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Alternating Furrow Irrigation of Peppermint (*Mentha piperita*)

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***Abstract*. Furrow irrigation of peppermint (*Mentha piperita* L.) has certain benefits over sprinkler irrigation, but usually wastes irrigation water. Alternate-furrow irrigation allows frequent application of small amounts of water, which is an advantage over conventional furrow irrigation. In a variation of alternate-furrow irrigation, alternating-furrow irrigation, every other furrow is irrigated at the first irrigation, and the remainder at the second, then this procedure is repeated throughout the season. It is a low-cost, low-energy alternative to sprinkler and center pivot irrigation systems. Our objective was to compare yield and water use of alternating-furrow irrigation with those of conventional every-furrow irrigation for peppermint. Field experiments in 1992 and 1993 indicated that the soil water content was adequate under both irrigation treatments, and the water savings for alternating-furrow irrigation were attributed to less runoff and less evaporation from the soil surface. There was no difference in yield between the systems, although alternating-furrow irrigation required about half of the water applied with the conventional treatment. One limitation of alternating-furrow irrigation occurred near the end of the growing season, when the plants lodged, partially dammed the furrow streams, and made timely furrow advance difficult. This problem was resolved by irrigating every furrow after lodging occurred.**

Peppermint is an important minor crop in the Pacific Northwest where >65% of the nation's 40,000 ha is grown. The essential oil of peppermint is distilled from the plant and used for flavoring in many commercial applications, and the leaves are harvested for herbal tea. Peppermint is a perennial crop that grows anew each spring from rhizomes. In Oregon, an established peppermint field reaches full canopy sometime in June, begins flowering in late July, and is customarily harvested in August according to percent flowering, as demonstrated in the classic field experiments of Bullis et al. (1948).

Intensive management is required in the planting, pest control, fertilization, irrigation, and harvesting of the crop. Peppermint is very sensitive to water stress (Charles et al., 1990; Clark and Menary, 1980; Mitchell, 1997) and, consequently, irrigation is practiced on all of the peppermint acreage in the northwest United States.

Where topography permits, furrow irrigation of peppermint is preferred for its potential to increase yield. Sprinkler irrigation damages the oil gland cells on the leaf, and reduces marketable oil yield by 20% compared with surface irrigation (Croteau, 1977). One limitation of furrow irrigation is the substantial amount of water required to ensure even distribution over the entire field. This results in inherent inefficiencies, as water is lost by excess infiltration at the top of the field and by runoff at the end of the field. Furthermore, even the smallest amount of water that can be applied by furrow irrigation often exceeds the crop's need. There is limited opportunity to improve irrigation efficiency of conventional furrow systems by increasing the interval between irrigation events, since peppermint is very sensitive to water stress.

Frequent irrigation is required during plant emergence in the spring, as peppermint requires moist soil conditions in the top 0.1 m of soil where the rhizomes are located. This surface soil layer has the greatest root density and nutrient uptake. While this surface soil layer must be kept moist, excessive irrigation can result in loss of nutrients via leaching and decrease peppermint oil yield (Mitchell, 1997). Modern alternatives, such as sprinkler and center pivot systems, reduce the amount of water applied per irrigation, but conversion from furrow irrigation to these systems requires large capital expenditures, as well as the increased energy costs associated with pumping.

Alternate-furrow irrigation has been investigated many times as a means to conserve water and consists of irrigating every other furrow of a field while leaving the off furrow dry (Box et al., 1963; Fishbach and Mulliner, 1972; Grimes et al., 1968; Musick and Dusek, 1974; New, 1971). We propose the alternating-furrow irrigation scheme, which consists of irrigating every odd furrow (nos. 1, 3, 5, etc.) during one irrigation event, then irrigating even furrows (nos. 2, 4, 6, etc.) during the following irrigation.

Peppermint should perform best under a surface irrigation system that permits frequent irrigation, yet minimizes excess water application. Our objective was to evaluate the yield and water use of alternating-furrow irrigation against conventional every-furrow irrigation for peppermint production.

Materials and Methods

As in the earlier studies of alternate-furrow irrigation, water was applied at the same time for both the study treatment and the every-furrow control (Crabtree et al., 1985; Musick and Dusek, 1974). Cognizant of how alternating-furrow irrigation may induce water stress in the lower third of the field, we managed irrigation to insure adequate irrigation there. The experiment was replicated four times in a strip-plot design, also called a split-block de-

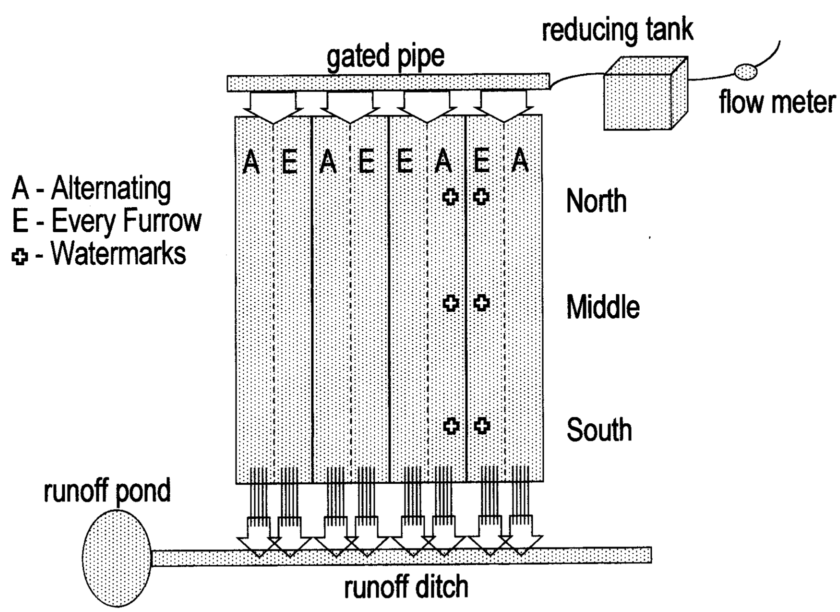

Fig. 1. Schematic of experiment.

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sign (Little and Hills, 1978). Alternating- and every-furrow irrigation methods were randomized as the main treatments and each experimental unit consisted of six furrows 170 m long (Fig. 1). The subunit treatments were three locations of the field at increasing distance from the irrigation source—the top (northern), middle, and bottom (southern) thirds of the field. Because these subunits were locations, they could not be randomized, and thus statistical inferences are not strictly valid for the location treatments. Nevertheless, we chose this design to isolate the effects that location in the field could have on the amount of water applied, since alternate-furrow irrigation may inadequately irrigate the bottom of the field and thereby reduce crop yield (Musick and Dusek, 1974).

The experiments were conducted on a 1.30-ha field, with 0.81 ha of peppermint surrounded by a rye border crop. The soil was a Madras loam (fine-loamy, mixed, mesic, Xerollic Durargid) that is a representative soil for central Oregon. The Madras loam is shallow, with the duripan varying in depth from 0.5 to 0.7 m. In 1989, the field was leveled to a slope of 2.0% with a 170-m irrigation run. Prior to this study, the field had been in a nonirrigated, wheat-fallow cropping system. Peppermint rhizomes were planted on 16 Mar. 1992. The field was sprinkler irrigated until 12 July, after which it was corrugated and the furrow irrigation treatments were imposed. In late Feb. 1993, the peppermint was tilled to a depth of 0.1 m in order to spread rhizomes and thereby increase stand density. In 1993, the first furrow irrigation occurred on 1 July because spring rains made earlier irrigation unnecessary. At this time, the crop was 0.23 m high and not at full canopy. Subsequent furrow irrigation was scheduled when soil water pressure decreased to –70 kPa (Table 1).

Furrows were formed with a rotary corrugator (Fig. 2) to enhance furrow uniformity and minimize damage to the peppermint rhizomes that a furrow shovel causes. A rotary corrugator consists of blades attached to 0.40-m-diameter wheels, adjustable for furrow width, that rotate counter to the direction being pulled. This power-driven implement makes corrugates that are cut, rather than dug, so that they are more rectangular with a smooth, flat bottom. To prevent flying soil and rock, a heavy metal plate is located over the cutting wheels, which pulverize the removed soil and place it on the bed in depths up to 0.05 m, depending on the size and spacing of the corrugates. The furrows were 0.12 m deep and 0.15 m wide at the bottom, on 0.61-m centers.

During each irrigation, the gates on the inlet pipe were adjusted to deliver water at 19 L·min^{-1}. The irrigation was halted when the soil wetting front had progressed halfway across the beds at the end of the field. Runoff measurements were made by channeling all five rows from each plot into a plastic pipe that discharged into a ditch. Water flow measurements were taken hourly from the pipe with a stopwatch, a collection bucket, and a 1000-mL graduated cylinder for precise volume measurement. The flow rate was integrated over time to calculate the runoff volume.

Table 1. Irrigation water applied to peppermint (mm), precipitation (precip; mm), and evapotranspiration (ET; mm) for the period since the prior irrigation in 1992 and 1993.

Date	Every-furrow			Alternating-furrow			Precipitation	ET_{mint}
1992								
16 July		50			25		0	23
17		58			29		0	6
24		53			26		5	33
31		56			28		1	44
7 Aug.		56			28		0	51
12		44			22		0	29
14		64			32		1	10
18		38			19		0	23
Total		419			209		7	219
Water application efficiency [(ET_{mint} – precip)/water applied]		51%			101%			
1993								
	Applied	Runoff	Net	Applied	Runoff	Net		
1 July	81	11	69	32	1	31	0	29
7	55	16	39	30	2	28	3	32
13	42	19	23	15	3	12	0	30
27	77	23	54	46	3	43	11	66
3 Aug.	68	21	47	27	2	25	3	43
6	37	7	30	37	10	27	1	20
11	50	27	23	50	15	35	0	28
Total	409	123	287	238	37	201	18	248
Runoff		30%			16%			
Water application efficiency [(ET_{mint} – precip)/water applied]	56%			97%				

Fig. 2. Rotary corrugator digging furrows in peppermint.

Soil water content was monitored with granular matrix sensors (GMS) (Watermark Soil Moisture Sensor model 200-SS; Irrometer Co., Riverside, Calif.) that measure soil tension (Eldredge et al., 1993). These sensors were previously calibrated to the soil water content for the Madras loam (Mitchell and Shock, 1996). After the furrows were formed, GMS were installed in one replication at the northern, middle, and southern tiers of each treatment, located at 30, 90, and 150 m from the gated pipe. At each location in 1992, 16 GMS were installed in a two-dimensional grid and resistance measurements were taken using a multiplexed datalogger (CR10; Campbell Scientific, Logan, Utah). Profile soil water was calculated by assigning a fraction of the cross-sectional furrow-bed area to each GMS, calculating volumetric water content from GMS resistance readings, and then summing all 16 water contents and dividing by the bed width. In 1993, GMS were placed in one replication in each of the three irrigation treatments at the north, middle, and south sections of the field. The north and south locations had four GMS per treatment, one each at depths of 0.03, 0.10, 0.20, and 0.40 m. The middle location had six GMS per treatment, one each at 0.03, 0.20, 0.40 m, and three additional GMS at 0.10 m.

Independent estimates of alfalfa (*Medicago* *sativa* L.) reference evapotranspiration (ET_{ref}) and daily peppermint water use (ET_{mint}), as well as precipitation, were obtained from an AgriMet weather station, managed by the U.S. Bureau of Reclamation, that was located 500 m from the experimental field. The ET_{mint} was estimated using a Kimberly-modified Penman equation (Docktor, 1994; Wright, 1982) and a crop coefficient (Kc) developed for peppermint at the same locale (Mitchell, 1997). The inflection points for the Kc curve were adjusted using thermal units to arrive at ET_{mint}.

The peppermint was harvested on 26 Aug. 1992 and 17 Aug. 1993. Fresh peppermint hay from three 3.05-m × 3.66-m areas of each subplot was weighed, and ≈4 kg of hay was reserved for oil analysis. Peppermint dry matter was estimated from the fresh mass using moisture content measurements from 1-kg samples for each plot. Oil samples were processed at a small research distillery as described in Mitchell and Crowe (1996). Oil and dry matter yield was compared with season-averaged profile water content using linear correlation analysis.

Results

Irrigation water applied. For all irrigation events, excepting the last two in 1993, less water was applied by the alternating-furrow treatment than by the every-furrow treatment (Table 1). For the last two irrigation events of 1993, equal amounts of water were applied to both treatments in order to overcome blockage of the furrow stream due to lodging of peppermint stems. In mid-July 1993, lodged plants partially dammed furrow streams, causing diversion of the water across the planting bed between furrows. Lodging of peppermint typically occurs in mid-July in central Oregon, which would permit the alternating-furrow treatment to be practiced up to that time. The removal of dry matter at harvest and the decay of residual plant matter prevents lodging from having a harmful effect on stream flow for the following season. In 1992, the 1st-year low-plant population minimized lodging.

In 1992, the total amount of water applied was 209 mm to the alternating-furrow treatment and 419 mm to the every-furrow treatment; in 1993, the values were 238 and 409 mm, respectively (Table 1). Thus, the alternating-furrow treatment received only 53% and 58%, in 1992 and 1993, respectively, of the water applied by the every-furrow treatment. In 1993, the alternating-furrow treatment received 70% (201 mm) of the net water applied (water applied less runoff) to the every-furrow treatment (287 mm).

Soil profile water. The alternating-furrow treatment was as successful as the every-furrow treatment in maintaining adequate soil moisture levels across the irrigation run. In 1992, total profile water varied by field location (Fig. 3). North and middle locations of all treatments had >100 mm water. The south location had less water, as anticipated for the end of the field. Despite roughly half the water use of the every-furrow treatment, the alternating-furrow treatment maintained similar soil moisture across the entire length of the plots.

In 1993, soil water tension indicated adequate moisture for both irrigation treatments, with readings ranging from 0 to –100 kPa during the entire season (Fig. 4).

Oil and dry matter yields. Oil and dry matter yields were not significantly affected by method of irrigation (Table 2). The 1992 oil yield (48.2 and 50.9 $kg \cdot ha^{-1}$) compared well with regional 1st-growing-year yields, which are frequently lower than average. The 1993 oil yield range of 59 to 65 $kg \cdot ha^{-1}$ compared well with average oil yields in central Oregon, which vary between 60 and 75 $kg \cdot ha^{-1}$. Thus, the yields were typical of yields in the region. The equivalent yields of the alternating-furrow irrigation treatment were achieved in spite of the lower applications of water.

In 1992, dry matter varied with field location ($P \leq 0.05$), with yields of 3.00 $Mg \cdot ha^{-1}$ at the top and middle of the field, and 2.57 $Mg \cdot ha^{-1}$ at the bottom of the field. Water stress typically reduces dry matter in peppermint, as mentioned earlier, and the bottom (south) end of the field received less water, as indicated by the soil water data above. In fact, the 1992 dry matter (averaged for each irrigation × location treatment over four replications) and season-averaged total profile water were highly correlated ($r = 0.80$).

The 1993 dry matter did not differ between locations. Furthermore, in 1993, no dry matter–soil water correlation existed, implying that the soil moisture was either not limiting or else was uniform across treatment and location.

Discussion

In every-furrow irrigation, by the time water reaches the end of the irrigation run, more water than necessary is likely to have infiltrated at the top of the run, resulting in excess

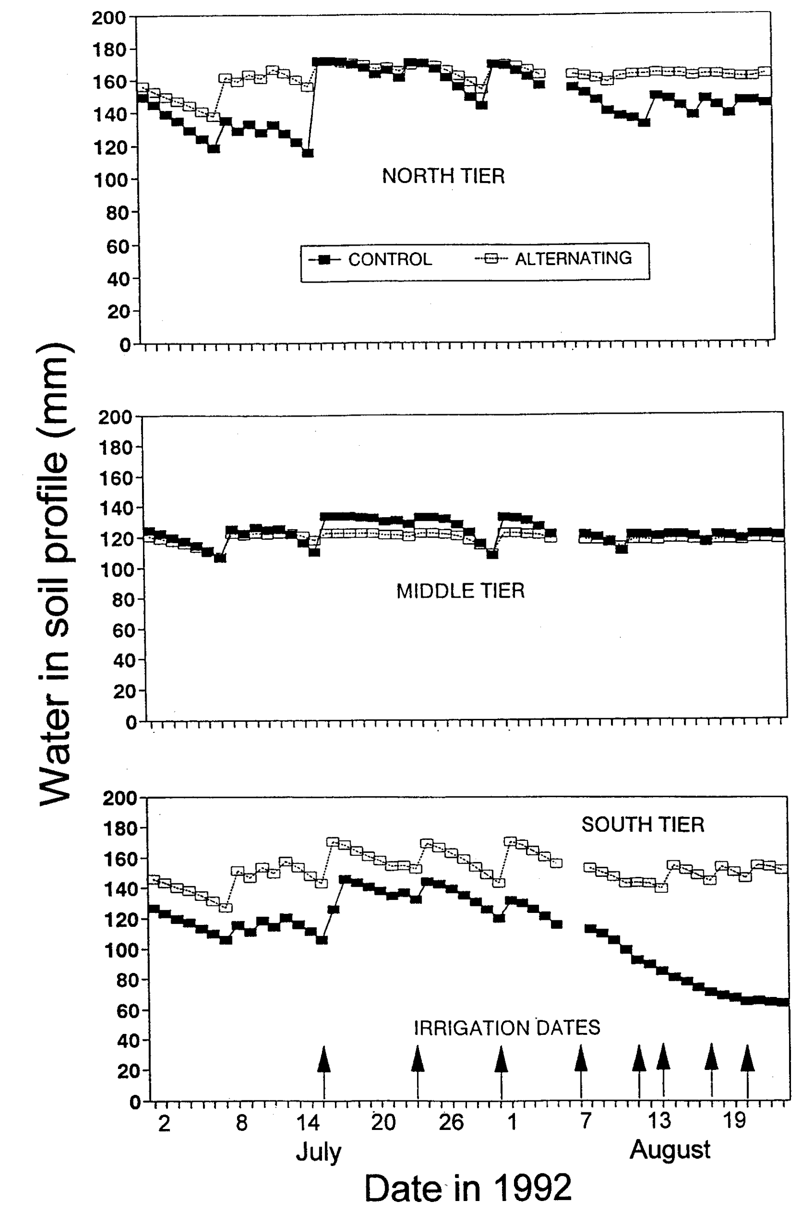

Fig. 3. Soil water in the profile for the alternating-furrow and every-furrow treatments in 1992. Arrows indicate irrigation events.

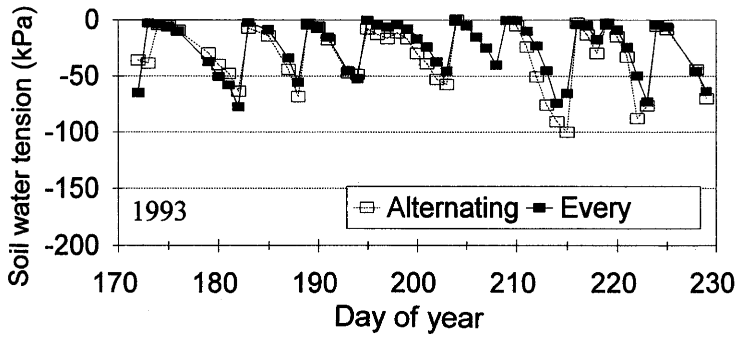

Fig. 4. Soil water tension at 100-mm depth for the alternating-furrow and every-furrow treatments in 1993. Sudden positive changes in tension indicate irrigation events.

Table 2. Effects of method of irrigation on yield of peppermint oil ($kg \cdot ha^{-1}$) and dry matter ($Mg \cdot ha^{-1}$) in 1992 and 1993.

		Method of irrigation		Difference significant
Yield	Year	Alternating	Every-furrow	at $P \leq$
Oil	1992	50.9	48.2	0.79
	1993	65.6	59.2	0.10
Dry matter	1992	3.19	2.52	0.09
	1993	3.97	3.87	0.93

water. In addition, applying enough water for the stream to advance the entire distance invariably results in water being lost as runoff. In contrast, alternating-furrow irrigation circumvents these inefficiencies by halving the amount of water applied and thus reducing runoff. Water application efficiency, calculated as (ET_{mint} – precipitation) divided by the amount of water applied, was very high for the alternating-furrow treatment (101% and 97% for 1992 and 1993, respectively), whereas the every-furrow treatment achieved only 51% and 56% efficiency in 1992 and 1993, respectively. The every-furrow application efficiencies are within the typical 50% to 70% range for surface irrigation, according to the National Research Council (1993, p. 390).

Alternating-furrow irrigation is not unique in producing equivalent yields with irrigation amounts less than estimated crop requirement; this has been observed in other high-efficiency irrigation systems. In a study on buried trickle irrigation of tomatoes (*Lycopersicon esculentum* Mill.), Phene et al. (1982) achieved high yield with 25% less water than required to replace estimated consumptive use. Commenting on this and similar studies, English et al. (1990) attributed the phenomenon to reduced soil evaporation, less drainage, and better nutrient availability.

Reduced drainage may also contribute to the high efficiency of alternating-furrow irrigation when the greater distance between the irrigated furrows prevents their wetting fronts from meeting. Should the wetting fronts meet, as they do in every-furrow irrigation, the lateral flow of water is suspended and water flows almost exclusively downward, thus increasing drainage.

Additionally, water loss from evaporation is apparently less under alternating-furrow than under every-furrow irrigation. Since water is applied to only half the furrows, the evaporative surface in alternating-furrow irrigation is much less than that of every-furrow irrigation. Our observation was that slightly more than half of the soil surface was wetted in alternating-furrow irrigation vs. the entire surface in every-furrow irrigation. Moreover, in our study, the peppermint crop did not reach full canopy until late July in 1992 and mid-July in 1993; this stage was delayed relative to most crops, due to the peppermint's establishment in 1992 and its spring tillage in 1993. Exposure of the soil surface during these seasons may have compounded the potential for greater evaporative losses under the every-furrow treatment.

Although the extrapolation of our results may be limited by this study's relatively short irrigation run (170 m) and moderate slope (2%), these good results are not unique. Several investigators studied alternate-furrow irrigation in the 1960s and early 1970s with results similar to ours: water was saved compared to every-furrow irrigation and yield was usually, but not always, unaffected in a wide variety of crops, including maize, cotton, grain sorghum, potatoes, sugar beets, and soybeans (Box et al., 1963; Crabtree et al., 1985; Fishbach and Mulliner, 1972; Grimes et al., 1968; Musick and Dusek, 1974; New, 1971). They cautioned that the practice could have a deleterious effect on water infiltration and yield in the lower one-fourth to one-half of the field, so that it was not recommended for soils with low permeability, or wide (presumably >1 m) furrow spacing. Decreases in yield under alternate-furrow irrigation were acceptable for the water savings in some instances. The lack of effect on yield in our peppermint trials makes alternating-furrow irrigation desirable rather than just tolerable.

In conclusion, peppermint oil and dry matter yields were not reduced, yet less water was used in the maintenance of adequate soil moisture under alternating-furrow compared with every-furrow irrigation. Irrigation requirements with this system may be less and perhaps should be reevaluated. Lodging may make it necessary to switch back from alternating-furrow to every-furrow irrigation towards the end of the growing season in peppermint, but should have no carry-over effect for the following season.

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