EFFECT OF SUSTAINED DEFICIT IRRIGATION ON HAY AND OIL YIELD OF NATIVE SPEARMINT (*Mentha spicata*)

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ABSTRACT

An experiment was conducted to quantify the local yield and crop water requirement responses of spearmint to different levels of water deficit in a Pacific Northwest arid environment. A line source sprinkler system was used to apply water to the test plots where the applied water varied nearly linearly with distance from the sprinkler line. This resulted in the application of varying irrigation amounts from full irrigation to 100% water deficit. The 100% irrigation amounts were controlled by neutron probe soil moisture measurements and irrigation scheduled to refill the soil water deficit to field capacity on a weekly basis. The varying irrigation amounts were confirmed with catch cans at each of five different irrigation levels and were read after all the irrigations to verify the amounts of applied water. The hay and oil yields at different water deficit levels were thereafter evaluated. The total oil content that was distilled from the mint hay samples stayed fairly constant despite significantly decreased mint hay yields with increased water deficit. The mint oil quality indicators improved with deficit irrigation. This study indicates that spearmint is a suitable crop for a sustained deficit irrigation management strategy that would reduce farm operation technicalities of regulated deficit irrigation while considerably conserving irrigation water and power.

INTRODUCTION

Water shortage is the most important factor restricting crop production in the world (Umar, 2006) as it constrains plant growth and production (Yadav et al., 1999). Full irrigation to increase yields to meet increasing food and fiber demands is not an option in water scarce regions (Geerts, et al. 2008a). Deficit irrigation is providing a possible solution to the dilemma of sustaining and/or increasing production Geets, et al 2008b).

With diminishing water and land resources the primary purpose of the world's irrigation is to sustain agricultural production and then strive for increased output, thereby providing a more stable supply of agricultural production (FAO, 2002). Water shortage challenge has thus shifted crop production function from the land productivity concept to water productivity (Sarwar and Perry, 2002; Zwart and Bastiaanssen, 2004; and Fereres and Soriano, 2007).

Crop response to deficit irrigation is becoming an important consideration for establishing irrigation management strategies under limited water supply conditions.

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Deficit irrigation is the practice of applying less than crop evapotranspiration demand with intent of imposing a managed level of water stress to the crop (Grant, 2008). The strategy is to maintain plants under certain water deficit for a prescribed duration of the growth season with the aim of controlling reproductive and vegetative growth to improve water use efficiency and/or crop quality. Deficit irrigation has been practiced in many areas of the world (English and Raja 1996). It requires precision irrigation and thus at its core it requires the understanding of the crop's evapotranspiration (Imtiyaz et al., 2000), crop response to water deficit and use of highly efficient irrigation systems.

The importance of quantification of local response to irrigation is of noted importance to establishing area-specific irrigation management strategies (Payero et al., 2008). For different crops, deficit irrigation has been shown to save irrigation water (Girona et al., 2005), increase WUE (yield/total irrigation water) improve crop quality (dos Santos et al., 2007), speed maturation (Gelly, et al., 2004) and may not seriously affect yields (Goldhamer, 1999). Water deficiency primarily affects crops by reducing the dry matter accumulation (Karam et al., 2003) due to reduced dry matter development (Lopez et al. 1996 a, b). These results have been explained on the basis of the plants compensatory mechanisms after experiencing moderate water deficit. The plants suppress biomass production and activate oil and/seed as a survival technique and in the process irrigation water may be saved to a certain degree without much reduction in crop yield (Cui et al., 2008).

The effects of deficit irrigation on different crops have been studied quite extensively for several decades (English and Raja, 1996). Deficit irrigation has been shown to have varying effects on quality attributes of various crops but its specific effect on spearmint oil yield and oil quality is not well understood. Mint is an important essential oil-producing crop grown for use in the pharmaceutical, cosmetic, food and flavor industries (Ram et al., 2006)

This study evaluated the response of spearmint crop to overhead-sprinkler-applied deficit irrigation. The viability of deficit irrigation for spearmint was assessed based on oil yield, oil quality, water use efficiency and dry matter production of a native spearmint crop in the semi arid climate of mid central Washington.

MATERIALS AND METHODS

Site Description

Field experiments were carried out during the 2008 growing season. The experimental fields were located at the Washington State University, Irrigated Agriculture Research and Extension Center (IAREC), Prosser, WA (46.29N 119.75W; 350 m.a.s.l.). The climate at Prosser is semi arid, with annual average precipitation of approximately 195 mm (7.7 inches) and an average annual alfalfa reference ET of 895 mm (35.3 inches). The soil at the experimental site is a Warden Silt Loam with a root zone field capacity of 22.5%, permanent wilting point was 7% and a bulk density of 1.37 g/cm^3.

Experimental Design

The experiment was conducted between early April and mid October 2008. The experiment was a split-block design with five irrigation treatments and 6 pest control treatments in three blocked replications. All plots were 20 ft x 10 ft. The line source sprinkler system had risers spaced 20 ft apart along the length of the field. The irrigation treatments were applied through an overhead line-source sprinkler system running in the middle of the minor blocks. This applied irrigation water at gradually decreasing amounts towards the outer experimental plots. The aim was to develop a well-defined crop response functions to irrigation levels ranging from dry-land to normal irrigation. The pest control treatments were randomized within each block across irrigation treatments. Finally, each irrigation and pest control block was replicated in three randomized units (pest study reported on a different document). In this paper we present results of analysis of the control plots in which standard cultivation practices were adopted for fertilization, weed and pest management during the growing season.

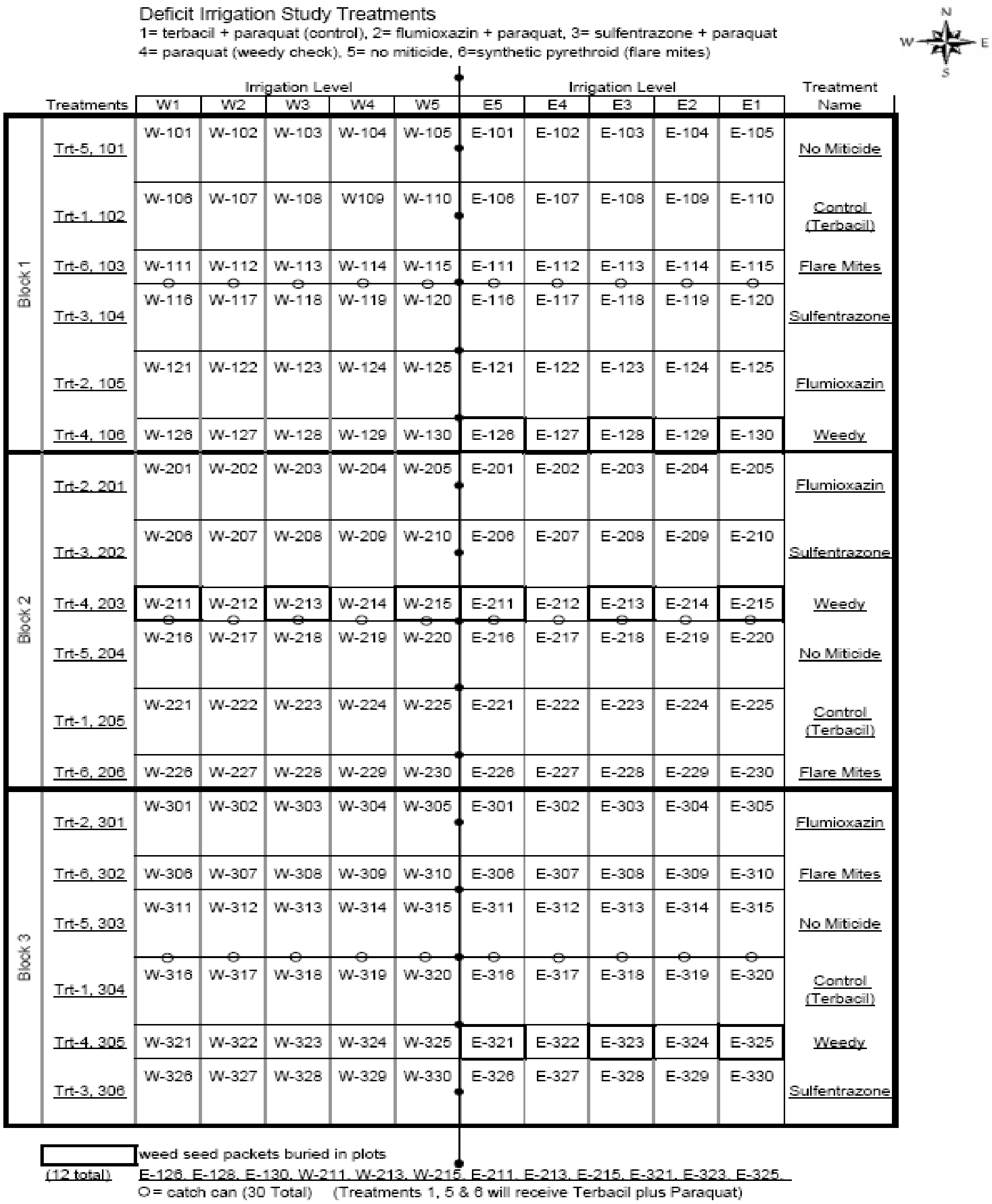

Figure 1. Experimental Plot Plan

Dry Matter and Oil Measurements

During each of two harvests, a representative swath from each plot was harvested using a plot combine harvester and weighed for total yield measurements. The green hay yield for each plot was determined from the weighed swath yield. A 9.5 kg (21 lb) sample of green hay was put in burlap sacks for transport to the lab for drying and analysis. At the second harvest, a smaller sample of the green hay was also taken for mint hay moisture content determination. The 9.5 kg (21 lb) samples were air dried and oil extracted by hydrodistillation and oil quality parameters determined by GC/MS. with Flame Ionization Detector analysis for oil component quantification.

Irrigation Requirement

A neutron scattering moisture gauge (503 DR Hydroprobe; CPN International Inc., Martinez, CA, USA) was used to make weekly soil moisture measurements. Irrigation was then scheduled to replenish the soil water deficit in the center-most (100% irrigation) plots to ensure that these plots didn't suffer any water shortages. The water applied decreased with distance from the central line irrigation line in the field (line-source experiment). Neutron probe readings were made through access tubes that were placed in the center of each plot across the center of the control blocks. The soil water balance was determined to provide scheduling information for each irrigation schedule. Computation and management of the irrigation management was carried out using a simple Excel datasheet. Irrigations were applied two to three times a week depending on level of soil water depletion within the limits of soil water infiltration rate. This was to manage the soil moisture depletion to a narrow margin to maintain the moisture content at a fairly stable range with minimal surface runoff and the 100% ET level maintained at near field capacity. Water deficit across the plots was created by applying lesser volume of water for the same irrigation interval on each irrigation level as dictated by the decreasing application from the line-source sprinkler line.

Harvest Index and Irrigation Water Use Efficiency

Harvest Index (HI) is the proportion of the marketable product to the harvestable product that is used in crop modeling (Stockle and Campbell, 1985; Bryant et al., 1992) to estimate water stress coefficient (Stockle and Campbell, 1985). Harvest index is an indicator of the production efficiency of the crop.

Irrigation Water Use Efficiency (IWUE) is a term used to promote irrigation water efficiency by relating level of crop production (marketable product) to irrigation level (Bos 1980). A high IWUE is an indicator of the increased value of the irrigation water with respect to the marketable product of the crop.

Harvest Index (HI, lbs of oil per acre-in of applied water) and irrigation water use efficiency (*IWUE*, ml oil/in water) were calculated as:

$$HI = \frac{OY}{GHY_{ac}} \qquad \text{(Equation 1)}$$

and,

$$IWUE = \frac{OC \times GHY_p}{I_p} \qquad \text{(Equation 2)}$$

where:

OY = oil yield (lbs/acre),
GHY_{ac} = green hay yield (ton/acre),
OC = oil yield (ml/lb per plot),
GHY_p = green hay yield (lb/plot) and
I_p = seasonal irrigation (in)

Statistical Analysis

To evaluate the effect of irrigation treatments on the oil and hay yield of the spearmint analysis-of-variance (ANOVA) was performed using Statistical Analysis Software (SAS 9.1.2, SAS Institute Ltd., USA) for each harvest of the crop. Regression analyses were also performed to evaluate yield factors and relationships.

RESULTS

Soil Moisture Content

For the 2008 growing season all treatments started with the same soil water content in the soil profile from the winter moisture recharge. Neutron probe readings at the start of the growing season in early April verified uniform soil moisture content in the top 48 inches of the soil profile. There was a cumulative precipitation of only 1.37 inches throughout the growing season. The growing season precipitation was minimal at the experimental location so that the evapotranspiration was mainly from ground water storage and/or irrigation water applied. Applied water ranged from 0.0 – 9.1 inches for the first cutting and 0.0 – 25.3 inches for the second cutting. The difference in irrigation water demands between first and second harvests are due to the profile water storage that was used in the first harvest relative to the second harvest thus a lower application.

The soil water balance scheduling system based on neutron probe measurements provided an accurate scheduling method as noted from the fairly stable profile water contents through the season. Except for the top 12 inches of the soil profile where moisture depletion was also very dependent on the evaporative effects of the weather conditions, the soil moisture depletion was entirely attributable to the crop withdrawal.

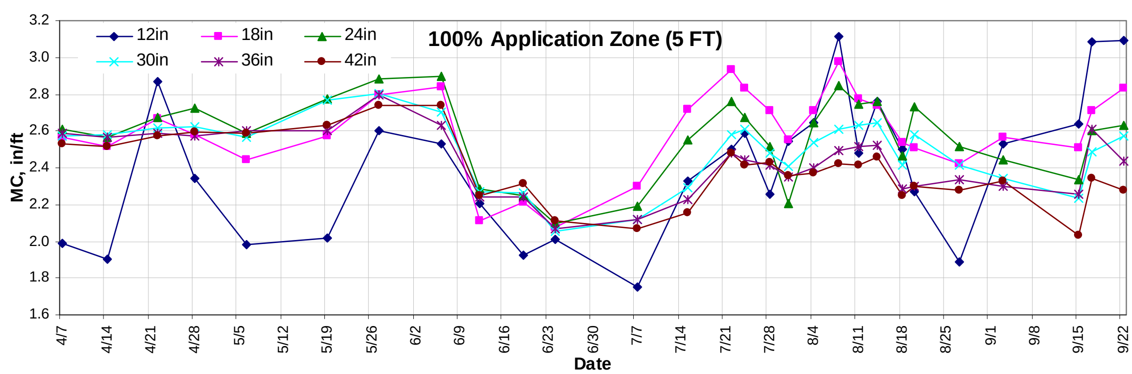

Figure 2. Seasonal Profile Moisture Content on the Scheduling Plots

There was a substantial increase in total irrigation water applied to the second cutting compared to the first cutting. This is attributable to higher evapotranspirative demand due to hotter weather and longer days. The water-stressed plots were able to utilize existing soil moisture, and only saw significant water stress toward the end of the first cutting growth period.

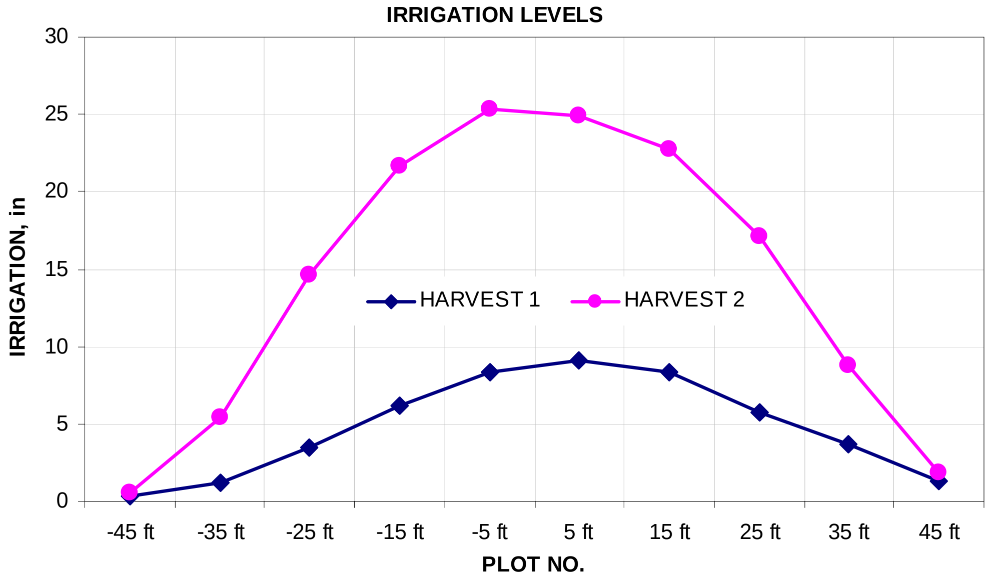

Figure 3. First and Second Harvest Applied Irrigation Water for Each Irrigation Level

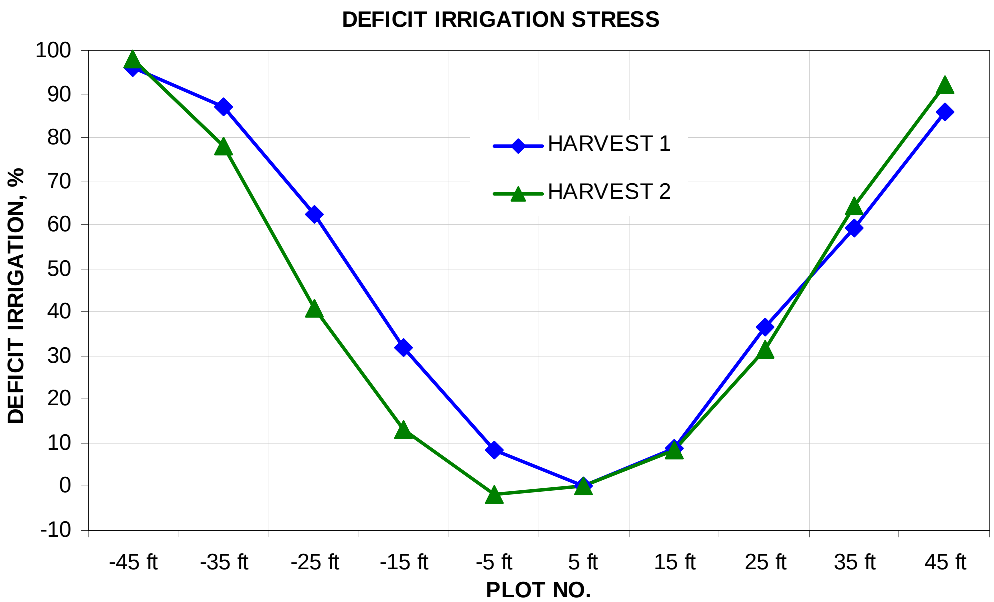

Figure 4. Deficit Irrigation Level (%) in the First and Second Harvests

Oil Quantity Yield

The spearmint oil yield was found to be fairly constant at about 60 lbs/acre for the first harvest (H1) but with a yield decrease from about 38 lbs/acre at full irrigation down to about 20 lbs/acre at 95% deficit irrigation on the second harvest (H2). These show that despite the substantial reduction in water supply to the crop we still obtain good oil yields. This loss of oil yield is estimated to be a fair foregone cost with respect to the extra water requirements to achieve the maximum yields.

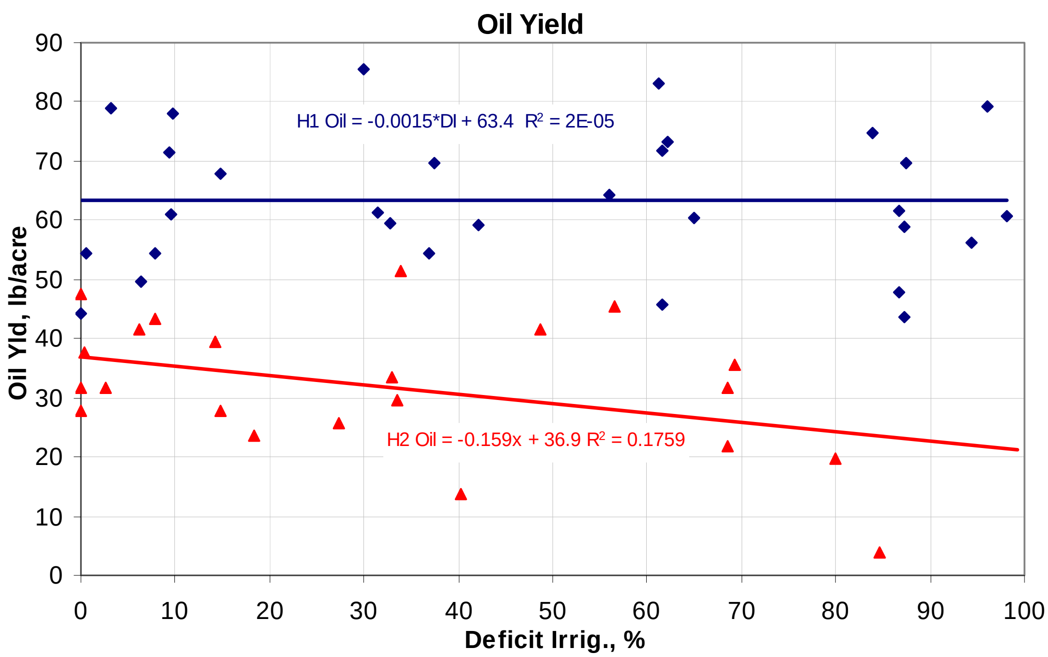

Figure 5. Oil Yields at the Various Deficit Irrigation Levels for H1 and H2

Harvest Index

The harvest index is a measure of the marketable oil yield per ton of harvested mint hay. This "oil concentration" was shown to increase substantially with increasing deficit irrigation. This indicates a possibility for cutting costs in the harvest, transportation and stilling processes if the oil yields per acre and overall oil quality can be maintained with deficit irrigation.

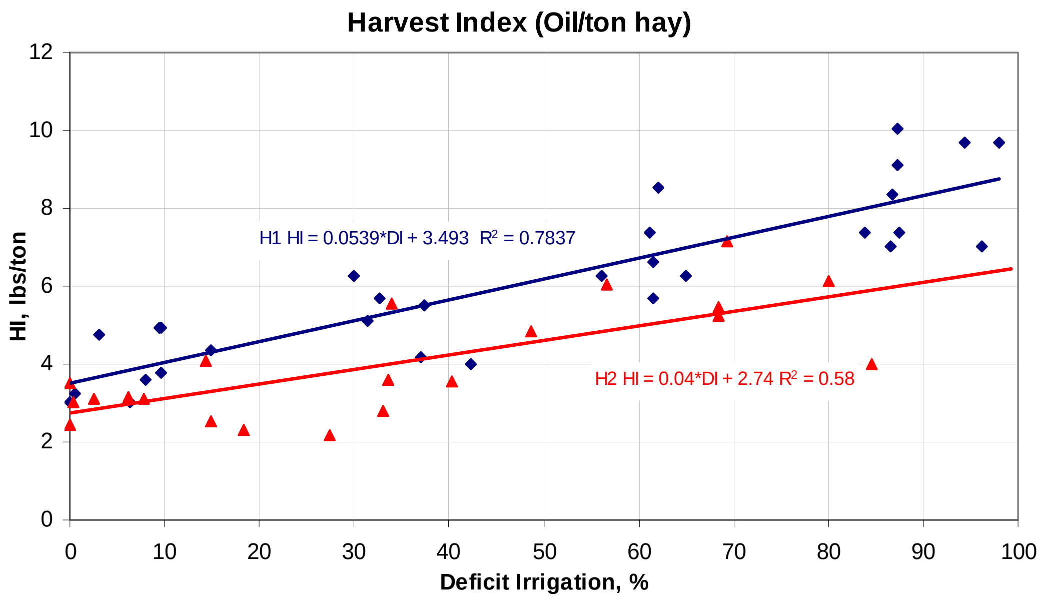

Figure 6. Harvest Indices at the Various Deficit Irrigation Levels for Both Harvests

Hay Yield

Another measure of the spearmint yield is the hay material produced. The mean wet hay yields at the different water stress levels indicate a decreasing biomass production with increasing deficit irrigation. A simple linear regression shows a reduction of between 9 and 11 ton/acre with a decrease in irrigation water of 95% from full irrigation. There were no significant yields at the most stressed plots for the second harvest.

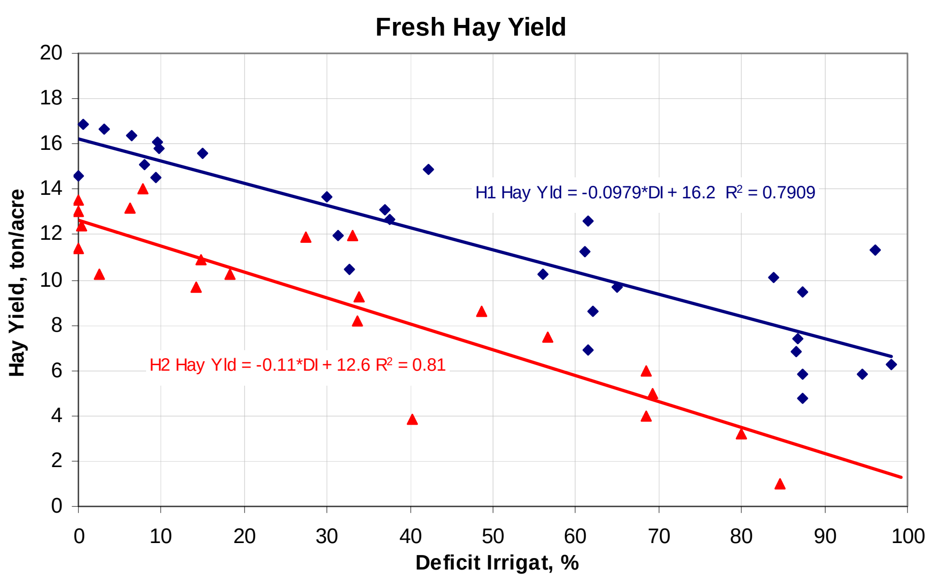

Figure 7. Fresh Hay Yield at the Various Deficit Irrigation Levels for Both Harvests

Irrigation Water Use Efficiency

The irrigation water use efficiency, which indicates the marginal increase in marketable yield from a unit increase in irrigation water, shows an exponential increase during the first harvest (H1) but only a slight increase up to 35% deficit irrigation in the second harvest (H2). This indicates that up to 35% stress level the deficit irrigation has positive effect on the total oil yield but beyond this level we start experiencing a general loss of marketable yield. A linear regression of the average seasonal yield shows a 0.04 ml/in increase in IWUE with increasing stress levels. The irrigation water use efficiency was attributable to the reduced ET and increased oil yields under water stress conditions. These results agree with the general conclusions by Ram Et al. (2006) that the irrigation water use efficiency is higher in the drier regimes and lower in wetter regimes.

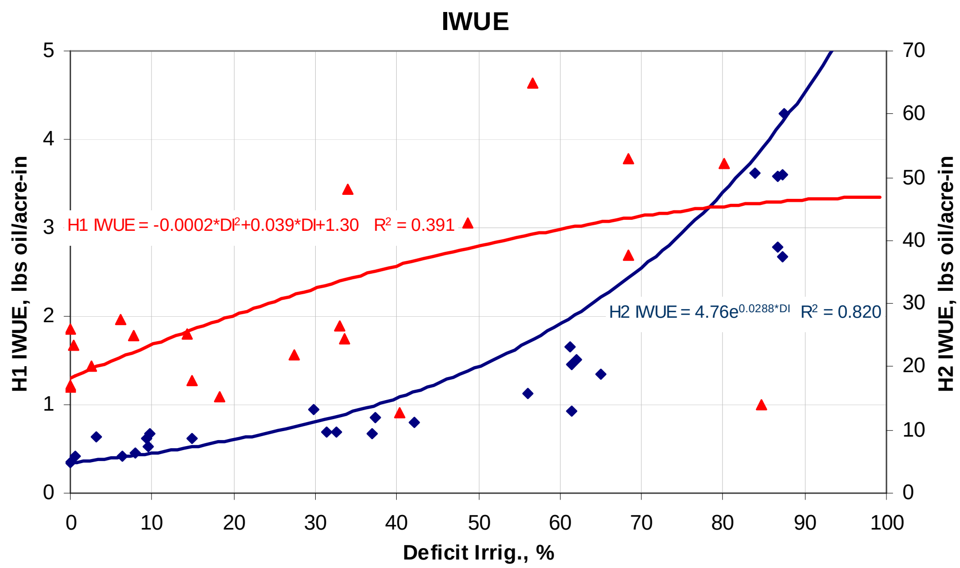

Figure 8. Irrigation Water Use Efficiency (IWUE) at the Various Deficit Irrigation Levels For Both Harvests

Oil Components

The percent composition of the various oil components was measured using gas chromatography with flame ionization detection (FID) standards. The results indicated that the Carvone oil content decreased with increased irrigation whereas the Limonene oil content increased. The increasing Carvone content and decreasing limonene contentsuggest an early/faster maturity of the spearmint with higher water stress. These results concur with those of Gershenzon et al. (2000), Singh and Saini (2008), and Delfine, et al. (2005). The compositions of Myrcene, Cineole, Terpineol, Bourbonene, Caryophylene, Farnesene, and Cubebene were also measured but there were no significant differences across water stress treatments.

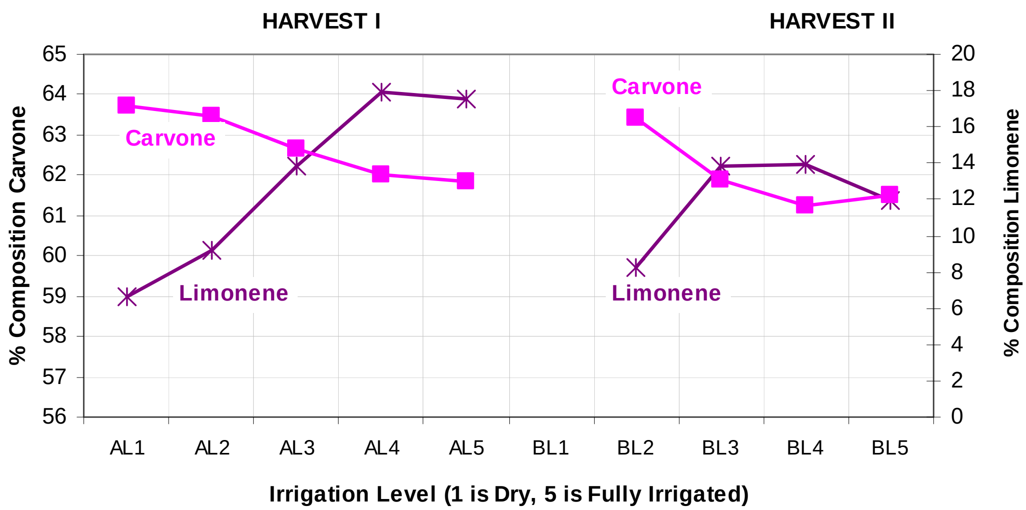

Figure 9. Percent Composition of Carvone and Limonene in the Mint Oil from Both Harvests

DISCUSSION AND CONCLUSIONS

Sustained deficit irrigation clearly decreased hay yields. Oil yields per acre were similar in the first harvest despite the lower hay yields. Oil yields decreased during the second harvest due to severe crop stand loss on the most water stressed plots (over 80% water deficit). The oil content (harvest index) per ton of harvested hay clearly increased with increasing water stress for both harvests. Similar results were found by Crowe (1994) in which he suggested that the more vigorous plants (less water stressed) have higher stem-to-leaf ratios with lower oil concentration and yield. Oil component analysis was also done and it was found that the Carvone content increased and Limonene content decreased while carvone content increased with increasing water stress demonstrating an earlier maturity for water stressed mint. Over time severe deficit irrigation caused a clear decrease in the plant population and stands health and therefore lower total oil yields per acre. It is likely that there is a potential to use deficit irrigation for increased profit mint grower's profits. Lower mint hay yields could mean faster harvesting, lower transportation costs, less time in the still, and lower stilling energy costs. The lower water use would also mean less wear and tear on pumps and irrigation machinery and subsequent lower pumping energy costs. If this can be done while maintaining or improving the overall oil yield and oil quality this should result in improved grower profits. This study thus shows that spearmint oil production harvest index is higher than for the hay yield confirming that oil production can be sustained at a higher level despite a reduction in vegetative growth, as suggested by Girona et al., (2002) and Lavee, et al. (2007). As noted earlier by Scavroni, et al. (2005), though a high dry matter content of spearmint does indicate a higher essential oil yield the relationship is not fully proportional and should not be used as a market measure of oil production. Due to the severe loss of crop stand at higher water deficits post harvest full irrigation on the stressed plots can be implemented to sustain leaf activity and promote nutrient storage and help rejuvenate the crop stand.

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