger millet. Application of PE herbicides followed by inter-cultivation at 45 DAS resulted in the lowest weed biomass in direct- seeded finger millet (Satish *et al.* 2018). At 40 DAS, the highest WCE was observed in HW at 15 and 30 DAS (98.92%), which was closely followed by PE pyrazosulfuron-ethyl 20 g/ha *fb* penoxsulam + cyhalofop-butyl 125 g/ha (98.35%) and PE pyrazosulfuron-ethyl 20 g/ha *fb* WHW at 25 DAS (98.32%). At 60 DAS, PE pyrazosulfuron-ethyl 20 g/ha *fb* WHW at 25 DAS resulted in the highest WCE (91.8%) which was closely followed by PE pyrazosulfuron-ethyl 20 g/ha *fb* penoxsulam + cyhalofop-butyl 125 g/ha (90.7%). Nibhoria *et al.* (2021) reported that WHW at 20-25 DAS and at 30-35 DAS resulted in higher WCE in pearl millet. Halder *et al.* (2005) also reported higher WCE and lower weed density in rice due to the application of pyrazosulfuron-ethyl 15 g/ha.

Effect on finger millet

Weed management resulted in higher productive tillers/m^2, fingers per ear head and ear head weight compared to weedy check (**Table 2**). Significant reduction in density of grasses and BLW and weed biomass reduced the crop weed competition and nutrient removal by weeds. This has facilitated better utilization of resources by crop. Increase in the availability of nutrients and moisture might have enhanced the nutrient uptake, photosynthesis, and movement of assimilates from source to sink. This in turn resulted in higher productive tillers, fingers per ear head and ear head weight. The treatment PE pyrazosulfuron-ethyl 20 g/ha *fb* WHW at 25 DAS recorded higher number of productive tillers, fingers per ear head and ear head weight compared to other treatments. This was due to effective management of weeds by PE application of pyrazosulfuron 20 g/ha *fb* WHW at 25 DAS. Ramedevi *et al*. (2021) and Prithvi *et al.* (2015) observed similar results in transplanted finger millet. Weed management might have resulted in the increased availability of nutrients and moisture. In addition to weed control, WHW improved the soil aeration and created a soil condition congenial for crop growth. All these factors resulted in the better expression of yield attributes in PE pyrazosulfuron-ethyl 20 g/ha *fb* WHW at 25 DAS (**Table 2**). Weedy check recorded the lowest productive tillers m^2, fingers and ear head weight.

Table 2. Yield attributes, grain yield and weed index as influenced by weed management practices in finger millet

Treatment	Productive tillers (no./m^2)	No. of fingers per ear head	Ear head weight (g)	Grain yield (t/ha)	Weed index (%)
Pretilachlor + bensulfuron-methyl 495 g/ha PE *fb* WHW at 25 DAS	78.0	10.9	10.2	1.34	36.85
Pretilachlor + bensulfuron-methyl 495 g/ha PE *fb* bispyribac-sodium 20 g/ha at 25 DAS	73.3	11.9	8.9	1.29	37.84
Pretilachlor + bensulfuron-methyl 495 g/ha *fb* penoxsulam + cyhalofop-butyl 125 g/ha at 25 DAS	74.7	13.1	9.4	1.30	37.18
Pyrazosulfuron-ethyl 20 g/ha PE *fb* WHW at 25 DAS	93.3	13.3	12.8	2.07	0.00
Pyrazosulfuron-ethyl 20 g/ha PE *fb* bispyribac-sodium 20 g/ha at 25 DAS	84.0	12.7	11.6	1.59	23.04
Pyrazosulfuron-ethyl 20 g/ha PE *fb* penoxsulam + cyhalofop-butyl 125 g/ha at 25 DAS	85.3	12.4	10.6	1.93	6.04
Oxyfluorfen 50 g/ha PE *fb* WHW at 25 DAS	69.3	10.8	9.0	1.16	43.72
Oxyfluorfen 50 g/ha PE *fb* bispyribac-sodium 20 g/ha at 25 DAS	66.0	11.9	9.5	1.11	46.28
Oxyfluorfen 50 g/ha PE *fb* penoxsulam+ cyhalofop-butyl 125 g/ha at 25 DAS	70.0	13.0	9.4	1.26	39.22
WHW at 15 and 30 DAS	80.0	12.9	9.8	1.46	29.63
HW at 15 and 30 DAS	78.7	12.1	10.3	1.30	37.21
Weedy check	60.0	8.1	7.8	0.96	53.88
LSD (p=0.05)	14.82	2.33	1.01	0.21	-

PE-Pre-emergence; WHW-wheel hoe weeding; HW-hand weeding

Table 3. Gross return, net return and B: C ratio as influenced by weed management practices in finger millet

Treatment	Gross return (x10^3 ₹/ha)	Cost of cultivation (x10^3 ₹/ha)	Net return (x10^3 ₹/ha)	B:C ratio
Pretilachlor + bensulfuron-methyl 495 g/ha PE *fb* WHW at 25 DAS	52296	42764	9532	1.22
Pretilachlor + bensulfuron-methyl 495 g/ha PE *fb* bispyribac-sodium 20 g/ha at 25 DAS	51556	40702	10855	1.27
Pretilachlor + bensulfuron-methyl 495 g/ha *fb* penoxsulam + cyhalofop-butyl 125 g/ha at 25 DAS	5200	42202	9799	1.23
Pyrazosulfuron-ethyl 20 g/ha PE *fb* WHW at 25 DAS	82888	41914	40974	1.98
Pyrazosulfuron-ethyl 20 g/ha PE *fb* bispyribac-sodium 20 g/ha at 25 DAS	63776	39852	23925	1.60
Pyrazosulfuron-ethyl 20 g/ha PE *fb* penoxsulam + cyhalofop-butyl 125 g/ha at 25 DAS	77260	41352	35909	1.87
Oxyfluorfen 50 g/ha PE *fb* WHW at 25 DAS	46592	41574	5018	1.12
Oxyfluorfen 50 g/ha PE *fb* bispyribac-sodium 20 g/ha at 25 DAS	44444	39512	4933	1.13
Oxyfluorfen 50 g/ha PE *fb* penoxsulam+ cyhalofop-butyl 125 g/ha at 25 DAS	50296	41012	9285	1.23
WHW at 15 and 30 DAS	58372	44552	13821	1.31
HW at 15 and 30 DAS	52148	47077	5072	1.11
Weedy check	38224	35077	3148	1.09

PE-Pre-emergence; WHW-wheel hoe weeding; HW-hand weeding

Effect on grain yield and weed index

Weed management resulted in a yield enhancement of 16.3 to 116.8% compared to weedy check (**Table 2**). The treatment PE pyrazosulfuron-ethyl 20 g/ha *fb* WHW at 25 DAS resulted in the highest grain yield (2.072 t/ha) which was comparable with PE pyrazosulfuron-ethyl 20 g/ha *fb* penoxsulam + cyhalofop-butyl 125 g/ha at 25 DAS (1.93 t/ha). The yield enhancement observed in these treatments was due to the production of higher number of panicles/m^2, fingers per ear head and ear head weight (**Table 2**). The result was in agreement with the findings of Pal *et al*. (2012) and Raj and Syriac (2015) in rice.

The percent reduction in yield due to weed infestation was denoted by weed index. Weed competition throughout the crop season resulted in a yield loss of 53.9% in weedy check. Amongst the treatments, the lowest weed index was recorded in PE pyrazosulfuron-ethyl 20 g/ha *fb* WHW at 25 DAS which was followed by PE pyrazosulfuron-ethyl 20 g/ha *fb* penoxsulam + cyhalofop-butyl 125 g/ha at 25 DAS. Pre-emergence application of pyrazosulfuron-ethyl *fb* WHW at 25 DAS or PoE penoxsulam + cyhalofop-butyl at 25 DAS resulted in a competition free environment which might have increased the availability and uptake of nutrients ultimately resulted in higher panicles/m^2 with higher yield (**Table 2**). Kujur *et al*. (2018) reported that weed management resulted in significant improvement in grain yield with lower weed index compared to weedy check in finger millet.

Effect on economics

The highest gross return was observed in the treatment PE pyrazosulfuron-ethyl 20 g/ha *fb* WHW at 25 DAS (82,888 ₹/ha) and it was followed by PE pyrazosulfuron-ethyl 20 g/ha *fb* penoxsulam + cyhalofop-butyl 125 g/ha at 25 DAS (77, 260 ₹/ha) (**Table 3**). Similar to gross return, the highest net return was also observed in PE pyrazosulfuron-ethyl 20 g/ha *fb* WHW at 25 DAS (40974 ₹/ha) and it was succeeded by PE pyrazosulfuron-ethyl 20 g/ha *fb* penoxsulam + cyhalofop-butyl 125 g/ha at 25 DAS (35909 ₹/ha). Similar trend followed for gross and net return. Higher grain yield resulted in higher gross return, net return, and B: C ratio in PE pyrazosulfuron-ethyl 20 g/ha *fb* WHW at 25 DAS and PE pyrazosulfuron-ethyl 20 g/ha *fb* penoxsulam + cyhalofop-butyl 125 g/ha at 25 DAS. Ramadevi *et al.* (2021) also reported that PE application of pyrazosulfuron-ethyl 15 g/ha resulted in higher grain yield and monetary returns in finger Weedy check resulted in the lowest gross return (38,224 ₹/ha), net return (3148 Rs/ha) and B:C ratio (1.09) due to lower grain yield resulted from severe crop weed competition.

It was concluded that yield and yield attributes of finger millet intercropped in coconut were significantly influenced by weed management. Significant reductions in weed density and weed biomass were observed due to weed management. Considering the weed control efficiency, weed index, grain yield, net return and B: C ratio, pre-emergence application of pyrazosulfuron-ethyl 20 g/ha *fb* wheel hoe weeding at 25 DAS could be adjudged as the cost-effective weed management practice for finger millet intercropped in coconut.

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RESEARCH NOTE

Weed management in organic kodo millet in Eastern dry zone of Karnataka

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ABSTRACT

A field experiment was conducted at Research Institute of Organic Farming field unit, University of Agricultural Sciences, Gandhi Krishi Vignan Kendra, Bengaluru during *Kharif* (rainy season) of 2021 to evaluate different organic weed management methods in kodo millet (*Paspalum scrobiculatum* L.). The experiment was laid out in randomized complete block design with 12 treatments, replicated thrice. Hand weeding at 20 and 40 DAS was significantly superior in reducing the weed density (34.7 and 22 no./m^2) and dry weight (4.8 and 5.3 g/m^2) at 30 DAS and at harvest, respectively. Hand weeding at 20 and 40 DAS, stale seed bed technique *fb* inter cultivation twice at 25 and 45 DAS, inter cultivation at 25 DAS *fb* one hand weeding at 45 DAS, two mechanicals (cycle weeder) weeding at 20 and 40 DAS and kodo millet + fodder cowpea as intercrop with in-situ mulching on 35 DAS *fb* one intercultivation at 40 DAS registered 0.93, 0.76, 0.73, 0.68 and 0.67 t/ha grain yield, respectively as against the grain yield of 0.22 t/ha in weedy check. Among the weed control treatments, highest net returns of ₹ 34452/ha was recorded under weed free treatment while the highest B: C ratio (2.34) was recorded with both hand weeding at 20 and 40 DAS and stale seed bed technique *fb* inter cultivation twice at 25 and 45 DAS followed by two mechanicals (cycle weeder) weeding at 20 and 40 DAS (2.13).

Keywords: Economics, Kodo millet, Organic cultivation, Weed management

In the tribal regions of India, kodo (*Paspalum scrobiculatum* L.) is one of the main food crops. It can be found across the tropics and subtropics of the world in moist regions. It was cultivated in southern Rajasthan and Maharashtra for 3000 years (Kajale 1977, De Wet *et al*. 1983). Today it is cultivated from Uttar Pradesh state of India to Bangladesh in North and North-east region and Kerala to Tamil Nadu in the South. Varagu, kodo, haraka and arakalu are the other names for this millet. It is the primary component of the diet's nutritional requirements for farmers in several regions of India who work on marginal or dry land. Millet kodo has approximately 11% protein which protein's nutritional value has been found marginally superior to that of foxtail millet. Kodo millet is cultivated in a variety of soil types and climates and in regions with vastly different temperatures and photoperiods. Nowadays, kodo millet is recommended as a substitute for rice next to finger millet to the patients who are all suffering due to diabetes (Vanithasri *et al*. 2012). Further, the burgeoning population of India may stabilize in an around 1.40 and 1.60 billion by 2025 and 2050, with the need of 380 and 450 million tonnes of food grains, respectively (Siddiq 2000). Hence, there is an urgent need to enhance the production and productivity of kodo millet to meet future demand for food requirements. This crop's tenacity is beneficial for adopting themselves to various ecological niches. The low output of kodo millet (*Paspalum scrobiculatum* L.) is gradually hampered by the slow initial growth of the plant, favourable conditions for weed growth and a large variety of heterogeneous weed flora. Numerous biotic and abiotic factors affect crops. Weed competition with crops for water, light, nutrients and space is one of the main biotic limitations that limits productivity. Weeds compete with crops more fiercely in their early phases of development than in later stages, which hurt crop growth and ultimately reduces the grain yield. Depending on the type and amount of weeds present, crop yields are severely reduced by weeds in the field. In general, yield losses vary from 15 to 20%, but in extreme cases, yield losses may might exceed 50%.

A field investigation was carried out during rainy season (*Kharif*) 2021 at Research Institute of Organic Farming field unit, University of Agricultural Sciences, Gandhi Krishi Vignan Kendra, Bengaluru coming under Eastern dry zone of Karnataka. The soil of the experimental site was sandy loam in texture,

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neutral in reaction (pH 6.58), low electrical conductivity (0.24 dS/m) with medium in organic carbon (0.59 %), available nitrogen (307 kg?ha), available phosphorus (38.7 kg/ha) and available potassium (197.2 kg/ha). The field experiment was laid out in randomized complete block design replicated thrice with 12 treatment combinations (**Table 1**). Before sowing of kodo millet, farm yard manure was applied for all the experimental plots based on N equivalent of recommended dose of fertilizer for the kodo millet. The gross plot size was 5.4 × 4.8 m and net plot size was 4.8 × 4.6 m. On August 3, 2021, seeds of the kodo variety "*RK 390-25*" were sown at a spacing of 30×10 cm. Total rainfall (881.2 mm) received during cropping period in 2021 was higher than 2020 (541.9 mm). Before sowing, stale seed-bed technique was practiced by irrigating the respective plots and then harrowing to remove two flushes of weeds in an interval of 7-8 days. Weed density and weed dry weight were recorded 30 days after sowing and at the time of harvest from pre-marked quadrants of 1 square m area. Weed control efficiency and weed index were worked out at various stages of crop growth to assess the efficiency of different organic weed management methods. The crop was harvested on 25th November, 2021. And at the time of harvest, yield parameters were recorded from representative samples and yield were recorded and economics were worked out based on the cost of inputs, labour charges and prices of outputs during the course of investigation. All the data presented in this paper was of single season and discussed at a probability level of five per cent. Since the weed data is larger, the original values subjected to square root transformation *i.e.*, $(\sqrt{x+1})$ transformation.

Effect on weeds

Major weed species observed in the experimental site were sedges like *Cyperus rotundus*; grassy weeds like *Cynodon dactylon*, *Eleusine indica*, *Echinocloa crusgalli*, *Dactyloctenium aegyptium*, *Digitaria marginata*; and broadleaved weeds like *Ageratum conyzoides*, *Alternanthera sessilis*, *Commelina benghalensis* and *Borroria hispida*. All the weed management practices followed, reduced both weed density and weed dry weight compared to unweeded treatment. Among them hand weeding at 20 and 40 DAS recorded lower weed density both at 30 DAS and at harvest (34.7 and 22.0/m^2, respectively). Other than control, it was found to be lower in stale seedbed technique + inter cultivation twice at 25 and 45 DAS (51.3 and 30.0/m^2, respectively) (**Table 1**). Boyd *et al*. (2006) reported that effective stale seedbed should minimize the soil disturbance and the movement of the seeds from deeper soil profile to the germination zone. Weed dry weight was found to be minimum in stale seedbed technique *fb* intercultivation twice at 25 and 45 DAS at 30 DAS and at harvest (7.07 and 7.49 g/m^2, respectively) than the weed free treatment. Higher weed biomass was reported in unweeded check (15.9 and 14.9 g/m^2). It was due to the initial weed seeds deposition in the soil from previous season which influenced increase in weed seed bank in the soil which were not disturbed or destroyed by any management practice after sowing. All these factors have influenced for higher weed density in the

Table 1. Weed density, weed dry weight, weed control efficiency and weed index as influenced by different organic weed management practices

Treatment	Weed density (no./m^2)		Weed dry weight (g/m^2)		Weed control efficiency (%)	Weed index (%)
	30 DAS	At harvest	30 DAS	At harvest		
Inter cultivation at 25 DAS + 1 hand weeding at 45 DAS	7.88(61.3)	6.10(36.7)	3.05(8.39)	3.19(9.23)	38.0	20.9
Stale seed bed technique + inter cultivation twice at 25 and 45 DAS	7.21(51.3)	5.55(30.0)	2.82(7.07)	2.91(7.49)	49.6	17.6
Straw mulching 5 t/ha at 10-15 DAS	8.50(72.0)	5.79(32.7)	3.34(10.4)	3.04(8.27)	44.4	40.3
Kodo millet + fodder cowpea as intercrop + one inter cultivation at 30 DAS	9.21(84.0)	5.87(34.7)	3.52(11.4)	3.02(8.42)	43.4	67.5
Kodo millet + fodder cowpea as smothering crop in between rows of kodo millet	8.37(70.0)	5.06(25.3)	3.13(8.93)	2.64(6.15)	58.6	68.6
Kodo millet + fodder cowpea as intercrop with in-situ mulching on 35 DAS + one intercultivation at 40 DAS	8.82(78.0)	5.66(32.7)	3.36(10.4)	2.84(7.48)	49.7	28.1
Mechanical (cycle weeder) weeding at 35 DAS	10.33(106.7)	5.90(34.7)	3.73(13.0)	3.07(8.79)	40.9	36.5
Two mechanicals (cycle weeder) weeding at 20 and 40 DAS	9.07(82.0)	6.39(40.7)	3.25(9.59)	3.29(10.1)	31.9	26.6
Cucumber leaf extract spray 100 ml/l, one at 2-4 leaf stage and another spray depending on the weed density	9.75(95.3)	6.59(42.7)	3.61(12.2)	3.37(10.5)	29.3	49.3
Ageratum conyzoides leaf extract spray 100 ml/l, one at 2-4 leaf stage and another spray depending on the weed density	10.1(102.0)	6.65(43.3)	3.75(13.1)	3.43(10.8)	27.4	55.5
Weed free check (hand weeding at 20 and 40 DAS)	5.96(34.7)	4.77(22.0)	2.41(4.80)	2.50(5.30)	64.4	-
Unweeded check (weedy check)	11.58(133.3)	7.54(58.7)	4.11(15.9)	3.91(14.9)	-	76.5
LSD (p=0.05)	1.53	-	0.58	-	-	

Values are subjected to $(\sqrt{x+1})$ transformation; original values are in parentheses; DAS- Days after sowing weedy check. These findings were in accordance with Pradhan and Sonboir (2009).

Hand weeding at 20 and 40 DAS recorded higher weed control efficiency (64.4%) and it was followed by stale seed bed technique + intercultivation twice at 25 and 45 DAS (49.6%). It was the result of the early control of weeds and disruption to the photosynthetic parts. The results of this study were similar with earlier findings of Ashok *et al.* (2003) and Ramamoorthy *et al.* (2009). Among various treatments, stale seedbed technique *fb* intercultivation twice at 25 and 45 DAS recorded lower weed index (17.6%) followed by intercultivation at 25 DAS *fb* one hand weeding at 45 DAS (20.9%) (**Table 1**). Weed free treatment recorded lowest weed index (0%) indicating that there was no reduction in grain and fodder yields due to weed infestation. The highest weed index (76.5%) was reported in unweeded check (control) as a result of uncontrolled weed growth which leads to higher competition with the crop. Similar results were obtained by Sharma and Jain (2003).

Effect on crops

Grain and straw yield of kodo millet were influenced by different organic weed management practices and the data pertaining to it is presented in **Table 2**. In comparison to all other treatments, weed free check (hand weeding at 20 and 40 DAS) recorded higher grain yield (0.93 t/ha) and straw yield (5.1 t/ha) and found to be statistically significant. This might be due to better control of weeds at critical crop-weed competition period and at tillering stage which resulted in production of a greater number of productive tillers, yield components and yield of the crop. This efficiency may be due to effective weed control at critical crop growth stage which lead to increase in availability of moisture, nutrients, light and space for the crop. Similar results were reported by Jawahar *et al.* (2019), who concluded that hand weeding at 20-25 and 30-45 DAS recorded higher grain yield compared to chemical weed management treatments in transplanted kodo millet. The lowest grain yield was obtained in unweeded control (0.22 t/ha). This reduced yield might be due to highest competition throughout the crop growth period. Similar findings were obtained by Patil *et al.* (2013) in finger millet. The straw yield of kodo millet was also extensively influenced by the various treatments. Higher straw yield was recorded under hand weeding at 20 and 40 DAS (5.1 t/ha) and more plant population owing to better weed control which might have contributed to maximum dry matter production and leaf area index and ultimately enhanced straw yield. Similar results were earlier reported by Chanu *et al.* (2018).

Economics

Hand weeding at 20 and 40 DAS recorded highest net returns (₹ 34452/ha), which was followed by stale seed bed technique *fb* inter cultivation twice at 25 and 45 DAS (₹ 28373/ha) and inter cultivation at 25 DAS *fb* 1 hand weeding at 45 DAS (₹ 24881/ha). The higher seed yield recorded with this treatment might be responsible for higher net returns. But in case of B:C ratio, both weed free check (hand

Table 2. Yield and economics of kodo millet as influenced by different organic weed management practices

Treatment	Grain yield (t/ha)	Straw yield (t/ha)	Net returns (₹/ha)	B:C ratio
Inter cultivation at 25 DAS + one hand weeding at 45 DAS	0.73	3.97	24881	2.09
Stale seed bed technique + inter cultivation twice at 25 and 45 DAS	0.76	4.17	28373	2.34
Straw mulching 5 t/ha at 10-15 DAS	0.55	3.89	16554	1.85
Kodo millet + fodder cowpea as intercrop +one inter-cultivation at 30 DAS	0.30	3.61	297	1.02
Kodo millet + fodder cowpea as smothering crop in between rows of kodo millet	0.29	3.11	1159	1.07
Kodo millet + fodder cowpea as intercrop with in-situ mulching on 35DAS + one inter-cultivation at 40 DAS	0.67	3.91	22024	2.04
Mechanical (cycle weeder) weeding at 35 DAS	0.59	4.11	19471	2.04
Two mechanicals (cycle weeder) weeding at 20 and 40 DAS	0.68	4.14	23437	2.13
Cucumber leaf extract spray 100 ml/l, one at 2-4 leaf stage and another spray depending on the weed density	0.47	3.80	10797	1.55
Ageratum conyzoides leaf extract spray 100 ml/l, one at 2-4 leaf stage and another spray depending on the weed density	0.41	3.83	7029	1.36
Weed free check (hand weeding at 20 and 40 DAS)	0.93	5.10	34452	2.34
Unweeded check (weedy check)	0.22	2.99	-2620	0.84
LSD (p=0.05)	0.13	0.51	-	

DAS- Days after sowing

weeding at 20 and 40 DAS) and stale seed bed technique *fb* intercultivation twice at 25 and 45 DAS recorded same value of 2.34 followed by inter cultivation at 25 DAS *fb* one hand weeding at 45 DAS with 2.09. The lowest B: C ratio was recorded in unweeded check (weedy check) with 0.84 due to maximum yield reduction compared to other treatments (**Table 2**). These results were in accordance with Meghana (2019).

It was concluded that stale seedbed technique *fb* intercultivation twice at 25 and 45 DAS and intercultivation at 25 DAS *fb* one hand weeding at 45 DAS found to be the best weed management methods among the treatments.

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