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Fertigation studies in Japanese mint (*Mentha arvensis* L.) under humid climate in Odisha, India

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The study was conducted to optimize the use of water and nutrients by Japanese mint (*Mentha arvensis* L.) with three moisture regimes [I_1 drip irrigation at 100%, I_2 at 80% and I_3 at 60% pan evaporation (PE)] and three fertility levels (F_1 100%, F_2 75% and F_3 50% recommended dose of NPK) with an extra (control) treatment having surface irrigation and soil application of fertilizer. The experiment was laid out in Factorial Randomized Block Design with three replications at the Experimental Farm of the Directorate of Water Management, Bhubaneswar India (20° 30' N lat., 87° 48' E long, 45 m above mean sea level) during winter (dry) seasons of 2005-2006 and 2006-2007. Drip irrigation increased the herbage and oil yield by 15.9 and 15.2%, respectively as compared to surface irrigation. It saved 29% water as compared to the latter (925 mm). Soil moisture regimes maintained at 100% PE significantly enhanced crop growth, herbage yield (34,798 kg ha^{-1}), essential oil yield (254 kg ha^{-1}) and N uptake (120 kg ha^{-1}) compared to 60% PE. Application of 100% recommended dose of fertilizer significantly produced maximum herbage (32,572 kg ha^{-1}) and oil yield (246 kg ha^{-1}). Combination of irrigation at 100% PE with 100% RD of fertilizer produced maximum quantity of oil (260 kg ha^{-1}) with improvement in its quality as compared to other levels tested.

Key words: Drip irrigation, fertilizer, Japanese mint, pan evaporation, recommended dose.

INTRODUCTION

Japanese mint, also known as corn mint or menthol mint (*Mentha arvensis* L.), is one of the commercially cultivated and important essential oil bearing industrial crops in northern semi-arid and sub tropical region of India. It is a potential source of natural menthol and other ingredients viz., mint terpenes, menthone, isomenthone, menthyl acetate etc., which are extensively used in pharmaceutical, cosmetic, food and flavour industries. India is currently producing more than 18,000 tonnes of mint oil per year and has emerged as a major world supplier of mint oil and menthol (Patra, 2008). Mint being a leafy herb, responds to frequent irrigation during dry season's months to obtain good growth and high yields as reported by Shormin et al. (2009). It absorbs

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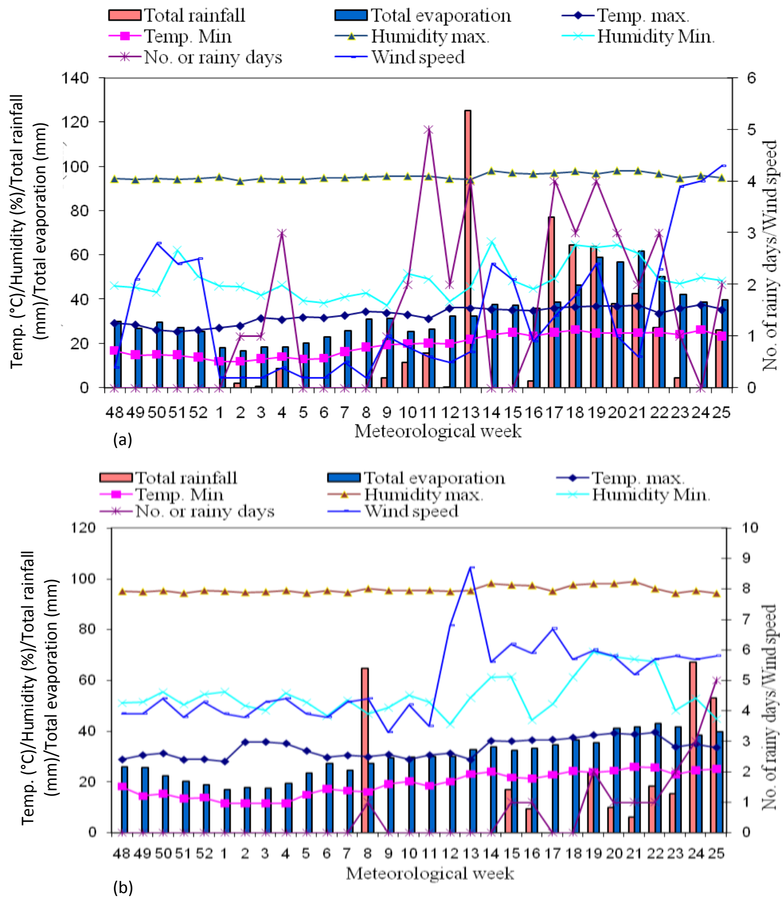

Figure 1. General climatic condition of experimental site during (a) 2005-2006, (b) 2006-2007.

substantial quantities of N, P and K as compared to other mint species. It responds well to high levels of nitrogen fertilizer, between 150 and 250 kg ha^{-1}, depending upon different agro-climatic conditions (Shormin et al., 2009). The irrigation requirement of mint differs from location to location depending on soil type, soil fertility status and climatic conditions. As little information is available on interaction effects of irrigation and fertilizer in a sandy loam acid soil under humid climate, the present investigation was undertaken to assess the irrigation and fertilizer in relation to its growth, yield and quality of the oil.

MATERIALS AND METHODS

Location of the experiment

The field experiment was conducted during winter (dry) seasons of 2005-2006 and 2006-2007 at the research farm of the Directorate of Water Management, Bhubaneswar, India, located at 20° 30' N latitude and 87° 48' E longitude at an elevation of 45 m above mean sea level. It is about 52 km away towards the west from the Bay of Bengal, representing warm, moist with hot and humid summer and mild winter.

Soil

The soil of the experimental site was a sandy loam with pH 5.7. The bulk density ranged from 1.44 to 1.52 g cm^{-3}, field capacity 19.47% to 26.10% (w/w %) and permanent wilting point 8.56 to 12.49% (w/w %). The available soil moisture was 111 mm per 0 to 60 cm soil depth with organic carbon content of 0.46% (Jackson, 1967). The available N was 159 kg ha^{-1} (Subbiah and Asija, 1956), P 21 and K 183 kg ha^{-1} (Jackson, 1973) in 0 to 15 cm soil profile.

Climate

The climate is warm, moist with hot and humid summer and mild winter. The mean annual rainfall of the place was 1439 mm (1995-2004). The total amount of rainfall received during the cropping seasons of mint was 464 mm in 2005-2006 and 359 mm in 2006-2007 in 42 and 23 rainy days respectively. The total evaporation from open pan evaporimeter was 959 and 850 mm, maximum temperature ranged from 25.5 to 37.5°C and 28.1 to 39.6°C, whereas minimum temperature ranged from 12.0 to 26.1°C and 11.5 to 25.9°C in 2005-2006 and 2006-07, respectively (Figure 1a and b). The former season (2005-2006) was hotter than the latter (2006-2007). The relative humidity varied from 93.3 to 98.1%; 94.0 to 98.9% in the morning and 37.2 to 66.0% and 44.4 to 71.3% in the afternoon hours. The weekly total radiation varied from 4306 to 7405 Wm^{-2} in 2005-2006 and 4305 to 7346 Wm^{-2} in 2006-2007. The

Table 1. Number of irrigations applied to Japanese mint.

Irrigation regimes based on pan evaporation	Number of irrigations per month							
2006	Dec	Jan	Feb	March	April	May	June	Total
100% PE	15	16	11	12	9	4	7	74
80% PE	15	16	11	12	9	4	7	74
60% PE	15	16	11	12	9	4	7	74
Surface irrigation	1	2	1	2	2	1	2	11
2007								
100% PE	15	15	10	16	12	11	5	84
80% PE	15	15	10	16	12	11	5	84
60% PE	15	15	10	16	12	11	5	84
Surface irrigation	1	1	2	2	2	2	1	11

One common pre-planting irrigation of 60 mm depth was given uniformly to all the treatments.

average wind speed ranged from 0.2 to 4.3 km hr^{-1} in 2005-2006 and 3.3 to 8.7 km hr^{-1} in 2006-2007.

Treatment details

The treatments were consisting of three irrigation regimes based on pan evaporation (I_1 drip irrigation at 100% PE, I_2 at 80% PE and I_3 at 60% PE) and three levels of fertilizer [($F_1$100%, F_2 75% and F_3 50% of the recommended dose of NPK that is, 150-60-60 kg N-P_2O_5-K_2O ha^{-1}) were tested in a Factorial Randomized Block Design with three replications. For comparison of experimental results between drip fertigation (DF) and surface irrigation, one treatment of surface irrigation and soil application of fertilizer was maintained as control.

Healthy and disease free suckers of variety "Koshi " were used for planting at the rate of 0.5 t ha^{-1}. The suckers were dipped in 0.5% benelate solution for 10 min before planting to safeguard against root rot disease. About 10 cm long pieces of suckers were placed at 5 cm soil depth in furrows spaced at 60 cm. It was covered with thin layer of soil followed by a light irrigation to ensure good sprouting. Suckers were planted in the second week of December during both the years. The recommended dose (RD) of fertilizer consisting of 150-60-60 kg N, P_2O_5 and K_2O, ha^{-1} was applied to the crop. Full dose of phosphorus was applied basally at the time of planting. It was placed in open furrows about 2.5 cm below the suckers and mixed well with the soil. Fertigation was given in equal splits at fortnightly interval from 15 days after planting (DAP) up to 30 days before harvest as per the treatment. Required amount of urea (46% N) and potash (60% K) were dissolved in water and fed to the drip system through a ventury. Fertigation was made by regulating the taps of the laterals by allowing the solution to the specified plots as per the treatments.

Irrigation scheduling

Differential amount of water was supplied as per treatment, on the basis of two days cumulative pan evaporation (CPE) through meteorological approach (Pruitt, 1966; Jenson et al., 1961) Cumulative pan evaporation for different treatments was computed using data from a standard US Weather Bureau Class A open pan evaporimeter. The depth of water during each irrigation was maintained at 6 cm in case of surface irrigation. The water was drawn from the secondary reservoir. First irrigation was given one day prior to planting. Subsequent irrigations were given at two days interval in drip irrigation and at 60 mm CPE value in case of surface irrigation method. Irrigation was applied after deducting the rainfall if rainfall event occurred between irrigation cycles. Computation of irrigation water through drip system was made according to the following equation.

$$\text{Amount of irrigation water in litre} = \frac{\begin{array}{c}\text{(Lateral spacing in mm} \times \text{dripper spacing in mm)} \\ \times \text{ Wetted area (60\%)} \times \text{crop coeficient at diferent} \\ \text{crop growth period} \times \text{two days} \\ \text{pan evaporation (mm)}\end{array}}{\text{Uniformity coefficient}}$$

The crop coefficient values of 0.60, 1.15 and 1.10 were used during vegetative, full growth and later part of the growth stages, respectively. In this experiment, the observed uniformity coefficient (UC) values varied from 92 to 94% for different treatments as discharge rate of drippers was measured frequently. Depending upon the discharge rate and UC, the time of operation of drip system was adjusted, and treatment wise irrigation water was applied. Time of operation of drip irrigation was calculated for 100% PE as follows as total number of drippers were 96 (32 in each plot).

$$T = \frac{IW}{Oem \times Nem} \times 60$$

Where, T = Time in minutes,IW = Irrigation water (litre) = depth of irrigation (100% PE in mm) x plot area (m^2), O_{em} = Output of emitter (litre h^{-1}), N_{em} = Number of emitters per plot.

The number of irrigations given per month at two days interval under drip irrigation was worked out to be 74 in 2005-2006 and 84 in 2006-2007 (Table 1). The number of irrigation applied in the second year was more than the first due to dry spells prevailed during the month of March. Ground water contribution was considered zero as the depth of ground water table during the study period in the experimental field was beyond 8 m. Effective rainfall was taken in to account for computing consumptive use of water. Water use under different irrigation treatments was calculated by adding different components of moisture use (irrigation water applied ± change in soil profile moisture + effective rainfall). Water use efficiency (WUE) was expressed as the ratio of oil yield to that of the water used in kg ha-mm^{-1}.

The soil moisture content (v/v %) was monitored with the help of TDR moisture meter (model TRIME FM) in all irrigation levels (in drip and surface irrigation method) after installing 1 m length

Table 2. Growth characters of menthol mint as influenced by different levels of irrigation regime and fertilizer during 2006.

Treatment	Plant height (cm)		Leaf area index		Leaf-stem ratio		Dry matter (g m^{-2})	
	35 days after first harvest	75 days after first harvest	Before first harvest	Before second harvest	35 days after first harvest	75 days after first harvest	35 days after first harvest	75 days after first harvest
Method of irrigation								
Control	17.0	45.1	5.22	3.09	1.08	0.87	127.5	234.9
DF	24.0	51.5	6.66	3.51	1.11	0.94	143.6	270.7
SE (m)±	0.10	0.28	0.023	0.005	0.005	0.004	0.22	0.29
CD (0.05)	0.290	0.82	0.071	0.015	0.015	0.014	0.65	0.87
Irrigation (I)								
I_1 = 100% PE	25.6	53.7	7.11	3.67	1.13	0.90	148.1	281.2
I_2 = 80% PE	24.0	51.8	6.95	3.57	1.10	0.86	146.3	276.8
I_3 = 60% PE	22.4	49.0	5.91	3.30	1.09	0.86	136.3	254.1
SE (m) ±	0.17	0.48	0.041	0.008	0.009	0.008	0.38	0.51
CD (0.05)	0.50	1.42	0.123	0.026	0.028	0.025	1.13	1.51
Fertility (F)								
F_1 = 100% RD	24.6	52.5	6.85	3.66	1.12	0.88	151.3	286.4
F_2 = 75% RD	24.2	51.7	6.67	3.55	1.11	0.87	144.8	273.2
F_3 = 50% RD	23.3	50.3	6.45	3.32	1.09	0.87	134.7	252.4
SE (m) ±	0.17	0.48	0.041	0.008	0.009	0.008	0.38	0.51
CD (0.05)	0.50	1.42	0.123	0.026	0.028	NS	1.13	1.51

access tube near the emitter in drip irrigation. In surface irrigation it was placed between two crop rows. The depth interval for soil moisture measurement was fixed at 20 cm, which was continued up to 80 cm soil depth. Total available soil moisture in 80 cm depth was 9.38 cm. The depletion of soil moisture at different depth was computed based on the observations recorded frequently to assess degree of moisture stress in plant under different irrigation treatment in drip and surface method.

Plant analysis

The crop was harvested by taking the first cut at 115 days after planting and the second at 75 days after the first cut during both the years. The essential oil was extracted from the fresh herbage through steam distillation method using Clevenger`s type extracting apparatus made of glass (British Pharma Copoeia, 1958). The volume of oil was recorded and oil percent was computed by the following formula.

$$\text{Oil content (\%, w/w) on fresh weight basis} = \frac{\text{Weight of oil}}{\text{Weight of fresh herb}} \times 100$$

The oil percentage was multiplied with corresponding fresh herbage yield of each treatment to get the oil yield. The oil was analysed at the Central Institute for Medicinal and Aromatic Plants, Lucknow, India by gas liquid chromatography (Hewlett Packard 5890, column AT 1000, temperature from 100 to 170°C raised to 5°C per minute, carrier gas-nitrogen at 1 ml min^{-1}) for principal chemical constituents such as limonene, menthone, isomenthone, methyl acetate, neomenthol and menthol. Nitrogen content in the plant sample was estimated by the micro-Kjeldahl method. Leaf area was determined using a LICOR Leaf Area Meter model 3100.

RESULTS AND DISCUSSION

Crop growth

Drip fertigation significantly increased the growth attributes such as plant height (41.4 and 14.0%), leaf stem ratio (2.8 and 8.0%) and dry matter accumulation (12.6 and 15.2%) of mint crop after 35 and 75 days of first harvest during both years as compared to surface method (Table 2). Increasing the level of irrigation from 60% PE to 100% PE significantly enhanced the growth attributes such as plant height, leaf stem ratio and dry matter accumulation after 35 and 75 days of first harvest. Irrigating the crop at 100% PE had maximum leaf-stem ratio, which decreased marginally with 80 and 60% PE by 0.8 to 4.4% in 2005-2006 and 2.5 to 8.4% in 2006-2007. Similarly, application of irrigation at 100% PE (I_1) had maximum LAI (3.76 to 7.27) followed by 80% and 60% PE (Table 2). It decreased from 2.3 to 13.3% during both the seasons by reducing the quantity of irrigation water from 100% PE to 60% PE. Maximum amount of dry matter was produced by application of irrigation water at 100% PE and minimum with 60% PE.

Frequent irrigation enhanced the growth parameters due to quick development of extensive root system, which created a conducive environment to absorb more water and nutrient. It is well known that proper supply of moisture and nutrients helps in maintaining high photosynthetic rate, which increases the cell elongation and its multiplication at a much faster rate. It is further

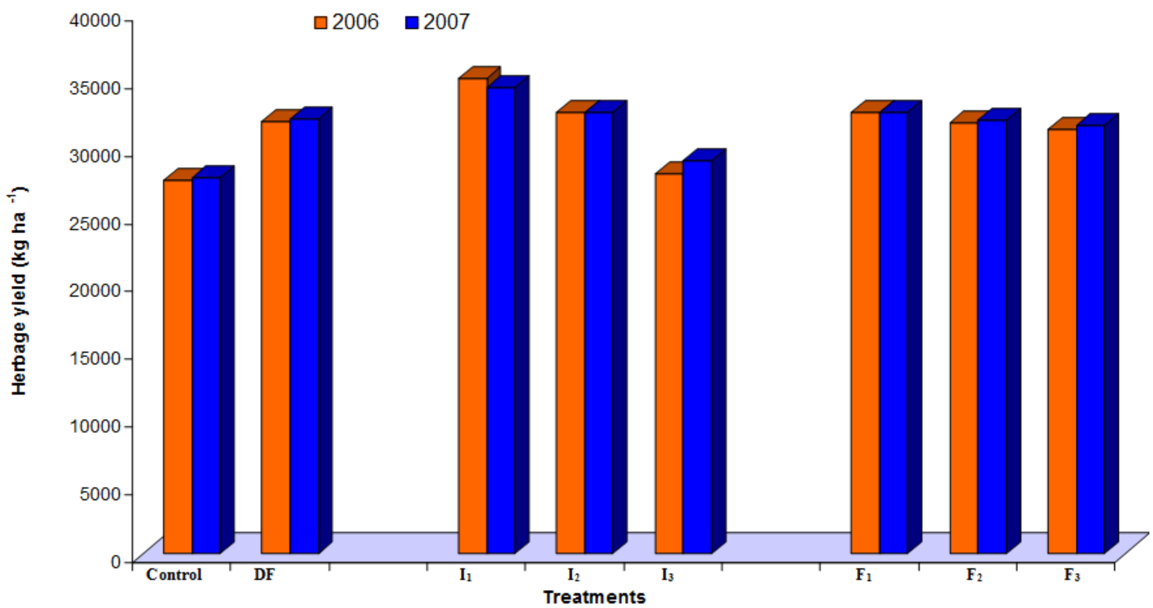

Figure 2. Effect of drip fertigation on herbage yield.

confirmed by the fact that higher Relative Growth Rate (RGR) and Crop Growth Rate (CGR) might be due to high rate of photosynthesis, which resulted in more accumulation of dry matter. Higher leaf temperature under low frequency irrigation might have increased respiration and decreased net assimilation rate resulting in low accumulation of dry matter. In the present study, all these factors cumulatively affected the plant growth from the initial stage to harvest under different irrigation regimes. Ram et al. (2006) and Shormin et al. (2009) obtained similar results. Plant height, leaf area index and dry matter accumulation were significantly influenced by application of 100% recommended dose of fertilizer. This may be attributed to more proliferation of root biomass resulting in more absorption of nutrients and water from the soil leading to production of higher vegetative biomass. At 35 days after first harvest, 100% RD increased LAI by 2.4 and 5% as compared to 75 and 50% RD, respectively. The dry matter was increased by 4.5 and 12.3% in 2005-2006 and 4.5 and 11.8% in 2006-2007, respectively in comparison with 75 and 50% RD at 35 days after first harvest. Adequate nutrition plays an important role on plant growth and development. It promotes vegetative growth through cell enlargement, multiplication and increase in the rate of photosynthesis (Patra et al., 2003; Rahman et al., 2003).

Herbage and essential oil yield

Herbage yield

Maximum herbage yield of 31, 925 kg ha^{-1} in 2005-2006 and 32, 142 kg ha^{-1} in 2006-2007 with mean yield of 32,034 kg ha^{-1} were recorded with drip fertigation (Figure 2). Drip fertigation increased the yield by 16% compared to surface irrigation. The herbage yield was affected by different irrigation levels during both the seasons. Maximum herbage yield of 34,463 to 35,132 kg ha^{-1} was obtained at 100% PE. The minimum yield of 28,079 to 29,010 kg ha^{-1} was recorded at 60% PE (I_3). Application of irrigation at 100% PE increased the total yield from 7.7 to 25.1% in 2005-2006 and 5.8 to 18.8% in 2006-2007. The mean yield increased from 6.7 to 21.9% due to favorable soil moisture conditions maintained throughout the crop growth period. The favorable effect of irrigation in enhancing herb yield of various mint species have also been reported by Singh et al. (2002), Ram et al. (2006) and Shormin et al. (2009).

Application of 100% RD (F_1) produced maximum yield (32,558 to 32,586 kg ha^{-1}) with mean yield of 32,572 kg ha^{-1}. These results are in close conformity with the findings of Fasina et al. (2008). Reduction of 25% (F_2) and 50% fertilizer (F_3) from the recommended dose (F_1) decreased the total herbage yield by 1.6 to 2.1% and 3.0 to 3.8%, respectively. The yield was reduced more in first harvest than in the second one. High yield of menthol mint with high rate of NPK has been reported on soils with low N content (Table 3).

Oil yield

Maximum oil yield was obtained with drip fertigation (232 to 240 kg ha^{-1}). Drip fertigation increased it from 17.0 to 20.3% at first harvest and 13 to 16.5% at the second

Table 3. Growth characters of menthol mint as influenced by different levels of irrigation regime and fertilizer during 2007.

Treatments	Plant height (cm)		Leaf area index		Leaf-stem ratio		Dry matter (g m^{-2})	
	35 days after first harvest	75 days after first harvest	Before first harvest	Before second harvest	35 days after first harvest	75 days after first harvest	35 days after first harvest	75 days after first harvest
Method of irrigation								
Control	19.9	52.2	6.18	3.20	1.06	1.08	137.0	233.8
DF	27.4	55.7	6.89	3.59	1.13	1.16	146.4	274.2
SE (m)±	0.25	0.53	0.020	0.005	0.004	0.004	3.39	0.37
CD (0.05)	0.743	1.57	0.060	0.015	0.014	0.012	NS	1.10
Irrigation (I)								
I_1 = 100% PE	30.0	57.7	7.27	3.76	1.19	1.12	153.0	290.2
I_2 = 80% PE	27.4	56.5	7.09	3.60	1.11	1.06	153.0	278.8
I_3 = 60% PE	24.9	53.0	6.30	3.41	1.09	1.06	133.2	253.6
SE (m) ±	0.43	0.92	0.036	0.009	0.008	0.007	5.87	0.64
CD (0.05)	1.29	2.72	0.107	0.028	0.024	0.021	17.60	1.90
Fertility (F)								
F_1 = 100% RD	28.3	57.7	7.02	3.66	1.14	1.10	154.0	288.8
F_2 = 75% RD	27.4	55.2	6.88	3.59	1.13	1.08	147.4	276.6
F_3 = 50% RD	26.6	54.2	6.76	3.52	1.11	1.06	137.8	257.1
SE (m) ±	0.43	0.92	0.036	0.009	0.008	0.007	5.87	0.64
CD (0.05)	1.29	2.72	0.107	0.028	0.024	0.021	NS	1.90

(Figure 3). The mean oil yield increased by 16.7%. Maximum yield was recorded with application of irrigation at 100% PE (250 and 257 kg ha^{-1}) followed by 80 and 60% PE. The total oil yield increased by 5.4 to 18.1% in 2005-2006 and 6.2 to 16.9% in 2006-2007 in case of I_1 as compared to I_2 and I_3. The mean oil yield in I_2 and I_3 decreased by 5.5 to 14.9% in comparison with I_1. Application of irrigation at 80% PE also increased the mean oil yield by 11% above that of 60% PE. The increase in yield in the above two treatments were due to favorable soil moisture conditions maintained throughout the crop growth period. Mentha is a succulent, multi-cut crop that has high water requirement during its growth period especially in dry months when the evaporation demand is relatively high. The favorable effect of irrigation in enhancing herb and oil yields of various mint species have been reported by Ram et al. (2006). It is evident from the results that the plant height, number of branches, number of leaves, crop growth rate and dry matter accumulation were significantly higher under high frequency irrigation than the low frequency ones, which contributed to higher herbage and oil yield.

Application of 100% RD (F_1) produced maximum oil (246 kg ha^{-1}) followed by F_2 (236 kg ha^{-1}) and F_3 (226 kg ha^{-1}). It increased the total oil yield from 4.0 to 7.9% in 2005-2006 and 3.9 to 9.0% in 2006-2007 and the mean yield by 4.0 to 8.5% as compared to F_2 and F_3 (Figure 3). The yield also increased from 3.7 to 4.9% by 75% RD as compared to 50% RD. Anwar et al. (2010) reported favorable effect of graded levels of NPK fertilizers on oil yield of mint.

Interaction effect of irrigation and fertility levels

Maximum quantity of oil (260 kg ha^{-1}) was harvested from the crop (Figure 3) at 100% PE irrigation level with 100% recommended dose of fertilizer (I_1F_1). It was significantly superior to other treatment combinations (Table 4). The oil yield has been maximized due to adequate availability of moisture, which enhanced the uptake of nutrients resulting in high herbage yield (Ram et al., 2006).

Nitrogen uptake

Uptake of N by the crop, in general, was higher in the first cutting than the second. The uptake was more in 2006-2007 than 2005-2006 (Figure 4). Drip fertigation increased the nitrogen uptake by 21.0% as compared to surface irrigation (95 kg ha^{-1}). Application of irrigation water at high frequency and application of fertilizers in the effective crop root zone through fertigation increased the uptake. Maximum amount of 120 kg N ha^{-1} was taken up by the plants through irrigation at 100% PE followed by 80% PE (119 kg ha^{-1}) and 60% PE (107 kg ha^{-1}). There was no significant difference in uptake between 100% PE and 80% PE. Application of irrigation at 80% PE

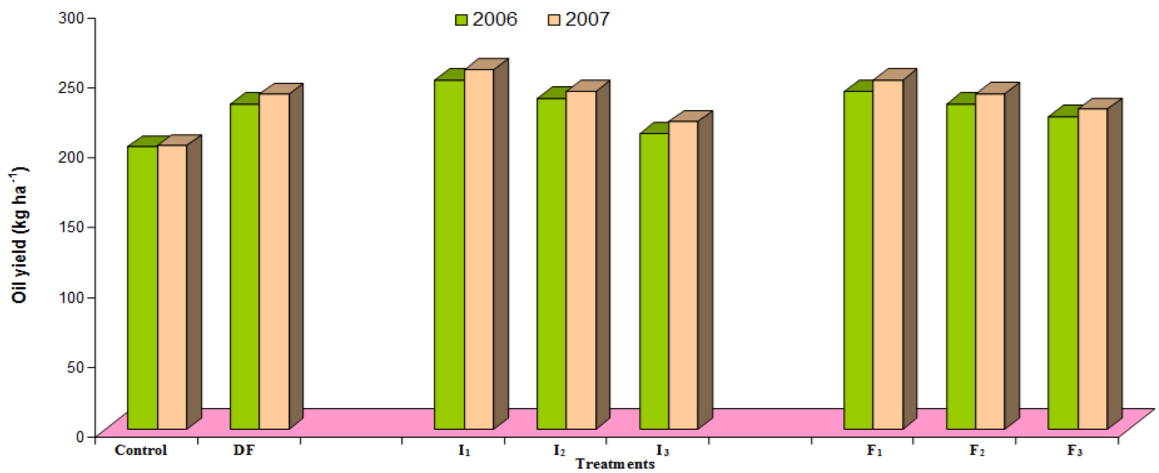

Figure 3. Effect of drip fertigation on oil yield.

Table 4. Interaction effect of irrigation and fertility on mean oil yield (2006 and 2007) of mint (kg ha^{-1}).

Irrigation	Fertilizer			
	F_1	F_2	F_3	I Mean
I_1	260	254	246	253
I_2	248	240	231	239
I_3	229	215	202	215
F mean	246	236	226	
		CD (0.05)= 5.10		

increased N uptake by 11.3% than that of 60% PE.

Maximum nitrogen (120 kg ha^{-1}) was taken up by plant that received 100% RD. Reduction of 25% fertilizer from 100% RD decreased the uptake by 2.6% and that of 50 by 7.7%. Application of 75% RD (F_2) increased the nitrogen uptake by 5.6% than 50% RD (F_3). High dose of N increased the total fresh herbage yield, which ultimately led to an increase in uptake of N. Saxena and Singh (1996) and Ram et al. (2006) reported more uptake of N under different water and N levels due to more vegetative growth.

Quality of essential oil

Surface irrigation with 100% RD (control) increased the limonene (4.53%) and menthyl acetate (6.56%) content (Table 5). Fertigation at 100% PE with 100% RD allowed the crop plants to synthesize more menthol (71.53%) than control. It also increased the terpinoids such as menthone (9.33%), isomenthone (3.41%) and neomenthol (2.14%) contents as compared to control. Anwar et al. (2010) reported that menthol content was not significantly affected due to NPK application but neo-menthol, menthyl acetate, isomenthone and menthone were considerably affected by fertilizer levels.

Soil moisture status

To assess soil moisture stress in plant through both drip and surface irrigation method, soil moisture content at 20, 40, 60 and 80 cm soil depth was monitored in drip fertigation at weekly interval, started from 2.2.2006 in first year and from 5.2.2007 in second year. The observations were continued up to 8.6.2006 and 10.6. 2007. In case of surface irrigation method, it was monitored before each irrigation.

The soil moisture status in surface layer was more as compared to deeper layer. Hence, the depletion of available soil moisture (ASM) in surface layer was less than deeper layer (Tables 6 and 7). The soil moisture in each soil depth under 100% PE was higher than 80% PE and 60% PE. Due to good amount of soil moisture, depletion of available soil moisture in 100% PE was minimum and ranged from 1.6 to 19.0%. Less amount of moisture was depleted from 0 to 20 cm soil depth when rainfall was received in the month of March, 2006. In case of 80% PE, the depletion of soil moisture ranged 4.35 to 20.8% in 0 to 20 cm soil depth. The depletion was

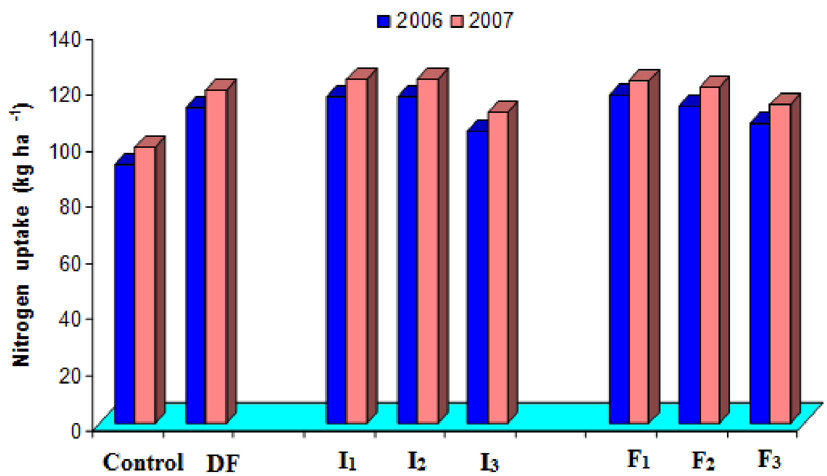

Figure 4. Effect of drip fertigation on nitrogen uptake.

Table 5. Effect of fertigation on quality of oil.

S/ No	Constituents (%)	Control	I_1F_1
1	Limonene	4.53	2.92
2	Menthone	5.10	9.33
3	Isomenthone	3.54	3.91
4	Menthyl acetate	6.56	1.41
5	Neomenthol	1.97	2.19
6	Menthol	67.15	71.53

higher in 20 to 40 cm soil depth than surface layer. In 40 to 60 and 60 to 80 cm soil layers, the depletion of ASM was quite low as crop water demand was fulfilled from 0 to 40 cm soil depth. The root density of this crop was also high in the surface layer. In case of 60% PE irrigation schedule actual soil moisture content in the surface layer was comparatively low than 80% PE and 100% PE as very low amount of irrigation water was provided each time to this treatment. .

In case of surface irrigation method, total 11 irrigations were given at 60 mm CPE in both the years. The actual soil moisture content determined at 20, 40, 60 and 80 cm soil depth before each irrigation ranged 13.7 to 15.8%, 19.1 to 20.3%, 21.0 to 22.9% and 22.8 to 24.2% (v/v) in respective depth during 2005-2006. The depletion of soil moisture in surface layer was 33.6 to 52.9%. The rate of soil moisture depletion decreased with soil depth and it was found that moisture depletion varied from 28.8 to 38.4% in 40 cm, 11.0 to 27.1% in 60 cm and 8.1 to 20.2% in 80 cm soil depth. Similar trend was observed during 2006-2007. The soil moisture content before each irrigation in 20 cm soil depth was 13.3 to 14.6% in 40 cm 18.2 to 19.8% in 60 cm 20.4 to 22.4% and in 80 cm 21.9 to 23.7%. The depletion of available soil moisture ranged from 44.6 to 56.6% in 20 cm, 32.8 to 44.0% in 40 cm, 15.2 to 32.2% in 60 cm and 12.4 to 27.9% in 80 cm soil depth. The total amount of rainfall received during the growth period in 2005-2006 was 196.0 mm and in 2007, 22.31 mm, which helped in reducing irrigation requirement of crop.

Consumptive use of water

The crop consumed more water in 2006-2007 than 2005-2006 (Figure 5). Application of water through furrow irrigation used more water than drip irrigation. The drip irrigation method saved 34.5 and 24% water in first and second year, respectively as compared to surface irrigation. It consumed on an average 654 mm of water as against 924 mm in surface irrigation method.

Drip irrigation at 100% PE required more water than the lower values of PE. Maximum amount of water (730 to 812 mm) was used at 100% PE followed by 80% PE (623 to 681 mm) and 60% PE (521 to 556 mm) during 2005-2006 and 2006-2007. The former (I_1) consumed 18.3 to 43.0% more water than I_2 and I_3. Irrigating the crop at 80% PE used 19.6 and 22.5% more water than that of 60% PE during 2005-2006 and 2006-2007, respectively.
Saxena and Singh (1996) reported that mint required 300 to 400 mm of water at IW/CPE ratio of 0.5 and 250 mm at IW/CPE 0.3 under shallow water table conditions (62 to 119 cm). Variation in fertility level affected the

Table 6. Effect of irrigation regimes on soil moisture depletion pattern (%) in mint (2006).

Date of observation	100% PE Soil depth (cm)				80% PE Soil depth (cm)				60% PE Soil depth (cm)			
	20	40	60	80	20	40	60	80	20	40	60	80
2.2.2006	8.9	1.5	3.4	16.7	10.7	14.4	0.8	14.2	15.3	16.0	0.8	10.7
9.2.2006	12.6	0.2	1.7	15.9	14.4	16.8	0.8	13.3	14.4	18.4	3.4	10.7
16.3.2006	19.0	10.4	5.1	14.4	20.8	12.8	7.6	11.6	20.8	15.2	9.3	9.9
23.3.2006	16.2	4.4	14.4	10.7	19.9	24.8	16.9	8.1	17.1	27.2	19.5	6.4
28.3.2006	3.0	1.2	5.9	13.3	1.2	19.2	9.3	10.7	1.6	21.6	11.9	8.1
1.4.2006	9.8	1.2	1.7	11.6	12.6	19.2	3.4	9.0	10.7	20.8	5.9	6.4
12.4.2006	19.0	5.3	5.1	7.3	21.7	26.4	7.6	4.7	19.9	29.6	9.3	2.1
19.4.2006	8.9	1.7	8.5	10.7	11.6	20.8	11.0	8.1	9.8	22.4	13.5	5.6
26.4.2006	14.4	11.2	9.3	1.3	19.0	36.8	11.0	1.3	15.3	38.4	13.5	3.0
3.5.2006	1.6	16.8	11.9	0.4	4.3	19.2	13.5	2.1	8.0	21.6	15.2	4.7
11.5.2006	2.5	12.8	11.0	4.7	5.2	15.2	13.5	1.3	7.1	16.8	15.2	1.3
18.5.2006	4.3	8.8	9.3	3.9	7.1	11.2	11.9	6.4	12.6	13.6	14.4	1.3
25.5.2006	6.1	10.4	4.2	5.6	8.9	12.8	6.8	3.0	11.6	15.2	8.5	0.4
1.6.2006	8.0	10.4	5.9	2.1	10.7	12.8	8.5	4.7	13.5	14.4	10.2	7.3
8.6.2006	8.9	12.0	6.8	3.9	11.6	14.4	9.3	6.4	15.3	16.8	11.9	9.0

Table 7. Effect of irrigation regimes on soil moisture depletion pattern (%) in mint (2007).

Date of observation	100% PE Soil depth (cm)				80% PE Soil depth (cm)				60% PE Soil depth			
	20	40	60	80	20	40	60	80	20	40	60	80
5.2. 2007	7.1	4.8	-5.1	-13.3	10.7	8.0	-0.8	-14.2	12.6	10.4	0.8	10.7
11.2.2007	8.9	4.0	0.8	-9.9	14.4	10.4	0.8	-13.3	14.4	13.6	3.4	10.7
18.3.2007	9.8	5.6	5.1	-9.9	15.3	12.8	7.6	-11.6	18.1	15.2	9.3	-9.9
25..3.2007	5.2	10.4	6.8	-8.1	16.2	16.8	11.0	-8.1	17.1	19.2	13.5	-6.4
30.3.2007	13.5	12.0	5.9	-13.3	16.2	19.2	9.3	-10.7	19.9	20.0	11.9	-8.1
3.4. 2007	9.8	17.6	8.5	-11.6	19.0	16.0	3.4	-9.0	16.2	20.8	5.9	-6.4
15.4.2007	19.0	16.8	5.1	-7.3	21.7	18.4	2.5	-4.7	19.9	21.6	9.3	-2.1
21.4.2007	8.9	18.4	8.5	-10.7	18.1	20.8	11.0	-8.1	17.1	22.4	13.5	1.3
28.4. 2007	14.4	19.2	9.3	-1.3	19.0	14.4	11.0	1.3	15.3	19.2	13.5	3.0
5.5.2007	10.7	16.8	11.9	-0.4	14.4	19.2	13.5	2.1	20.8	21.6	15.2	4.7
13.5.2007	11.6	12.8	11.0	-4.7	16.2	15.2	13.5	-1.3	21.7	16.8	13.5	1.3
20.5.2007	13.5	8.8	9.3	-3.9	16.2	11.2	11.9	6.4	12.6	13.6	11.9	1.3

Table 7. Contd.

27.5.07	11.6	10.4	4.2	0.4	18.1	12.8	6.8	-3.0	20.8	15.2	8.5	2.1
3.5.07	12.6	10.4	5.9	2.1	19.9	11.2	8.5	4.7	22.6	14.4	10.2	7.3
10..6.07	14.4	12.0	6.8	3.9	20.8	14.4	9.3	6.4	24.5	16.8	11.9	9.0

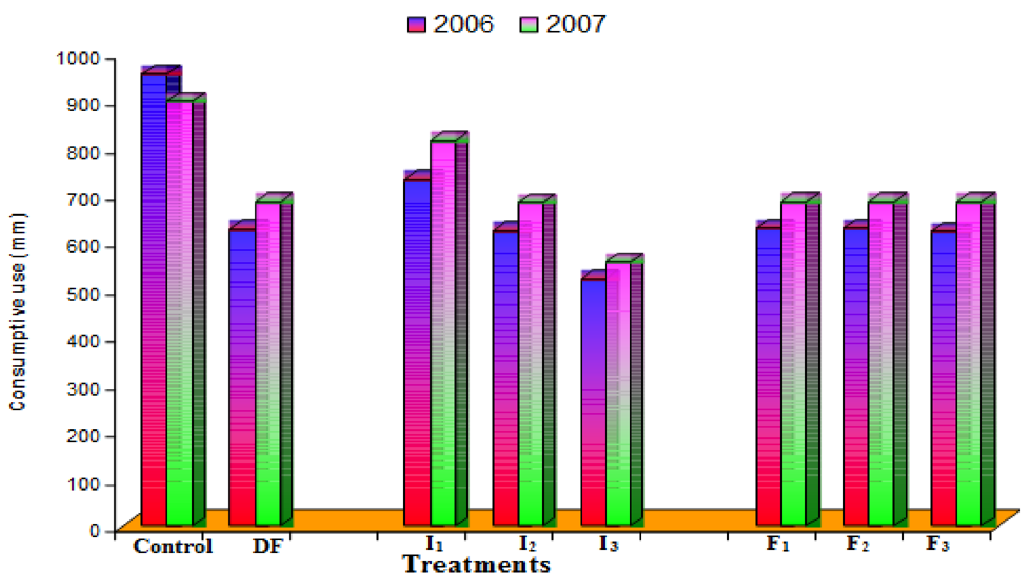

Figure 5. Effect of drip fertigation on consumptive use.

consumptive use only in 2006. However, maximum amount of 655 mm was used by the plants receiving 100% RD, which was equal to that of 75% RD and at par with 50% RD (652 mm). The interaction effect was not significant.

Water use efficiency

Irrigation method affected the water use efficiency (WUE) in both the years (Figure 6). Irrigating the crop through drip system increased WUE by 65.3% as compared to surface irrigation (control). The average WUE was 0.362 kg oil ha-mm^{-1} in case of the former and 0.219 kg ha-mm^{-1} in case of the latter. Kannan (2006) reported increased water use efficiency (20 to 50%) due to drip irrigation compared to surface irrigation in case of medicinal coleus crop. Similar findings were reported by Imtiyaz et al. (2000). Water use efficiency decreased with an increase in irrigation water application. Maximum WUE of 0.40 kg oil ha-mm^{-1} water was recorded with 60% PE (I_3) followed by 80% PE (0.368 kg ha-mm^{-1}) and 100 % PE (0.329 kg ha-mm^{-1}). Application of more water decreased WUE. Irrigating the crop at 80% PE increased the WUE by 11.9% as compared to 100% PE.

Maximum WUE (0.375 kg ha- mm^{-1}) was recorded with 100% RD (F_1) which decreased with

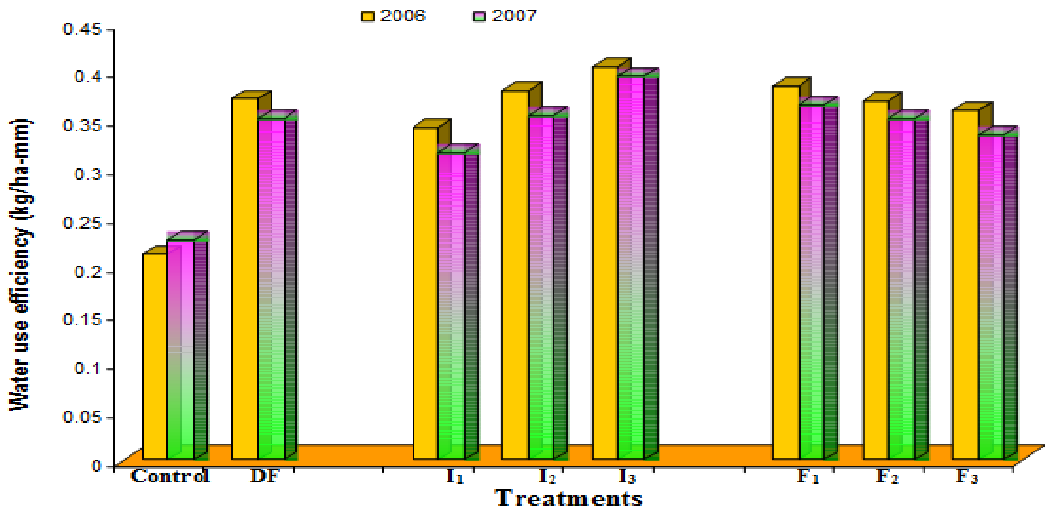

Figure 6. Effect of drip fertigation on water use efficiency.

reduction of fertilizer dose. It decreased by 3.7 and 7.2% due to reduction of 25 and 50% fertilizer from 100% RD, respectively. Drip irrigation increased the water productivity by 69%. The productivity decreased with increased in irrigation level but it increased with increased in fertility level. Kumar and Sood (2011) reported similar findings. Application of 75% RD had higher WUE (3.7%) than 50% RD. It was due to high herbage and oil yield that required more water for absorption of nutrients and trapping the CO_2 for photosynthesis.

Conclusion

Japanese mint could be grown with drip irrigation at 100% PE with 100% recommended dose of fertilizer to give the highest oil yield of 260 kg ha^{-1}. It required 777 mm of water and saved 29% of water. It absorbed 120 kg N ha^{-1} and produced high quality oil.

Conflict of Interest

The authors have not declared any conflicts of interest.

REFERENCES

Anwar M, Chand S, Patra DD (2010). Effect of graded levels of NPK on fresh herb yield, oil yield and oil composition of six cultivars of menthol mint (*Mentha arvensis* Linn.). Indian J. Natural Prod. Resour. 1:74-79.

Fasina AS, Awe GO, Aruleba JO (2008). Irrigation suitability evaluation and crop yield – An example with *Amaranthus cruentus* in Southwestern Nigeria. Afr. J. Plant Sci. 2(7):061-066,

Imtiyaz M, Mgadla NP, Chepete B, Manase SK (2000). Response of six vegetable crops to irrigation schedules. Agric. Water Manage. 45(3):331-342.

Jackson ML (1967). Soil Chemical Analysis, Prentice Hall of India Ltd., New Delhi.

Jenson MC, Middleton JE, Pruitt WO (1961). Scheduling irrigation from pan evaporation. Circular 386, Washington Agricultural Experiment Station.

Kannan K (2006). Drip fertigation in medicinal coleus (*Coleus forskohlii*). Unpublished Ph.D thesis, Agricultural College and Research Institute, Tamilnadu Agricultural University, Madurai, Tamilnadu.

Kumar V, Sood M (2011). Effect of transplanting time, spacing and fertilizers on herbage and oil yield of *Mentha piperita* L. Int. J. Farm Sci. 1(2):68-74.

Patra DD, Anwar M, Chand Sukhmal (2000). Integrated nutrient management and waste recycling for restoring soil fertility and productivity in Japanese mint and mustard sequence in Uttar Pradesh, India. Agric, Ecosyst. Environ. 80(3):267-275.

Pruitt WO (1966). Empirical methods of estimating evapotranspiration using primarily evaporation pans. Proc. Conf. on evapotranspiration and role in water resources management. American Society of Agricultural Engineers, St. Joseph.

Rahman M, Islam A, Osman KT (2003). Effect of N, P and K fertilizers on growth and herb and oil yield of *Mentha arvensis* in Bangladesh. J. Med. Arom. Plant Sci. 25:661-667.

Ram D, Ram M, Singh R (2006). Optimization of water and nitrogen application to menthol mint (*Mentha arvensis* L.) through sugarcane trash mulch in a sandy loam soil of semi-arid subtropical climate. Bioresour. Technol. 97(7):886-893.

Saxena A, Singh JN (1996). Yield and nitrogen uptake of Japanese mint (Mentha arvensis) under various moisture regimes, mulch application and nitrogen fertilization, J. Med. Arom. Plants Sci. 18:477–480.

Shormin TM, Akhter hossain khan, Alamgir M (2009). Response of different levels of nitrogen fertilizer and water stress on the growth and yield of Japanese mint (*Mentha arvensis*). Bangl. J. Sci. Ind. Res. 44(1):137-145.

Singh M, Sharma S, Ramesh S (2002). Herbage, oil yield and oil quality of patchouli (*Pongestemon cablin*) influenced by irrigation, organic mulch and nitrogen application in semi-arid tropical climate. Ind. Crops Prod. 16:101–107.

Subbiah BV, Asija GL (1956). A rapid procedure for the estimation of available nitrogen in soils, Curr. Sci. 25:259