International Journal of Plant & Soil Science

34(1): 71-79, 2022; Article no.IJPSS.83014
ISSN: 2320-7035

Dry Matter Accumulation and Growth Indices of Fennel (*Foeniculum vulgare* Mill.) as Affected by Different Weed Management Practices and Plant Geometry

Meena Choudhary [a*¥], A. C. Shivran [a£], Manish Kakraliya [b¥], Sheeshpal Choudhary [a¥] and Kiran Doodhwal [c¥]

[a] Department of Agronomy, Sri Karan Narendra Agriculture University, Jobner, Rajasthan 303329, India.
[b] Department of Agronomy, CCS Haryana Agricultural University, Hisar, Haryana 125004, India.
[c] Department of Soil Science and Agricultural Chemistry, Rajasthan College of Agriculture, MPUAT, Udaipur, 313001, India.

Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/IJPSS/2022/v34i130826

Open Peer Review History:
This journal follows the Advanced Open Peer Review policy. Identity of the Reviewers, Editor(s) and additional Reviewers, peer review comments, different versions of the manuscript, comments of the editors, etc are available here: https://www.sdiarticle5.com/review-history/83014

Original Research Article

Received 17 November 2021
Accepted 23 January 2022
Published 25 January 2022

ABSTRACT

An experiment was conducted during rabi seasons of 2016-17 and 2017-18 at Agronomy Farm, S.K.N. Agriculture University, Jobner, Jaipur, Rajasthan, to get a suitable combination of sowing at different plant geometries and weed management. The experiment was managed in a split-plot design with three replications. The main plot treatments comprised four plant geometries, viz. 50 x 20 cm, 50 x 25 cm, 60 x 15 cm and 60 x 20 cm and subplots consisted of six treatments of weed management, viz. weedy check, two hand weeding (HW) at 25 and 50 days after sowing (DAS), pendimethalin @ 0.75 kg/ha pre emergence (PE), oxadiargyl @ 75 g/ha (PE), pendimethalin @ 0.75 kg/ha (PE) + one HW at 30 DAS and oxadiargyl @ 75 g/ha (PE) + one HW at 30 DAS. Sowing of fennel with plant geometry 60 x 20 cm showed superior performance in respect of dry-matter accumulation, growth indices and yield as compared to plant geometries 50 x 20 cm, 50 x 25 cm

¥Ph.D. Scholar;
£Professor;
**Corresponding author: E-mail: meenac1191@gmail.com;*

and 60 x 15 cm. Among weed management treatments, hand weeding twice 25 and 50 DAS registered significantly highest dry matter accumulation, growth indices viz. crop growth rate (CGR), relative growth rate (RGR) and yield of fennel, thus, hold a great promise in fennel production under semi-arid conditions of Rajasthan.

Keywords: Fennel; plant geometry; weed management; pendimethalin; oxadiargyl.

1. INTRODUCTION

Fennel (*Foeniculum vulgare* Mill.) commonly known as saunf is a major seed spices grown during *rabi* season which is cultivated in an 0.75 lakh hectares and produces of 1.27 million tonne with national average yield of 1697 kg/ha [1]. In Rajasthan the production reached the level of 0.28 lakh tonne with productivity of 1052 kg/ha and acreage 0.27 lakh hectares [1]. It belongs to Apiaceae family. In India it is mainly cultivated in states of Gujarat, Rajasthan and to some extent in Karnataka, Uttar Pradesh, Punjab, Andhra Pradesh and Madhya Pradesh as a *rabi* season crop. To obtain maximum dry matter production of fennel, it is important and essential to enhance the growth of crop and increases yield and this could be achieved largely by providing the most optimum plant population per unit area and balanced nutrient under field conditions, which could be provided by optimizing the spacing. The plants grown in the wider spacing exhibit more horizontal and continuous vegetative growth due to less population pressure per unit area therefore, they give high yield per unit area [2]. However, plants grown under normal spacing will have optimum population density per unit area which provides optimum conditions for luxuriant crop growth and better plant canopy area due to maximum light interception, photosynthetic activity, assimilation and accumulation of more photosynthates into plant system and hence they produce more seed, straw and biological yields [3].

Fennel is slow growing crop during its initial stage and gets severe competition from the weeds during this stage. If unchecked, it may reduce the seed yield to the tune of 91.4 percent [4]. Extent of loss caused by weed is the highest among all the loss causing agent like insect pest and disease. To control the weeds in fennel, manual weeding is the standard practice. Sometimes, scarcity of labour does not permit mechanical weeding to keep the field weed free. In such situations, the use of herbicides is the way to eliminate the weed crop competition. However, it is well known that the efficacy of pre-emergence herbicides depends upon soil moisture [5]. Therefore, weed management is one of the most crucial factors in realizing optimum dry matter production and yields. Therefore, the present study was conducted to find suitable plant geometry and weed management method for realizing higher dry matter production, growth indices and yield of fennel.

2. MATERIALS AND METHODS

A field experiment was carried out during *rabi* seasons of 2016-17 and 2017-18 at Agronomy farm, S.K.N. College of Agriculture, Jobner located at 45 km west of Jaipur at 26^0 05' North latitude, $75^0$28' East longitude and at an altitude of 427 metres above mean sea level. The climate of this region is a typically semi-arid, characterized by extremes of temperature during both summers and winters. The average annual rainfall of this tract varies from 350 mm to 450 mm most of which is contributed by S-W monsoon during the period of July to September. The soil texture of the field was loamy sand with 8.2 pH, 1.24 dS/m EC, 0.21% organic carbon, 128.6 kg/ha available N, 15.4 kg/ha available P and 148.6 kg/ha available K. The experiment was conducted in Split Plot Design with three replications consisting four sowing plant geometries G_0 (50 x 20 cm), G_1 (50 x 25 cm), G_2 (60 x 15 cm), G_3 (60 x 20 cm) and six weed management measures viz. W_0 (Weedy check), W_1 (Two HW at 25 and 50 DAS), W_2 [Pendimethalin @ 0.75 kg/ha (PE)], W_3 [Oxadiargyl @ 75 g / ha (PE)], W_4 (Pendimethalin @ 0.75 kg / ha (PE) + one HW at 30 DAS) and W_5 (Oxadiargyl @ 75 g/ha (PE) + one HW at 30 DAS). Herbicides were spray at pre emergence of both weed and crop. Seed rate of 10 kg/ha of fennel cultivar 'RF-205' was used in this study. Sowing was done with *khera* method in rows, keeping 50 and 60 cm spacing with approximate depth of 2-3 cm. The seeds were treated with bavistin @ 2 g/kg seeds to protect the crop from seed borne diseases at the time of sowing. A uniform half dose of nitrogen and 40 kg P_2O_5 phosphorus were applied manually through DAP and urea at the time of sowing and remaining dose of nitrogen was

applied at vegetative stage. According to recommendations, all other cultural practices were carried out. Biometrical observations and yield were recorded by following standard practices. Data were recorded on growth attributes, viz. dry-matter accumulation and indices, seed and straw yields. For the assessment of dry matter production per plant, total five plants were selected randomly from each experimental plot and its finally converted into one m^2 area. Growth indices viz. Crop growth rate (CGR) and Relative growth rate (RGR) were calculated by using the following formulae:

2.1 Crop Growth Rate (CGR)

The CGR of a plant for a time 't' is defined as the increase in dry weight of plant material from a unit area per unit of time. It was calculated by following formula [6] from the periodic dry matter recorded at different stages.

$$CGR\ (g/m^2/day) = (W_2 - W_1) / (t_2 - t_1)\ S$$

Where,

W_1 = Dry matter of crop at time t_1
W_2 = Dry matter of crop at time t_2
t_1 = Time of first observation.
t_2 = Time of subsequent observation.
S = Spacing

2.2 Relative Growth Rate (RGR)

The RGR of a plant at an instant in time (t) is defined as the increase in dry weight of plant material per unit of material already present per unit of time.

The RGR of the crop was calculated by the following formula [6].

$$RGR\ (mg/g/day) = ((Log_e\ W_2 - Log_e\ W_1)) / (t_2 - t_1)\ W_1$$

Where,

W_1 = Total dry matter of crop at time t_1
W_2 = Total dry matter of crop at time t_2
t_1 = Time at first observation.
t_2 = Time at second observation.

Harvesting was done manually and after threshing, cleaning and drying, the seed, straw and biological yields of fennel were calculated and expressed in q/ha. The observations recorded for various parameters were statistically analyzed to observe the significant difference among the treatment. The significance of the difference among the treatments means was assessed by the LSD at 5% level of probability.

3. RESULTS AND DISCUSSION

3.1 Effect of Plant Geometry

Dry matter accumulation, growth indices viz. CGR, RGR and yield varied significantly due to sowing of fennel at different plant geometries during both the years and in pooled mean (Tables 1 to 3). The significantly maximum crop dry matter was recorded with plant geometry of 60 × 20 due to availability of more ground area per plant which implied that individual plant at wider plant geometry received higher resources like; sunlight, water and nutrients with comparatively lower competition. Larger canopy development, associated with profuse branching with chlorophyll content might have increased interception, absorption and utilization of solar energy, which resulted in formation of higher photosynthetes. Hence, the higher photosynthetic activity per unit area and more dry matter production led to increase in growth indices *viz*. CGR and RGR. The relative growth rate (RGR) showed differential value at different growth stages. It might be due to the juvenility of plants at earlier growth periods and shading effects of upper leaves on older ones at later growth stages. The finding corroborates with the results reported by [7].

Sowing of fennel with plant geometry 60 x 20 cm recorded the maximum seed, straw and biological yields with the respective values of 22.13, 74.46 and 96.59 q/ha and proved significantly superior to rest of the treatments (Table 4). The quantum increase in seed yield due to G_3 (60 x 20 cm) was11.31, 14.84 and 29.33 per cent, straw yield of 11.55, 15.35 and 29.36 per cent and biological yield of 11.49, 15.24 and 29.35 per cent as compared to lower density planting at 50 x 25 cm, 50 x 20 cm and 60 x 15 cm, respectively. Marked improvement in yield of the crop with increase in spacing appears to be on account of vigorous growth of the plants as evident from profuse branching and higher biomass accumulation per plant. The profuse branching seems to have led to greater initiation of flowering and adequate supply of metabolites due to the increase in biomass per plant which might have helped in retention of flower thereby, greater seed formation and seed growth. This was ultimately reflected in increased seed, straw and biological yields. These findings are in close conformity of [8] in fennel, [9-11] in ajwain.

Table 1. Effect of plant geometry and weed management on dry matter accumulation of fennel

Treatments	Dry matter accumulation (g)/m^2											
	35 DAS			70 DAS			105 DAS			At harvest		
	2016-17	2017-18	Pooled	2016-17	2017-18	Pooled	2016-17	2017-18	Pooled	2016-17	2017-18	Pooled
Plant geometry (cm)												
G_0 - 50 x 20	15.48	14.30	14.89	72.69	71.99	72.34	145.96	136.38	141.17	378.97	345.36	362.16
G_1 - 50 x 25	15.60	14.85	15.22	74.74	74.76	74.75	150.52	141.08	145.80	389.61	356.16	372.88
G_2 - 60 x 15	14.21	13.31	13.76	66.92	65.81	66.36	136.42	123.24	129.83	351.77	323.42	337.60
G_3 - 60 x 20	16.55	16.03	16.29	92.03	92.08	92.06	160.36	152.29	156.32	414.69	387.58	401.13
SEm±	0.25	0.23	0.16	1.40	1.39	0.91	2.40	2.22	1.51	6.28	5.79	3.95
CD (P=0.05)	0.88	0.81	0.49	4.83	4.81	2.81	8.32	7.67	4.67	21.73	20.05	12.19
CV (%)	6.98	6.79	6.89	7.74	7.75	7.74	6.88	6.81	6.85	6.94	6.96	6.96
Weed management												
W_0 - Weedy check	9.96	8.24	9.10	43.54	43.36	43.45	89.61	79.20	84.40	269.32	257.58	263.45
W_1 – Two HW at 25 & 50 DAS	18.15	17.62	17.88	91.02	90.69	90.85	173.06	162.02	167.54	438.72	403.56	421.14
W_2 - Pendimethalin @ 0.75 kg /ha (PE)	17.56	17.25	17.41	88.32	87.75	88.03	168.38	158.91	163.64	426.28	390.51	408.40
W_3 – Oxadiargyl @ 75 g/ha (PE)	11.46	9.70	10.58	57.53	57.41	57.47	118.35	107.82	113.09	298.58	271.65	285.11
W_4 - Pendimethalin @ 0.75 kg /ha (PE) + One HW at 30 DAS	17.87	17.52	17.70	90.19	89.88	90.03	171.99	161.26	166.62	437.45	402.29	419.87
W_5 .Oxadiargyl @ 75 g/ha (PE) + One HW at 30 DAS	17.75	17.40	17.57	88.98	87.87	88.42	168.49	160.27	164.38	432.20	393.20	412.70
SEm±	0.26	0.25	0.20	1.36	1.42	1.09	2.47	2.34	1.87	6.34	5.86	4.77
CD (P=0.05)	0.74	0.42	0.56	3.88	4.07	3.06	7.06	6.69	5.27	18.11	16.74	13.42
CV (%)	5.78	6.02	6.47	6.14	6.47	6.98	5.77	5.87	6.40	5.72	5.75	6.34

Table 2. Effect of plant geometry and weed management on crop growth rate (CGR) during different stages

Treatments	CGR (g/m^2/day)											
	0- 35 DAS			35-70 DAS			70-105 DAS			105-At harvest		
	2016-17	2017-18	Pooled	2016-17	2017-18	Pooled	2016-17	2017-18	Pooled	2016-17	2017-18	Pooled
Plant geometry (cm)												
G_0 - 50 x 20	1.038	1.028	1.033	3.270	3.296	3.283	4.187	3.680	3.933	13.315	11.942	12.628
G_1 - 50 x 25	1.068	1.068	1.068	3.379	3.424	3.401	4.331	3.789	4.060	13.662	12.291	12.976
G_2 - 60 x 15	1.147	1.128	1.138	2.510	2.500	2.505	3.309	2.735	3.022	10.255	9.532	9.894
G_3 - 60 x 20	1.578	1.578	1.578	3.595	3.621	3.608	3.254	2.867	3.060	12.111	11.204	11.658
SEm±	0.028	0.028	0.018	0.067	0.067	0.044	0.067	0.059	0.041	0.223	0.200	0.139
CD (P=0.05)	0.097	0.097	0.056	0.232	0.233	0.135	0.231	0.204	0.127	0.770	0.693	0.427
CV (%)	9.814	9.892	9.853	8.91	8.89	8.90	7.52	7.64	7.59	7.66	7.55	7.62
Weed management												
W_0 - Weedy check	0.687	0.684	0.685	1.751	1.832	1.792	2.421	1.886	2.154	9.416	9.334	9.375
W_1 – Two HW at 25 & 50 DAS	1.435	1.430	1.433	3.801	3.812	3.806	4.313	3.755	4.034	13.918	12.637	13.278
W_2 - Pendimethalin @ 0.75 kg /ha (PE)	1.393	1.384	1.388	3.690	3.678	3.684	4.209	3.745	3.977	13.513	12.116	12.814
W_3 – Oxadiargyl @ 75 g/ha (PE)	0.907	0.905	0.906	2.402	2.489	2.446	3.196	2.652	2.924	9.443	8.571	9.007
W_4 - Pendimethalin @ 0.75 kg /ha (PE) + One HW at 30 DAS	1.422	1.417	1.420	3.772	3.775	3.773	4.300	3.757	4.029	13.908	12.610	13.259
W_5 .Oxadiargyl @ 75 g/ha (PE) + One HW at 30 DAS	1.403	1.385	1.394	3.715	3.676	3.696	4.180	3.811	3.995	13.817	12.186	13.001
SEm±	0.022	0.022	0.018	0.056	0.056	0.046	0.062	0.053	0.046	0.206	0.188	0.156
CD (P=0.05)	0.063	0.033	0.051	0.159	0.161	0.128	0.177	0.153	0.130	0.588	0.538	0.440
CV (%)	6.301	6.327	7.378	6.05	6.07	6.97	5.70	5.66	6.41	5.77	5.80	6.50

Tale 3. Effect of plant geometry and weed management on relative growth rate (RGR) of fennel at different stages

Treatments	RGR (mg/g/day)								
	35- 70 DAS			70-105 DAS			105 DAS- at harvest		
	2016-17	2017-18	Pooled	2016-17	2017-18	Pooled	2016-17	2017-18	Pooled
Plant geometry (cm)									
G_0 - 50 x 20	16.30	18.12	17.21	4.78	4.35	4.57	5.59	5.59	5.59
G_1 - 50 x 25	16.47	17.85	17.16	4.77	4.28	4.53	5.54	5.53	5.53
G_2 - 60 x 15	16.88	18.44	17.66	4.98	4.36	4.67	5.63	5.92	5.77
G_3 - 60 x 20	17.66	18.73	18.20	3.62	3.24	3.43	5.46	5.49	5.48
SEm±	0.27	0.28	0.18	0.07	0.06	0.04	0.08	0.08	0.05
CD (P=0.05)	0.93	0.99	0.56	0.24	0.21	0.13	0.29	0.29	0.17
CV (%)	6.79	6.61	6.70	6.40	6.39	6.41	6.40	6.22	6.31
Weed management									
W_0 - Weedy check	18.28	22.43	20.36	5.54	4.63	5.08	7.00	7.72	7.36
W_1 – Two HW at 25 & 50 DAS	15.85	16.27	16.06	4.12	3.73	3.93	5.16	5.13	5.15
W_2 - Pendimethalin @ 0.75 kg /ha (PE)	16.05	16.27	16.16	4.17	3.84	4.00	5.18	5.08	5.13
W_3 – Oxadiargyl @ 75 g/ha (PE)	18.84	22.32	20.58	5.15	4.50	4.83	5.54	5.65	5.60
W_4 - Pendimethalin @ 0.75 kg /ha (PE) + One HW at 30 DAS	15.99	16.27	16.13	4.15	3.76	3.96	5.18	5.15	5.17
W_5 .Oxadiargyl @ 75 g/ha (PE) + One HW at 30 DAS	15.96	16.16	16.06	4.12	3.89	4.00	5.25	5.06	5.16
SEm±	0.30	0.34	0.24	0.08	0.07	0.06	0.10	0.10	0.07
CD (P=0.05)	0.86	0.97	0.69	0.22	0.19	0.16	0.27	0.28	0.21
CV (%)	6.19	6.40	6.82	5.82	5.75	6.31	6.00	6.05	6.50

Table 4. Effect of plant geometry and weed management on seed, straw and biological yields of fennel

Treatments	Seed yield (q/ha)			Straw yield (q/ha)			Biological yield (q/ha)		
	2016–17	2017–18	Pooled	2016–17	2017–18	Pooled	2016–17	2017–18	Pooled
Plant rectangularity (cm)									
50 x 20	19.92	18.62	19.27	65.80	63.28	64.54	85.72	81.91	83.81
50 x 25	20.49	19.28	19.88	67.86	65.63	66.75	88.35	84.91	86.63
60 x 15	17.82	16.40	17.11	58.86	56.25	57.56	76.68	72.66	74.67
60 x 20	22.61	21.66	22.13	75.32	73.59	74.46	97.93	95.25	96.59
SEm±	0.30	0.32	0.21	1.36	1.29	0.86	1.66	1.57	1.06
CD (P=0.05)	1.05	1.12	0.63	4.69	4.45	2.66	5.76	5.42	3.26
CV (%)	6.37	7.26	6.80	8.59	8.43	8.51	8.10	7.94	8.03
Weed management									
Weedy check	14.75	13.61	14.18	48.92	47.38	48.15	63.67	60.99	62.33
Two HW at 25 & 50 DAS	22.75	21.93	22.34	73.80	71.87	72.84	96.55	93.80	95.18
Pendimethalin @ 0.75 kg /ha (PE)	21.94	20.98	21.46	71.11	69.67	70.39	93.05	90.65	91.85
Oxadiargyl @ 75 g/ha (PE)	17.18	15.00	16.09	62.15	57.50	59.82	79.33	72.50	75.91
Pendimethalin @ 0.75 kg /ha (PE) + One HW at 30 DAS	22.53	21.32	21.93	73.60	71.36	72.48	96.13	92.68	94.41
Oxadiargyl @ 75 g/ha (PE) + One HW at 30 DAS	22.10	21.10	21.60	72.17	70.37	71.27	94.27	91.47	92.87
SEm±	0.44	0.40	0.32	1.11	1.07	0.89	1.59	1.53	1.23
CD (P=0.05)	1.26	1.14	0.89	3.18	3.06	2.50	4.55	4.37	3.46
CV (%)	7.56	6.95	7.90	6.03	5.73	6.62	6.33	5.98	7.05

3.2 Effect of Weed Management

Dry matter accumulation at all the growth stages, growth indices viz. CGR, RGR and yield of fennel were significantly influenced by different weed management treatments (Tables 1-4). Two HW at 25 and 50 DAS treatment recorded the significantly higher crop dry matter at all the stages. As well as maximum values of CGR was also recorded under two hand weeding treatment but RGR values maximum in weedy check treatment. Pendimethalin @ 0.75 kg/ha and one HW at 30 DAS, oxadiargyl @ 75 g/ha (PE) and one HW at 30 DAS and pendimethalin @ 0.75 kg/ha (PE) were the next better and equally effective treatments in improving dry matter accumulation and crop growth rate of fennel. However, the significantly minimum value of RGR for all the stages of crop growth except 105 DAS-at harvest was exhibited by two hand weeding treatments. Application of pendimethalin @ 0.75 kg/ha (PE) + one hand weeding at 30 DAS and oxadiargyl @ 75 g/ha (PE) + one hand weeding at 30 DAS were the next better and statistically similar treatments in respect of this character (Tables 1-3). The maximum values of these growth parameters under these treatments is due to better control of weeds throughout the crop growth period which resulted in better availability of moisture and nutrients to the crop resulting in favourable condition for crop, consequently crop attained luxuriant growth having smothering effect on weed. These results are in conformity with [12-14] in fenugreek.

Among weed control measures, treatment two HW at 25 and 50 DAS (W_1) recorded the significantly higher seed, straw and biological yields of fennel in comparison to weedy check which was at par with W_4, W_5 and W_2 (Table 4). Higher seed, straw and biological yields under these treatments might be due to effective control of weeds which in turn significantly reduced crop – weed competition resulting in better congenial condition for growth and development of the crop which in turn increase the values of growth and yield attributes under these treatments. In addition to this the least weed population and dry weight of weeds were recorded under these treatments was also responsible for better seed, straw and biological yields. Results of the present investigation are in cognizance with the finding of [15].

4. CONCLUSION

Thus, it can be concluded that two hand weedings at 25 and 50 DAS or integration of pendimethalin @ 0.75 kg/ha with one hand weeding at 30 DAS, oxadiargyl @ 75 g/ha with one hand weeding at 30 DAS and pendimethalin @ 0.75 kg/ha along with sowing of fennel with plant rectangularity 60 x 20 cm is optimum for realizing higher dry matter accumulation, growth indices and yield of fennel under semi arid eastern plan zone of Rajasthan.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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