IRRIGATION AND NITROGEN FERTILITY OF PEPPERMINT IN CENTRAL OREGON, I. YIELD AND OIL QUALITY*

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Abstract

This report summarizes two years of an experiment to test the effects of irrigation and nitrogen (N) fertility on peppermint at the Central Oregon Agricultural Research Center in Madras, OR. In 1992 and 1993, the dry matter and oil yields were greatly affected by irrigation level and N-fertilizer level. Both oil concentration and oil quality were influenced by irrigation level, but not by N rate.

Introduction

It is conceivable that the optimal irrigation management of peppermint may include water stress to produce more oil yield. Many peppermint growers in the Northwest believe that a certain amount of water stress may improve peppermint oil yields (Weber, 1978). Loomis (1976) proposed a stress management theory to increase leaf retention. However, other scientists have found that peppermint produces optimum yield at highest levels of irrigation (Clark and Menary, 1980). Preliminary results of peppermint irrigation studies at Purdue University suggest that full irrigation is the optimal management practice (Simon and Joly, 1989). Scientists have also found that reducing irrigation early in the season did not seem to stress the peppermint plant (Clark and Menary, 1980).

With growing concern over environmental pollution, including agricultural contributions of nitrogen (N) in the form of nitrate to groundwater, it is imperative to know the N rates for optimum economic yield, as well as N rates for minimal groundwater contamination. The present N-fertilization practice for central Oregon is to apply a total of 250-300 lb/ac of N to a peppermint crop divided into several applications. Although peppermint yields best under high N fertilization, the fact that multiple applications are practiced suggests that much of the N is lost. Only 150 lb/ac of N is accounted for by the above-ground plant (Hee, 1974). The remaining 100-150 lb/ac may be lost below the root zone due to excessive irrigation. The process of nitrification transforms fertilizer N to nitrate, a very soluble N form which is then susceptible to being carried below the root zone by excess applied water.

Fertilizers that release nitrate slowly have the promise of reducing nitrate leaching. Supplemental additions of N in the irrigation water have been found to increase oil yield under some situations (Heuttig, 1969). This is now a common practice among growers. The yield response to summer applied N may result from applying N as the plant requires it. This suggests that N may be washed out of the root zone by rainfall or excess irrigation. If

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excess irrigation is responsible for N loss, then the use of a slowly soluble N fertilizer should increase the amount of N available to the plant.

To answer the questions of slow-release N fertilizer requires knowledge of the quantity of water and N fertilizer that is required for optimal oil yield. Tested together, we will be able to look at the irrigation and nitrogen interaction. The first report will disclose the yield effects, while the second report will cover nitrate leaching.

Objectives

The objectives of the experiment were to investigate management practices of irrigation, nitrogen fertilizer rates, split applications, and slow-release fertilizer.

Materials and Methods

Experimental Design

The research was carried out at the Central Oregon. Agricultural Research Center (COARC) in Madras, Oregon on second-year peppermint, variety 'Murray'. The peppermint was planted in March 1991, and tilled to enhance stand in February 1992. A line-source sprinkler system was set up to control applied water to the experimental plot. The line- source system is a low cost method for applying water at different rates to different sectors of the plot (Hanks et al., 1976). The trial was replicated eight times, and nitrogen treatments were super-imposed on the irrigation treatment in a split block (or strip plot) design. Plots were 25 X 8 ft with the longest side parallel to the sprinkler line.

In 1993, the experiment was truncated to four replications, and another single-year experiment was established on a nearby uniform stand of peppermint to avoid the residual effects of nitrogen fertilizer from the previous years. The original experiment will be called the multi-year experiment since it will have the same the fertility and irrigation practices over several years. The single-year experiment was designed in the same fashion, except that it had smaller plot measuring 9 X 8 ft, and an additional NO treatment of no nitrogen fertilizer. In February 1993, two of the four replications of the multi-year experiment were tilled to enhance stand density.

In 1992, irrigation water was applied at five rates based on water loss from the 4th irrigation level, with 15 receiving full irrigation and the others the following amounts: 14 = 83 percent of 15, 13 = 67 percent, 12 = 52 percent, and Il = 50 percent. In 1993, the 14 level was irrigated according to depletion reported by the Bureau of Reclamation's AgriMet weather system until mid-June, when soil water content indicated that following that irrigation scheme may result in excess water applied. Thereafter, water was applied according to depletion.

In both years, irrigation occurred twice weekly during June and July. Catch cans were used to monitor the amounts of applied water. In 1992, soil water content was measured with Watermark sensors five days per week and with the neutron probe twice weekly. Sensors were buried at three depths: 2 to 4 inches, 6 to 8 inches, and 20 to 22 inches. Ten sets of sensors were applied in two replications of the five irrigation levels. Neutron meter access tubes were installed in each of five irrigation levels of 12 N treatments. The meter measured soil water content in 6-inch increments, with the total depth varying from 2 to 7 ft , depending on the strength of the hardpan layer at the 2-ft depth.

In 1993, three sets of 48 sensors were attached to a datalogger as described by Light et al. (1993). Sensors were buried the same depths as above with the addition of sensors buried horizontally 0.5 inches below the soil surface. In 1993, the neutron measurement were taken every other week.

Fertility Treatments

The N fertility treatments were applied to the peppermint irrigation experiment. Treatment fertilizers were applied in the spring with additional differential rates were applied in summer (Table 1). For spring application, nitrogen was applied as urea (46-0-0) with a 3-ft wide fertilizer spreader which was calibrated to the listed rates. In 1992, aqueous urea-ammonia solution (32-0-0) was applied with a hand-held sprayer during summer irrigations to simulated irrigation-applied fertilizer. In the October 1992, 50 lb/ac of N was applied to all the plots of both the single and multi-year experiments. In 1993, the supplemental fertilizer was applied as urea. Soil N measurements were taken in March, throughout the summer, and after fall growth.

The 1992 harvest was on July 29, approximately 10 days earlier that usual. In 1993, the single-year experiment was harvested on August 10. The multi-year experiment was harvested according to maturity level: Il and 12 of the non-tilled section were harvested on August 9, treatments 13, I4,and 15 were harvested on August 12, and the tilled blocks were harvested August 16.

Table 1. Fertilizer trial rates, Madras, OR, 1991-1993.

Fertilizer plot	Spring	Summer	Total
		--lb/ac-------	
N0*	0	0	0
Ni	50	0	50
N2	150	0	150
N3	250	0	250
N4	250	100**	350
N5 PCU***	250	0	250
N6	150	100**	250

* treatment exists only in single year experiment and in an extra PCAPS plot
** split application of 50 lb/ac each
*** polymer-coated urea

Sub samples of the plot were 40 inches wide by 25 ft long, which produced enough peppermint forage to distill in burlap sacks. Due to time and cost considerations, only three replications of the nitrogen experiment and three replications of the irrigation experiment were used for peppermint oil analysis. Sacked peppermint was quickly dried in the open air, and stored indoors until distillation. In 1992, there was a delay in peppermint oil distilling until November due to lack of availability of the USDA facility in Corvallis, OR. In 1993, the oil was distilled at a small-scale research distillery at COARC. The 1992 oil quality analysis was performed by A.M. Todd, Kalamazoo, Michigan and the 1993 analysis by Wm. Lehman Inc., Bremen, Indiana.

Results

The 1992 yield data for irrigation effects across all N treatments (Table 2) shows that the highest yield was achieved with the maximum irrigation rate (15). In 1993, irrigation was managed so that 15 would have excess water, resulting in 14 having the maximum yield for both the single and multi-year experiments. In answer to the question of whether water stress may increase yield: the 1992 data produced no evidence that it does, and the 1993 data indicated that excess irrigation may have reduced yield by lowering the oil concentration. In 1993, the 14 treatment had the highest yields in both the single-year and multi-year experiments, but the mean tests did not indicate a significant difference in dry matter yield between the 13, 14, and IS treatments.

Table 2. Irrigation level effects on peppermint dry matter yield, oil yield, and concentration for 1992 and 1993 and the 1993 single year experiment, Madras, OR. Column means followed by a common letter are not significantly different at the a =0.05 level.

Ratio		Dry Matter Yield			Oil Yield			Oil/Dry Matter		
Irrigation Level			multi	single		multi	single		multi	single
		1992	1993	1993	1992	1993	1993	1992	1993	1993
	-percent-	-------]			--------- lb/ac --------				----percent	
Il	50	793 a	5012 a	1975 a	24.2 a	34.5 a	21.5 a	3.05	0.69	1.09
12	52	1098 b	4538 a	3039 a	28.9 a	41.6 a	27.5 a	2.63	0.92	0.91
13	67	1362 be	6796 b	5280 b	31.8 a	64.7 b	37.8 ab	2.34	0.95	0.72
14	83	2055 d	6638 b	4954 b	30.1 a	69.2 b	61.8 c	1.47	1.04	1.24
15	100	2446 e	6744 b	5671 b	46.2 b	60.6 b	55.9 be	1.90	0.90	0.99

Table 3. Impact of Irrigation Level on Peppermint Oil Quality, Madras, OR, 1992.

Level Constituents	Signif.	Change	I1	I2	I3	I4	I5
			Irrigation				
			%				
MENTHOL	*	-	40.95	40.12	39.23	39.54	39.77
MENTHONE	**	+	13.94	16.12	18.45	20.57	20.84
HEADS	**	-	13.34	12.68	12.37	11.63	11.04
CINEOLE	**	-	6.78	6.50	6.37	6.02	5.78
ESTER	**	-	7.02	5.77	5.18	4.74	4.38
MENTHOFURAN	**	?	2.64	3.76	3.77	3.10	3.45
NEOMENTHOL	**	-	4.38	4.02	3.70	3.53	3.39
D-ISOMENTHONE	**	+	2.60	2.69	2.78	2.89	2.80
GERMANCRENE-D	**	+	2.19	2.22	2.34	2.42	2.62
B-CARYOPHYLLENE	**	-	3.07	2.79	2.68	2.54	2.46
BETA PINENE	*	-	1.95	1.88	1.87	1.79	1.72
LIMONENE	**	-	2.20	2.13	1.97	1.70	1.56
ALPHA PINENE	*	-	0.95	0.91	0.92	0.88	0.84
PULEGONE	*	?	0.84	1.14	1.04	0.82	0.83
B-BOURBONENE	**	-	0.85	0.75	0.66	0.60	0.59
3-OCTANOL	**	+	0.18	0.19	0.20	0.24	0.26
MYRCENE	**	-	0.28	0.28	0.28	0.26	0.25
PARA CYMENE	**	-	0.21	0.18	0.12	0.14	0.10
			MEAN				
SABINENE HYDRATE	NS		2.18				
PIPERTONE	NS		0.42				
GAMMA TERPINENE	NS		0.25				
TERPINOL	NS		0.23				
ALPHA TERPINENE	NS		0.13				

* significant at the 5%, ** at the 1% level, NS not significantly different.
\+ or - is the increase/decrease in concentration with increasing irrigation.

Figure 1 shows how oil and dry-matter yield were influenced by irrigation level. The treatments I3, I4, and I5 were not significantly different, yet there appearred to be a decrease in oil content for I5, which resulted from a decrease in oil concentration for that treatment. Possible explanations of the lower concentration (Table 2) are a greater stem biomass induce by high irrigation and/or the oil gland damage by sprinkler irrigation (Croteau, 1977).

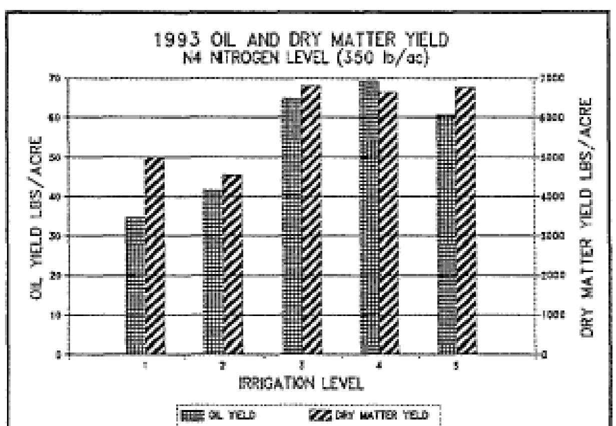

Figure 1. Irrigation effects on oil and dry matter yields for 350 lb/ac treatment for the 1993 single-year experiment, Madras, OR.

In 1992, the irrigation-rate yield data (Table 2) showed that the highest yield was achieved with the maximum irrigation rate (I5). Dry matter yield was better differentiated between treatments than oil yield. This can be explained by the increase in oil/dry matter concentration. Such an increase in concentration is usually associated with maturity (Bullis et al., 1948; White et al., 1987), which may have been induced by water stress. However, the concentration effects differed by the year. In 1992, the concentration increased with stress (lower irrigation), but in 1993 the concentration was highest at the optimal irrigation level, 14 (Table 2). This was true for both the single and multi-year experiments. This effect is also illustrated in Figure 3, which compares dry matter with oil yield for 1993 yield data. Differences in weather during the two years may account for this discrepancy between years, with 1992 being warmer than normal, and 1993 cooler than normal with more precipitation. Hence, the overall concentrations were lower throughout the region in 1993 probably due to more stem growth and lesser heat units. The stress-induced maturity-concentration effect of 1992 was not seen in 1993 because of differential harvest dates, or the lack of maturity difference due to cooler weather.

Oil Quality

In 1992, the irrigation variable affected 17 out of 23 oil constituents (Table 3), including the principal components of menthol, menthone, esters, and menthofuran. In 1993, three of the four constituents tested were signifantly affected by irrigation level with menthofuran being the exception. In its influence on oil quality constituents, water stress appeared to be related to maturity. During the period up to 50 percent bloom, the oil may increase in menthol, esters, and menthofuran (Bullis et al., 1948; White et al., 1987). These same constituents increase with irrigation level (Table 3 and Figure 2). The ester content was the most sensitive parameter of irrigation stress or maturity. Menthofuran was significantly affected by irrigation level in 1992, but not in 1993, and in both years it is hard to interpret because it did not vary uniformly (Figure 2). Neither the substantial water stress imposed on Il nor the nitrogen fertility treatments made oil quality undesirable.

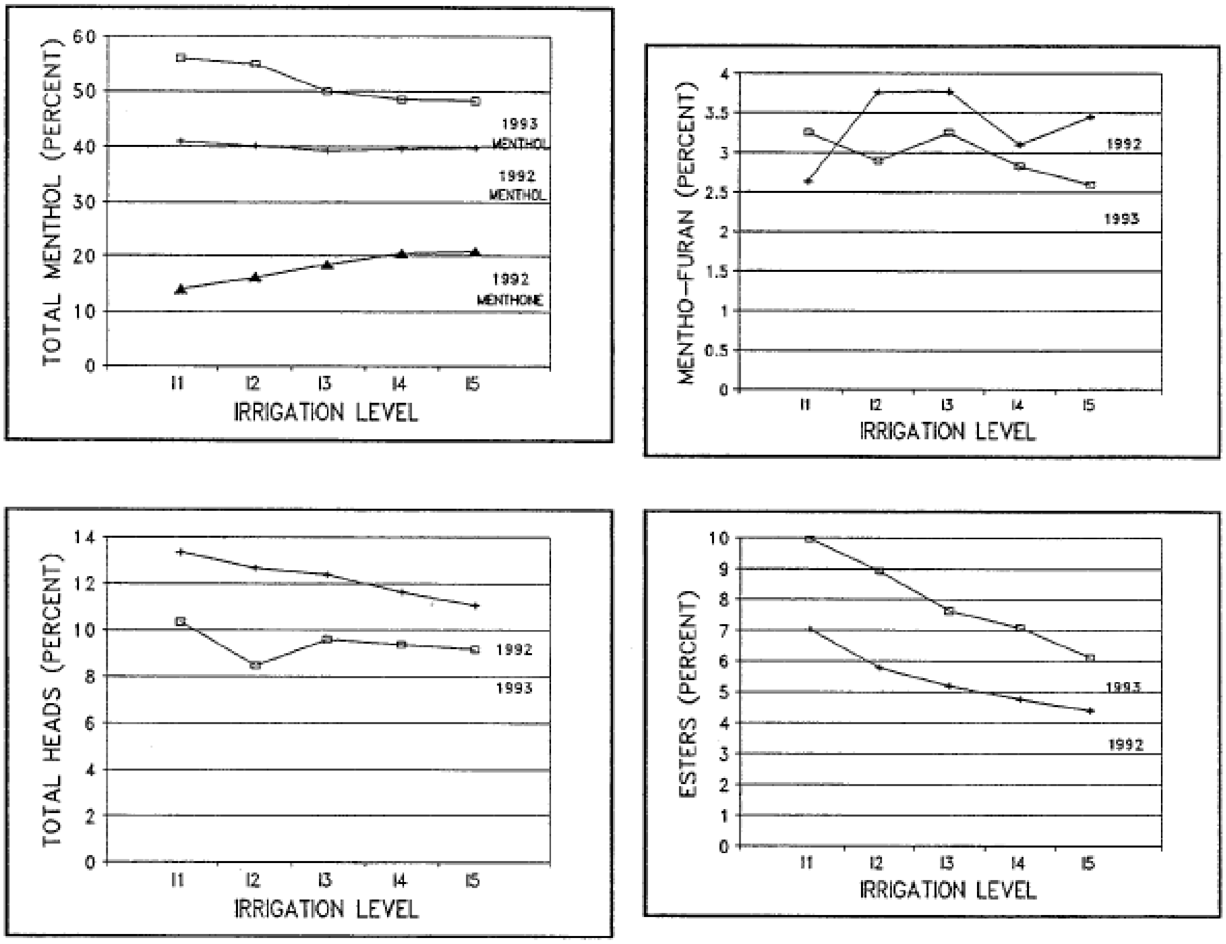

Figure 2. Peppermint oil constituents menthol, menthone, menthofuran, total heads, and esters as influenced by irrigation treatments for 1992 and 1993, Madras, OR.

Nitrate Fertility and Irrigation Interactions

Dry matter yield data are shown in Figures 3, 4, and 5 for all irrigation and nitrogen treatments over both years. In 1992, the supplemental summer nitrate application treatments (N4 and N6) were the top yielding treatments for I5, which was the optimal irrigation treatment that year (Figure 3 and 4). In 1993, the N3 (250 lb/ac) treatment yielded better than the higher rates for most irrigation levels including excess irrigation (I5). But as Figure 6 shows, the polymer-coated urea (N5) and the split application treatment (N4) yielded better than the single application (N3) for the high irrigation rate only. This is attributable to leaching that occurred under high irrigation, which made the slow-release and split-applied methods favorable for plant growth. In the absence of leaching, a single spring application was sufficient.

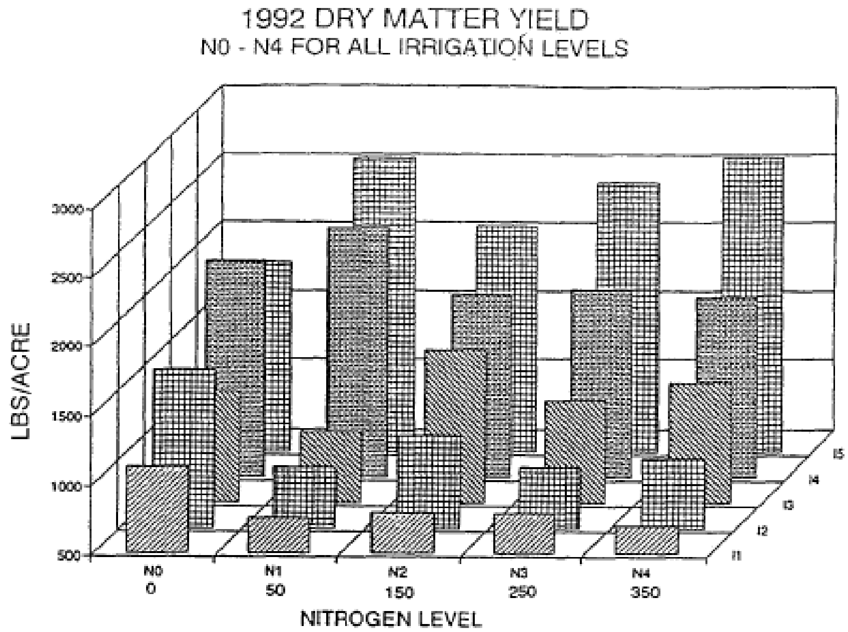

Figure 3. Peppermint dry-matter yield for nitrogen fertilizer rates, Madras, OR, 1992.

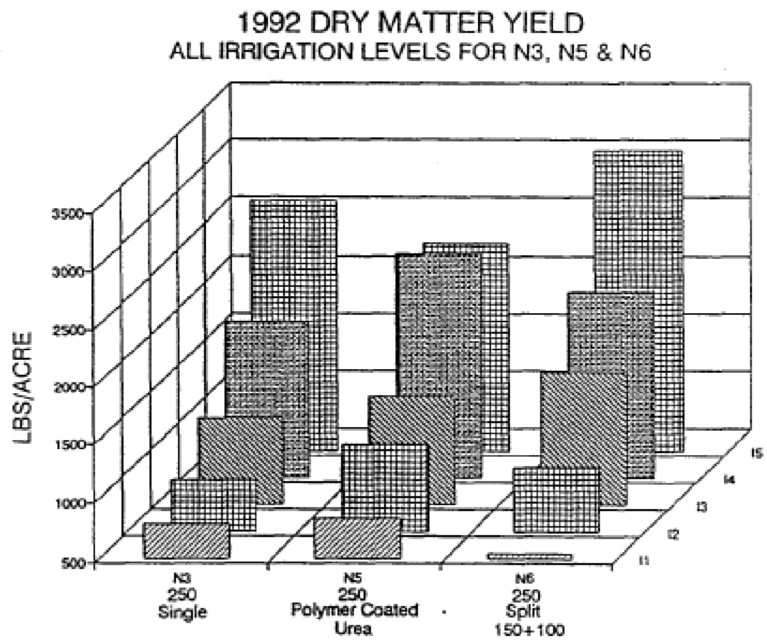

Figure 4. Peppermint dry-matter yield for nitrogen applied in a single spring application, as polymer-coated urea, and as a split-application, Madras, OR, 1992.

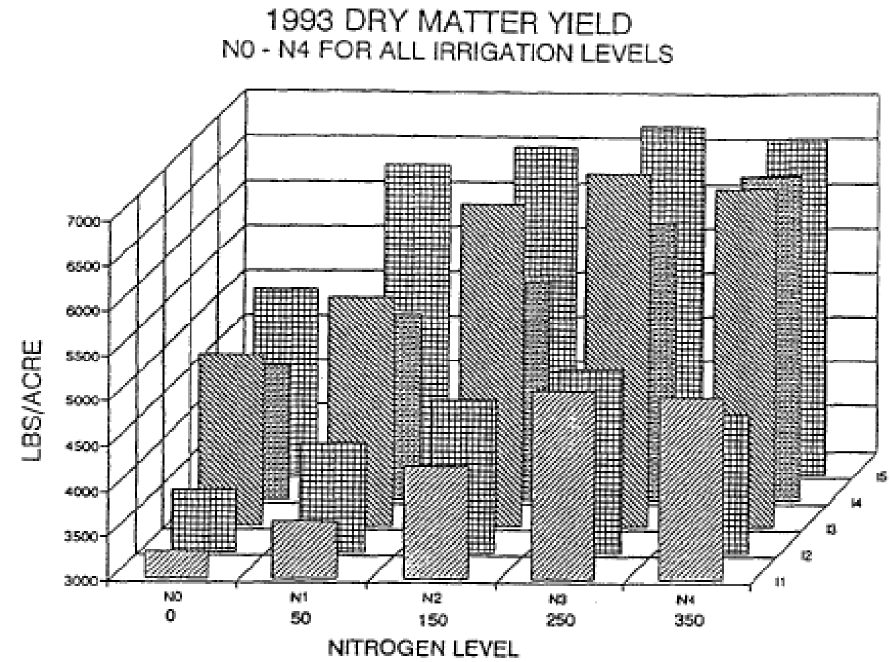

Figure 5. Peppermint dry-matter yield for nitrogen fertilizer rates, Madras, OR, 1993.

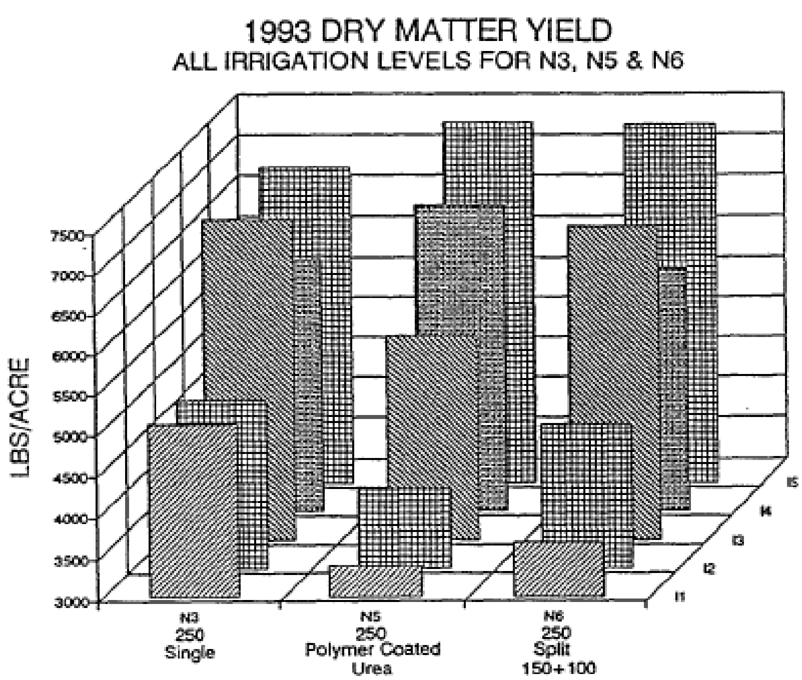

Figure 6. Peppermint dry-matter yield for nitrogen applied in a single spring application, as polymer-coated urea, and as a split-application, Madras, OR, 1993.

At low irrigation levels, low rates of N performed better than their counterparts due to a probable salinity effect of the fertilizer that can depress yield. Dow et al. (1981) showed that peppermint is salt sensitive at soil salinities of 2 mmhos/cm, which may have occurred in areas of the root zone after the fertilizer was applied. At the highest irrigation level, the polymer-coated urea treatment (N5) yielded slightly less than the 250-1b/ac control (N3), but it also had less N applied (225 lb/ac). At lower irrigation levels, N5 yielded more than all but the lowest N treatment. This supports our field observations that the polymer-coated urea avoided a salinity effect that cause mild necrosis in some leaf margins for the high N treatments in early June.

Soil Nitrogen Dynamics of Slow-release Fertilizer

Periodic soil sampling of the top 12 inches showed the amount of N in the soil before, during, and after the 1992 growing season. Comparison of the soil inorganic N for treatments N5 (Figure 7) and N3 (Figure 8) showed the polymer-coated urea delayed the release of N to the soil. Initially, in March 1992, the N5 had more residual soil N, but then N5 showed lower N until July 22. After July 22, the N5 treatment had more soil N than N3. Unfortunately, harvest occurred July 29, so the crop had little time to take advantage of the higher soil N of the polymer-coated urea. In comparison to N1 (50 lb/ac), the N5 treatment showed more soil N for all dates except June 17 (Figure 9). The August 11 samples showed a higher concentration for the N5 soil. (Total N is reported instead of nitrate, because our soil consistently tested over 90 percent nitrate in total inorganic N.)

Following harvest, some polymer-coated urea was observed still in pellet form. Sampling of the surface layer (0 to 0.5 inches) of the soil in August (Figure 10) showed over 50 lb/ac of N in that layer. Figure 10 also shows a 200 lb/ac drop in soil N during the post-harvest period from August to November. These 200 lb/ac may have been assimilated by the plant, or leached below the root zone. Total N appeared to move downward for the N5 under high irrigation, IS, where the N at the 12 to 24-inch layer increased in time, while N in the 0 to 12-inch layer decreased over the same period. This is typical for other N treatments as well.

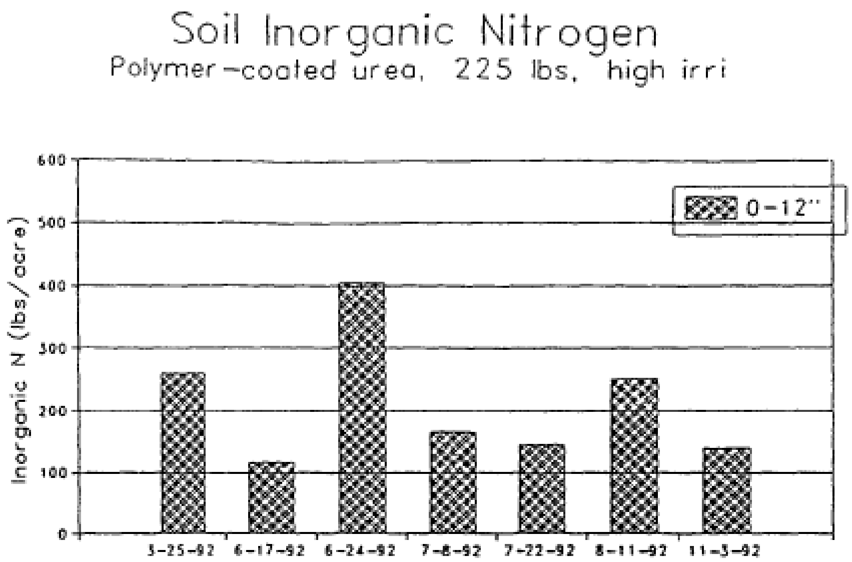

Figure 7. Soil inorganic N in top foot under 250 lb/ac polymer-coated urea, Madras, OR, 1992. Harvest occurred on July 29, 1992.

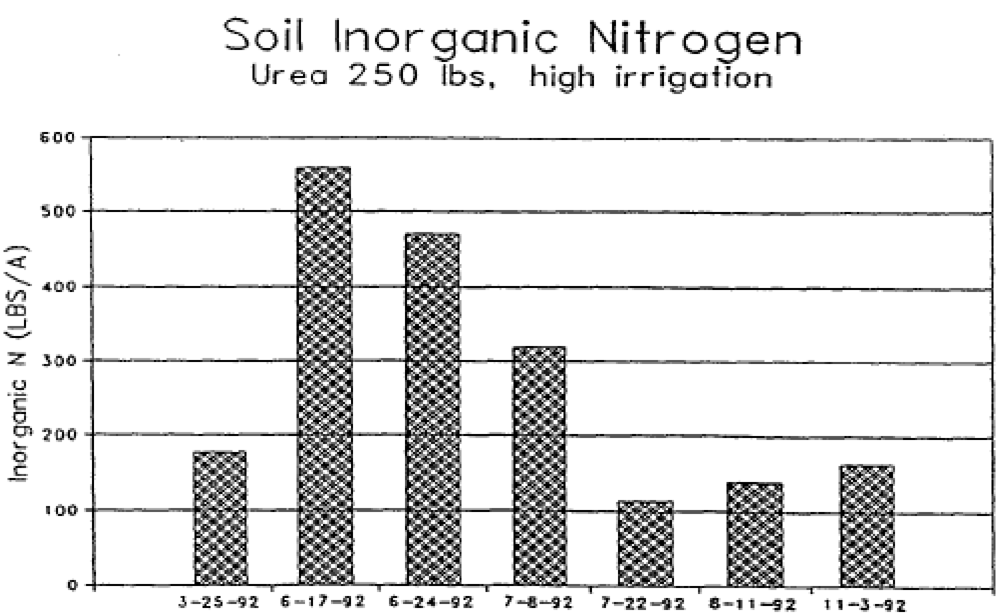

Figure 8. Soil inorganic N in top foot under 250 lb/ac N as urea, Madras, OR, 1992.

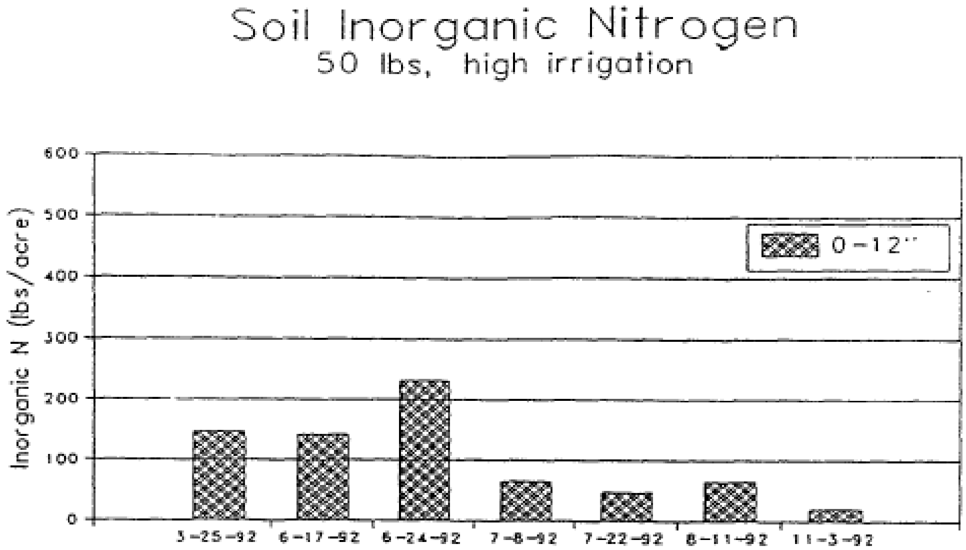

Figure 9. Soil inorganic N in top foot for 50 lb/ac treatment, Madras, OR, 1992.

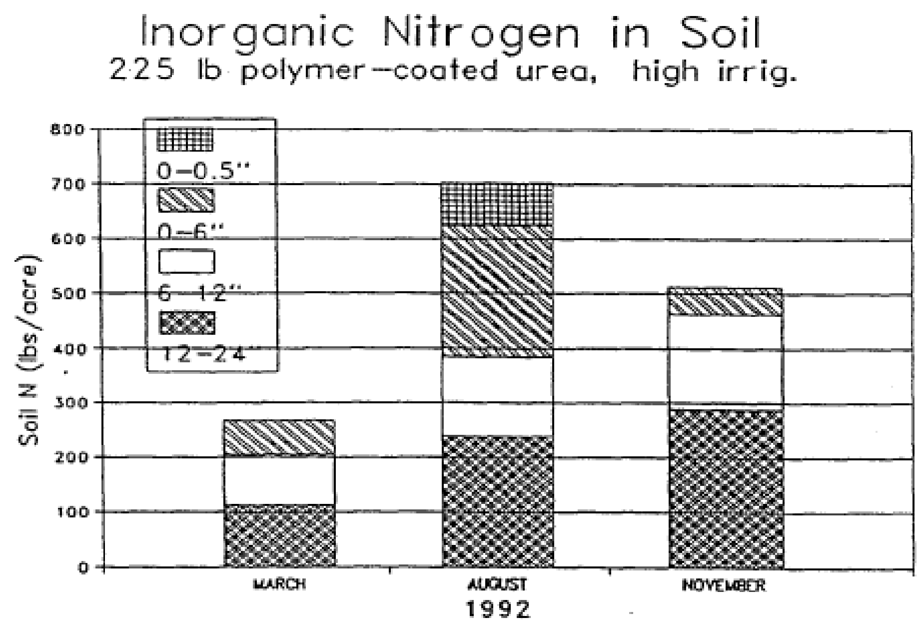

Figure 10. Soil inorganic N for entire profile of polymer-coated urea, Madras, OR, 1992.

To summarize: within the constraints of our experiment (equal irrigation intervals and variable amounts) there is no evidence that stress can improve oil yield, but excess irrigation may reduce it. Two years of data show that optimal irrigation with minimal leaching appears to be the best irrigation strategy for oil production.

Two years of data indicate that split-application of fertilizer and slow-release nitrogen forms only have the potential to increase yield when excess irrigation promotes nitrate leaching. Under low irrigation conditions, high N rates can cause salinity stress. Under high irrigation rates, high N applied as split applications may be needed to achieve maximum yield.

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