Response to Water Availability Challenges in Irrigated Agriculture: A Case Study on Response of Native Spearmint to Deficit Irrigation

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Introduction

Nearly 40% of food and agricultural commodities are produced through irrigated agriculture on about 17% of agricultural land (FAO, 2002). Irrigation uses take almost 60% of all the world's large freshwater withdrawals (Kenny et al., 2009). Increasing municipal and industrial demands for water plus climate change have steadily decreased water allocated for agriculture. There is need therefore to increase food production with less water. Scheduling irrigations below the maximum crop requirement and allowing some extent of water stress either during a particular growth stage or throughout the entire growing season with minimal effects on yield quality and quantity is one way to reduce crop water use and increase water productivity. The aim of this study was to quantify the effect of different stress levels applied at different times during the growing season on native spearmint's oil yield, quality and grower profitability.

Materials and methods

❖The field experiment was conducted at the WSU IAREC, Prosser WA during the growing season of 2011.

❖The mint field which was planted in 2010 is a completely randomized block design with 4 replications of each treatment.

❖The two factors under study included level of irrigation (or stress) and timing of the stress. Four levels of irrigation were considered; 100, 80, 54 and 40% of the crop water requirement. Timing also had four levels T1, T2, T3 and T4. For T1, the stress levels were applied throughout the growing season. For T2, T3, and T4, the plants were fully irrigated and the stress levels only applied 21, 14, and 7 days before harvest.

❖At each harvest, a swather 3.25ft wide was used to cut hay from a representative area16 ft. long and 3.25 ft. wide from each experimental unit. The cut hay was weighed and 21 pounds of this hay then packed in burlap sacks, air dried for 7 days before being taken in for distillation.

❖In the economic analysis, costs that were affected directly or indirectly by the changes in water use were considered variable costs and the rest of the costs fixed. The total cost of production was the sum of the variable and fixed costs.

Results

❖Irrigation and crop water use amounts

Table 1. Mean irrigation and ETc values per cutting*

Treatments		Irrigation (inches)	Crop water use, ETc (inches)
Irrigation level	Timing		
100%	T1,T2,T3,T4	12.91a	16.34 a
80%	T3	12.07 bc	15.92 b
80%	T4	11.78 bcd	15.66 bc
40%	T4	9.53 e	15.50 cd
80%	T1	10.33 f	15.29 cde
80%	T2	12.36 ab	15.24 de
54%	T4	10.32 f	14.91 ef
54%	T3	10.99 gh	14.67 fg
40%	T3	10.40 fh	14.67 fg
40%	T2	11.27 dg	14.65 fg
54%	T2	11.65 cd	14.47 g
54%	T1	7.00 i	12.89 h
40%	T1	5.16 j	12.07 i
SE mean		0.123	0.081
Cutting			
1		10.42 a	14.77 a
2		11.40 b	15.4 b
SE mean		0.044	0.029

*Mean comparison in columns is by Tukey's method ($p<0.05$). Means that don't share a letter are significantly different. Values are means of four replications.

❖Fresh hay yields

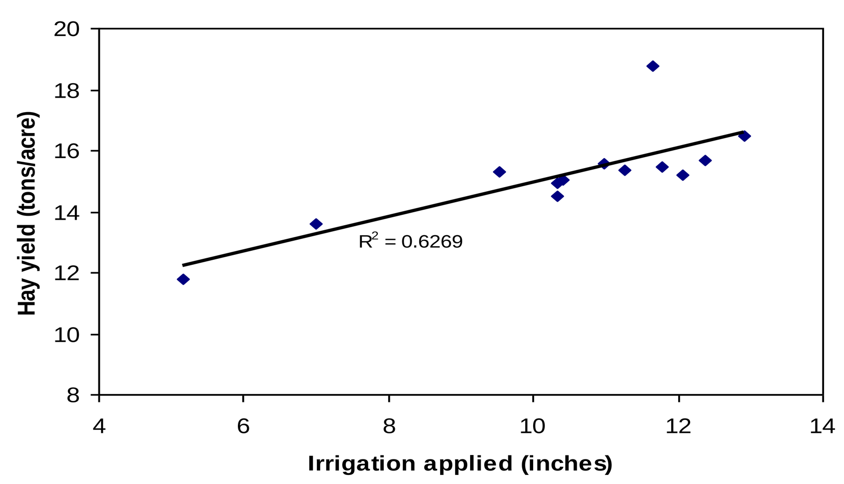

Fig. 1. Changes in fresh hay yields due to irrigation amounts applied

Table 2. Fresh hay yields per cutting for 2011*

Irrigation level (%)	Fresh hay yield (ton/acre)	Timing	Fresh hay yield (ton/acre)	Cutting	Oil yield (lb/acre)
40	14.37a	T1	13.92a	1	19.85a
54	15.60a	T2	16.64a	2	11.03b
80	15.31a	T3	15.61a	SE mean	0.315
100	16.48a	T4	15.59a		
SE mean	0.445	SE mean	0.445		

*Means that don't share a letter are significantly different

Results (cont'd)

❖Oil yield

Table 3. Mean oil yield per cutting for 2011

Irrigation level (%)	Oil yield (lb/acre)	Timing	Oil yield (lb/acre)	Cutting	Oil yield (lb/acre)
40	67.61a	T1	68.80a	1	68.24a
54	72.13a	T2	70.77a	2	71.01a
80	68.15a	T3	67.42a	SE mean	1.794
100	70.62a	T4	71.51a		
SE mean	2.537	SE mean	2.537		

*Mean comparison by Tukey's method ($p<0.05$). Means that don't share a letter are significantly different

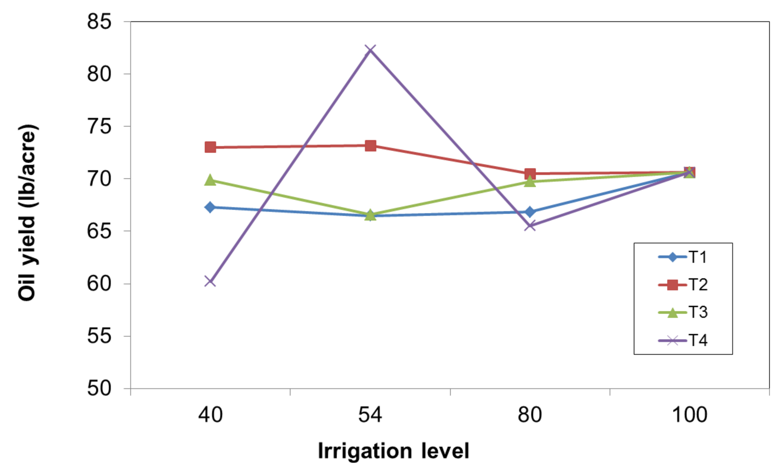

Fig. 2. Mean oil yield per treatment per cutting for the year 2011

❖Water use efficiency

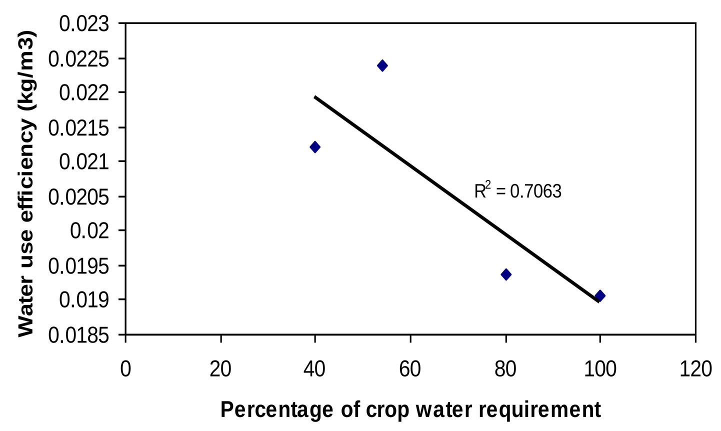

Fig. 3. Variation of water use efficiency among irrigation levels

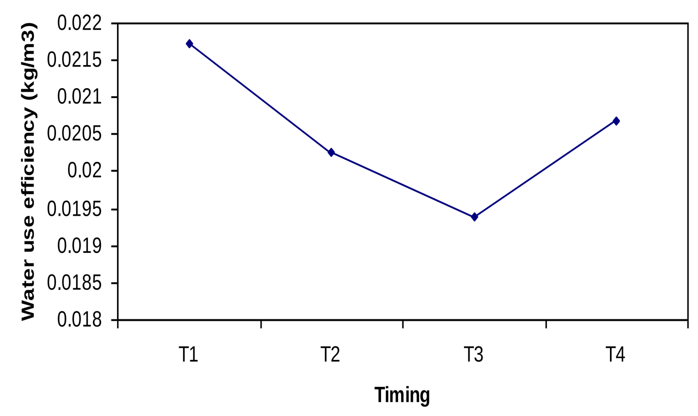

Fig. 4. Variation of water use efficiency among timings

❖Oil concentration

Table 4. Mean oil concentration for each treatment for 2011

Treatments		Oil concentration
Irrigation level	Timing	(%)
40	T4	0.191a
80	T4	0.204a
54	T3	0.211a
54	T4	0.217a
100	T1,T2,T3,T4	0.218a
80	T1	0.227a
40	T2	0.232a
80	T2	0.233a
80	T3	0.236a
40	T3	0.24ab
54	T2	0.25ab
54	T1	0.265ab
40	T1	0.323b
SE mean		0.0161

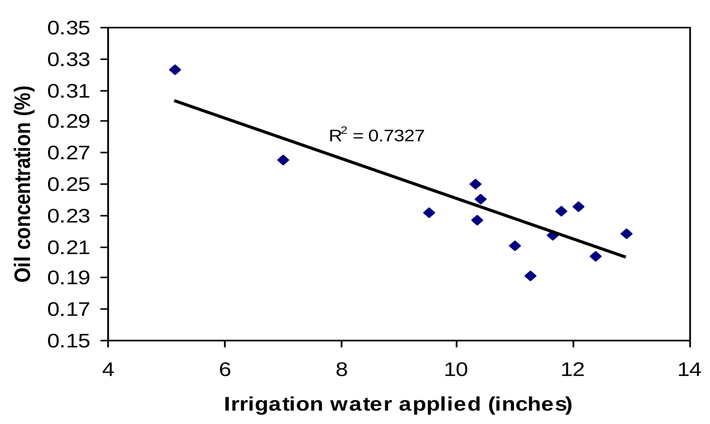

Fig. 5. Changes in oil concentration with changes in irrigation amounts applied

Table 5. Mean oil concentration per cutting

Cutting	Oil concentration (%)
1	0.158a
2	0.304b
SE mean	0.0057

❖Oil component analysis

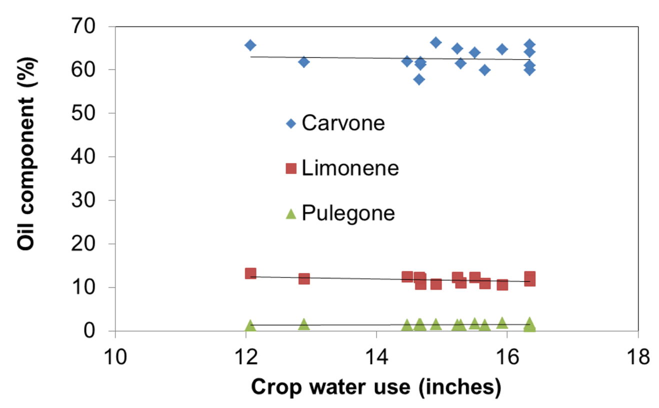

Fig. 6. Main oil components for native spearmint

❖ Economic analysis

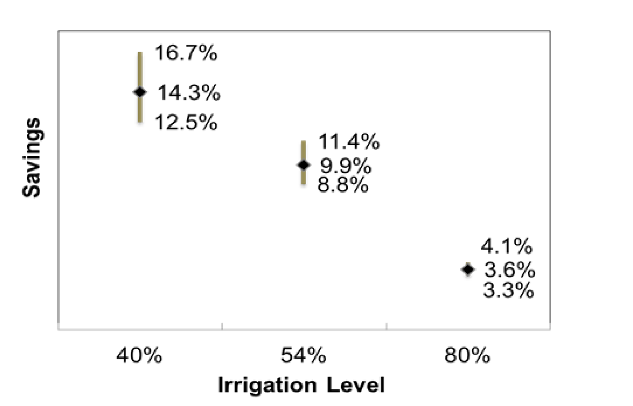

Fig. 7. Proportional cost savings with respect to the full irrigation scenario

Results cont'd

❖ Economic analysis (Cont'd)

Table 6. Full year of production*

Irrigation levels	Production cost ($)	Saving in costs	Mint yield (lb/acre)	Revenue** ($)	Profit ($)
40%	1989.2	14.3%	135.2	2190.6	201.4
54%	2079.2	9.9%	144.3	2337.0	257.8
80%	2213.4	3.6%	136.3	2208.1	-5.3
100%	2295.5	0.0%	141.2	2288.1	-7.5

*Production, costs and revenue per acre
**Crop price used is $16.2 per pound native spearmint oil

Discussion

❖The significant differences ($p < 0.001$) in irrigation and crop water use amounts indicate that treatments were effective in providing a wide range of soil water deficits.

❖Interaction between irrigation levels and timing was significant for fresh hay yields ($p = 0.039$), and there were also significant differences among treatments and cuttings. Fresh hay yields increased linearly with increase in the amount of irrigation applied.

❖There was no interaction between irrigation levels and timing for oil yield ($p = 0.125$). There were also no significant differences in oil yield among irrigation levels ($p = 0.554$), timing (p = 0.656"), and cuttings ($p = 0.277$). This implies that considerable water can be saved by allowing some level of water stress to native spearmint plants, either throughout their growing period or within three weeks prior to harvest without affecting oil yields.

❖Temperature regulates flowering in mint, the timing of which is important since oil composition and yield are at optimum levels at flowering (Biggs and Leopold, 1955). This explains why hay yields for the second cutting were almost half those for the first cutting yet the oil yield for the second cutting was slightly higher than that for the first cutting. The GDD prior to the first harvest and second harvest were 1547.1 and 1889.2 respectively (40°F Base).

❖Both water use efficiency and oil concentration increased with increasing water stress, suggesting that water stress may induce early flowering in native spearmint since oil yields are optimum at flowering. Also, since less biomass is produced as water stress increases, shading of the lower leaves is minimized and the plant is therefore able to retain the more mature leaves. Oil quality and quantity is a result of both old and young leaves (Loomis, 1978).

❖The oil component analysis didn't show significant differences among treatments for the major native spearmint oil constituents.

❖Fresh hay yield per acre decreased with increasing water stress although oil yield per acre didn't significantly change as water stress increased, there is therefore less biomass to handle during harvesting and distillation, and also less residue to dispose off after the distillation process, this translated to reduction in costs of producing mint oil. Another cost that is reduced when hay yields are reduced is machinery fueling and lubrication; transportation costs are reduced and distillation takes less time and energy.

Conclusions

❖Water stress reduces biomass production in native spearmint.

❖Same oil yield with less water suggests that water stress may have encouraged essential oil accumulation.

❖Deficit irrigation can improve on water productivity of native spearmint.

❖When managed properly, deficit irrigation can reduce native spearmint's production costs and increase grower returns.

Acknowledgements

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