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Irrigation scheduling in *Mentha arvensis* L. based relay and sequential cropping with *Triticum aestivum* L.

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ABSTRACT : The soil of the experimental site was sandy loam in texture, neutral in reaction, rich in organic carbon, low in available nitrogen and high in available phosphorus and potassium. The bulk density of the top 0-15 cm soil was 1.46mg/m^3. The basic infiltration rate was 1.3cm/hour. Twelve treatments comprising of three cropping systems (timely planted menthol mint, wheat + menthol mint relay system and wheat–late transplanted mint sequential cropping) and four irrigation schedules (IW:CPE ratio 0.6, 0.8, 1.0 and 1.2) were set in a Factorial Randomized Block Design with three replications. Different treatments failed to bring significant variations in number of tillers/m^2 at 65DAS. However, higher number of tillers/m^2 was scored by conventional wheat planting. The yield attributes of wheat (number of ears/m^2, ear length, number of grains/ear, grain weight/ear and 1000 grain weight) expressed non-significant variations due to alteration in planting pattern. Timely planted sole mint exhibited the lowest mint oil equivalent yield, followed by the transplanted crop. The relayed crop yielded the maximum mint oil equivalent yield. Among different IW:CPE ratios, significant increase in mint oil equivalent yield was observed at higher moisture regimes. IW:CPE ratio 1.2 had the maximum and 0.6 the minimum mint oil equivalent yield. The interaction effect revealed that irrigation of relay cropped mint at IW:CPE ratio 1.2 produced the highest oil equivalent yield. The wheat + mint relay cropping system gave the maximum gross (Rs. 140079/ha) and net returns (Rs. 74509/ha) and B:C ratio (1.13). Timely sown sole mint fetched higher gross and net returns and B:C ratio than wheat– transplanted mint with non-significant differences. Irrigation at higher IW:CPE ratios resulted in significant increase in gross return for every successive irrigation levels. For net return and B:C ratio, IW:CPE ratio 1.2 proved to be the best although it was statistically at par with 1.0 IW:CPE ratio.

KEY WORDS : DAS, CPE, LAI, CGR, WUE

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The menthol mint (*Mentha arvensis* L.), a potent source of menthol oil has occupied a prime position in Indian agriculture due to its number of industrial applications. It has emerged as a competent cash crop in north Indian plains in view of high market price for its essential mint oil. 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 1.75 lakh ha area with a production of 55000 tonnes (*www.business-standard.com*). Presently about

75% of the world requirement of menthol crystallized from mint oil is met by India. India exports approximately 25,000 tonnes all forms of mentha oil including crystals. The domestic consumption of India is about 40% of global consumption (*www.indianiveshcommodity.blogspot.in*). Japanese or menthol mint (*Mentha arvensis* L.) is a succulent, multi-cut perennial crop containing 75-85% menthol. Mint oil has wide applications in pharmaceutical, agro-chemicals and flavoring industries (Tassou *et al.*, 2004). This herb is considered to be stimulant, carminative and used for allaying nausea, flatulence and vomiting. The oil is also used as antiseptic, preservative and gastro stimulant. It is one of the most important flavoring substances, following vanilla and citrus. The area under menthol mint is mainly confined to central parts of Indo-Gangatic plains encompassing the northern states of Punjab, Haryana, Uttar Pradesh, Bihar and *Tarai* belt of Uttarakhand (Kumar *et al.*, 2001). These areas are pre-dominated by rice-wheat cropping system. Incorporating medicinal and aromatic plants in traditional crop rotations is a viable concept. Their inclusion in cropping systems not only favours the economics but also pave way for agro based enterprises in the region. Besides, mint could be a better substitute for high water requiring summer rice crop which is rapidly exhausting the ground water table at an alarming rate. After paddy harvest and before next paddy transplanting there is a gap of about 6-7 months. The period begins with low ET demand (winter months) to high ET demand (summer months). The entire period rely largely on irrigation water. Wheat (November sown) requires about 3-4 irrigations, while the mint 10-12 irrigations. However, taking only wheat or mentha alone leaves about 2 months fallow period which may result in poor system and water productivity. Thus, to make efficient use of irrigation and the available growing period, there is a need to look at these two crops in a system mode. Relay planting of mint in wheat and mint transplanting after wheat are the feasible options. For better water productivity, it needs to be dealt and utilize in a system perspective too. Rathi *et al.* (2014) also found wheat + menthol mint intercropping system more remunerative as compared to sole cropping of wheat crop. The added advantages noted with wheat+ mint relay cropping is the irrigation provided to wheat, is also used for establishment of mint crop. Also, the border effect is helpful in compensating the wheat yield in relay cropping system. Further, 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. 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 microclimate advantageous to the plant growth and development (Zhang *et al.*, 2012). Water is one of the most crucial inputs for mint growth, herb and oil yields expression. Mint is a shallow rooted, high water demanding crop. Its active growth period coincides with the pre- monsoon hot summer months when the soil moisture is inadequate and soil and air temperature is high leading to high ET. Both excess as well as sub-optimal soil moisture conditions decrease the growth, herbage and oil yields (Shormin *et al.*, 2009). Also adequate soil moisture supply to the root zone of the crop favours optimum utilization of nutrients. As ET demand of atmosphere is very high during pre-monsoon period, maintenance of adequate soil moisture is essential through proper monitoring and scheduling of irrigation. On the contrary, Ram *et al.* (2010) at CIMAP, Lucknow did not found significant reduction in oil content at 1.5 IW/CPE ratio against the lower IW: CPE ratios. Soil moisture regimes maintained at 1.2 IW:CPE ratio significantly increased the crop growth and herb and essential oil yields as compared to 0.9 IW:CPE ratio. The scheduling of irrigation on the basis of climatological approach (IW:CPE ratio) has been considered to be more scientific and practical as it takes care of both rainfall and evaporation. The water requirement of mint differs from location to location depending on the soil type and climatic factors. Under different menthol mint growing systems, it experiences variable climatic conditions across the growing period. Therefore, it may affect the irrigation requirement and application time. In order to maximize the water productivity and judicious use of water, it has to be seen in system mode, utilizing the entire available period for crop cultivation. Considering the above facts and figures, the present study entitled "Irrigation scheduling in *Mentha arvensis* L. based relay and sequential cropping with *Triticum aestivum* L." was conducted with the following objectives: (i) To study the effect of cropping systems and irrigation schedules on growth and productivity of menthe, (ii) To workout optimum irrigation requirement and application schedule for mentha based cropping systems, (iii) To workout water use parameters, (iv) To work out the economics.

Research Procedure

The details of the materials used, procedures followed and techniques employed for planning and execution of the experiment have been described in this chapter.

Experimental site:

The field experiment was conducted at the Bhagwant University Agriculture farm Ajmer Rajasthan during *Rabi*-summer season of 2015-16. Geographically, Ajmer is situated at the foot hills of Himalayas at 26.4^0 North latitude and 74.6^0 East longitudes and at an altitude of 480 m above mean sea level.

Treatments:

The experiment comprising of 12 treatment combinations with three cropping systems and four irrigation schedules in mint crop was laid out in Factorial Randomized Block Design with three replications.

Varietal description :

The wheat variety PBW-550 used for the study is an ideal short duration variety. PBW 550 has high yield potential and high degree of resistance to leaf and stripe rusts. It is recommended for cultivation in North-Western plain zone. For mint cultivation, CIM Saryu, a high oil yielding variety was selected. This variety was developed through intensive selection at CIMAP. It has potential to produce 2.74 t/ha of herb with 0.84-1.0 % oil and the average oil yield is 265-290 kg/ha **(**CSIR Annual Report, 2009-10). Its oil contains 79-80% menthol.

Nutrient management :

Both the wheat crop under wheat-mint sequential cropping and relay cropping were fertilized uniformly with 120kg N, 60kg P_2O_5 and 40kg K_2O per hectare. At basal, one third dose of nitrogen and the entire amount of phosphorus and potassium were applied through NPK mixture (12:32:16), urea (46% N) and MOP (60% K_2O). The remaining N was top dressed in two equal splits at CRI stage and 65 days after sowing (DAS). For fertilization in timely planted sole mint, 100kg N, 60kg P_2O_5 and 40kg K_2O per hectare were applied. Half of nitrogen and entire amount of phosphorus and potassium were applied as basal dose through the same above mentioned fertilizer sources. For the remaining nitrogen, urea was top dressed in two equal splits at 45 and 65DAS. In relay cropped mint, at initial stage, the mint was allowed to grow under residual nutrient that was applied to wheat. Fertilization was done after the harvesting of wheat crop. Half of nitrogen and entire amount of phosphorus and potassium was applied through same fertilizers just after harvesting and the remaining half of nitrogen was applied through urea at 15 days after wheat harvesting. In transplanted mint, half dose of nitrogen and entire amount of phosphorus and potassium were applied as basal. The remaining half of N was applied through urea at about 20 days after transplanting.

Water management :

In timely planted mint crop, irrigation was not required at the time of planting owing to good rainfall in January. Even irrigation was not applied in the entire month of February because of intensive rainfall. A common irrigation was applied in all the sole mint plots on 20th March for proper crop establishment. After crop establishment, irrigations were scheduled as per the treatments. In wheat + mint (2:1) relay cropping system, a pre-sowing irrigation was given to ensure better emergence and establishment of wheat. Later, irrigation was applied at crown root initiation stage. Thereafter, irrigation was not necessary for the wheat crop due to well distributed rainfall throughout the growing period. However, an extra light irrigation (2cm) was given just 15 days before harvesting to save the relay cropped mint from water stress. Further, irrigation was applied just after the harvesting of wheat and then the respective plots were subjected to irrigations according to IW: CPE ratio based treatments. At each irrigation, 6cm water depth was maintained by using Parshall flume. 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 based on IW: CPE ratios. In fact, the irrigation treatment in the above mentioned cropping systems was planned in such a fashion that in wheat, critical stage approach was taken into consideration, while in mint, after the establishment of the crop, irrigations at 6cm depth were applied on the basis of cumulative pan evaporation. The date of the irrigations applied to different cropping systems according to IW: CPE ratios are tabulated in table.

Pest management:

For controlling the weeds in both sole and skipped row wheat, hoeing was performed at 20DAS. In timely planted sole, relay cropped and transplanted mint 3, 2 and 1 hand hoeing was done, respectively. Later, the mint crop experienced a minor attack of borer which was controlled by the application of Nuvan 76 SC @0.5 litre/ha (380g a.i./ ha).

Harvesting and threshing:

Wheat harvesting was done manually when more than 90% of grains in the panicle were fully ripe and free from greenish tint. After removing border plants as well as sampling area, the individual net plot area was measured and harvested manually. The produce of individual plots was threshed by Pullman thresher just three days after harvesting. The produce was then collected in cloth bags. Sucker planted sole and relayed mint was manually harvested at 125 DAP. Whereas, transplanted mint was harvested at 55 days after transplanting in main field. Leaving the border and sampling areas, the mint crop was harvested and then used for oil extraction.

Observations in wheat :

Growth studies :

The following observations for growth studies were made at 65 days after sowing and at harvest stages:

Plant height :

The height of ten randomly selected plants from 3rd and 4th row from the North was measured with a meter scale from the base of the shoot to the top of the tallest leaf before emergence of spike. After ear emergence, height was measured upto the base of spike and reported in cm.

Number of shoots per m^2 :

Total shoot number was counted from marked area of two meter row length of crop in the 3rd and 4th row from North. From this total number of shoots/m^2 was computed.

Dry matter accumulation :

The plants from the 25cm row length, each from 3rdand 4th row were taken for recording their dry matter at all the stages of the crop growth under consideration. The plant samples were clipped close to the ground and collected in polythene bags. Thereafter, the plants were dried in drier at 70±2^{0}C temperature upto constant weight. After drying, their weights were recorded on electronic balance and reported as g/m^2.

Yield and yield attributing characters :

Number of ears per m^2:

The number of ears was counted from the marked observational area of two meter row length from each of the 3rd and 4th row and expressed as number of ears per meter square.

Ear length :

The 20 ears randomly selected from net plot area were used for measuring ear length. Ear length was measured from its base upto the tip excluding the awns and expressed in cm.

Grain weight per ear :

Selected 20 ears were harvested and threshed manually. After cleaning and drying, the weight of the grains was recorded and the average was reported as the grain weight per ear.

Number of grains per ear :

The number of grains of 20 ears were counted and divided by number of ears to get grains/ear.

1000-grain weight:

From the grain produce of the net plot, thousand grains were counted from each sample and weighed and reported as 1000- grain weight in gram.

Grain yield :

The entire produce from each net plot was threshed by Pullman thresher. The grains were cleaned by winnowing and weighed and expressed as kg/ha.

Straw yield :

The total produce from net plot was obtained by subtracting the grain yield from the total biomass produce of the net plot and expressed as kg/ha.

Observations in Menthol Mint :

The following observations on yield and growth were recorded at 80 and 100 days after planting and at harvest.

Growth studies :

Plant height:

Ten plants were randomly selected from the field and tagged. Plant height was measured from the base of the plant to the tip of the apical leaf with the help of a metre scale. It was averaged and expressed in cm.

Number of leaves per m²:

Plants collected from 25cm row length were used for the recording of number of green leaves and values were expressed as number of green leaves per m^2.

Leaf area index (LAI) :

Plants were taken from each plot from 25 cm row length and their leaves were separated. Leaf area was measured by using leaf area meter. LAI was calculated by dividing the leaf area by spacing of the plants.

Leaf stem ratio :

Five plants were taken from 3rd row of each plot and their leaves and stems were separated. The weight of fresh leaves and stem was recorded separately to work out the leaf: stem ratio.

Dry matter accumulation :

Plants from 25 cm row length were clipped close to the ground at the time of the observations. The plant samples were initially dried in shade and later in drier at 70 ± 2^0C temperatures to obtain dry matter accumulation.

Root shoot ratio :

At 100DAP, two plants from the 3rd row of the plots, were dug out separately from a depth of 30 cm soil depth along with square shaped soil mass (block) with 25 cm side length. The root portion of plants along with soil mass was put in a fine meshed nylon bag. The bags with all contents were immersed in a running water in a nearby *pucca* channel for about 1 hour so that soil mass gets loosened and all the roots were recovered during washing. After thoroughly cleaning, the roots were cut off from the shoots and then weight of fresh roots and shoots were recorded separately and their ratio was computed on fresh weight basis.

Crop growth rate (CGR) :

Crop growth rate (g/m²/day) was calculated by using following formula:

$$CGR = \frac{W_2 - W_1}{t_2 - t_1}$$

where, W_1 and W_2 were plant dry weight (g) at time t_1 and t_2, respectively.

Yield parameters :

Fresh herbage yield:

The freshly harvested herbage from the net plot area was weighed by electronic spring balance and was reported on kg per hectare basis.

Oil content :

After harvest, the essential oil content was estimated from 100g fresh plant samples taken from each net plot. The oil was extracted by hydro distillation using Clevenger's apparatus. Mint leaves were crushed and then transferred into the distillation flask. Approximately 1/3rd of the flask was filled with water. The flask was then connected to a condenser containing 100-120 ml of water and heated through heating mantle. On boiling the water for 45 minutes, vapour moved to the condenser in which both vapour and oil were present, the vapour was condensed to water and oil present floated on the top as oil is lighter than water. The distillation was completed in about 8 hours. The volume of oil was recorded and multiplied by specific gravity 0.9 (Yaseen, 1988**)** to put it on weight/weight basis. The oil content was computed by using the following formula:

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

Oil yield:

The oil content was multiplied with the corresponding fresh herbage yield to get the total oil yield and expressed in kg/ha. The following formula was used to calculate oil yield:

$$\text{Oil yield (kg/ha)} = \frac{\text{Oil content (\%) x Herbage yeild (kg/ha)}}{100}$$

Studies on cropping system :

Mint oil equivalent yield:

Mint oil equivalent yield (MOEY) of system was calculated by using the following formula:

$$\text{MOEY (t/ha)} = \frac{\text{Wheat yield (t/ha) x Price of wheat (Rs./t)}}{\text{Price of mint oil (Rs./t)}} + \text{Oil yield of mint (t/ha)}$$

Water use parameters :

Consumptive water use :

The value of evapo-transpiration (ET) from the profile was computed by using the following formula:

$$ET\,(mm) = \sum_{i=1}^{n} \frac{(MAi - MBi) \times BDi \times di}{100} + ER$$

where, Mai=% moisture on oven dry basis after irrigation on i^{th} layer, MBi= Per cent moisture on oven dry basis before irrigation on i^{th} layer, BDi= Bulk density of the i^{th} layer (Mg/m^3) di= Depth of i^{th} layer (mm), n=Number of layer, Σ= Summation of ER= Effective rainfall (mm).

In order to account for the water used by the crop between the period date of irrigation to date of moisture sampling after irrigation, the total water lost from open pan evaporation (E_0) was multiplied with 0.85 to get actual ET. The CU (consumptive use) for any one cycle was computed as: $Cu=ET+0.85E_0$ The crop water for the entire growth period was the summation of all these values.

$CU = \sum_{j=1}^{n} cu_j$ where, CU= Consumptive use, n= Number of intervals, J= J^{th} cycle

cu_j= Consumptive use in the J^{th} time interval

Water use efficiency (WUE):

Water use efficiency (kg/ha-cm) of the systems was calculated by using the following formula:

WUE= Y/U

where, Y= Mint oil equivalent yield (kg/ha) and U= Seasonal consumptive use of water (cm)

Irrigation water use efficiency:

Irrigation water use efficiency of the systems was worked out by using the following formula:

$$\text{Irrigation WUE (Kg/ha-cm)} = \frac{\text{Mint oil equilvalent yield (kg)}}{\text{Total irrigation depth (ha-cm)}}$$

Water productivity:

Water productivity of the systems was calculated by dividing the mint oil yield with total water received (irrigation + rainfall) by the crop and expressed as kg/ha-cm.

RESEARCH ANALYSIS AND REASONING

Based on the data recorded during the course of investigation, the results and discussion of the field experiment entitled "Irrigation scheduling in *Mentha arvensis* L. based relay and sequential cropping with *Triticum aestivum* L" has been presented in this chapter in tabulated forms and illustrated through figures wherever necessary.

Studies on wheat:

Plant height:

The data pertaining to plant height of wheat at different plant growth stages are summarized in the Table 1. The effect of planting pattern on plant height was significant at all the growth stages under consideration.

At 65DAS and harvest, plant height was found to be significantly higher in skipped row wheat than conventional planting of wheat. The increased height was attributed to higher light interception and utilization of other resources due to border row effect. In skipped row system, individual wheat plant has greater space for exploitation throughout the growing season. Though, mint was planted after 70 days of wheat sowing, its growth was too slow to offer any competition to the wheat crop.

Dry matter accumulation:

The data pertinent to dry matter accumulation of wheat at different plant growth stages are summarized in the Table 1. At 65DAS and at harvest, dry matter accumulation per m^2 did not show any significant variation due to alteration in planting pattern. Though skipped row planting had 33% reduced plant population, it caused a reduction of 2.8 and 4.7% only in dry matter accumulation at 65DAS and harvest, respectively.

Table 1 : Plant height, dry matter and number of tillers of wheat as affected by planting pattern

Treatments	Plant height (cm)		Dry matter (g/m^2)		Number of tillers/m^2
	65 DAS	At harvest	65 DAS	At harvest	65 DAS
Skipped row wheat	61.6	89.6	639.8	1308.0	545
Conventional wheat	60.4	87.6	658.2	1372.4	598
S.E. ±	0.3	0.5	35.8	57.3	19.1
C.D. (P=0.05)	0.9	1.6	NS	NS	NS

NS=Non-significant

Tillers/m^2:

Data regarding number of tillers/m^2 of wheat at different plant growth stages are summarized in the Table 1. The effect of planting pattern on shoot number was non-significant at 65DAS. However, number of tillers/ m^2 with conventional planting pattern was 9.7% greater than the skipped row cropping, simply because of higher plant population. But inspite of having merely 67% plant population of the sole wheat crop, the wheat under skipped row system showed a decline in number of tillers by only 8.9%. Probably as a result of better penetration of light which was offered by the bare row zones that were skipped for later planting of mint crop, resulting in higher photosynthesis even in lower leaves.

Yield attributes and yield :

Non-significant differences were recorded between skipped row and conventional wheat in terms of the yield attributing characters. All the yield attributes except ears/ m^2 were found to be higher in skipped row planting over conventional planting. 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. However, number of ears/ m^2 had declined by 7.4% in skipped row system compared to conventional wheat planting on the account of less number of tillers.

In spite of having 33% lower population, the wheat in skipped row planting had managed to achieve a yield that was just 7.2% lower than conventional planting. It was due to compensation in number of tillers to a tune of 26.8% in skipped row wheat which accounts for compensation in grain yield to an extent of 28.2%. It implies that paired row planting of wheat has the higher potential in compensation of yield penalty owing to increased tillering. Besides, numerically higher values of all yield attributing characters, except ears/m^2, also contributed to the compensation of yield in skipped row wheat to some extent. Straw yield also did not change due to crop establishment methods. But conventional planting results in marginally higher straw yield that was attributed to higher plant stand.

Studies on mint :

Growth studies :

The growth parameters of mint crop under different treatments are discussed as follows:

Table 2 : Yield attributes and yields of wheat as affected by different planting pattern

Treatments	Ears/ m^2	Ear length (cm)	Number of grains/ ear	1000 grain weight (g)	Grain weight / ear (g)	Grain yield (kg/ha)	Straw yield (kg/ha)
Skipped row wheat	318	10.9	48.7	44.1	2.15	4507	6868
Conventional wheat	343	10.4	46.5	43.2	2.01	4852	6869
S.E. ±	10.74	0.2	1.0	0.75	0.07	128	122
C.D. (P=0.05)	NS	NS	NS	NS	NS	NS	NS

NS=Non-significant

Table 3 : Plant height of mint as influenced by different treatments

Treatments	Plant height (cm)		
	80 DAP	100 DAP	At harvest
Cropping system			
Sole mint	30.1	42.0	53.0
Relay cropped mint	14.1	24.4	39.2
Transplanted mint	20.3	26.6	36.5
S.E. ±	0.6	0.6	0.7
C.D. (P=0.05)	1.8	1.7	2.0
Irrigation schedule			
IW:CPE 0.6	20.4	28.1	39.0
IW:CPE 0.8	20.5	29.1	40.4
IW:CPE 1.0	21.7	31.2	43.0
IW:CPE 1.2	23.4	34.9	49.2
S.E. ±	0.7	0.7	0.8
C.D. (P=0.05)	2.1	1.9	2.4

Plant height :

Plant height of mint as affected by different treatments is presented in Table 3.

At harvest, timely planted sole mint recorded 13.8 and 16.5 cm more plant height compared to relay cropped and transplanted mint, respectively. More plant height in timely planted sole mint crop was due to lack of competition and absence of shading effect than relay cropped wheat and relatively longer duration in main field as compared to transplanted mint. Between the other two cropping systems at 80 days after planting, transplanted mint produced taller plants than relay cropped mint with 44% more plant height. However, after harvesting of wheat, as the competition and shading effect offered by wheat on mint was eliminated and crop was irrigated and fertilized, the growth of timely planted relay cropped mint was triggered. The enhancement was upto such an extent that at 100DAP, it improved plant height of relay cropped mint by 73% over 80DAP, while the corresponding increase in transplanted mint was 31% only. Subsequently, the relay cropped mint attained a 7.4% more plant height than that of the transplanted mint during harvest. Among irrigation treatments, at 80DAP, the crop raised under 1.2 IW:CPE ratio attained the maximum plant height at all the crop growth stages. It was statistically indifferent with IW:CPE ratio 1.0 but produced significantly taller plants than IW:CPE ratios of 0.6 and 0.8 treatments. Plant height did not vary significantly among the IW:CPE ratios of 0.6, 0.8 and 1.0. Although an increasing trend was observed with increase in moisture supply. At 100 DAP and harvest, plant height increased with the increasing moisture supply and was found to be the maximum in IW:CPE 1.2 ratio. It was significantly superior to the remaining treatments. Narrow IW:CPE ratios resulted in shorter plants might be due to reduction in cell elongation as a consequence of moisture stress. At all the crop growth stages, the crop raised under IW:CPE ratio 0.6 recorded the lowest plant height and it did not differ significantly with IW:CPE 0.8 but was significantly inferior to the IW:CPE 1.0 and 1.2 treatments.

Number of leaves:

Number of mint leaves as affected by different treatments is presented in Table 4. The data depicts that different cropping systems and irrigation schedules significantly influenced the number of leaves. At all the growth stages, timely planted sole mint produced significantly higher number of leaves than the mint crops in other two cropping systems.

Irrigation scheduled at IW:CPE 1.2 produced the maximum number of leaves. It produced 25.2, 73.9 and 140.8% higher number of leaves than IW:CPE 1.0, 0.8 and 0.6, respectively. Higher number of leaves in wider IW:CPE ratio *i.e.* 1.2 might be due to better uptake and assimilation of nutrient particularly nitrogen under higher moisture regimes. Nitrogen uptake is strongly associated with leaf and canopy development.

Leaf area index :

Data on leaf area index at various growth stages are presented in Table 5. Leaf area index of mint in all the cropping systems increased with advancement of crop age and reached to the maximum at harvesting stage. At all the growth stages, timely planted sole mint showed

Table 4 : Mint leaves under different cropping systems and irrigation schedules

Treatments	No. of leaves/m^2		
	80 DAP	100 DAP	At harvest
Cropping system			
Sole mint	2468	6018	13163
Relay cropped mint	836	2708	4566
Transplanted mint	413	1038	1863
S.E. ±	48	118	241
C.D. (P=0.05)	141	347	707
Irrigation schedule			
IW:CPE 0.6	843	2276	3889
IW:CPE 0.8	1087	2808	5387
IW:CPE 1.0	1346	3598	7480
IW:CPE 1.2	1680	4337	9367
S.E. ±	56	137	278
C.D. (P=0.05)	163	401	816

significantly higher leaf area index than both relay and transplanted mint crops. The higher LAI in timely planted sole mint crop over relay cropped and transplanted mint was due to more number of leaves as a result of better conducive growth environment during initial stages. The higher LAI was also strongly associated with greater number of leaves in sole mint crop.

Leaf stem ratio:

The data pertaining to leaf stem ratio of mint at different crop growth stages are summarized in the Table 6. Ratio of leaf to stem indicates plant foliage production in relation to stems. Narrow ratio reflects less leaf but more stem growth. The results revealed that the leaf stem ratio expressed by the crop decreased with the advancement of crop growth due to senescence of lower leaves. Leaf stem ratio exhibited significant variations due to different tested treatments at all the stages of crop growth.

At 80 DAP, the relay cropped mint recorded 56.2 and 31.8% higher leaf stem ratio than the sole and transplanted mint, respectively indicating lesser stem and lower branching in relay cropped mint because of the mutual shading effect of wheat on mint crop at initial stages. But as soon as the wheat was harvested, branching was enhanced in relayed mint resulting in 19.7% decrease in leaf stem ratio at 100 DAP as compared to the same at 80 DAP. At 100 DAP, the relay cropped mint showed 59.1 and 37.6% higher leaf stem ratio over the timely planted sole mint and late transplanted mint, respectively. Finally at harvest, the maximum leaf stem ratio was scored by transplanted mint followed by relay

Table 5 : Leaf area index of mint under different cropping systems and irrigation schedules

Treatments	Leaf area index		
	80 DAP	100 DAP	At harvest
Cropping system			
Sole mint	1.93	4.95	6.24
Relay cropped mint	0.33	2.65	4.44
Transplanted mint	0.36	1.77	2.66
S.E. ±	0.03	0.12	0.13
C.D. (P=0.05)	0.09	0.35	0.39
Irrigation schedule			
IW:CPE 0.6	0.62	2.64	3.72
IW:CPE 0.8	0.84	2.94	4.25
IW:CPE 1.0	0.95	3.30	4.78
IW:CPE1.2	1.10	3.61	5.04
S.E. ±	0.04	0.14	0.15
C.D. (P=0.05)	0.10	0.40	0.45

Table 6 : Leaf stem ratio of mint under different treatments

Treatments	80 DAP	100 DAP	At harvest
Cropping system			
Sole mint	1.46	1.15	0.85
Relay cropped mint	2.28	1.83	1.11
Transplanted mint	1.73	1.33	1.21
S.E. ±	0.04	0.05	0.02
C.D. (P=0.05)	0.11	0.13	0.05
Irrigation schedule			
IW:CPE 0.6	2.08	1.63	1.20
IW:CPE 0.8	1.92	1.58	1.07
IW:CPE 1.0	1.71	1.42	1.05
IW:CPE 1.2	1.58	1.11	0.90
S.E. ±	0.04	0.05	0.02
C.D. (P=0.05)	0.13	0.16	0.06

cropped mint, indicating better branching as well as growth in the relay cropped mint in between the period of 100 DAP to maturity.

Dry matter accumulation :

Dry matter of mint as affected by different treatments is presented in Table 7 and data revealed that different cropping systems and irrigation schedules significantly influenced the dry matter accumulation of mint. Timely planted sole mint registered the maximum dry matter accumulation at all the crop growth stages. It was significantly higher than the remaining treatments as it had better growth and photosynthesis due to conducive environment.

It was significantly superior to the remaining treatments while IW:CPE ratio 0.6 registered significantly lower dry matter. More number of leaves and higher LAI values resulted in maximum light interception and eventually greater accumulation of photosynthates under higher moisture regimes *i.e.* IW:CPE ratio 1.2.

Crop growth rate (CGR) :

Data pertaining to crop growth rate at various intervals as influenced by different treatments are presented in Table 9. Among different cropping systems, during 80-100DAP, timely planted sole mint crop recorded 41.6 and 195.6% higher CGR than relay cropped mint and transplanted mint, respectively. At 100-125DAP, the relay cropped mint exhibited higher CGR than other cropping systems, having non-significant difference with timely planted sole mint crop.

In general, the crop growth rate declined at 100-125 DAP as compared to the growth rate during 80-100 DAP period, except in transplanted mint. The possible reasons of slackness in growth rate during maturity stage in timely planted sole mint and relayed mint crop may be due to higher canopy coverage in former stage, by which lower leaves operated under shade. Thus the lower leaves started senescing and the rate of increase in dry matter decreased later. However, the reverse trend was noticed in transplanted mint, with higher CGR value in between 100-125 DAP interval than 80-100 DAP interval. The mint crop was transplanted at the age of 70 days. In transplanted condition, root development might have been prevented to some extent due to transplanting shock. This might have created some obstruction in the path of its

Table 7 : Dry matter accumulation of mint under different cropping systems and irrigation schedules

Treatments	Dry matter accumulation (kg/ha)		
	80 DAP	100 DAP	At harvest
Cropping system			
Sole mint	1423	3459	4988
Relay cropped mint	312	1751	3425
Transplanted mint	240	1029	1970
S.E. ±	26	53	89
C.D. (P=0.05)	76	155	262
Irrigation schedule			
IW:CPE 0.6	499	1489	2660
IW:CPE 0.8	605	1857	3119
IW:CPE 1.0	685	2297	3777
IW:CPE 1.2	845	2676	4287
S.E. ±	30	61	103
C.D. (P=0.05)	87	179	303

Table 8: Interaction effect of cropping systems and irrigation levels on dry matter accumulation (at harvest) of mint

Dry matter accumulation (kg/ ha)				
Cropping system	Irrigation schedule			
	IW:CPE 0.6	IW:CPE 0.8	IW:CPE 1.0	IW:CPE 1.2
Sole mint	3580	4342	5613	6415
Relay cropped mint	2815	3217	3667	4032
Transplanted mint	1585	1798	208	2415
S.E. ±	179			
C.D. (P=0.05)	524			

growth in initial stages *i.e.* during 80-100 DAP.

Root shoot ratio:

Root shoot ratio of mint at 100 DAS as affected by different treatments is presented in Table 10. The data regarding the effect of cropping systems on root shoot ratio expressed the highest value in relay cropped mint. This was attributed to the moisture competition faced by mint crop under relay cropping situations. As at initial growth stages of the relay cropped mint, the wheat crop was at its reproductive stage which exploited soil moisture extensively through well established root system. Eventually the mint crop was subjected to water stress, which finally resulted in higher root growth in search of water from deeper soil layers. Timely planted sole mint recorded lower root shoot ratio over transplanted mint because of more shoot growth than root growth.

Different irrigation schedules based on IW:CPE ratios were unable to mark a significant influence on root: shoot ratio.

Yield parameters :

Herbage yield :

The data regarding herbage yield as influenced by different cropping systems and irrigation schedules are summarized in Table 11.

Fresh herbage yield of mint differed significantly under varying cropping systems. Timely planted sole mint crop produced the maximum herbage yield. It was significantly superior to relay cropped and transplanted

Table 9 : Effect of different treatments on crop growth rate of mint

	CGR (kg/ha/day)	
Treatments	80-100 DAP	100-125 DAP
Cropping system		
Sole mint	101.8	61.1
Relay cropped mint	71.9	67.0
Transplanted mint	34.5	37.6
S.E. ±	3.0	2.3
C.D. (P=0.05)	8.8	6.7
Irrigation schedule		
IW:CPE 0.6	49.5	46.8
IW:CPE 0.8	62.6	50.5
IW:CPE 1.0	80.6	59.2
IW:CPE 1.2	91.6	64.4
S.E. ±	3.5	4.5
C.D. (P=0.05)	10.2	7.7

Table 10 : Root shoot ratio of mint at 100 DAS as influenced by different treatments

Treatments	Root shoot ratio
Cropping system	
Sole mint	0.27
Relay cropped mint	0.68
Transplanted mint	0.42
S.E. ±	0.03
C.D. (P=0.05)	0.08
Irrigation schedule	
IW:CPE 0.6	0.52
IW:CPE 0.8	0.48
IW:CPE 1.0	0.43
IW:CPE 1.2	0.40
S.E. ±	0.03
C.D. (P=0.05)	NS

NS=Non-significant

mint crops. The fresh herbage yield in timely planted sole mint was higher due to higher values of the growth parameters such as plant height, number of leaves and leaf area index. It showed 66.7% higher herbage yield than that of the relay cropped mint due to no competition for light and other resources and higher growth rate from early growth stages. Owing to longer growing duration in main field, the timely planted sole mint showed 192.9% increase in herbage yield than transplanted mint. Because of low temperature in initial stages, mint planted in January got fully established and when approached to higher temperature at later stages, it picked up growth without any limitation. Whereas, the mint transplanted in April was exposed to higher temperature soon after planting, hence could not combat the harsh growing conditions (high temperature) in absence of well developed root system. A yield decline of 43.1% was recorded in transplanted mint over relay cropped mint because besides having a two months shorter growing duration in the main field compared to relay cropped mint, it was subjected to transplanting shock and higher temperature from early stages that ultimately resulted in slower growth rate. A significant increase in herbage yield was observed with increasing moisture supply. Increase in herbage yield by 83.2, 60.5 and 24.4% was obtained when crop irrigated at IW:CPE ratio of 1.2, 1.0 and 0.8 over that IW:CPE ratio of 0.6, respectively.

The interaction effect for herbage yield of mint presented in Table 12 was found to be significant. The mint yield of sole timely planted crop increased significantly upto IW:CPE ratio 1.2. For relay cropped and transplanted mint, yield did not increase significantly beyond IW:CPE ratio 1.0. Hence, data indicates that sole mint crop due to more canopy development have higher ET demand and eventually required frequent irrigations. At all the ratios, the yield decreased significantly from timely sole to relay cropped and relay cropped to late transplanted.

Oil content :

Data pertaining to oil content as affected by different treatments are presented in Table 11. A significant difference in oil content was realized in mint crop grown under different cropping systems. The oil content was found to be the maximum in transplanted mint, followed

Table 11 : Mint herbage, oil content and oil yield as affected by different treatments

Treatments	Herbage yield (kg/ha)	Oil content (%)	Oil yield (kg/ha)
Cropping system			
Sole mint	18630	0.66	121.2
Relay cropped mint	11177	0.84	93.2
Transplanted mint	6360	0.95	59.7
S.E. ±	436	0.02	2.8
C.D. (P=0.05)	1280	0.06	8.3
Irrigation schedule			
IW:CPE 0.6	8500	0.85	67.8
IW:CPE 0.8	10507	0.82	81.1
IW:CPE 1.0	13643	0.81	101.9
IW:CPE 1.2	15572	0.79	114.6
S.E. ±	504	0.02	3.3
C.D. (P=0.05)	1478	NS	9.6

NS=Non-significant

Table 12 : Interaction effect of different cropping systems and irrigation schedules on mint herbage yield (kg/ha)

Mint herbage yield (kg/ha)

Cropping system	Irrigation schedule			
	IW:CPE 0.6	IW:CPE 0.8	IW:CPE 1.0	IW:CPE 1.2
Sole mint	12877	15680	21477	24487
Relay cropped mint	8328	9865	12372	14145
Transplanted mint	4295	5977	7082	8085
S.E. ±	873			
C.D. (P=0.05)	2559			

by relay cropped mint. An increase in oil content by 73.9 and 27.3% was observed in transplanted and relay cropped mint over that of the sucker planted sole mint, respectively.

Oil yield :

The data defining the effect of different cropping systems and irrigation schedules on the oil yield are summarized in Table 11. Approximately, 30.0 and 103.2% higher oil yield was observed in sole mint over relayed and transplanted mint, respectively. Since oil yield is a function of herbage yield and oil content, hence inspite of lower oil content, the sole mint exhibited highest oil yield, as a result of increase in herbage yield. Irrigation scheduling also exerted significant effect on oil yield of menthol mint. Oil yield showed an increasing trend with increased level of irrigation being the maximum at 1.2 IW:CPE ratio. However, the differences in oil yield between 1.0 and 1.2 IW:CPE ratios were non-significant.

The interaction effect of different cropping systems and irrigation levels on oil yield of mint was found to be significant and summarized in Table 13 and Appendix X. At all the irrigation levels except IW:CPE ratio 0.6, timely planted sole mint significantly out yielded the remaining treatments. In timely planted sole mint, increasing frequency of irrigation beyond 0.8 IW:CPE ratio produced significantly higher mint oil yield over its lower frequency of irrigation. In late transplanted mint, IW:CPE 1.2 being on par with IW:CPE 1.0 ratio produced significantly higher mint oil yield than remaining IW:CPE ratios.

Studies on cropping system :

Mint oil equivalent yield :

Mint oil equivalent yield refers to the total productivity of the cropping system in terms of mint oil. Data pertaining to mint oil equivalent yield as regulated by different treatments are tabulated in Table 14. Mint oil equivalent yield exhibited significant variations due to different cropping systems and irrigation schedules. The mint oil equivalent yield (MOEY) was recorded to be highest in wheat + mint (2:1) relay cropping followed by wheat – transplanted mint sequential cropping. In spite of higher oil yield in timely planted sole mint, the MOEY in wheat + mint (2:1) and wheat – transplanted mint was found to be 36.0 and 12.8% higher over timely planted sole mint crop. This was attributed to the contribution of additional bonus wheat yield in these systems that ultimately resulted in increased mint oil equivalent yield. Though, wheat – transplanted mint cropping system produced 7.7% higher wheat yield than wheat + mint (2:1) relay cropping system, the decline in MOEY was 36.0% which finally resulted in 17.0% reduction in MOEY in wheat – transplanted mint system over the wheat + mint (2:1) relay system.

The interaction effect of different cropping systems and irrigation levels on mint oil equivalent yield of the systems was found to be significant. At all the irrigation levels, the oil equivalent yield was significantly higher in relay cropped mint, followed by transplanted crop. The differences between transplanted mint and timely planted sole mint were not significant beyond IW:CPE ratio 0.8.

Cost of cultivation :

Data pertaining to cost of cultivation as affected by different treatments are given in Table 14. The data on economics revealed that maximum cost of cultivation was observed in wheat + mint relay cropping system, followed by the wheat – transplanted mint cropping system. Sole mint showed the lowest cost of cultivation due to skipping of wheat cultivation in the system. The cost of cultivation for wheat + mint (2:1) system was 2.7 and 14.2% higher than Wheat – mint sequential system and sucker planted sole mint crop. This higher cost in relay system over Wheat – transplanted mint system was incurred by an extra weeding operation and higher cost for oil extraction because of higher herbage yield in relay cropping system.

Table 13 : Interaction between cropping systems and irrigation schedules for mint oil yield

	Mint oil yield (kg/ha)			
Cropping system	IW:CPE 0.6	IW:CPE 0.8	IW:CPE 1.0	IW:CPE 1.2
Irrigation schedule				
Sole mint	88.40	102.45	138.46	155.46
Relay cropped mint	72.48	84.3	101.72	114.37
Transplanted mint	42.35	56.66	65.72	73.87
S.E. ±		5.68		
C.D. (P=0.05)		16.67		

Gross return :

Gross return varied significantly due to different cropping systems. Highest gross return was received from the wheat + mint (2:1) system. It provided approximately 36.0% higher gross return than sole mint crop because of higher mint oil equivalent yield of the system which was largely associated with inclusion of wheat crop in the system. Due to similar reasons, wheat – mint sequential cropping gave 12.8% increase in gross return over sole mint. An increase in gross return by 20.5% in relay system against wheat – late mint sequential cropping was obtained due to lower mint oil equivalent system provided by the later one.

Table 14 : Mint oil equivalent yield under different treatments

Treatments	Mint oil equivalent yield (kg/ha)
Cropping system	
Sole mint	121.19
Wheat + mint (2:1)	164.80
Wheat – transplanted mint	136.71
S.E. ±	2.94
C.D. (P=0.05)	8.62
Irrigation schedule	
IW:CPE 0.6	121.62
IW:CPE 0.8	130.02
IW:CPE 1.0	149.65
IW:CPE 1.2	162.32
S.E. ±	3.40
C.D. (P=0.05)	9.96

Cost of mint oil – Rs. 850/kg Cost of wheat – Rs. 13.5/kg

Table 15 : Interaction effect of cropping systems and irrigation schedules on mint oil equivalent yield

Mint oil equivalent yield (kg/ha)

	Irrigation schedule			
Cropping system	IW:CPE 0.6	IW:CPE 0.8	IW:CPE 1.0	IW:CPE 1.2
Sole mint	88.40	102.45	138.46	155.46
Wheat + mint relay cropping	148.96	156.21	171.36	182.68
Wheat – transplanted mint	127.50	131.41	139.14	148.81
S.E. ±		5.88		
C.D. (P=0.05)		17.25		

Table 16: Mint economics under different cropping systems and irrigation schedules

Treatments	Cost of cultivation (Rs./ha)	Gross return (Rs./ha)	Net return (Rs./ha)	B:C ratio
Cropping system				
Timely planted sole mint	57377	103015	45638	0.78
Wheat + mint (2:1)	65571	140079	74509	1.13
Wheat – transplanted mint	63862	116208	52346	0.82
S.E. ±	-	2500	2500	0.04
C.D. (P=0.05)	-	7332	7332	0.12
Irrigation schedule				
IW:CPE 0.6	58086	103376	45290	0.76
IW:CPE 0.8	60376	110519	50143	0.82
IW:CPE 1.0	63395	127206	63810	1.00
IW:CPE 1.2	67222	137968	70746	1.05
S.E. ±	-	2887	2887	0.05
C.D. (P=0.05)	-	8466	8466	0.13

Net return:

The maximum net return was harvested from the wheat + mint (2:1) relay cropping system with 63.3% higher net return over sole mint. The present study depicts 14.7% higher net return in wheat – transplanted mint system over sucker planted timely sole mint. Irrigation scheduling also exerted a significant effect on the net return. Highest net return was observed in IW:CPE ratio 1.2 that was statistically on par with 1.0 IW:CPE ratio. Crop raised under 1.2 IW:CPE ratio fetched 56.2, 41.1 and 10.2% higher net return as compared to 0.6, 0.8 and 1.0 IW:CPE ratio, respectively. However, the differences between 0.6 and 0.8 IW:CPE ratio and 1.0 and 1.2 IW:CPE ratio were found to be non-significant.

Benefit cost ratio :

Relay cropping of mint with wheat gave the maximum B: C ratio. It was followed by transplanted mint and timely planted sole mint. However, the differences between transplanted mint and sole mint were found to be the non-significant. The higher B: C ratio in wheat + mint relay system was due to higher net return over cost of cultivation. Among the irrigation levels, 1.2 IW:CPE ratio proved to be the best having non-significant difference with IW:CPE ratio1.0. The increase in frequency of irrigation from 0.6 to 0.8 IW:CPE ratio also exhibited no significant increase in B:C ratio. At IW:CPE ratio 1.2, the crop gave 38.1% higher B: C ratio than 0.6 IW:CPE ratio.

Water use studies :

The water use parameters of mint cultivation under different treatments are given in Table 15 and are discussed as follows:

Irrigation depth :

The total irrigation depth showed variations due to different cropping systems and levels of irrigations. Among different cropping systems, sole mint system recorded the lowest irrigation depth mainly because of its shorter duration than other two systems *i.e.* from February to first week of June while in transplanted and relay mint its period was extended from middle of November to first week of June. The same reason lies behind the lower amount of rainfall received by the crop. Highest irrigation depth was observed in wheat + mint (2:1) relay cropping system.

Conclusion :

Based on the findings of the present study, it can be inferred that on sandy loam soil, the relay cropping of mint in wheat is a better option to achieve higher mint oil equivalent yield, water productivity and monetary returns. For irrigation scheduling in mint, IW:CPE ratio 1.0 can be beneficial from mint oil equivalent point of view, irrespective of the cropping systems.

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