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RESEARCH PAPER

Weed management through cover crop mulching and herbicide application on growth and yield of *rabi* maize

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Abstract: A field experiment was conducted at Main Agricultural Research Station, University of Agricultural Sciences, Dharwad, Karnataka during *rabi*, 2022-23 on *Vertisols* to study the effect of cover crop mulching and herbicide application on weeds, growth and yield of *rabi* maize. The experiment was laid out in a split plot design with three replications. The main plots consisted of two cover crops with two mulching periods *i.e.,* cowpea and sunhemp at 30 and 45 DAS. The subplot consisted of four treatments with herbicide application rates *viz.,* no herbicide, pre-emergence application of pendimethalin 1, 0.75 and 0.5 kg *a.i.* ha^{-1}. In the maize + sunhemp (1:2) system mulching of sunhemp at 45 DAS with pre-emergence application of pendimethalin1kg *a.i.* ha^{-1}reduced the dry weight of weeds at 40 and 60 DAS (6.53 and10.13 g m^{-2}, respectively) and enhanced the weed control efficiency (87.7 and 83.3%, respectively) over other treatments. While, cowpea mulching at 30 DAS with pendimethalin 1 kg *a.i.* ha^{-1} recorded significantly lower weed index (6.0%) and higher cob length (16cm), hundred grain weight (28.7 g), grain yield per plant (124.5 g), grain yield (5267 kg ha^{-1}), stover yield (6955 kg ha^{-1}), gross returns (₹ 1,05,852 ha^{-1}), net returns (₹ 60,019 ha^{-1}) and B:C ratio (2.18). This was on par with cowpea mulching at 30 DAS with pendimethalin 0.75 kg *a.i.* ha^{-1}. The weed free check recorded a higher grain yield of 5600 kg ha^{-1}, while the weedy check resulted in lower yields.

Key words: Covercrops, Maize, Mulching, Pre-emergence, Pendimethalin

Introduction

Maize (*Zea mays* L.) is known as 'Queen of Cereals' because of its high production potential and wider adaptability. It is grown in 194 m ha in more than 170 countries globally with 1148 mt of production (2020-21). Among the maize growing countries, India ranks 4th in area and 7th in production representing around four per cent of world maize area and two percent of total production. During 2021-22 in India, maize was grown in 9.95 mha with 33.73 mt of production and a productivity of 3387 kg ha^{-1}(Anon, 2022). Karnataka, Rajasthan, Andhra Pradesh, Bihar, Maharashtra and Uttar Pradesh are the primary maize producing states, collectively contributing to 60 per cent of the area and 70 per cent of the country's production. Karnataka being the largest producer of maize, has an area of 1.59 m ha with the production of 5.22 mt. The average productivity of maize in Karnataka is 3279 kg ha^{-1}. Although maize is primarily a *kharif* season crop, in recent years *rabi* maize has gained a significant place in total maize production in India. *rabi* maize covers an area of 2.17 m ha with the grain production of 11.04 mt, with an average productivity of 5084 kg ha^{-1}. In Karnataka, *rabi* maize is grown in an area of 0.19 m ha with the production of 0.70 mt and the productivity of 3621 kg ha^{-1}. The potentiality of the maize crop can be fully exploited by adapting suitable agronomic practices. Amongst them, weed management play a significant role in enhancing the crop yield. Weed management is a crucial aspect of crop production and it plays a significant role in maximizing crop yield and quality.

Maize being a widely spaced crop, gets infested with several weeds and subjected to heavy weed competition which often causes considerable losses in yield ranging from 28 to 100 per cent (Patel *et al*., 2006). Maize is sensitive to weeds especially during early stages of development and thus weed infestation from germination to 45 DAS causes maximum reduction in yield. Traditionally, herbicides have been widely used to control weeds in maize fields. Using herbicides such as pendimethalin, atrazine and alachlor for pre- emergence weed control in maize, along with post-emergent application of 2,4-D sodium salt is practised. However, this method is facing significant challenges, including the depletion of biodiversity due to environmental pollution, the substantial economic expenses linked to herbicides and the increasing prevalence of herbicide-resistant weeds. Considering these factors, the integration of ecological weed management strategies is a prevalent component of comprehensive crop management aimed at reducing chemical usage and safeguarding biodiversity. Integrated weed management approaches, encompassing the use of minimal herbicide doses, the adoption of covercrops, the application of inorganic mulches and the augmentation of crop density, can be effectively employed for weed control in small holder farms.

One promising approach to weed management in maize is the use of cover crops and reduced herbicide application rate. Cover crops are grown primarily to protect and improve the soil, enhance nutrient cycling and suppress weeds. By establishing cover crops within the maize production system, farmers can create a more diverse and resilient agro-ecosystem that reduces the reliance on herbicides. This approach provides effective weed suppression, improves soil health, reduces herbicide reliance and promotes sustainable agricultural practices. By adapting these strategies, farmers can achieve better weed control while safe guarding the environment, enhancing long-term productivity and ensuring the economic viability of maize production systems.

Material and methods

A field experiment was conducted at Main Agricultural Research Station Dharwad during *rabi* 2022-23. The soil type of the experiment site was clay soil (Vertisols). The soil was neutral in pH (7.25), normal in salt content (0.39 dS m^{-1}), low in organic carbon content (0.49%) and available nitrogen (258.8 kg ha^{-1}), medium in available phosphorus (28.3 kg ha^{-1}) and high available potassium (361.4 kg ha^{-1}). The experiment was laid out in split plot design with three replications and comprising sixteen treatment combinations with two controls outside. The main plot comprised of maize + cowpea (1:2) and mulching of cowpea at 30, maize + cowpea (1:2) and mulching of cowpea at 45 DAS, maize + sunhemp (1:2) and mulching of sunhemp at 30 and maize + sunhemp (1:2) and mulching ofsunhemp at 45 DAS. Meanwhile, subplots consisted of herbicide rates *viz*., no herbicide, pre-emergence application of pendimethalin 1, 0.75 and 0.5 kg *a.i.* ha^{-1} and two control treatments weedy check and weed free. The maize hybrid DKC-9144 and local varieties of cowpea and sunhemp were sown with 60 x 20 cm spacing for maize. Cover crops were sown in the middle of two rows of maize. Recommended dose of fertilizer was applied for the sole crop maize (150:65:65 N:P_2O_5:K_2O kg ha^{-1}), cowpea (12.5:25:12.5N:P_2O_5:K_2O kg ha^{-1}), sunhemp (0:20:20N:P_2O_5:K_2O kg ha^{-1}). The weeds were up rooted from 0.5 m^2 area and oven dried to a constant weight at 65°C. The dry weight of weeds was weighed at 40 and 60 DAS and then the original values were subjected to square root transformation of $\sqrt{X+0.5}$ for statistical analysis, where x signifies the original value suggested by Bartlett (1947). The weed control efficiency and weed index was calculated using the standard formula .

The harvested cobs from each net plot were threshed and dried to record grain weight and 100 grain weight. The plants from each net plot were harvested by sickle after plucking of cobs and stover weight was taken after complete sun drying. The experimental data obtained was subjected to statistical analysis by adapting Fisher's method of analysis of variance as outlined by Gomez and Gomez (1984). The level of significance used in 'F' test was at 5 per cent. The mean value was subjected to Duncan's Multiple Range Test (DMRT) using the corresponding error mean sum of squares and degree of freedom values.

Result and discussion

Effect on weeds

In the experiment the grasses, sedges and broadleaved weeds were observed. The broad-leaved weeds were *Commelina benghalensis, Alternanthera sessilis, Phyllanthus niruri, Euphorbia hirta, Euphorbia geniculata, Parthenium hysterophorus, Portulaca oleracea, Cyanotis axillaris* and *Trianthema portulacastrum*. Among the grasses, *Cynodon dactylon, Dactyloctenium aegyptium*, *Dinebra retroflexa* and *Brachiaria eruciformis* were dominant. *Cyperus rotundus* was noticed under sedges category. Weed management studies conducted by Pradeep *et al.* (2017) and Jadhav *et al.* (2022) found a similar diverse range of weeds in *rabi* maize.

Cover crops influenced total weed dry weight at 40 and 60 DAS (Table 1). Maize + sunhemp (1:2) and mulching of sunhemp at 45 DAS recorded lower total dry weight of weeds. The per cent decrease in weed dry weight was to the tune of 81.57 and78.92 percent at 40 and 60 DAS, respectively, over the weedy check. Mulching with cover crops, particularly at 30 and 45 DAS, has contributed to effective weed management. This might be due to the higher smothering efficiency of sunhemp and cowpea when mulched at later stage as it increased the fresh biomass and dry matter. Sunhemp mulching at 45 DAS (3.21 t ha^{-1}) recorded significantly higher dry matter followed by cowpea mulching at 45 DAS (2.19 t ha^{-1}). However, the lower dry matter was found in cowpea and sunhemp mulching at 30 DAS. Cover crop mulch is a physical barrier, preventing weed emergence and access to light, thereby suppressing weed growth. Kumar *et al.* (2019) reported that decomposition of mulched cover crops can release allelopathic compounds that inhibit weed growth. The weed control efficiency was influenced by cover crop mulching at 30 and 45 DAS (Table 1). The maximum weed control efficiency at 40 DAS (81.7%) and 60 DAS (78.7%) was obtained in maize + sunhemp (1:2) and mulching of sunhemp at 45 DAS. This was on par with maize + cowpea (1:2) and mulching of cowpea at 45 DAS (79.2 and 76.0%, respectively). Weed index is a measure of yield reduction due to weed competition. Maize + cowpea (1: 2) and mulching of cowpea at 30 DAS recorded lower weed index (10.2%) and it was on par with cowpea mulching at 45 DAS and sunhemp mulching at 30 DAS. It might be due to the of weed free environment during the entire growing period of the crop resulting in increased maize grain yield. Bhuvaneshwari (2009) reported that nutrients removed by weeds were significantly lower compared to weedy check. Higher weed index was recorded in weedy check (33.1%). This was due to lower grain yield of maize in weedy check as a result of greater competition offered by unchecked weed growth for nutrients, moisture, space and light as indicated by poor growth and yield components (Krishnamurthy *et al*., 1981).

Among the herbicide application rates, the dry weight of weeds (Table 1) decreased with the pre-emergence application of pendimethalin1kg *a.i.* ha^{-1} at 40 and 60 DAS (9.22 and 13.03 g m^{-2}) and it was on par with pendimethalin 0.75 kg *a.i.* ha^{-1}. Maximum weed dry weight was recorded in no herbicide treatment. Higher WCE of 82.5 and 78.7 per cent at 40 and 60 DAS were obtained by applying pendimethalin 1 kg *a.i.* ha^{-1}. This was on par with pendimethalin 0.75 kg *a.i.* ha^{-1}. The better weed control in these treatments was because, herbicides curb the germination and growth of the majority of weeds for longer period possibly due to their longer persistence in soil. The results corroborated with the findings of Nadiger *et al.* (2013). Higher yield reduction due to weed competition was without the application of herbicide (17.3%). This was due to lower grain yield of maize due to greater competition offered by the weeds for nutrients, moisture, space and light as indicated by poor growth and yield components. The lower weed index was recorded in the application of pendimethalin 1 kg *a.i.* ha^{-1} (8.9%). This was mainly due to effective control of all type of weeds at critical crop competition period for space and nutrients. Similar results were obtained by Deshmukh *et al*. (2008).

Interaction between cover crop mulching and herbicide application rates significantly influenced weed dry weight and weed control efficiency. Maize+sunhemp(1:2) and mulching of sunhemp at 45 DAS with pendimethalin 1 kg *a.i.* ha^{-1} resulted in

Table 1. Dry weight of weeds and weed control efficiency as influenced by cover crop mulching and herbicide application

Treatments	Dry weight of cover crops (tha^{-1})	Dry weight of weeds (gm^{-2}) 40 DAS	Dry weight of weeds (gm^{-2}) 60 DAS	Weed control efficiency (%) 40 DAS	Weed control efficiency (%) 60 DAS	Weed index (%)
Mainplot: Cover crops						
M_1	0.90^{c}	3.81^{ab}(14.38)	4.34^{ab}(18.62)	72.7^{b}	69.8^{b}	10.2^{b}
M_2	2.19^{b}	3.35^{bc}(10.88)	3.86^{bc}(14.58)	79.2^{a}	76.0^{a}	12.0^{b}
M_3	0.92^{c}	3.90^{a}(15.05)	4.40^{a}(19.15)	71.2^{b}	68.7^{b}	13.2^{ab}
M_4	3.21^{a}	3.14^{c} (9.67)	3.64^{c}(12.98)	81.7^{a}	78.7^{a}	16.6^{a}
S.Em. ±	0.18	0.17	0.19	2.25	2.43	1.63
Subplot:Herbicide rate						
H_0	1.81^{a}	4.10^{a}(16.52)	4.59^{a}(20.92)	68.6^{c}	66.0^{c}	17.3^{a}
H_1	2.00^{a}	3.09^{c}(9.22)	3.66^{c}(13.03)	82.5^{a}	78.7^{a}	8.9^{d}
H_2	1.68^{a}	3.32^{c}(10.80)	3.94^{bc}(15.30)	79.6^{a}	75.0^{ab}	11.4^{c}
H_3	1.74^{a}	3.70^{b}(13.45)	4.09^{b}(16.47)	74.2^{b}	73.5^{b}	14.3^{b}
S.Em±	0.12	0.16	0.16	2.15	2.20	1.35
Interactions						
M_1H_0	0.90^{e}	4.38^{ab}(18.73)	4.99^{ab}(24.40)	64.3^{f}	60.4^{d}	14.1^{b-e}
M_1H_1	0.89^{e}	3.20^{e-h}(9.87)	3.94^{c-f}(15.13)	81.4^{a-c}	75.2^{a-c}	6.0^{f}
M_1H_2	1.02^{e}	3.50^{c-g}(12.00)	4.09^{c-e}(16.40)	77.4^{b-d}	73.6^{a-c}	8.8d-f
M_1H_3	0.81^{e}	4.17^{a-c}(16.93)	4.36^{bc}(18.53)	67.8^{ef}	69.9^{c}	12.2^{b-f}
M_2H_0	1.97^{d}	3.80^{b-e}(14.00)	4.19^{c-e}(17.22)	73.5^{c-e}	72.3^{bc}	16.0^{a-c}
M_2H_1	2.33^{cd}	3.06^{f-h}(8.87)	3.46^{ef}(11.47)	83.1^{a-c}	81.4^{ab}	7.9^{ef}
M_2H_2	2.20^{d}	3.07^{f-h}(9.13)	3.90^{c-f}(14.87)	82.4^{a-c}	75.6^{a-c}	10.6^{c-f}
M_2H_3	2.28^{cd}	3.46^{d-g}(11.53)	4.01^{c-f}(15.67)	77.8^{b-d}	74.6^{a-c}	13.5^{b-e}
M_3H_0	0.95^{e}	4.48^{a}(19.60)	5.11^{a}(25.73)	62.7^{f}	58.1^{d}	17.8^{ab}
M_3H_1	1.30^{e}	3.47^{d-g}(11.60)	3.99^{c-f}(15.40)	77.7^{b-d}	74.9^{a-c}	9.3d-f
M_3H_2	0.72^{e}	3.71^{b-f}(13.47)	4.23^{cd}(17.60)	74.6^{b-e}	71.0^{bc}	11.9^{b-f}
M_3H_3	0.72^{e}	3.96^{a-d}(15.53)	4.28^{cd}(17.87)	69.8^{d-f}	70.9^{bc}	13.8^{b-e}
M_4H_0	3.44^{a}	3.76^{b-f}(13.73)	4.07^{c-e}(16.33)	74.0^{c-e}	73.1^{a-c}	21.3^{a}
M_4H_1	3.49^{a}	2.63^{h}(6.53)	3.24^{f}(10.13)	87.7^{a}	83.3^{a}	12.6^{b-e}
M_4H_2	2.77^{bc}	2.98^{g-h}(8.60)	3.56^{d-f}(12.33)	83.8^{ab}	79.9^{a-c}	14.5^{b-d}
M_4H_3	3.14^{ab}	3.20^{e-h}(9.80)	3.69^{c-f}(13.13)	81.4^{a-c}	78.9^{a-c}	17.9^{ab}
S.Em±	0.25	0.32	0.32	4.29	4.41	2.70
Control						
Weedycheck	-	7.27 (52.47)	7.88 (61.60)	-	-	33.1
Weedfree	-	0.71 (0.00)	0.71 (0.00)	100	100.0	-
S.Em. ±	-	0.22	0.23	2.88	3.01	2.95
C.D.	-	0.63	0.66	8.28	8.66	6.01

Note: Means followed by the same letter (s) within a column and row are not differed significantly by DMRT (P = 0.05), DAS- Days after sowing

Treatmentdetails:

Mainplot (M):
- M_1: Maize+Cowpea (1:2)and mulching of cowpea at 30 DAS
- M_2: Maize + Cowpea (1:2) and mulching of cowpea at 45 DAS
- M_3: Maize + Sunhemp (1:2) and mulching of sunhemp at 30 DAS
- M_4: Maize + Sunhemp (1:2) and mulching of sunhemp at 45 DAS

Subplot(H):
- H_0: No herbicide
- H_1: Pre-emergence application of Pendimethalin 1 kg *a.i.* ha^{-1}
- H_2: Pre-emergence application of Pendimethalin0.75kg *a.i.*ha^{-1}
- H_3: Pre-emergence application of Pendimethalin 0.5 kg *a.i.* ha^{-1}

Control ; 1. Weedy check 2. Weed free

lower weed dry weight at 40 and 60 DAS (6.53 and10.13gm^{-2}, respectively) with enhanced weed control efficiency (87.7 and 83.3%, respectively). It was on par with cowpea mulching at 30 and 45 DAS with pendimethalin 1kg *a.i.* ha^{-1} and sunhemp mulching at 45DAS with pendimethalin 0.75kg *a.i.*ha^{-1}.While, cowpea mulching at 30 DAS with pendimethalin1kg *a.i* ha^{-1} resulted in lower weed index (6.0%) and it was on par with cowpea mulching either at 30 or 45 DAS with pendimethalin 0.75 kg *a.i* ha^{-1}.

Effect on grain and stover yield of maize

The results showed that maize + cowpea (1:2) and mulching cowpea at 30 DAS recorded significantly higher cob length (15.6 cm), hundred grain weight (27.3 g), grain yield per plant (118.2g), grain yield (5026 kg ha^{-1}) and stover yield (6667kg ha^{-1}).This was on par with maize + cowpea (1:2) and mulching of cowpea at 45 DAS and maize + sunhemp (1:2) and mulching of sunhemp at 30DAS (Table2). Significantly lower grain and stover yield were recorded in maize+sunhemp (1:2) and mulching of sunhemp at 45DAS (4669 and 6247kg ha^{-1}, respectively). The increase in grain and stover yield was to the tune of 7.1and 6.3 per cent in cowpea mulching at 30 DAS over sunhemp mulching at 45 DAS. The improvement in grain weight per plant in maize is intrinsically linked to the enhancement of cob length and hundred grain weight. Longer cob length provides more space for kernels to develop, while an

Table 2. Influence of covercrop mulching and herbicide application rates on yield attributes of *rabi* maize

Treatments	Cob length (cm)	Hundred grain weight (g)	Grain yield plant^{-1} (g)	Grain yield (kgha^{-1})	Stover yield (kg ha^{-1})
Mainplot:Covercrops					
M_1	15.6^{a}	27.3^{a}	118.2^{a}	5026^{a}	6667^{a}
M_2	15.5^{a}	25.6^{ab}	115.7^{a}	4930^{a}	6591^{a}
M_3	15.4^{a}	25.7^{ab}	114.6^{ab}	4857^{ab}	6641^{a}
M_4	14.4^{b}	24.5^{b}	108.3^{b}	4669^{b}	6247^{b}
S.Em. ±	0.34	0.73	2.59	92.5	114
Subplot:Herbiciderate					
H_0	14.8^{b}	24.6^{b}	107.8^{c}	4629^{c}	6201^{c}
H_1	15.6^{a}	27.1^{a}	120.1^{a}	5097^{a}	6808^{a}
H_2	15.3^{ab}	26.5^{a}	117.2^{a}	4958^{a}	6700^{ab}
H_3	15.1^{ab}	24.9^{b}	111.6^{b}	4796^{b}	6438^{bc}
S.Em. ±	0.28	0.73	1.69	76	150
Interactions					
M_1H\	15.1^{a-e}	26.3^{a-d}	111.2^{d-f}	4810^{b-e}	6410^{a-c}
M_1H_1	16.0^{a}	28.7^{a}	124.5^{a}	5267^{a}	6955^{a}
M_1H_2	15.9^{ab}	27.8^{ab}	121.9^{ab}	5107^{a-c}	6808^{ab}
M_1H_3	15.3^{a-e}	26.5^{a-c}	115.4^{b-e}	4920^{a-e}	6497^{a-c}
M_2H_0	15.2^{a-e}	25.1^{b-d}	109.7^{e-g}	4703^{d-f}	6132^{bc}
M_2H_1	15.9^{ab}	27.0^{a-c}	122.7^{ab}	5155^{ab}	6810^{ab}
M_2H_2	15.5^{a-d}	26.1^{a-d}	119.0^{a-d}	5011^{a-d}	6802^{ab}
M_2H_3	15.4^{a-d}	24.5^{b-d}	111.4^{d-f}	4850^{b-e}	6622^{a-c}
M_3H_0	14.8^{a-e}	24.2^{cd}	108.6^{e-g}	4600^{ef}	6250^{a-c}
M_3H_1	15.8^{a-c}	27.0^{a-c}	120.2^{a-c}	5077^{a-c}	6944^{a}
M_3H_2	15.5^{a-d}	27.0^{a-c}	116.5^{b-e}	4929^{a-e}	6868^{a}
M_3H_3	15.3^{a-e}	24.6^{b-d}	112.9^{c-f}	4822^{b-e}	6503^{a-c}
M_4H_0	14.0^{e}	22.8^{d}	101.8^{g}	4404^{f}	6014^{c}
M_4H_1	14.6^{b-e}	25.9^{a-d}	113.1^{c-f}	4890^{b-e}	6523^{a-c}
M_4H_2	14.5^{c-e}	25.1^{b-d}	111.5^{d-f}	4788^{c-e}	6321^{a-c}
M_4H_3	14.4^{de}	24.1^{cd}	106.7^{fg}	4596^{ef}	6129^{bc}
S.Em. ±	0.55	1.46	3.38	152	300
Control					
Weedycheck	12.2	20.1	69.9	3746	5528
Weedfree	16.9	31.8	130.5	5600	7167
S.Em. ±	0.42	0.96	2.59	114	204
C.D	1.21	2.80	7.46	328	587

Note: Means followed by the same letter (s) within a column and row are not differed significantly by DMRT (P = 0.05), DAS- Days after sowing

Treatmentdetails:

Mainplot (M):

M_1: Maize+Cowpea (1:2) and mulching of cowpea at 30 DAS

M_2: Maize + Cowpea (1:2) and mulching of cowpea at 45 DAS

M_3: Maize + Sunhemp (1:2) and mulching of sunhemp at 30 DAS

M_4: Maize + Sunhemp (1:2) and mulching of sunhemp at 45 DAS

Subplot(H):

H_0: Noherbicide

H_1: Pre-emergence application of Pendimethalin 1 kg *a.i.* ha^{-1}

H_2: Pre-emergence application of Pendimethalin 0.75kg *a.i.*ha^{-1}

H_3: Pre-emergence application of Pendimethalin 0.5 kg *a.i.* ha^{-1}

Control: 1. Weedy check 2. Weed free

increase in hundred grain weight results in larger and heavier individual grains. It was due to reduced weed competition in these treatments. These results agree with the findings of Saini *et al.* (2013). The higher grain yield was mainly due to minimum crop weed competition throughout the crop growth stage. In addition, lower nutrient depletion and lesser dry matter production of weeds and thereby increasing the nutrient uptake by crop influenced the growth and yield attributes favoring grain and stover yields of maize. Similar findings were also reported by Walia *et al.* (2007).The use of cowpea as live mulch increased the maize yield by 23.7% over the weedy check and this result is in conformity with the findings of Singh *et al.* (2015). Higher grain and stover yield in weedfree check might be due to minimum crop weed competition throughout the crop growth stage.

Significantly lower grain and stover yield was observed in weedy check due to higher weed density, weed dry weight, greater removal of nutrients and moisture by weeds. Severe crop-weed competition resulted in poor source and sink development with poor yield components.

Among the herbicide application rates, the yield level with pre-emergence application of pendimethalin either1or 0.75 kg *a.i.* ha^{-1} were significantly higher over without application of herbicide. The increase in yield with the application of pendimethalin either1or

Table 3. Influence of covercrop mulching and herbicide application rates on economics of *rabi* maize

Treatments	Cost of cultivation (₹ ha^{-1})	Gross returns (₹ ha^{-1})	Net returns (₹ ha^{-1})	B:C ratio
Mainplot:Covercrops				
M_1	50042	105852[a]	55811[a]	2.11[a]
M_2	49972	103867[a]	53896[a]	2.08[a]
M_3	51070	102451[ab]	51381[ab]	2.01[ab]
M_4	50891	98384[b]	47493[b]	1.93[b]
S.Em. ±	-	1786	1786	0.04
Subplot:Herbiciderate				
H_0	49341	97548[c]	48207[c]	1.98[b]
H_1	51338	107391[a]	56053[a]	2.09[a]
H_2	50949	104528[a]	53579[ab]	2.05[ab]
H_3	50346	101088[b]	50743[bc]	2.01[ab]
S.Em. ±	-	1534	1534	0.03
Interaction				
M_1H0	48913	101328[b-e]	52415[b-f]	2.07[a-c]
M_1H_1	50885	110904[a]	60019[a]	2.18[a]
M_1H_2	50498	107580[a-c]	57082[a-c]	2.13[ab]
M_1H_3	49870	103597[b-e]	53727[a-e]	2.08[a-c]
M_2H_0	48836	98972[d-f]	50136[c-g]	2.03[a-d]
M_2H_1	50801	108547[ab]	57746[ab]	2.14[ab]
M_2H_2	50428	105652[a-d]	55224[a-d]	2.10[a-c]
M_2H_3	49821	102297[b-e]	52476[b-f]	2.05[a-d]
M_3H_0	49829	97007[ef]	47178[e-g]	1.95[b-d]
M_3H_1	51934	107095[a-c]	55161[a-d]	2.06[a-d]
M_3H_2	51554	104068[a-e]	52514[b-f]	2.02[a-d]
M_3H_3	50961	101634[b-e]	50673[b-f]	1.99[a-d]
M_4H_0	49787	92884[f]	43097[g]	1.87[d]
M_4H_1	51731	103019[b-e]	51288[b-f]	1.99[a-d]
M_4H_2	51316	100810[c-e]	49494[d-g]	1.96[b-d]
M_4H_3	50730	96823[ef]	46093[fg]	1.91[cd]
S.Em. ±	-	3068	3068	0.06
Control				
Weedycheck	43194	79352	36158	1.84
Weedfree	53352	117737	64385	2.21
S.Em ±	-	2269	2269	0.05
C.D	-	6522	6522	0.13

0.75 kg *a.i.*ha^{-1} was to the tune of 9.18 and 6.63 per cent. The same trend was observed in stover yield. The yield increase might be due to improved yield attributes such as number of cobs perplant, cob length, hundred grain weight and grain yield per plant. These were higher in the treatment receiving pendimethalin 1kg *a.i.*ha^{-1}.The enhanced yield attributes can be attributed to weed control measures, as they reduce competition from weeds, improve weed control efficiency and optimize crop plants input utilization. These results are in confirnmation with the findings of Sharma *et al.* (2016). The increase in grain yield with the application of pendimethalin either 1 or 0.75 kg *a.i.* ha^{-1} can be traced back to the significant increase in cob length, hundred grain weight and grain yield per plant over no herbicide application. In the study by Mathukia *et al.* (2014) similar results were obtained.

Among the interaction, maize + cowpea (1:2) and cowpea mulching at 30 DAS with pendimethalin 1 kg *a.i.* ha^{-1} recorded significantly higher cob length (16 cm), hundred grain weight (28.7 g), grain yield per plant (124.5 g), grain yield (5267 kg ha^{-1}) and stover yield (6955 kg ha^{-1}). This was on par with the application of cowpea mulching at 30 DAS with pendimethalin 0.75 kg *a.i.* ha^{-1}. It might be due to the successful control of all types of weed flora in crop field. While weedy check recorded significantly lower grain and stover yield (3746 and 5528 kg ha^{-1}, respectively) (Table 2). It can be attributed to the adverse effect of weed competition on growth and development of the maize crop for essential resources such as nutrients, water and sunlight leading to reduced yields.

Economics

Economic benefits are the final aim of the any intervention made in the traditional package of practices for raising crops. Maize + cowpea (1:2) and mulching of cowpea at 30 DAS recorded higher gross returns (₹ 1,05,852ha^{-1}), net returns (₹ 55,811ha^{-1}) and B:C ratio (2.11) and it was on par with cowpea mulching at 45DAS and sunhemp mulching at 30 DAS. Higher grain and stover yield of maize obtained because of mulching, effectively suppressed weed growth and conserved soil moisture to the crop. Further due to lower grain yield and stover yield, maize + sunhemp (1:2) system with mulching of sunhemp at 45 DAS recorded lower gross returns, net returns and B:C ratio (Table 3). These findings are also in conformity with Sraw *et al.* (2016).

Application of pendimethalin 1 kg *a.i.* ha^{-1} as pre-emergence resulted in higher gross returns, net returns and B:C ratio to 9.16, 13.99 and 5.26 percent, respectively over no herbicide application. This was on par with the application of pendimethalin 0.75 kg *a.i.* ha^{-1}.This might be due to higher yields. These results are in agreement with findings of Rao *et al.* (2016).

Maize+cowpea (1:2) and mulching of cowpea at 30 DAS+pendimethalin1kg *a.i.* ha^{-1} as pre-emergence recorded higher gross returns, net returns and B:C ratio. This is due to higher grain and stover yield and monetary returns. However, lower gross returns, net returns and B:C ratio were observed in maize+sunhemp (1:2) and mulching at 45DAS with no application of herbicide and it might be due to lower grain and stover yield further reducing the returns. While, weedy check recorded lower gross returns, net returns and B:C ratio of 35.33, 55.02 and 12.62 per cent over cowpea mulching at 30 DAS with pendimethalin 1 kg *a.i.* ha^{-1}. Weedy check suffered from intense weed competition, leading to reduced crop growth, lower yields and ultimately diminished returns.

Conclusion

Based on these results, it can be concluded that intercropping maize+cowpea (1:2) and cowpea mulching at 30 DAS with the pre-emergence application of pendimethalin 1 kg ha^{-1} resulted in higher hundred grain weight, grain yield per plant, grain yield, stover yield, net returns and B:C ratio with lower weed dry weight, weed index and higher weed control efficiency.This was followed by cowpea mulching at 45 DAS with pendimethalin1kg *a.i.* ha^{-1} and cowpea mulching at 30 DAS with pendimethalin 0.75 kg *a.i.*ha^{-1}. Although sunhemp was efficient in weed control, it adversely affected the yield when mulched at 45 DAS. Therefore, suggesting cowpea mulching at 30 or 45 DAS with pre-emergence application of pendimethalin 0.75 kg ha^{-1} to farmers can result in higher yields with maximum weed control.

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