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Research Paper

Water balance and water productivity of Japanese mint (*Mentha arvensis*) as affected by irrigation and mulching

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ABSTRACT

A field experiment was conducted during the spring season (March to July) of 2014 and 2015 at the Punjab Agricultural University, Ludhiana, in sandy-loam soil, to study the effect of irrigation and mulching regimes on field water balance and water productivity of Japanese mint (*Mentha arvensis* L.). Mean seasonal soil-moisture storage and transpiration were significantly more in flood irrigation and drip irrigation at 120% of evapotranspiration than drip irrigation at 100% and 80% of evapotranspiration during both years of the experiment. Mulching @ 6 t/ha and 3 t/ha resulted in an increase of 8.50% and 7.19% mean seasonal transpiration and a decrease of 33.97% and 22.86% mean seasonal evaporation as compared to the treatment where no mulch was applied. Water productivity (l/ha-mm) was significantly higher in flood irrigation (0.36) and drip irrigation at 120% of evapotranspiration (0.38) as compared to drip irrigation at 100% (0.32) and drip irrigation at 80% of evapotranspiration (0.32). Compared to flood irrigation, drip irrigation at 80%, 100% and 120% of evapotranspiration saved about 60%, 52% and 44% of irrigation water respectively. The highest net returns (₹73,140/ha) and benefit: cost ratio (2.17) were recorded in drip irrigation at 120% of evapotranspiration compared to other irrigation regimes. Mulching @ 6 t/ha also recorded the highest net returns and benefit: cost ratio (₹64,580/ha and 2.06).

Key words: Benefit: cost ratio, Drip irrigation, Evapotranspiration, Herb yield, Leaf-area index, Mint oil yield

Japanese mint, also known as corn mint, or menthol mint, is one of the commercially cultivated and important essential oil-bearing industrial crops in northern semi-arid and sub-tropical regions of India (Singh and Saini, 2008). It is a potential source of natural menthol and other ingredients like mint terpenes, menthone, isomenthone, menthyl acetate etc. Mentha plays a very significant role in the agricultural economy. The crop is economically significant not only for its contribution to the livelihood of thousands of farmers but also for its highly diversified industrial use in confectionary, cosmetics and pharmaceutical sectors. India is one of the largest producers and exporter of mentha oil and its derivatives. In India, the production of mentha oil was about 38,000 metric tonnes, covering an area of around 0.30 million ha, with an average productivity of around 120 kg/ha during 2014 (MCX, 2015). The global production of mentha oil stands at around 48,000 tonnes (MCX, 2015). Japanese mint occupies predominant position (about 15,000 ha) and contributes more than 80% of total production of essential oil in Punjab.

Irrigation is the key input for securing optimum productivity and quality of the crop. By providing optimum irrigation through drip lines in exact quantity, the yield and water productivity of this medicinal crop could be increased to sustain the ever-increasing demand (Behera *et al*., 2014). During the summer months, irrigation water productivity can be enhanced with straw mulching by curtailing unproductive water loss through evaporation.

Mulching also plays multipurpose role through smothering of the weeds by cutting light penetration, conserving moisture, improving the microorganism population and nutrient dynamics which favourably affects the crop yield (Brar *et al*., 2014). In Japanese mint, mulching with paddy straw is known to conserve soil moisture and reduce soil temperature under arid and semi-arid conditions which enhances the herbage and oil yield (Khera *et al*., 1986). There is lack of information on effect of drip irrigation and mulching on field water balance. Thus, an experiment was conducted to study the effects of irrigation and mulching on water balance components, water use and yield of Japanese mint.

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MATERIALS AND METHODS

The experiment was conducted at research farm, Department of Soil and Water Engineering, Punjab Agricultural University, Ludhiana (30°56' N, 75°52' E, 247 m above mean sea-level), during the spring seasons (March to July) of 2014 and 2015. The soil was sandy loam, with *p*H 8.2 and medium in available organic carbon, nitrogen, phosphorus and potassium. The bulk density of the profile ranged from 1.71 to 1.80 Mg/m^3. The soil retained 264 and 98 mm water at field capacity and wilting point, in 1.2 m profile respectively. The crop received 100.9 and 73.3 mm rainfall during 2014 and 2015, respectively. The treatments comprised 4 irrigation regimes, viz. flood irrigation at 1.2 irrigation water: cumulative pan evaporation (IW: CPE) ratios ($IWF_{1.2}$), drip irrigation at 100% ($IWD_{100\%}$), 120% ($IWD_{120\%}$) and 80% ($IWD_{80\%}$) of evapotranspiration, in the main plot and 3 rates of mulching i.e. 0 (M_0), 3 (M_1) and 6 (M_2) t/ha in the sub-plot. All plots received 2 common irrigations of 5 cm (immediately after transplanting and 7 days after transplanting). The flood irrigation was applied on the basis of cumulative pan evaporation and drip irrigation that of evapotranspiration calculated with Cropwat 8.0 model by multiplying respective crop coefficients (Allen *et al*., 1998). The paddy straw was spread @ 3 and 6 t/ha between the rows after transplanting of Japanese mint. The treatments were replicated thrice in a split-plot design. In case of flood irrigation, water was measured using water meter and that of drip irrigation from dripper discharge. After pre-sowing irrigation, the field was prepared by conventional tillage. Japanese mint crop (var. Kosi) was transplanted in 45 cm apart rows on 28 March 2014 and 30 March 2015. Nitrogen was applied @ 60 kg N/ha as urea in 2 equal splits- at time transplanting and after 45 days thereafter. Full dose of P (16 kg/ha) was applied at the time of transplanting through diammonium phosphate. Soil water content was determined gravimetrically in 0–15, 15–30, 30–60, 60–90, 90–120 cm depths and multiplied with corresponding soil layer bulk density to get volumetric moisture content, which was further multiplied with depth of layer to calculate soil water storage. Actual crop evapotranspiration (ET_a) was estimated using the soil water balance equation as:

$$ET_a = I + P - R - D \pm \Delta SW$$

where I is the irrigation water (mm), P is the precipitation (mm), R is the surface runoff (mm), D is the deep drainage (mm) or mean seasonal drainage (mm) and ÄSW is the change in soil profile moisture storage (mm). Runoff was absent as sufficient dikes were provided. Deep drainage was zero when soil profile moisture storage was less than field capacity. When the soil-moisture storage exceeded the field capacity storage of soil profile (0–120 cm) after irrigation or rainfall, then deep drainage was calculated as difference between the field capacity storage of soil profile (0–120 cm) and soil moisture storage plus irrigation/ rainfall. The actual evapotranspiration (ET_a) was partitioned into soil evaporation (E_s) and plant transpiration (T_p) as:

$$E_s = ET_a \times e^{-\alpha\, LAI}$$

$$T_p = ET_a - E_s$$

where α is the extinction coefficient of radiation, the value of which was set as 0.56 (locally calibrated) and LAI is the leaf-area index (measured using SunScan canopy analyzer of Delta T Devices) at different stages. LAI during crop growth and senescence was estimated by following equation:

$$LAI\ (t) = at^b$$

where 'a' and 'b' are the (curve fitted) constants given in Table 3 and 't' is days after transplanting.

The crop was harvested when lower leaf started falling on 7 July in 2014 and 9 July in 2015 with sickle to determine herb and mint oil yield. Essential mint oil content in 500 g of fresh herb from each plot was extracted with Clevenger's apparatus at harvesting of crop and mint oil percentage was calculated on v/w basis on fresh herb weight. Real water productivity of crop was calculated by dividing mint oil yield (Y) with total seasonal transpiration. The statistical significance of the treatment effects on different parameters was inferred from least significant difference (LSD) at 5 % level of significance using analysis of variance for split-plot design. Net returns were calculated as difference of gross returns and total cost. Benefit: cost ratio was calculated by dividing the net returns with variable cost calculated as per PAU package and practices for cultivation of mentha crop.

RESULTS AND DISCUSSION

Field water balance components

Rainfall and irrigation: Rainfall received up to 60 days after transplanting was 51.3 mm. Rainfall received from 60 to 100 days after transplanting was 33.85 mm. During the active growth period of Japanese mint (40 to 80 days after transplanting) 35.3% rainfall was received. Compared to flood irrigation, drip irrigation at 80, 100 and 120% of evapotranspiration saved about 60, 52 and 44% of irrigation water, respectively.

Seasonal transpiration: Seasonal transpiration was significantly more under drip irrigation at 120% of evapotranspiration ($IWD_{120\%}$) and flood irrigation ($IWF_{1.2}$) than drip irrigation at 100% ($IWD_{100\%}$) and 80% of evapotranspiration ($IWD_{80\%}$) during both the years. The mean seasonal transpiration was 390.9, 351.2, 399.3 and 299 mm under $IWF_{1.2}$, $IWD_{100\%}$, $IWD_{120\%}$ and $IWD_{80\%}$ respectively

(Table 1). It was significantly higher under mulch than that of un-mulched treatments. Compared to no-mulch treatment, seasonal transpiration was 7.19 and 8.50% higher under mulching @ 3 t/ha (M_2) and mulching @ 6 t/ha (M_3) respectively. Higher mean seasonal evapotranspiration under $IWD_{120\%}$ and M_2 may be because of increased soil moisture storage at root zone of crop (Singh *et al*., 2015).

Seasonal soil evaporation: A significant reduction in seasonal soil evaporation was observed with mulching. Mulching @ 3 t/ha and 6 t/ha reduced the seasonal soil evaporation by 22.86 and 33.97% as compared to no-mulch treatment (Table 1). Seasonal soil evaporation was found non-significant under irrigation regimes. Mulch reduces soil-moisture evaporation by acting as a barrier between soil and environment. Reduction in soil-moisture evaporation with mulching was also observed by Li *et al.* (2005).

Seasonal soil water storage: Soil-moisture storage represents the difference in initial (at transplanting) and final (at harvesting) soil-moisture storage (Table 1). Pooled analysis showed the net gain of 4.6 mm in soil-moisture storage under $IWF_{1.2}$, while the other treatments exhibited a net loss. The difference in soil-moisture storage in different irrigation level was due to application of variable amount of irrigation water (Singh *et al*., 2015). There was no significant difference in soil-moisture storage between mulching and no mulching.

Seasonal drainage: Seasonal drainage was significantly higher under flood irrigation ($IWF_{1.2}$) as compared to drip irrigation at 120% ($IWD_{120\%}$), 100% ($IWD_{100\%}$) and 80% ($IWD_{80\%}$) of evapotranspiration due to application of more amount of irrigation water during both the years. Pooled analysis showed significantly highest mean seasonal drainage under $IWF_{1.2}$ (383.4 mm), followed by $IWD_{120\%}$ (47.2 mm), $IWD_{100\%}$ (31.1 mm) and the lowest under $IWD_{80\%}$ (28.9 mm) (Table 1). Differences were not significant between seasonal drainage of mulch treatments.

Leaf-area index

The coefficients for the calculation of leaf-area index (LAI) equation are given in Table 2. A good agreement (R^2 = 0.99) was observed between the fitted and observed val-

Table 2. Leaf-area index estimation coefficients of the equation LAI (t) = at^b

Treatment	A	B	R^2
	Mean of leaf-area index		
Irrigation			
$IWF_{1.2}$	0.0736	0.891	0.99
$IWD_{120\%}$	0.0839	0.870	0.99
$IWD_{100\%}$	0.0793	0.831	0.99
$IWD_{80\%}$	0.0837	0.790	0.99
Mulching			
M_0	0.0785	0.847	0.99
M_1	0.0836	0.849	0.99
M_2	0.0885	0.817	0.99

$IWF_{1.2}$, Flood irrigation at irrigation water/cumulative open pan evaporation ratio 1.2; $IWD_{100\%}$, drip irrigation at 100% of evapotranspiration; $IWD_{120\%}$, drip irrigation at 120% of evapotranspiration; $IWD_{80\%}$, drip irrigation at 80% of evapotranspiration; M_0, no mulch, M_1, mulch @ 3 t/ha, M_2, mulch @ 6 t/ha

Table 1. Effect of different irrigation and mulching treatments on mean seasonal transpiration, soil-evaporation, soil moisture storage and drainage of Japanese mint (pooled data of 2 years)

Treatment	Mean seasonal transpiration (mm)	Mean seasonal evaporation (mm)	Mean seasonal change in soil-water storage (mm)	Mean seasonal drainage (mm)
Irrigation				
$IWF_{1.2}$	390.9	158.5	4.6	383.4
$IWD_{120\%}$	399.3	147.4	–31.0	47.2
$IWD_{100\%}$	351.2	167.1	–48.4	31.1
$IWD_{80\%}$	299.0	175.2	–73.9	28.9
SEm±	6.87	1.49	14.3	6.17
CD (P=0.05)	20.6	NS	42.8	18.5
Mulching				
M_0	342.2	199.9	–51.8	109.9
M_1	366.8	154.2	–45.2	124.2
M_2	371.3	132.0	–37.2	134.1
SEm±	5.8	5.8	1.41	2.34
CD (P=0.05)	17.4	17.4	NS	NS

$IWF_{1.2}$, Flood irrigation at irrigation water/cumulative open pan evaporation ratio 1.2; $IWD_{100\%}$, drip irrigation at 100% of evapotranspiration; $IWD_{120\%}$, drip irrigation at 120% of evapotranspiration; $IWD_{80\%}$, drip irrigation at 80% of evapotranspiration; M_0, no mulch, M_1, mulch @ 3 t/ha, M_2, mulch @ 6 t/ha ues. Periodic leaf- area index of Japanese mint is presented in Table 3. Significant increase in LAI was observed under irrigation from 60 to 100 days after transplanting during both the years. The $IWF_{1.2}$ and $IWD_{120\%}$ maintained higher LAI throughout the cropping season of both the years due to development of extensive root-system, which created a conductive environment to absorb more water and nutrients for better growth (Ram *et al*., 1995). The leaf-area index increased significantly by mulching. It was higher under M_1 and M_2 than M_0. Mulching is helpful in conserving better soil moisture which results in absorption of more water and nutrients for production of higher vegetative biomass (Khera *et al*., 1986; Ram *et al*., 2006).

Table 3. Effect of irrigation and mulching on periodic leaf-area index of Japanese mint (pooled data of 2 years)

Treatment	Days after transplanting			
	40	60	80	100
Irrigation				
$IWF_{1.2}$	1.76	2.87	3.78	4.65
$IWD_{120\%}$	1.91	3.01	3.85	4.74
$IWD_{100\%}$	1.63	2.37	3.00	3.81
$IWD_{80\%}$	1.46	2.04	2.78	3.34
SEm±	0.02	0.10	0.09	0.18
CD (P=0.05)	NS	0.30	0.27	0.55
Mulching				
M_0	1.35	2.14	2.81	3.33
M_1	1.75	2.70	3.52	4.34
M_2	1.98	2.92	3.79	4.74
SEm±	0.08	0.10	0.08	0.13
CD (P=0.05)	0.23	0.30	0.25	0.40

$IWF_{1.2}$, Flood irrigation at irrigation water/cumulative open pan evaporation ratio 1.2; $IWD_{100\%}$, drip irrigation at 100% of evapotranspiration; $IWD_{120\%}$, drip irrigation at 120% of evapotranspiration; $IWD_{80\%}$, drip irrigation at 80% of evapotranspiration; M_0, no mulch, M_1, mulch @ 3 t/ha, M_2, mulch @ 6 t/ha

Herb and mint oil yield

Herb and mint oil yield was more in $IWD_{120\%}$ and $IWF_{1.2}$ than $IWD_{100\%}$ and $IWD_{80\%}$ because of higher availability of moisture (Table 4). The mean herb yield was 20.97, 17.56, 22.04 and 14.90 t/ha and mint oil yield was 140.4, 110.4, 150.9 and 94.0 l/ha under $IWF_{1.2}$, $IWD_{100\%}$, $IWD_{120\%}$ and $IWD_{80\%}$ respectively. Mulching @ 3 t/ha and 6 t/ha significantly increased the mint oil yield by 21.17% and 35.20% as compared to no-mulch treatment (Table 4). Higher yield under mulching is attributed to conservation of moisture due to less evaporation which results in the better establishment of the crop (Khera *et al*., 1986; Ram *et al*., 2006).

Water productivity

Water productivity was significantly affected by irrigation and mulching treatments (Table 5). Water productivity under $IWD_{120\%}$ was 5.6% higher than that under $IWF_{1.2}$ and 22.6% higher than $IWD_{100\%}$ and $IWD_{80\%}$. Water productivity increased with an increase in transpiration, which is directly related to crop yield. The maximum water productivity was observed under mulching as compared to no-mulching. Water productivity of M_1 and M_2 was 13.3% and 26.7% higher than M_0. Higher water productivity under higher irrigation regimes and mulching was owing to

Table 4. Effect of irrigation and mulching on pooled mean fresh herb yield, mint oil yield, net returns and benefit: cost ratio of Japanese mint (pooled data of 2 years)

Treatment	Mean fresh herb yield (t/ha)	Mean mint oil yield (l/ha)	Net returns (× 10^3₹/ha)	Benefit: cost ratio
Irrigation				
$IWF_{1.2}$	20.97	140.44	64.91	2.06
$IWD_{120\%}$	22.04	150.87	73.14	2.17
$IWD_{100\%}$	17.56	110.43	36.79	1.59
$IWD_{80\%}$	14.90	93.98	22.04	1.35
SEm±	1.20	7.87	–	–
CD (P=0.05)	3.60	23.6	–	–
Mulching				
M_0	17.01	103.97	31.64	1.51
M_1	19.56	125.98	51.44	1.83
M_2	20.48	140.57	64.58	2.04
SEm±	0.51	4.53	–	–
CD (P=0.05)	1.52	13.6	–	–

$IWF_{1.2}$, Flood irrigation at irrigation water/cumulative open pan evaporation ratio 1.2; $IWD_{100\%}$, drip irrigation at 100% of evapotranspiration; $IWD_{120\%}$, drip irrigation at 120% of evapotranspiration; $IWD_{80\%}$, drip irrigation at 80% of evapotranspiration; M_0, no mulch, M_1, mulch @ 3 t/ha, M_2, mulch @ 6 t/ha

Table 5. Effect of irrigation and mulching treatments on water productivity of Japanese mint (pooled data of 2 years)

Treatment	Irrigation (mm)	Rainfall (mm)	Total water (mm)	Water productivity (l/ha-mm)
Irrigation				
$IWF_{1.2}$	850.25	87.1	937.35	0.36
$IWD_{120\%}$	475.65	87.1	562.75	0.38
$IWD_{100\%}$	408.90	87.1	496.00	0.32
$IWD_{80\%}$	342.05	87.1	429.15	0.32
SEm±	–	–	–	0.01
CD (P=0.05)	–	–	–	0.03
Mulching				
M_0	512.95	87.1	600.05	0.31
M_1	512.95	87.1	600.05	0.35
M_2	512.95	87.1	600.05	0.39
SEm±	–	–	–	0.01
CD (P=0.05)	–	–	–	0.02

$IWF_{1.2}$, Flood irrigation at irrigation water/cumulative open pan evaporation ratio 1.2; $IWD_{100\%}$, drip irrigation at 100% of evapotranspiration; $IWD_{120\%}$, drip irrigation at 120% of evapotranspiration; $IWD_{80\%}$, drip irrigation at 80% of evapotranspiration; M_0, no mulch, M_1, mulch @ 3 t/ha, M_2, mulch @ 6 t/ha

higher availability of moisture, which resulted in more transpiration with better development of crop (Behera *et al*., 2015).

Economics

The highest net returns (₹73,140/ha) and benefit: cost ratio (2.17) of Japanese mint were recorded under $IWD_{120\%}$, followed by $IWF_{1.2}$ and $IWD_{100\%}$, and the lowest under $IWD_{80\%}$ (Table 4). Reduction in frequency of irrigation reduced the benefit: cost ratio due to low herbage and oil yield. Behera *et al*. (2013) also reported higher benefit: cost ratio under drip irrigation as compared to flood irrigation. Irrespective of irrigation regimes, M_3 resulted in the highest net returns (₹64,580/ha) and benefit: cost ratio (2.04), followed by M_2 and M_0 owing to more availability of soil moisture throughout the growing season (Singh *et al*., 2015) which have enhanced mint oil yield.

It was concluded that mulching @ 6 t/ha maintained adequate soil moisture through reducing soil evaporation which in turn helped in increasing leaf-area index, fresh herb yield and mint oil yield. Compared to flood irrigation, drip irrigation at 120% of evapotranspiration saved about 44% of irrigation water and resulted in 7.43% higher mint oil yield. Mint herb and oil yields were reduced under drip irrigation at 80% of evapotranspiration due to moisture stress.

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