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Potential of weed seedbank dynamics and economic feasibility of weed management practices in *rabi* fennel (*Foeniculum vulgare* Mill.)

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ABSTRACT

An experiment was conducted during rabi season of 2011-12 at Junagadh to find out most suitable and economically viable method of weed control in rabi fennel (Foeniculum vulgare Mill.). The dominant weed species observed were Cyperus rotundus L., Chenopodium album L., Digera arvensis Forsk and Asphodelus tenuifolius L. Cav. Results revealed that besides weed free treatment, significantly higher plant height, number of branches plant^{-1}, number of umbels plant^{-1}, number of seeds umbellate^{-1}, test weight, seed weight per plant, and seed and stover yields of fennel were recorded with pre-emergence (PRE) application of pendimethalin at 0.90 kg ha^{-1} + post-emergence (POE) application of fenoxaprop-ethyl at 75 g ha^{-1} at 45 DAS which was at par with PRE application of pendimethalin at 0.90 kg/ha + hand weeding (HW) at 45 DAS and HW twice at 15 and 45 DAS. These treatments also recorded lower weed density and dry weight of weeds along with highest net returns (Rs 81993 and Rs 81442 ha^{-1}) and B:C ratio owing to lower weed index and higher weed control efficiency. However, the highest depletion of weed seedbank was observed with PRE application of pendimethalin at 0.90 kg ha^{-1} + HW at 45 DAS.

Keywords: Glyphosate, oxadiargyl, pendimethalin, propaquizafop-ethyl, quizalofop-ethyl weed seedbank.

Fennel, (*Foeniculum vulgare* Mill.) A native of southern Europe and Mediterranean area, is an important seed spice. Area under direct seeded *rabi* fennel is increasing day by day, because it is more profitable than other *rabi* crops like wheat, gram, cumin, mustard etc. In spite of this, the productivity of *rabi* fennel is low as compared to its potential yield. Indian farmers pay reasonable attention towards cultivation, especially in respect of seedbed preparation, manuring and irrigation, however, not careful about weed control aspect which remains one of the constraints in boosting up the production. Therefore, field should be kept weed free at initial stage of crop establishment by employing available weed control methods. Though manual weeding is commonly employed practice but availability of labour itself is a problem and it requires high drudgery and is a costly practice. Therefore, it is essential to find out an appropriate and economical method of weed control to keep fennel fields weed free. Initial slow growth of fennel leads to severe weed crop competition and reduces growth, as well as yield as high as 91.4% (Mali and Suwalka, 1987). Application of herbicides in fennel to control the weeds effectively leads to increase in seed yield from 43.2 to 86.9 % (Voevodin and Borisenko, 1981). Soil weed seedbanks are reserves of viable seeds present on the surface and in the soil. The seedbank consists of new seeds recently shed by a weed plant as well as older seeds that have persisted in the soil for several years. The seed bank is an indicator of past and present weed populations in soil. Management of weeds in particular area would require prior information on weed seedbank which can helpful in designing weed management practices related to a particular micro-climate in an area. With this view, a seedbank study was conducted.

A field experiment was conducted at Instructional Farm, Junagadh Agricultural University, Junagadh (Gujarat) during *rabi* season of 2012. The experiment was laid in Randomized Block Design with three replications. The soil of experimental field was clay in texture, slightly alkaline in reaction (pH 8.0 and EC 0.56 dS m^{-1}), low in available N (238 kg ha^{-1}), medium in available P_2O_5 (36.8 kg ha^{-1}) and K_2O (221 kg ha^{-1}). The experiment comprised ten treatments, namely, pendimethalin 0.90 kg ha^{-1} as PRE + HW at 45 DAS, oxadiargyl 75 g ha^{-1} as early POE at 7 DAS + HW at 45 DAS, glyphosate 1.0 kg ha^{-1} as early POE at 7 DAS + HW at 45 DAS, pendimethalin at 0.90 kg ha^{-1} as PRE + quizalofop-ethyl 40 g ha^{-1} POE at 45 DAS, pendimethalin 0.90 kg ha^{-1} as PRE + fenoxaprop-ethyl 75 g ha^{-1} POE at 45 DAS, pendimethalin 0.90 kg ha^{-1} as PRE + propaquizafop 75 g ha^{-1} as POE at 45 DAS, pendimethalin 0.90 kg ha^{-1} as PRE + oxadiargyl 75 g ha^{-1} as POE at 45 DAS, HW twice at 15 and 45 DAS, weed free and unweeded check. The fennel variety 'GF-11'

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was sown in second week of November at a spacing of 60 × 20 cm using seed rate of 8 kg ha^{-1} and fertilized with 90:30:0 kg $N:P_2O_5:K_2O$ ha^{-1}. Herbicidal solutions as PRE at 2 DAS and POE application at 45 DAS were sprayed with the help of knapsack sprayer using flat fan nozzle with a spray volume of 500 l ha^{-1}. As per schedule hand weeding in the respective plots was done manually. In weed free plots, the weeds were removed manually after every ten days for ensuring weed free condition. Weed index (WI), weed control efficiency (WCE) and herbicidal efficiency index (HEI) were also worked out as per formula given by Gill and Kumar (1969), Kondap and Upadhyay (1985) and Krishnamurthy *et al*. (1995), respectively to assess the efficiency of different weed management practices. Data on species wise weed count at 30 DAS, 60 DAS and at harvest by counting weeds present in 1 × 1m quadrate, dry weight of weeds and for the study of weed seed bank, five soil samples should be taken from the soil before sowing of the crop and one composite sample was prepared, while plot-wise samples were taken after harvest of the crop. The soil samples were drawn by core sampler of 2 cm in diameter from 15 cm depth as per the FAO protocol (Forcella *et al.*, 2011). Each soil core was individually bagged and numbered. Seed extraction should be done by sieving of the samples through copper sieves of 5 mm in diameter followed by their rinsing by water and sieving of the samples through a descending series of sieves up to 0.5 mm in diameter. Seeds were then dried at the room temperature and separated manually and sample-wise seed count was recorded. The experimental data recorded for growth parameters, yield attributes and yield parameters and economics were statistically analyzed for level of significance. (PRE = Pre emergence, POE= Post Emergence and HW= Hand Weeding).

Weed parameters

The weed flora in the experimental field constituted by monocot weeds *viz*., *Brachiaria* Spp. (7.67%), *Indigoflora glandulosa* L. (7.00%), *Asphodelus tenuifolius* L. Cav. (5.00%) and *Dactyloctenium aegyptium* Beauv (1.33%), dicot weeds *viz*., *Digera arvensis* Forsk (18.67%), *Chenopodium album* L. (16.33%), *Physalis minima* L. (7.67%), *Portulaca oleracea* L. (5.67%), *Euphorbia hirta* L. (4.00%) and *Leucas aspera* Spreng (1.33%), and sedge weed *Cyperus rotundus* L. (25.33%).

Besides weed free treatment, the lowest weed population recorded with HW twice at 15 and 45 DAS, which remained at par with pendimethalin + HW at 45 DAS and pendimethalin + fenoxaprop-ethyl. Next to weed free, HW twice or pendimethalin + HW at 45 DAS was at par with pendimethalin + oxadiargyl at 45 DAS in reducing dry weight of weeds (Table 3) which might be attributed to the effective control of early, as well as late flushes of weeds and did not allow weeds to regenerate, which reflected in less number of weeds and ultimately lower weed biomass. The unweeded check recorded significantly the highest dry weight of weeds owing to uncontrolled condition favoured luxurious weed growth leading to increased weed dry matter. These findings are in conformity with those reported by Thakral *et al.* (1995), Chaudhary (2000), Thakral *et al.* (2007) and Meena and Mehta (2009). Besides weed free treatment, the highest WCE (93.63) was obtained with HW twice at 15 and 45 DAS, followed by pendimethalin as PRE + HW at 45 DAS (93.31). Next to weed free, minimum WI and maximum HEI (0.52 and 98.84%) was obtained with pendimethalin PRE + fenoxaprop-ethyl POE at 45 DAS, closely followed by pendimethalin PRE + HW at 45 DAS (0.91 and 98.06%). This might be due to elimination of weeds by manual weeding and herbicides (Table 3). The combined effect on dry weight of weeds and seed yield under these treatments might have been responsible for excellent weed indices, whereas the highest WI (49.97%) was observed in the unweeded check, which showed that reduction in seed yield due to uncontrolled weeds was near 50.0 per cent as compared to weed free. This resulted in reduced seed yield due to uncontrolled weeds. The result confirms the findings of Thakral *et al.* (2007), Meena and Mehta (2009) and Nagar *et al*. (2009). The weeds can be checked by adopting various methods like eco-physical, biological, chemical and recently through combining direct and indirect approach *i.e.* integrated weed management (Kundu *et al*., 2009).

The potential of soil weed seedbank dynamics drastically influenced by different weed management practices. The lowest weed seedbank was recorded with treatment pendimethalin PRE + HW at 45 DAS as PRE applied pendimethalin controlled weeds right from the germination and those escaped were controlled by hand weeding at 45 DAS, hence did not allow to set the weed seeds, which was almost same with the weed free and remained at par with pendimethalin PRE + oxadiargyl POE at 45 DAS and HW twice at 15 and 45 DAS. The treatments *viz*., pendimethalin + quizalofop-ethyl, pendimethalin + fenoxaprop-ethyl and pendimethalin + propaquizafop were found to increase weed seedbank. This might be ascribed to the post-emergent herbicides *viz*., Quizalofop-ethyl, Fenoxaprop-ethyl and Propaquizafop are grassy weed killers, leaving dicot weeds to produce seeds. Treatment unweeded check

Table 1:Effect of different treatments on growth, yield attributes and yield of fennel

Treatments	Plant height (cm) at harvest	No. of branches plant^{-1}	No. of umbels plant^{-1}	No. of umbellate umbel^{-1}	No. of seeds umbellate^{-1}	1000-seed weight (g)	Seed weight plant^{-1} (g)	Seed yield (kg ha^{-1})	Stover yield (kg ha^{-1})
Pendimethalin 0.90 kg ha^{-1} PRE+HW at 45 DAS	146.3	6.5	11.3	23.3	24.1	6.57	27.87	1824	4447
Oxadiargyl 75 g ha^{-1} early POE+HW at 45 DAS	130.9	5.0	7.7	18.9	19.1	6.02	14.27	1045	2947
Glyphosate 1 kg ha^{-1} early POE +HW at 45 DAS	127.7	4.2	7.2	18.7	19.1	6.01	13.77	1086	2994
Pendimethalin 0.90 kg ha^{-1} PRE + Quizalofop-ethyl 40 g ha^{-1} POE at 45 DAS	137.1	4.9	8.4	21.9	20.1	6.05	15.47	1321	3664
Pendimethalin 0.90 kg ha^{-1} PRE + Fenoxaprop-ethyl 75 g ha^{-1} POE at 45 DAS	149.9	6.6	12.0	23.0	25.3	6.62	29.33	1831	4507
Pendimethalin 0.90 kg ha^{-1} PRE + Propaquizafop 75 g ha^{-1} as POE at 45 DAS	136.5	5.0	8.2	21.3	19.1	6.03	16.07	1325	3644
Pendimethalin 0.90 kg ha^{-1} PRE + Oxadiargyl 75 g ha^{-1} as POE at 45 DAS	137.4	5.2	8.3	22.9	19.2	6.14	15.43	1315	3557
HW at 15 and 45 DAS	146.6	6.7	10.6	23.6	23.3	6.52	28.00	1799	4496
Weed free	153.1	7.1	12.7	23.7	25.5	7.30	31.10	1841	4512
Unweeded check	126.6	3.9	6.3	17.1	16.2	5.71	10.17	921	2668
LSD (0.05)	**14.7**	**1.0**	**2.2**	**NS**	**4.1**	**0.82**	**4.27**	**368.56**	**821**

Table 2. Effect of integrated weed management on weed population and soil weed seedbank dynamics

Treatments	Monocot weeds m^{-2} at			Dicot weeds m^{-2} at			Sedge weeds m^{-2} at			Weed seedbank $core^{-1}$		
	30 DAS	60 DAS	Harvest	30 DAS	60 DAS	Harvest	30 DAS	60 DAS	Harvest	Initial	Final	Addition(+) /Depletion(-)
Pendimethalin 0.90 kg ha^{-1}	1.22	1.17	1.05	2.27	1.34	1.44	2.60	1.56	1.66	210	74	-136 (-65)
PRE+HW at 45 DAS	(1.00)	(1.00)	(0.67)	(4.67)	(1.33)	(1.67)	(6.33)	(2.00)	(2.33)			
Oxadiargyl 75 g ha^{-1} early	1.34	1.68	1.77	2.38	2.54	2.40	3.27	2.67	2.68	210	147	-63 (-30)
POE+HW at 45 DAS	(1.33)	(2.33)	(2.67)	(5.33)	(6.00)	(5.33)	(10.33)	(6.67)	(6.67)			
Glyphosate 1 kg ha^{-1} early POE	1.86	1.84	1.56	4.22	2.57	2.59	2.53	2.18	2.78	210	161	-49 (-23)
+HW at 45 DAS	(3.00)	(3.00)	(2.00)	(17.3)	(6.67)	(6.33)	(6.33)	(4.33)	(7.33)			
Pendimethalin 0.90 kg ha^{-1} PRE												
+ Quizalofop-ethyl 40 g ha^{-1}	1.46	2.60	2.61	2.66	3.67	3.39	3.36	3.76	3.52	210	278	+68 (+32)
POE at 45 DAS	(1.67)	(6.33)	(6.33)	(6.67)	(13.0)	(11.00)	(11.00)	(13.6)	(12.00)			
Pendimethalin 0.90 kg ha^{-1} PRE												
+ Fenoxaprop-ethyl 75 g ha^{-1}	1.34	1.22	1.17	2.65	3.58	3.13	2.67	1.58	1.72	210	242	+32 (+15)
POE at 45 DAS	(1.33)	(1.00)	(1.00)	(6.67)	(12.3)	(9.33)	(6.67)	(2.00)	(2.67)			
Pendimethalin 0.90 kg ha^{-1} PRE												
+ Propaquizafop 75 g ha^{-1} as	1.46	2.04	1.74	2.54	3.76	3.52	3.22	2.95	2.72	210	221	+11 (+5)
POE at 45 DAS	(1.67)	(3.67)	(2.67)	(6.00)	(13.6)	(12.00)	(10.00)	(8.33)	(7.00)			
Pendimethalin 0.90 kg ha^{-1} PRE												
+ Oxadiargyl 75 g ha^{-1} as	1.34	2.08	1.68	2.81	0.88	1.05	3.13	2.85	2.80	210	99	-111 (-53)
POE at 45 DAS	(1.33)	(4.00)	(2.33)	(7.67)	(0.33)	(0.67)	(9.33)	(7.67)	(7.33)			
HW at 15 and 45 DAS	1.05	1.22	1.17	1.34	1.34	1.44	1.34	1.34	1.68	210	125	-85 (-40)
	(0.67)	(1.00)	(1.00)	(1.33)	(1.33)	(1.67)	(1.33)	(1.33)	(2.33)			
Weed free	0.71	0.71	0.71	0.71	0.71	0.88	0.71	0.88	1.17	210	76	-134 (-64)
	(0)	(0)	(0)	(0)	(0)	(0.33)	(0)	(0.33)	(1.00)			
Unweeded check	2.78	4.41	4.63	5.95	7.26	7.33	4.03	4.93	5.04	210	2264	+2054 (+978)
	(7.33)	(19.0)	(21.00)	(35.3)	(52.3)	(53.67)	(16.00)	(24.6)	(25.33)			
LSD (0.05)	**0.41**	**0.52**	**0.51**	**0.73**	**0.71**	**0.67**	**0.77**	**0.71**	**0.72**	**-**	**73**	**-**

Note: $\sqrt{x+0.5}$ transformation (Figures in parenthesis are original values in case of weed count and percent addition/depletion of seedbank).

Table 3:Effect of different weed management practices on dry weight of weeds at harvest, weed indices and economics of fennel

Treatments	Dry weight of weeds at harvest (kg ha-1)	Weed index (%)	Weed control efficiency (%)	Herbicidal efficiency index (%)	Cost of cultivation (Rs. ha-1)	Net returns (Rs. ha-1)	B : C ratio
Pendimethalin 0.90 kg ha-1 PRE+HW at 45 DAS	84	0.91	93.31	98.06	36882	81442	3.21
Oxadiargyl 75 g ha-1 early POE+HW at 45 DAS	237	43.22	81.01	13.49	36976	31622	1.86
Glyphosate 1 kg ha-1 early POE +HW at 45 DAS	282	41.02	77.40	17.88	36402	34717	1.95
Pendimethalin 0.90 kg ha-1 PRE + Quizalofop-ethyl 40 g ha-1 POE at 45 DAS	494	28.23	60.43	43.45	36745	49841	2.36
Pendimethalin 0.90 kg ha-1 PRE + Fenoxaprop-ethyl 75 g ha-1 POE at 45 DAS	196	0.52	84.30	98.84	36882	81993	3.22
Pendimethalin 0.90 kg ha-1 PRE + Propaquizafop 75 g ha-1 as POE at 45 DAS	303	28.03	75.73	43.84	36711	50052	2.36
Pendimethalin 0.90 kg ha-1 PRE + Oxadiargyl 75 g ha-1 as POE at 45 DAS	104	28.54	91.66	42.82	36840	49186	2.34
HW at 15 and 45 DAS	80	2.28	93.63	-	36608	80301	3.19
Weed free	0	0.00	100.00	-	39751	79703	3.01
Unweeded check	1248	49.97	0.00	-	33603	26984	1.80
LLSD (0.05)	**84**	-	-	-	-	-	-

Market Price:

Commodity	**Rs. kg^{-1}**	**Herbicides**	**Rs. kg^{-1} or lit^{-1}**	**Herbicide**	**Rs. kg^{-1} or lit^{-1}**
Fennel seeds	: 60.00	Pendimethalin	: 400	Quizalofop-ethyl	: 1350
Fennel stover	: 2.00	Oxadiargyl	: 930	Fenoxaprop-ethyl	: 1500
		Glyphosate	: 270	Propaquizafop	: 1400

B:C = Benefit : Cost Ratio

recorded the highest size of weed seedbank due to production of large number of weed seeds under uncontrolled condition leading to increase in seedbank of 978 % in the initial seedbank (Table 2).

Growth, yield attributes, yield and economical parameters

The weed management treatments significantly influenced the different growth parameters of fennel crop. Perusal of data revealed that besides weed free treatment, highest plant height and number of branches plant^{-1} at harvest were recorded with pendimethalin + fenoxaprop-ethyl, which was at par with pendimethalin + HW at 45 DAS and HW twice at 15 and 45 DAS (Table 1). These resulted into less weed-crop competition throughout the growth stage and created favourable environment for plant growth with respect to availability of nutrients, water, light and space, which might have accelerated the photosynthetic rate, thereby increasing the supply of carbohydrates leading to increase in growth characters of fennel plants. These findings are in agreement with those of Thakral *et al.* (1995), Chaudhary (2000), Meena and Mehta (2009), Nagar *et al.* (2009) and Patro *et al*. (2014).

Yield attributes, seed and stover yield were significantly influenced by different weed management practices. Results revealed that besides weed free treatment, significantly the highest yield attributes like number of umbels plant^{-1} (12.0), number of seeds umbellate^{-1} (25.3), test weight (6.62), seed weight plant^{-1} (29.33), and seed and stover yields (1831 and 4507 kg ha^{-1}) were recorded with pendimethalin + fenoxaprop-ethyl at 45 DAS, which was statistically at par with pendimethalin + HW at 45 DAS and HW twice at 15 and 45 DAS (Table 1). The improved yield attributes under these treatments might be attributed to effective weed control resulting in lesser competition of weeds which might have ultimately resulted in the better utilization of nutrients and moisture available in the soil by crop leading to increased rate of photosynthesis and supply of photosynthates to various metabolic sinks might be reflected in terms of increased yield attributes and yield of seed spices. Analogous findings have been reported by Bhati (1994) and Meena and Mehta (2009).

The different weed management practices significantly influenced gross return, net return and B : C ratio in fennel. It was clear that pendimethalin PRE + fenoxaprop-ethyl POE at 45 DAS gave the maximum net return (Rs. 81993) and B : C ratio (3.22), followed by pendimethalin PRE + HW at 45 DAS, HW twice at 15 and 45 DAS and weed free treatment (Table 3). The lower net returns and B : C ratio in weed free treatment might be because of more cost was required to create weed free condition for entire period in the crop season.

An experiment was conducted during *rabi* season of 2012 at Junagadh to find out most suitable and economically viable method of weed control in *rabi* fennel (*Foeniculum vulgare* Mill.). The dominant weed species observed were *Cyperus rotundus* L., *Chenopodium album* L., *Digera arvensis* Forsk and *Asphodelus tenuifolius* L. Cav. Results revealed that besides weed free treatment, significantly higher plant height, number of branches plant^{-1}, number of umbels plant^{-1}, number of seeds umbellate^{-1}, test weight, seed weight plant^{-1}, and seed and stover yields of fennel were recorded with pre-emergence (PRE) application of pendimethalin at 0.90 kg ha^{-1} + post-emergence (POE) application of fenoxaprop-ethyl at 75 g ha^{-1} at 45 DAS which was at par with PRE application of pendimethalin at 0.90 kg ha^{-1} + hand weeding (HW) at 45 DAS and HW twice at 15 and 45 DAS. These treatments also recorded lower weed density and dry weight of weeds along with highest net returns (81993 and 81442 Rs ha^{-1}) and B:C ratio owing to lower weed index and higher weed control efficiency. However, the highest depletion of weed seedbank was observed with PRE application of pendimethalin at 0.90 kg ha^{-1} + HW at 45 DAS.

It is concluded that effective management of weeds along with profitable seed yield and net returns of direct seeded *rabi* fennel can be obtained with pendimethalin PRE + fenoxaprop-ethyl POE at 45 DAS or pendimethalin PRE + HW at 45 DAS or HW twice at 15 and 45 DAS or keeping the crop weed free throughout crop period according to availability of labours.

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