



Productivity of menthol mint (*Mentha arvensis*) and wheat (*Triticum aestivum*) as relay and sequential cropping system under different irrigation scheduling

GURVINDER SINGH¹, TANAY SAHA², SUBHASH CHANDRA³, AMIT BHATNAGAR⁴ AND SAMARTH⁵

Govind Ballabh Pant University of Agriculture and Technology, Pantnagar, Uttarakhand 263 145

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ABSTRACT

A field experiment was conducted at Govind Ballabh Pant University of Agriculture and Technology, Pantnagar, Uttarakhand, India during 2014–15 and 2015–16 to assess the impact of irrigation schedules (IW: CPE 0.6, 0.8, 1.0 and 1.2) on mentha (*Mentha arvensis* L.) growth, productivity, profitability and irrigation water productivity under variable cropping systems (sole mint, wheat + mentha relay cropping and wheat-transplanted mint). Sole mint recorded the maximum values of all the growth parameters, with an exception in leaf: stem. It also produced the maximum fresh herbage (22,170 kg/ha) as well as the oil yields (196.6 kg/ha). The maximum oil content (0.96%) was obtained with transplanted mint crop. Relay cropping of mint with wheat in 2:1 row pattern recorded the maximum mentha oil equivalent yield (MOEY), net return (143.5×10^3 ₹/ha) and benefit: cost ratio (2.08). Irrigation water productivity was found maximum (5.35 kg oil/ha-cm) with sole planting of mentha. Irrigating the crop at 1.2 irrigation water (IW) to cumulative pan evaporation (CPE) ratio registered significantly highest plant height, leaf area index, lateral spread, dry matter accumulation, fresh herbage and oil yields. Oil content and leaf: stem expressed a declining trend with increasing the irrigation frequency under wider IW: CPE. Irrigation at IW: CPE 1.2 gave the maximum MOEY (233.4 kg/ha), net return (134.4×10^3 ₹/ha) and benefit: cost ratio (1.93). However, the maximum irrigation water productivity was realized at 0.6 IW: CPE. Wheat + mentha relay cropping (2:1) at IW: CPE 1.2 was better option than others with respect to MOEY and economics.

Key words : Economics, IW: CPE, Menthol mint, Relay cropping, Transplanted mint, Wheat

Menthol mint (*Mentha arvensis* L.), a potent source of menthol oil (75–85%) occupies a prime position in Indian agriculture due to its extensive use in pharmaceutical, agro-chemicals and flavoring industries (Tassou *et al.*, 2004). India is a leading producer of mint oil, contributing approximately 85% of the total world production (Anwar *et al.*, 2010). In India, it is cultivated on 0.3 million ha area with a production of 32,000 tonnes menthol oil. Menthol mint cultivation is mainly confined to central parts of Indo-Gangetic Plains in the states of Punjab, Haryana, Uttarakhand, Uttar Pradesh and Bihar, with maximum area in Uttar Pradesh (Khanuja *et al.*, 2005). These areas are pre-dominated by rice-wheat cropping system and facing the typical monoculture sickness problems. Inclusion of mint crop in traditional wheat crop rotation is a viable concept to overcome such problems. It not only favors the

economics but also pave way for agro-based enterprises in the region. After harvesting of *kharif* paddy, in *rabi* season adoption of either wheat (November-April) or mint (February-June) does not improve the system productivity up to a desired level as the field remains fallow for a longer period and resources are not fully utilized. As the cropping system is highly location specific, it urges for evaluation of these two crops in a system mode to ensure efficient use of the available growing period. Relay planting of mint in wheat and mint transplanting after harvesting of wheat are the feasible options for system intensification. Relay cropping of mentha during late ontogeny of wheat owing to varying rooting pattern can exploit moisture from relatively larger volume of soil, hence, affects water use and water productivity. Further, intercropping of mint with wheat could be more remunerative than their sole cropping. Rathi *et al.* (2014) also found wheat + menthol mint intercropping system more remunerative as compared to sole cropping of wheat crop.

The active growth period of mentha coincides with hot summer months when the soil moisture remains inadequate coupled with high soil and air temperature and high

¹Corresponding author Email: guruagronomy@gmail.com

^{1,4}JRO, Agronomy, ²Ex-PG Student, Agronomy, ³Chief Scientist, Agronomy, ⁵Ph.D Student, Agronomy, Govind Ballabh Pant University of Agriculture and Technology, Pantnagar, Uttarakhand 263 145

evapo-transpiration (ET). Moreover, being a shallow rooted crop, its water demand further increase under these conditions. Both excess as well as sub-optimal soil moisture conditions decrease the growth, herbage and oil yields (Shormin *et al.*, 2009). Hence, the maintenance of adequate soil moisture is essential through proper monitoring and scheduling of irrigation. The scheduling of irrigation on the basis of climatological approach (IW: CPE) has been considered more scientific and practical as it takes care of both rainfall and evaporation. Water requirement of mint varies under different cropping systems because of variable micro-climatic situations across the growing period. According to Zhang *et al.* (2012), intercropping systems could promote the full use of cropland water by plant roots, increase the water storage in root zone, reduce the inter-row evaporation and control excessive transpiration, and create a special micro-climate, advantageous to the plant growth and development. In transplanted mint, the water demand increases due to its exposure to high temperature and lower relative humidity conditions. Thus, under various cropping systems the mint crop reflects a variation in water use; therefore, optimization of irrigation schedule is necessary under variable mentha-based cropping systems to get higher crop and water productivity.

As the research work on this aspect is very scanty, hence, the current study was designed to determine the effect of cropping systems and irrigation schedules on growth, productivity, economic viability and irrigation water productivity of mentha.

MATERIALS AND METHODS

The field experiment was carried out at G.B. Pant University of Agriculture and Technology, Pantnagar (29° N latitude, 79.5° E longitude and 243.8 m above mean sea-

level), Uttarakhand, India during 2014-15 and 2015-16. The experimental site is located in the *Tarai* (young alluvial soils with shallow to medium water table) belt of Uttarakhand. The area is characterized by a sub-humid and sub-tropical climate. Soil of the experimental site was sandy loam in texture, low in available nitrogen (230 kg/ha), medium in available phosphorus (21.8 kg/ha) and potassium (213 kg/ha) and high in organic carbon (0.87%) with neutral in reaction (pH 7.2). The bulk density of top 0-15 cm soil was 1.46 Mg/m³. The soil moisture content at field capacity and permanent wilting point was 20.0 and 8.0%, respectively.

The experiment comprised of 12 treatment combinations with three cropping systems (timely planted sole menthol mint, wheat + mint relay cropping system and wheat-late transplanted mint sequential cropping system) and four irrigation schedules in mint (IW:CPE 0.6, 0.8, 1.0 and 1.2) was laid out in Factorial Randomized Block Design with three replications. ‘PBW 550’ and ‘CIM kranti’ varieties of wheat and mint, respectively were used for the experimental study. For timely planted sole mint crop, the disease free healthy suckers (4-5 cm long) were planted in end to end fashion at a depth of 4 to 5 cm in furrows spaced 40 cm apart in the first week of February. In relay cropping system of mint with wheat the wheat was sown in mid November in skipped-row planting pattern i.e. after every two rows of wheat (20 cm apart), one row was skipped which was later used for mint planting in February. In wheat-transplanted mint sequential system, after wheat harvest (mid April), mint seedlings were transplanted at a spacing of 40 cm x 25 cm. The gross area for every plot was 12.8 m². Wheat crop was fertilized uniformly with 120 kg N, 26.2 kg P and 33.3 kg K per hectare through NPK fertilizer (12:32:16), urea (46% N) and

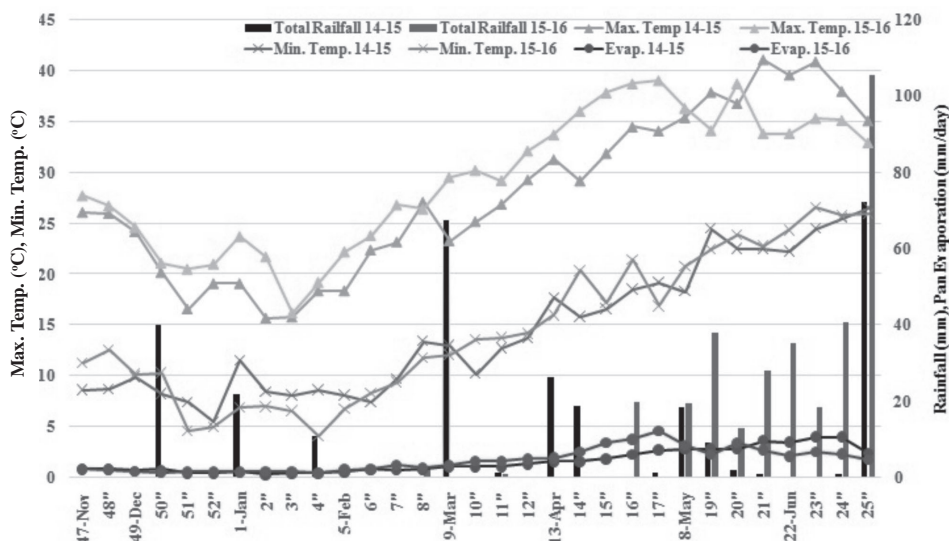


Fig. 1. Weather condition during crop period of 2014-15 and 2015-16

MOP (60% K₂O). For fertilization in timely planted sole mint, 100 kg N, 26.2 kg P and 33.3 kg K per hectare were applied. Half of nitrogen and full dose of phosphorus and potassium were applied as basal and the remaining nitrogen through urea was top dressed in two equal splits at 45 and 65 days after sowing (DAS). For relay and transplanted mint, fertilization was done after the harvesting of wheat crop. Half of nitrogen and total amount of phosphorus and potassium were applied after pre-sowing irrigation in harvested wheat and the remaining half of nitrogen was applied through urea at 20 days after wheat harvesting. In transplanted mint, the remaining half of N was applied through urea at 20 days after transplanting. In timely planted sole mint crop, a common irrigation was given for proper crop establishment and after that irrigations were scheduled when CPE reached at a pre-determined level among different IW: CPE ratios. A uniform irrigation depth of 6 cm was maintained by using Parshall flume. In wheat + mint (2:1) relay cropping system, wheat was irrigated following the recommended package of agronomic practices. After wheat, mint was subjected to irrigations according to IW:CPE based treatments. In wheat-transplanted mint cropping system, wheat was irrigated similar to wheat in relay cropping system. After harvesting of wheat, mint was transplanted followed by an immediate irrigation. To ensure the crop establishment, irrigation was given at 7 days after transplanting. Later on, the irrigations were given based on IW: CPE ratios. Sole mint crop was harvested in second fortnight of May while, relay and transplanted mint crops were harvested in the end of June.

Mentha and wheat crops received 218.6 mm and 187.3 mm and 376.6 mm and 3.4 mm rainfall during crop period of 2014-15 and 2015-16, respectively. During 2014-15, in sole mint crop, total 2, 3, 4 and 5 irrigations were applied in 0.6, 0.8, 1.0 and 1.2 IW: CPE, respectively, while in wheat + mentha relay cropping system, number of irrigations were 6, 8, 9 and 10, in 0.6, 0.8, 1.0 and 1.2 IW: CPE, respectively and in transplanted mint, 7, 8, 9 and 11 irrigations, respectively. During 2015-16, in sole mint crop, total 7, 9, 9 and 10 irrigations were applied in 0.6, 0.8, 1.0 and 1.2 IW: CPE ratios, respectively. In wheat + mentha relay cropping system, numbers of irrigations were 9, 9, 10 and 11, in 0.6, 0.8, 1.0 and 1.2 IW: CPE, respectively. In transplanted mint, a total 8, 9, 9 and 10 irrigations were given. During first year of the study (2014-15) due to frequent rains throughout the crop season, relatively less number of irrigations were required than 2015-16 which received major amount of rainfall during May and June (372.2 mm) at harvest stage of crop.

The data on growth parameters of mentha viz. plant height, lateral spread, leaf area index (LAI), leaf: stem and dry matter accumulation were recorded at crop harvest

stage. The net plot area was harvested for recording the fresh herbage yield. The essential oil content in the fresh biomass was estimated by the hydro-distillation method. The oil content was computed by using the following formula:

$$\text{Oil content \% (fresh weight basis)} = \frac{\text{Weight of oil (g)}}{\text{Weight of fresh herbage (g)}} \times 100$$

The oil content was multiplied with the corresponding fresh herbage yield to get the total oil yield and expressed in kg/ha. Mint oil equivalent yield (MOEY) of system was calculated by using the following formula:

$$\text{MOEY (t/ha)} = \frac{\text{Wheat yield (t/ha)} \times \text{Price of wheat (₹/t)}}{\text{Price of mint oil (₹/t)}}$$

+ Oil yield of mint (t/ha)

The economics was worked out on the basis of prevailing market prices of inputs and outputs (mentha oil ₹900/l and wheat, ₹17,000/t). B: C ratio was obtained by dividing the net return with its cost of cultivation. Irrigation water productivity of the systems was worked out by using the following formula:

$$\text{Irrigation water productivity (kg/ha-cm)} = \frac{\text{Mint oil equivalent yield (kg/ha)}}{\text{Total irrigation depth (cm)}}$$

RESULTS AND DISCUSSION

Growth Parameters

Sole mint crop produced significantly taller plants and more LAI than relay and transplanted mint crops. The respective increase in plant height of sole mint crop was to the tune of 71.7 and 81.3%, whereas the increment per cent in LAI was 40.5 and 134.6%, respectively. Relay cropped mint recorded significantly higher LAI than transplanted mint by 66.9% (Table 1). Sole mint recorded significantly wider plant spread than remaining cropping sequences. Better growth in terms of plant height, lateral spread and LAI of sole mint crop was due to timely planting of crop, absence of intercropping competition and shading effect caused by wheat in relay cropping system. Relatively longer duration of sole mint in main field as compared to transplanted mint crop also helped in full expansion of its growth. Kumar *et al.* (2002) also observed 26.2% higher plant height in timely planted sole mint than mint relay cropped with wheat.

Sole mint crop also recorded 45.6 and 153.2% higher dry matter accumulation than relay cropping and transplanted mint crops, respectively. Relay cropped mint was also significantly superior to transplanted mint for dry matter accumulation. As a consequence of higher leaf area which accumulated greater amount of photosynthates. Shorter growing period in main field, exposure to higher temperature at initial stages of crop growth and transplanting shock were some of the probable reasons behind the

lower LAI and dry matter accumulation in transplanted mint crop. The inferiority of relay cropped mint to sole mint crop for accumulation of dry matter was largely because of lesser light interception at initial growth stages due to its underneath position in standing wheat crop. The seedling phase of mint and the reproductive phase of wheat were overlapped over a period of about two months. During this period, the mint crop did not get any opportunity for its growth because of shading effect and capturing of available resources by the actively grown up wheat crop. Although, after harvesting of wheat, the mint growth was improved but it was not enough to cope up the early growth inhibitory effect caused by wheat crop. Hence, a lower dry matter was accumulated by the relay cropped

mint. Singh *et al.* (1998) also observed higher dry matter accumulation in January planted mint than the transplanted mint crop of April.

Plant height, lateral spread and LAI values increased with the increasing moisture supply and were found to be the maximum at IW: CPE 1.2. Narrow IW: CPE resulted in shorter plants due to reduction in cell elongation as a consequence of moisture deficit stress. Carpita (1996) reported that moisture stress may promote lignin synthesis, leading to increased stiffness of cell walls and reduction of cell elongation. Similarly, the inhibition in leaf growth was due to reduction of cell expansion and cell division as a result of moisture deficit stress. Kumar *et al.* (2013) reported that water stress reduced the LAI by producing

Table 1. Mint growth parameters at harvest as influenced by different treatments (pooled data of 2 years)

Treatment	Plant height (cm)	Leaf area index	Lateral spread (cm)	Dry matter accumulation (kg/ha)	Leaf : stem
<i>Cropping system</i>					
Sole mint	58.2	6.24	57.6	4,988	0.76
Wheat + mint (2:1)	33.9	4.44	31.9	3,425	1.19
Wheat-transplanted mint	32.1	2.66	29.4	1,970	1.48
SEm±	1.1	0.13	1.0	89	0.03
CD (P=0.05)	3.3	0.39	2.9	262	0.09
<i>Irrigation schedule (IW:CPE)</i>					
0.6	37.3	3.72	36.8	2,660	1.21
0.8	41.4	4.25	38.7	3,119	1.17
1.0	42.9	4.78	40.5	3,777	1.12
1.2	43.9	5.04	42.5	4,287	1.07
SEm±	1.3	0.15	1.1	103	0.04
CD (P=0.05)	3.8	0.45	3.3	303	0.11

IW, Irrigation water; CPE, Cumulative pan evaporation

Table 2. Mentha yields as affected by different treatments (pooled data of 2 years)

Treatment	Wheat grain yield (kg/ha)	Fresh herbage yield (kg/ha)	Oil content (%)	Oil yield (kg/ha)	Mint oil equivalent yield (kg/ha)
<i>Cropping system</i>					
Sole mint	–	22,170	0.89	196.6	196.6
Wheat + mint (2:1)	4,441	17,370	0.94	162.1	242.5
Wheat-transplanted mint	3,984	12,050	0.96	115.2	187.2
SEm±	–	235	0.004	2.21	2.29
CD (P=0.05)	–	670	0.011	6.30	6.53
<i>Irrigation schedule (IW:CPE)</i>					
0.6	–	13,230	0.95	125.8	176.9
0.8	–	16,380	0.94	152.8	203.3
1.0	–	18,790	0.91	170.1	221.5
1.2	–	20,390	0.91	183.3	233.4
SEm±	–	271	0.004	2.56	2.66
CD (P=0.05)	–	773	0.011	7.30	7.59

IW, Irrigation water; CPE, Cumulative pan evaporation

smaller and lesser number of leaves. Further, better growth in terms of plant height, lateral spread and higher LAI under high moisture regimes resulted in maximum light interception and eventually greater accumulation of photosynthates. Saxena and Singh (1998) also observed that high irrigation frequencies scheduled at CPE 50 mm produced 5.5 and 9.9% higher dry matter of mint than CPE 100 and 150 mm, respectively.

Transplanted mint recorded significantly maximum leaf: stem (1.48) followed by relay cropped mint (1.19). Timely planted sole mint showed the lowest leaf: stem (0.76). It was declined by 19.6 and 48.6% against relay cropped and transplanted mint, respectively. Leaf: stem has an inverse relation with vegetative growth. Higher vegetative growth in sole mint was largely associated with more branching or stem growth rather than development of leaves which finally resulted in to lower leaf: stem. Poor growth of relay cropped and transplanted mint crop might be reasoned for comparatively less diversion of photosynthates for stem formation than the leaves which resulted in higher leaf: stem. Singh *et al.* (1998) also observed 35.4% reduction in leaf: stem in timely sown mint crop of mid January than that of transplanted late in mid April. The leaf: stem was found to be the maximum (1.21) in relatively more water stressed environment i.e. at IW: CPE 0.6 and it decreased with increased frequency of irrigations as better moisture regime favored more branching. The reduction in leaf: stem with an increase in irrigation frequency might be ascribed to more growth in favor of branching which caused greater senescence of lower leaves due to mutual shading. According to Singh *et al.* (1999), the negative relationship between the irrigation level and leaf: stem is possible due to the fact that plants

under the influence of higher soil moisture grew faster with higher internodal length and branches, with more diversion of photosynthates towards stem rather than to leaves and also due to shading of lower leaves.

Wheat grain yield

Wheat under intercropping system produced 11.5% higher grain yield than sole wheat. It was probably because of the border row effect which offers better utilization of light and resources as a result of availability of more space under skipped row planting.

Fresh herbage yield

Timely planted sole mint crop produced the maximum herbage yield (22,170 kg/ha). It produced 27.6 and 83.9% higher fresh herbage yield than relay cropped and transplanted mint, respectively. Higher fresh herbage yield in timely planted sole mint was due to its better plant growth such as plant height, lateral spread, dry matter accumulation and leaf area index. Because of exposure to suitable low temperature at initial stages and due to longer growth duration in main field, timely planted mint made well established root and shoot growth. Whereas, the mint transplanted in April was exposed to unfavorable higher temperature right from planting, hence could not combat the harsh growing conditions effectively as low temperature is required for development of its roots (Farrav and Williams, 1991). Similarly, Ram *et al.* (1998) also observed 51.7% lower herbage yield in April transplanted mint crop than January planted mint crop due to higher temperature during active growth phase which enhances respiration and initiates reproductive phase. Subsequently, the plants were hardly left with photosynthates needed for proper

Table 3. Mint economics and water use parameters under different treatments (pooled data of 2 years)

Treatment	Cost of cultivation ($\times 10^3$ ₹/ha)	Net return ($\times 10^3$ ₹/ha)	Benefit: cost	Total irrigation depth (cm)	Irrigation water productivity (kg oil/ha-cm)
<i>Cropping system</i>					
Sole mint	60.1	112.5	1.87	36.8	5.35
Wheat + mint (2:1)	69.0	143.5	2.08	54.0	4.49
Wheat-transplanted mint	69.3	94.2	1.36	53.3	3.52
SEm \pm	-	2.03	0.03	-	-
CD (P=0.05)	-	5.80	0.08	-	-
<i>Irrigation schedule (IW:CPE)</i>					
0.6	61.2	93.7	1.53	39	4.54
0.8	64.8	112.7	1.74	46	4.43
1.0	67.5	126.2	1.87	50	4.42
1.2	69.6	134.4	1.93	57	4.09
SEm \pm	-	2.35	0.04	-	-
CD (P=0.05)	-	6.70	0.11	-	-

IW, Irrigation water; CPE, Cumulative pan evaporation

vegetative growth. Moreover, relay cropped mint produced 44.1% higher fresh herbage yield than transplanted mint crop. Since, it had two months longer growing period in the main field compared to transplanted mint hence recorded more values of growth parameters and finally the fresh herbage yield.

Crop irrigated at IW: CPE 1.2 produced the maximum fresh herbage yield (20,390 kg/ha). It was significantly superior to the remaining IW: CPE. Higher fresh herbage yield in wider IW: CPE of 1.2 was closely associated with the beneficial effect of more frequent irrigations on growth parameters like plant height, leaf area index and dry matter accumulation. The crop subjected to lower moisture regime under narrow IW: CPE ratios were incapable of full exploitation of the applied and native nutrients in the soil. The roots under moisture stress condition might have tended to penetrate deeper into the soil in quest of water and reduced root activity in the top soil layer might rendered lower nutrient uptake where nutrients were applied. Lower utilization of nutrients and less availability of soil moisture had resulted in reduced vegetative growth and consequently poor fresh herbage yield. In higher moisture regimes, the crop covered the ground at faster rate and developed sufficient photosynthetic area as evident by LAI which resulted in the higher herbage yield (Saxena and Singh, 1996).

Oil content

The maximum oil content (0.96%) was noticed in transplanted mint which was followed by relay cropped mint (0.94%) and timely planted sole mint crop (0.89%). The reduction in oil content in timely planted sole mint can be explained by its positive correlation with leaf to stem ratio and negatively with herbage yield. Being the site for synthesis of oil, the proportion of leaf over stem decides the oil concentration in mint. Hence, development of leaves is of great significance in increasing oil concentration. Higher branching of sole mint crop resulted in lesser leaf: stem, which led to decline in oil content. These results confirm the findings of Kumar *et al.* (2002) who found 7.8 and 25.0% higher oil content in mint transplanted after wheat and mint relayed with wheat over that of the timely planted sole mint, respectively. Lower leaf: stem and oil content with increased herbage production in menthol mint has also been reported by Ram and Kumar (1998).

Among IW: CPE ratios, the highest oil content was observed at 0.6 IW: CPE. There was a decreasing trend in oil content with increase in moisture level. The reduction in oil content with an increase in irrigation frequency under wider IW: CPE ratios was attributed to the fact that under optimum moisture regimes the crop made higher

vegetative with more stem growth and thus exhibited the lower oil content.

Oil yield

Sole mint crop produced the maximum oil yield of 196.6 kg/ha. It was higher by 21.2 and 70.7% than relayed and transplanted mint crop, respectively. Since, the oil yield is a function of fresh herbage yield and its oil content; hence, in spite of having lower oil content, the sole mint crop recorded the maximum oil yield because of higher fresh herbage yield. Similarly due to lower herbage yield, the transplanted mint gave the minimum oil yield. Kumar *et al.* (2002) also reported lower oil yield of mint in relay cropping because of the lower herbage yield although the essential oil content in the herbage was higher than in the sole crop of mint. Oil yield exhibited an increasing trend with increased level of irrigation being the maximum at 1.2 IW: CPE. It was because of higher fresh herbage yield in this treatment.

Mint oil equivalent yield

Mint oil equivalent yield refers to the total productivity of the cropping system in terms of mint oil. The mint oil equivalent yield (MOEY) was recorded to be the highest in wheat + mint (2:1) relay cropping. This was attributed to the contribution of additional bonus wheat yield in this system (Table 2). The mint oil equivalent yield increased with increasing moisture supply being the maximum at IW: CPE 1.2. MOEY exhibited a positive relation with oil yield of the mint crop, since the irrigation treatments were designed only for the mint crop under different cropping situations. Hence, the effect of irrigation on mint oil equivalent yield has nothing to do with the wheat yield of the respective systems. Therefore, higher the oil yield of the mint, higher was the mint oil equivalent yield.

Irrigation water productivity

Sole planting of mentha recorded the maximum irrigation water productivity (5.35 kg oil/ha-cm) which was 19.2 and 51.9% higher than relay cropping with wheat and transplanted mint after wheat harvest, respectively. Though the relay cropping recorded higher MOEY but because of receiving higher irrigation depth (54.0 cm), it resulted in lower irrigation water productivity than sole mint crop. Transplanted mint crop recorded the lowest irrigation water productivity (3.52 kg oil/ha-cm) because of its lowest MOEY as well as the higher irrigation depth (53.3 cm). Subjecting the crop to different irrigation schedules, it was observed that crop raised under 0.6 IW:CPE was superior to other IW:CPE ratios when irrigation water productivity is concerned. Irrigation water productivity declined gradually with increase in frequency of

irrigation. Crop irrigated at 0.6 IW: CPE ratio recorded 2.5, 2.7 and 11.0% higher irrigation water productivity than 0.8, 1.0 and 1.2 IW: CPE, respectively. The low irrigation water productivity at wider IW: CPE was due to more depth of irrigation water although increased oil yield.

Economics

The maximum cost of cultivation was observed in wheat-transplanted mint cropping system (Table 3), whereas, sole mint showed the lowest cost of cultivation due to omission of wheat cultivation in the system. Cost of cultivation increased with increased level of irrigation due to the extra cost incurred by more number of irrigations at higher values of IW: CPE. Nakawuka *et al.* (2014) also reported higher cost of cultivation due to increased level of irrigation. Relay cropping of mint with wheat gave the maximum net return (Table 3). It earned 27.6% higher net return than sole mint crop because of higher mint oil equivalent yield. Timely planted sole mint crop gave 19.4% higher net return than transplanted mint crop. It was due to 5.0% higher MOEY in sole mint crop. Crop subjected to irrigation at IW: CPE 1.2 recorded the maximum net return, while IW: CPE 0.6 the minimum. The maximum B: C ratio of 2.08 was observed with relay cropping of mint with wheat. It was followed by timely planted sole mint crop. The statistically lowest B: C ratio was noted in transplanted mint crop. Among the irrigation levels, 1.2 IW: CPE recorded the maximum B: C ratio. It was significantly superior to the remaining IW: CPE ratios except IW: CPE 1.0

From the findings of the present study, it can be inferred that the relay cropping of mint in wheat is a better option to achieve higher mint oil equivalent yield, and monetary returns. For irrigation water productivity, timely planting of sole mint crop was the best. For irrigation scheduling, IW: CPE of 1.2 was the most productive and profitable, hence can be advocated.

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