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Title: THE EFFECT OF NITROGEN FERTILIZATION ON PEPPERMINT OIL QUALITY AND CONTENT

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Two field experiments were established during the spring of 1970 in an effort to characterize the effects of nitrogen fertilizer and plant maturity on the yield, composition and quality of peppermint (*Mentha piperitta* var. Mitcham) oil. These experiments were located in central Oregon, near Madras, and in the Willamette Valley, near Corvallis, thus representing the two major peppermint producing regions in the state of Oregon. The objectives of these experiments were (1) To evaluate the effects of various nitrogen treatments on oil yield when harvested at different stages of plant maturity and (2) To determine how the various terpene compounds, which characterize oil quality were affected by nitrogen fertilizer treatments and crop maturity. The experiments were maintained over a period of two years, 1970 and 1971.

Both the Corvallis and Madras experiments were randomized block designs having five replications. The nitrogen fertilizer treatments applied to the plots varied in both rate and time of application. Plant maturity treatments consisted of sampling plots at various degrees of inflorescence. These samples were evaluated for oil yield and composition.

Oil yield determinations were made using steam distillation and water separation techniques similar to commercial mint oil distilleries. Measurement of terpene hydrocarbons, menthyl acetate, menthone, menthol and menthofuran was accomplished using liquid gas chromatography. The samples of oil were also evaluated for odor by professional graders.

Generally, higher oil yields were obtained with heavier nitrogen rates. For Willamette Valley peppermint, rates of 200 to 250 pounds of nitrogen per acre appeared optimum. Slightly higher rates of 250 to 300 pounds of nitrogen per acre seem optimum for high oil yields in the central Oregon production areas.

The level of terpene hydrocarbons, the light boiling fractions of mint oil constituents, generally decreased with crop maturation. Nitrogen treatments had little effect on terpene hydrocarbon contents. Acceptable levels of terpene hydrocarbons (9.5% to 13.5%) were obtained for samples taken at and beyond 50 percent bloom regardless of nitrogen treatments.

Menthone contents of 20% to 30% are considered normal for Oregon peppermint oils. Samples taken during 50% bloom appeared to best satisfy this criterion. Heavier rates of nitrogen fertilization (200 to 300 pounds of nitrogen per acre) resulted in increased menthone contents.

Menthol contents decreased with heavier nitrogen fertilization and increased with crop maturity. Results indicate that 200-250 pounds of nitrogen per acre is optimum for peppermint that is harvested at 50 percent bloom and beyond; producing oil having approximately 50-60% menthol.

Generally, menthyl acetate levels increased with crop maturity. The 5.0 to 7.5% menthyl acetate content considered desirable for Oregon peppermint oil may be achieved by harvests timed at 50% bloom in the Willamette Valley and just prior to 50% bloom in central Oregon with 250 to 300 pounds of nitrogen per acre being applied in both cases.

Menthofuran contents increased with crop maturity and inflorescence. Plots harvested at 50 percent and full bloom at Corvallis showed decreases in menthofuran contents with increasing nitrogen rates. Menthofuran contents of less than 3% are desired for Oregon peppermint oil. Results indicate that harvests should be made prior to 50% bloom in order to avoid excessive menthofuran contents. Heavy nitrogen rates (200 lb N/A or greater) may also aid in maintaining low menthofuran contents.

Effect of Nitrogen Fertilization on Peppermint Oil Quality and Content

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INTRODUCTION

Peppermint (Mentha piperita var. Mitcham) is grown extensively in the Willamette valley and central portions of the state of Oregon. As of 1970, 38,000 acres were reported in peppermint production in Oregon (Oregon Commodity Data Sheet, January 5, 1971). This constituted about 49 percent of the peppermint acreage harvested in the United States in 1970.

Oregon peppermint growers have long recognized the importance of nitrogen fertilizers for the attainment of high oil yields. Rates of nitrogen applied to peppermint crops by growers vary between 150 pounds to 400 pounds of nitrogen per acre. Heuttig (1969) indicated that 200 pounds to 250 pounds of nitrogen per acre appeared optimum for peppermint grown in western Oregon.

In addition to oil yields, oil quality is also an important consideration in peppermint production. Many growers are concerned about the effects of various cultural practices, particularly nitrogen fertilization and crop maturity, on the quality of the oil obtained at harvest time. Of the many terpene compounds present in mint oil, menthofuran is of particular importance. A high proportion of this chemical present in mint oil produces an undesirable odor, hence, lowering product quality.

Recognizing the importance of both yield and quality in peppermint production, the objectives of this study were: (1) To evaluate the effects of various nitrogen treatments on oil yield when harvested at different stages of plant maturity and (2) To determine how the various terpene compounds, which characterize oil quality were affected by nitrogen fertilizer treatments and crop maturity.

LITERATURE REVIEW

Essential oil formation in peppermint is the result of many complex metabolic processes partly influenced by environmental and nutritional conditions. These factors play a governing role in determining oil quality, composition and yield. Environmental factors such as day length and temperature limit the production of peppermint oil having acceptable commercial quality (containing principally menthone, menthol and menthyl esters with little or no pulegone or menthofuran) to certain geographical areas (Burbott and Loomis, 1967).

Both field, greenhouse and growth chamber or controlled environment studies have been performed by researchers concerned with peppermint oil production, physiology and biochemistry. Many field experiments were carried out by agricultural scientists interested in the effects of various management practices such as fertilization, irrigation, disease control, time of harvest, etc. on oil quality and yield. More fundamental studies pertaining to peppermint physiology and terpene biochemistry were conducted by researchers under controlled environmental conditions.

Field Studies

Bullis, Price and Kirk (1948) investigated the effect of maturity on yield and quality of peppermint oil in western Oregon and found that oil and hay yields increased until the full bloom stage. Subsequent hay yields remained nearly constant while oil yields decreased. Menthol and ester contents of oil increased progressively with plant maturity.

It has been reported (Watson and St. John, 1955) that the Yakima Valley of south central Washington produced higher yields of peppermint oil per acre than any other known area. Maximum oil yield was coincident with the full bloom stage of development. Profuse blossoming of mint in this area results in oil containing a high level of menthofuran and is therefore of lower quality. The total menthol and ester contents were found to increase with further plant maturity.

Research on the physical and chemical properties of peppermint oil produced in Michigan (Laughlin, 1960) showed that an increase in ester (menthyl acetate) and menthol contents occurred with continuing plant maturity while the menthone content declined. A significant relationship between menthol and menthone contents was reported.

Baird (1959) investigated oil quality and yield in relation to plant nutrient status. Nitrogen, phosphorus, potassium and sulfur fertilizers were used. Of these, nitrogen appeared to have the greatest influence on oil and hay yield. A significant negative correlation between total leaf nitrogen and menthofuran content was found.

Huettig (1969) found that the nitrate-nitrogen concentration in the stems increased with an increase in the amount of nitrogen fertilizer applied. Higher rates of nitrogen also increased oil content of the hay. A delayed application (July 1) of nitrogen had a stimulating effect on oil content of the hay and also total oil yield. Hay yields increased with increasing nitrogen fertilizer rates up to 250 lb N per acre. With rates higher than 250 lb N per acre a decline in hay yield was observed. Delayed nitrogen fertilizer application also resulted in lower hay yields.

The time of nitrogen fertilizer application was reported to have an effect on plant maturity (Heuttig, 1969). Plots that received all of the nitrogen fertilizer by June 1 were further along in maturity at harvest time as opposed to plots receiving nitrogen throughout the growing season and plots receiving a delayed nitrogen application. Those plants receiving 200 lb N per acre or more were reported to have more leaves and lateral stems than those receiving a lesser amount.

In central Washington peppermint growers use 200 to 400 lb N per acre (Nelson, Mortensen and Early, 1971c). Experiments show that mint hay removes about 150 lb N per acre. Optimum yields were obtained from plots receiving 200 lb fertilizer + soil NO_3-N per acre. Slightly more potassium was removed in the hay than nitrogen and the possibility of reduction in the amount of soil potassium available for subsequent crops was suggested.

Meadow mint had major changes in oil components (decrease in menthone, increase in menthol, menthyl acetate, and menthofuran) earlier in the season than did row mint (Nelson, Mortensen and Early, 1971c). Well established meadow mint started growth earlier in the spring and was therefore subjected to a longer period of warm temperatures than row mint.

Growth Chamber and Greenhouse Studies

Peppermint is markedly influenced by photoperiod (Steward et al., 1962). Long days are required for flowering while short days induce the production of numerous stolons. Night interruption studies by Langston and Leopold (1954) confirmed peppermint's status as a long day plant. They also determined that a photoperiod of 14 hours or less resulted in the lack of essential oil production. Longer days produced increases in both the fresh weight of the mint plants and the yield of essential oil.

In the greenhouse, peppermint grown under long day conditions had a lower soluble nitrogen content and better growth compared to that grown under short day conditions (Steward et al., 1959). Nitrogen metabolism responds to day length and was accentuated by a high Ca/K ratio in the nutrient solution. Under those conditions nitrogen was used more effectively. Under a short day length, however, a lower Ca/K ratio provided better vegetative growth. The characteristic calciole habit of peppermint was therefore suggested to be a property associated with those plants grown under long day conditions.

Nutrient deficiency symptoms were determined by Steward et al. (1962). Visual symptoms of acute calcium deficiency under long day conditions were particularly apparent. Extreme sulfur deficiency resulted in decreased protein synthesis accompanied by an accumulation of free amino acids. Arginine was the predominant amino acid in the leaves. Amides were more prominent in the stems and roots.

Night temperature proved to be an important factor in modifying the effects of photoperiod on the metabolism of keto and amino acids (Steward et al., 1962). The accumulation of α-ketoglutarate and glutamine which was induced under long days, was accentuated by low night temperatures. High night temperatures resulted in a depletion of α-ketoglutarate and the formation of asparagine.

The use of $^{14}CO_2$ has permitted the study of some of the biochemical aspects of peppermint oil synthesis. Incorporation of the label was found in peppermint oil in less than 15 minutes after mint plants were exposed to an atmosphere containing $^{14}CO_2$ (Reitsema et al., 1961). Essential oil continued to be synthesized for several hours in the dark and was not halted by the cessation of photosynthesis. $^{14}CO_2$ experiments also showed that the menthol fraction of mint oil was derived from menthone.

Battaile and Loomis (1961) have also shown with $^{14}CO_2$ experiments the rapid synthesis of monoterpenes in young leaves which are still expanding. A lack of de novo synthesis of terpenes was observed in mature leaves. Among the first terpenes formed were unsaturated ketones. Incorporation of the label into methone took somewhat longer and the labeling of menthol required several days. Unsaturated ketones and menthofuran were abundant in young leaves, where as the older leaves had relatively more menthol and menthyl acetate.

Further study of the relationship of terpene biosynthesis to leaf development showed monoterpenes accumulating in mature leaves, in contradiction to prior results of $^{14}CO_2$ experiments (Burbott and Loomis, 1969). The total amount of monoterpenes per leaf pair was monitored during the development of the plant and was found to increase steadily up to the time of blooming. A burst of terpene synthesis coincided with the onset of flowering. The period of rapid terpene synthesis was followed by a rapid decline in terpene production. The authors suggest that monoterpenes may serve as substrates for energy metabolism in the secretory cells after other stored substrates have been used.

Burbott and Loomis (1967) investigated the effects of light and temperature on the monoterpenes in peppermint. Long day conditions promoted growth and an increase in the total amount of monoterpenes. Short nights or cool nights with full light intensity during the day resulted in the stimulation of menthone formation and depressed the accumulation of menthofuran and pulegone. Interrupted night and low light intensity experiments indicate that photoperiod, as such, does not have direct influence on terpene composition. It is suggested that warm nights cause the depletion of respiratory substrates in the terpene producing cells which result in oxidizing conditions. Cool nights, in turn, maintain a relatively high level of respiratory substrates which result in reducing conditions.

Burbott (1963) investigated the metabolic interrelationships and interconversions of terpenes in peppermint. Time course studies with $^{14}CO_2$ confirmed Reitsema's scheme that pulegone yields menthone; menthone yields menthol; and menthol yields menthyl acetate. Conversions of pulegone to menthone; menthone to menthol and menthyl acetate; and piperitenone to pulegone, menthone and piperitone were observed in peppermint tissue using labeled terpenes as substrates.

EXPERIMENTAL MATERIAL AND METHODS

Experimental Locations

Two field experiments were established during the spring of 1970 in an effort to characterize the effects of nitrogen fertilizer and plant maturity on the yield, composition and quality of peppermint (Mentha piperita var. Mitcham) oil. These experiments were located at the O.S.U. Vegetable Crops Farm near Corvallis, Oregon and on the Central Oregon Agricultural Experiment Station at Madras, Oregon. The legal descriptions of both locations are given in Table 1. It is felt that the location of these two experiments are representative of the two major peppermint producing regions in the state of Oregon.

Table 1. Legal description of experimental locations.

Experiment	County	Legal Description[1]
Corvallis	Linn	Sec. 36, T. 11S, R. 5W
Madras	Jefferson	Sec. 34, T. 10S, R. 13E

[1] With reference to Willamette meridian.

The soils involved in the Corvallis and Madras experiments were the Cloquato and Madras series respectively. A summary of the soil chemical analysis results for each location is given in Table 2.

Table 2. A summary of the chemical analysis of soil samples taken from the experimental locations.

Experimental Location	pH	ppm P	ppm K	Meq. per 100 g Ca	Meq. per 100 g Mg	Meq. per 100 g Na
Corvallis	6.0	49.0	375	18.1	6.4	0.23
Madras	7.1	42.8	558	12.5	5.6	1.60

Experimental Design and Treatments

Both the Corvallis and Madras experiments were randomized block designs having five replications. Nitrogen fertilizer treatments in 1970 were applied to first year row mint at Corvallis and to an established mint stand (meadow mint) at Madras. Nitrogen treatments were repeated on the same plots in 1971 for both locations.

The nitrogen fertilizer treatments varied in both rate and time of application. Rates of nitrogen fertilizer used at Corvallis were 50, 100, 200 and 300 lb N per acre. At Madras, 0, 40, 100, 150, 200, 250 and 350 lb N per acre rates were used. All plots at the Corvallis experiment received 50 lb N per acre as ammonium phosphate sulphate (16-20-0) on April 11th of each year. Similarly, plots at Madras, with the exception of the zero nitrogen rate, received 40 lb N per acre as ammonium sulfate (21-0-0) on April 24th of each year. Plots at both locations received the remaining amounts of nitrogen as ammonium nitrate (34-0-0) with the times of application distributed between June 1st and July 15th. Times of application for the remaining nitrogen applied for each rate variable were coded as follows: (A) the remaining nitrogen was distributed and applied at equal rates on June 1st, July 15th, July 1st, and July 15th; (B) all of the remaining nitrogen was applied June 1st; (C) all of the remaining nitrogen was applied July 1st. Tables 3 and 4 present the rates and times of application for the nitrogen treatments used at Corvallis and Madras respectively.

Table 3. Rates and times of nitrogen application for the Corvallis locations.

Treatment No.	Total N Applied (lb N/A)	Time of Application Code	Date and Rate of N Application				
			4/11	6/1	6/15	7/1	7/15
1	50		50	--	--	--	--
2	100	A	50	13	12	13	12
3	100	B	50	50	--	--	--
4	200	A	50	38	37	38	37
5	200	B	50	150	--	--	--
6	200	C	50	--	--	150	--
7	300	A	50	63	62	63	62

Plant maturity treatments consisted of sampling plots in the experiments at various degrees of flowering. Samples for oil yield and composition at Corvallis during 1970 were taken when the majority of plots in the experiment were in the bud stage, 50% bloom and 100% or full bloom. Estimations of the degree of bloom was made subjectively considering the experiment as a unit. Midway into the harvesting season it became apparent that those plots receiving the higher rates of nitrogen appeared relatively less mature (as characterized by a lower degree of flowering) than plots which received lower nitrogen rates. In order to account for the effect of nitrogen on plant maturity observed in 1970, the plots in the 1971 experiment were assessed for their stage of maturity and sampled accordingly. Stratification of sampling was made on various nitrogen rates used as outlined in Table 5.

Samples for oil yield and composition at Madras were taken at 15% and 50% bloom in 1970. The 1971 samples were taken at the bud stage and 50% bloom. Bloom estimates were made considering the experiment as one unit. Individual plot evaluations were not conducted. Table 6 presents the stage of maturity treatments for each location.

Table 4. Rates and times of nitrogen application for the Madras location.

Treatment No.	Total N Applied (lb N/A)	Time of Application Code	Date and Rate of N Application				
			4/24	6/1	6/15	7/1	7/15
1	0		--	--	--	--	--
2	40		40	--	--	--	--
3	100	A	40	15	15	15	15
4	150	A	40	28	27	28	27
5	150	B	40	110	--	--	--
6	200	A	40	40	40	40	40
7	200	B	40	160	--	--	--
8	250	A	40	53	52	53	52
9	250	B	40	210	--	--	--
10	350	A	40	78	77	78	77

Table 5. Sampling dates for the N treatments at three different stages of maturity at the Corvallis location, 1971.

N Treatments lb N/A	Bud Sampling Date	50% Bloom Sampling Date	Full Bloom Sampling Date
50	July 30	August 13	August 25
100A	August 2	August 16	August 28
100B	August 2	August 16	August 28
200A	August 7	August 21	September 2
200B	August 7	August 21	September 2
200C	August 7	August 21	September 2
300A	August 7	August 21	September 2

Table 6. Stage of maturity for oil samples taken from each experimental location.

Sample No.	Corvallis		Madras	
	1970	1971*	1970	1971
1	Bud	Bud	15% bloom	Bud
2	50% bloom	50% bloom	50% bloom	50% bloom
3	Full bloom	Full bloom	---	---

*Estimates based on individual treatments.

Field Plot Technique

The Corvallis experiment was hand planted on April 11th, 1970, using certified root stock from central Oregon. The individual plots were 8 feet wide and 15 feet long. Four rows of peppermint root stock on a two foot spacing were placed in each plot. Dyfonate soil insecticide was incorporated as a preplant application at four lb per acre for the control of symphylans. The experiment was flamed with a propane field burner in October 1970 as is conventionally done to the mint grown in the Willamette Valley for the control of Verticillium wilt.

The Madras experiment involved three year old mint. Plot dimensions were 10 feet wide by 40 feet long. The mint was plowed in the fall as is commonly done in the generally wilt-free area of central Oregon. Fertilizer treatments were weighed out and applied by hand to plots at both experimental locations. Both experiments were treated with the herbicide terbicil at 1.5 lb active ingredient per acre in the spring for weed control.

Samples for oil analysis were taken in 1970 at Corvallis by harvesting four feet of the innter two rows of each plot. In 1971, a 4 ft by 4 ft quadrant sample was taken. Sufficient area was excluded from the sample to minimize border effects.

At Madras, a forage plot harvester was used to harvest a 3.5 ft wide swath down the middle of each plot, thus minimizing any border effects. The mint hay was weighed and a sample for moisture content was taken. The moisture content was subsequently used to compute the dry weight of mint hay harvested. An 8 to 10 lb sample of mint was taken for oil analysis. Although samples for oil analysis were taken twice during the harvesting season, mint hay yields were measured only at 50% bloom.

Samples of mint hay for oil analysis were placed in a loose weave two-bushel burlap potato sack. The samples were allowed to air dry to approximately 25% moisture content prior to distilling. Drying before distilling is essential to obtain efficient removal of oil from the hay.

Oil Analysis

The oil was removed from the air-dried samples by steam distillation. The distillation apparatus (Figure 1) was composed of the following basic parts: (1) a modified 16 qt pressure cooker, (2) a glass condenser, and (3) an oil collector. All components that came into contact with the oil or vapor were constructed out of glass, aluminum, or teflon. Pipes and tubing which supplied steam and cooling water for the condensor completed the apparatus.

Each sample was placed in a cooker and the lid secured. Steam was metered into the bottom of the cooker with a needle valve. As steam passed through the sample it vaporized the oil. The oil vapor and steam mixture was then transferred from the cooker to the condensor via teflon and aluminum tubing where it was liquified. Condensate temperature was maintained at 110°F by regulating the amount of steam entering the cooker and the flow of cooling water passing through the condensor. The mint oil was separated from the condensate mixture in the oil collector by density differences. Peppermint oil (density of 0.9 g/cm^3) (Heuttig, 1969) is readily separated as it floats to the water's surface. Oil produced from each

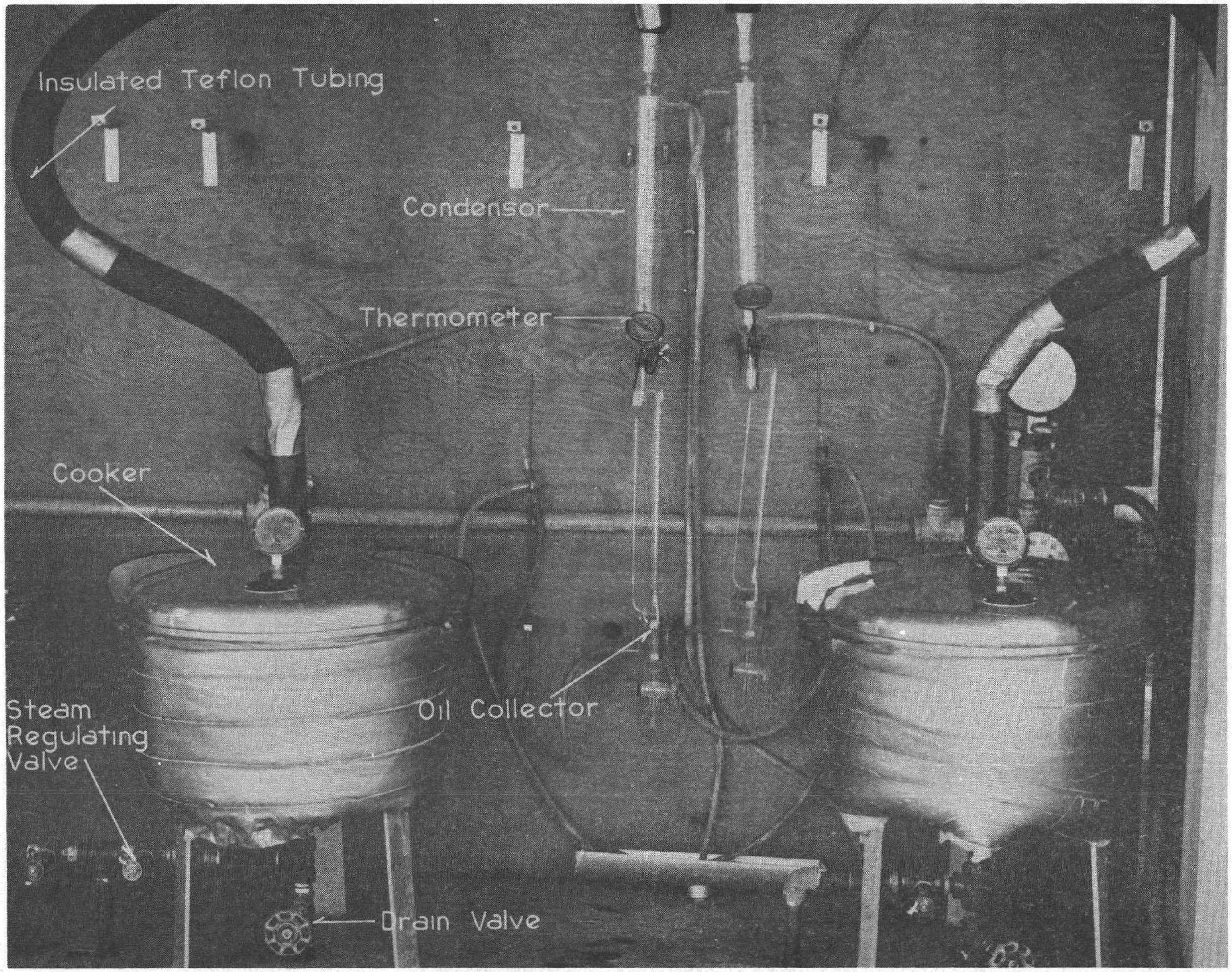

Figure 1. Distillation apparatus used to remove oil from peppermint hay.

sample was measured in the graduated tube portion of the oil collector (Figure 2).

The majority of the oil was released in the first 15 minutes of the distillation process, however, in order to insure complete oil removal, each sample was distilled for a period of 50 minutes. The entire quantity of oil removed from the same was transferred to a separatory funnel, shaken to insure complete mixing, and a five ml portion put into screw top glass vials for shipment to A.M. Todd Co., Kalamazoo, Michigan for composition and quality analysis.

The quantity of oil contained per unit weight of plant material (oil content) was calculated and expressed as a percent (weight basis; oil density = 0.9 g/cm^3). Oil yields in lb of oil per acre were computed for the Madras plots as follows:

$$Y = H \times OC \times DW$$

where:

Y = oil yield, lb/A

H = hay yield, lb/A (fresh weight)

OC = oil content of hay, % dry weight

DW = % dry weight of hay sample

Since the Corvallis plots were of smaller size, the weight of oil produced per area harvested (16 ft^2) was measured directly and converted to yield in lb per acre.

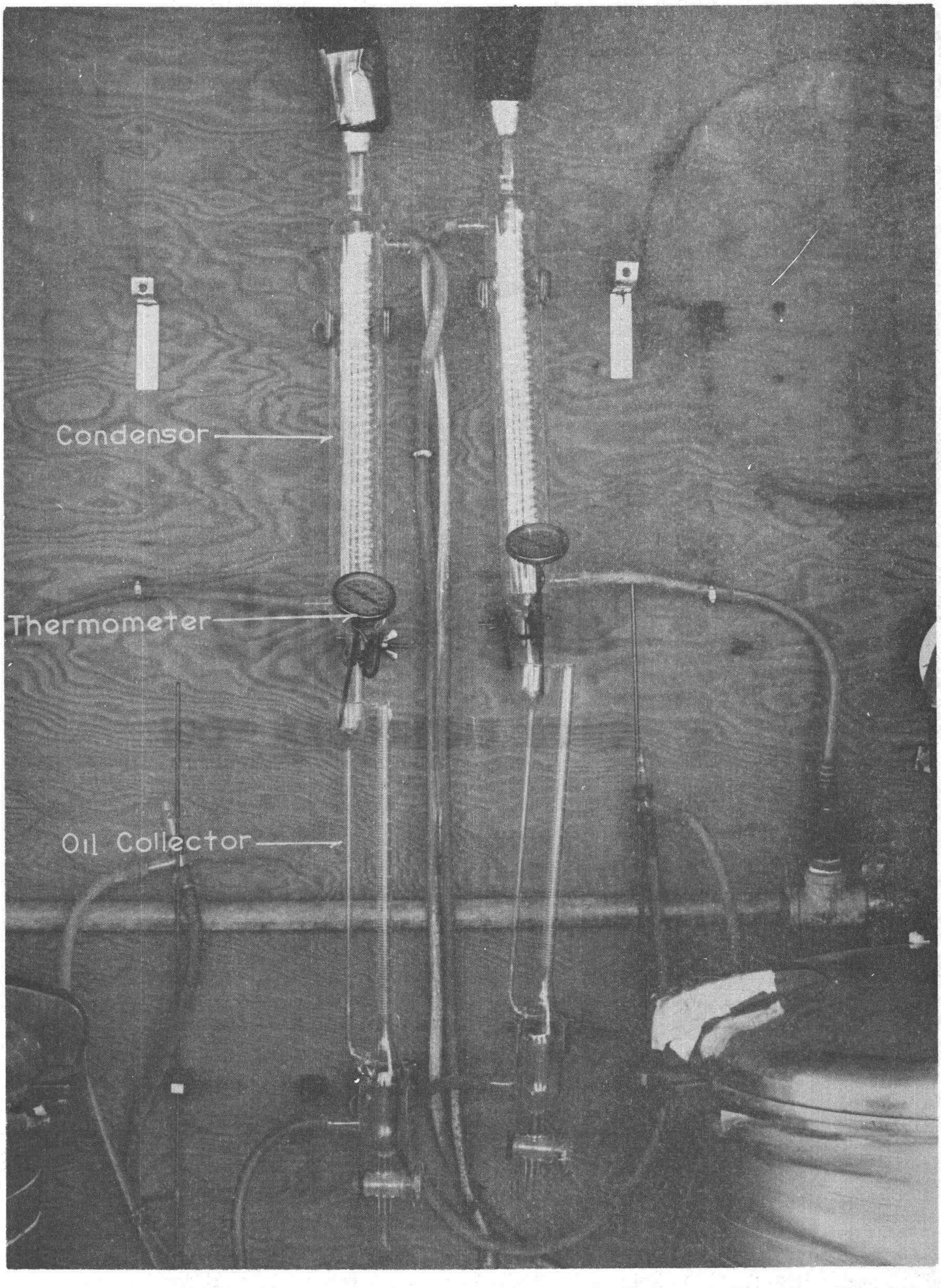

Figure 2. Distillation apparatus showing oil condenser and collector units.

Oil composition, analysis and quality evaluation were completed by A. M. Todd Company. Measurement of terpene hydrocarbons, methyl acetate, menthone, menthol and menthofuran was accomplished using liquid gas chromatography. The samples were also evaluated and graded for odor with respect to A. M. Todd Company's commercial peppermint oil standards.

Soil and Plant Chemical Analysis

Soil samples were collected prior to fertilizer treatment applications from the zero to six inch depth. A composite sample of each replication was taken at both locations. The samples were air dried in the laboratory, ground, and passed through a 14 mesh seive in preparation for chemical analysis. Analysis for pH and K, Ca, Mg, Na, and P contents were conducted according to methods used by the Oregon State University Soil Testing Laboratory (Alban and Kellogg, 1959). Results of the analysis were presented in Table 2.

Samples of plant tissue for nutrient analysis were taken from plots at the Corvallis location in 1970 during the last week of June and at each of the harvest dates. Sections of stems six inches below the most recently matured leaves were collected and the leaves removed. The stems were then dried at 70° C using a forced draft oven for at least 48 hours. Each sample was ground in a Wiley mill in preparation for chemical analysis. The tissue samples were chemically digested using nitric and perchloric acid (Jackson, 1958). Ca, Mg, K, Zn, and Mn contents in the digest were determined with a Perkin-Elmer 303 atomic absorbtion spectrometer (David, 1970). Na contents were determined using a Beckman DU flame spectrophotometer. P contents were determined by the molybidivanadophosphoric acid colorimetric method (Jackson, 1955). Ca, Mg, K, P, Zn, and Mn analysis were done on the June samples only. All samples were assayed for NO_3-N contents by steam distillation with MgO and Devarda alloy (Bremmer, 1966).

Statistical Analysis

Analysis of variance of the data was performed with a CDC 3300 digital computer using programs from the Oregon State Statistical Analysis Program Library. Additional computations for F-tests and multiple comparisons among means were made using an electronic desk calculator.

EFFECTS OF NITROGEN TREATMENTS AND PLANT MATURITY ON OIL YIELD

The Corvallis experiment in 1970 and 1971 showed that maximum oil yields occurred with the 200 lb N/A fertilizer rate (Table 7). The heavier 300 lb N/A rate resulted in slightly lower oil yields, however, the differences in yields between the 200 and 300 lb rates were non-significant (P = .05).

Table 7. Effects of nitrogen treatments on oil yields at the Corvallis and Madras locations.

Nitrogen Treatment lb N/A	Oil Yield (lb oil/A)			
	Corvallis		Madras	
	1970	1971	1970	1971
0	--	--	--	51
40	--	--	45	--
50	54	49	--	--
100A	55	57	63	--
100B	51	58	--	--
150A	--	--	70	108
150B	--	--	--	94
200A	59	66	70	124
200B	61	71	--	111
200C	56	77	--	--
250A	--	--	73	101
250B	--	--	--	107
300A	52	64	--	--
350A	--	--	86	128
LSD (.05)	N.S.	13	15	--

Oil yields of 108, 124, 101 and 128 pounds per acre were produced with 150, 200, 250 and 350 pounds of nitrogen per acre respectively at Madras in 1971. While the difference between the 200 and 350 pound nitrogen rates were not statistically significant, the highest yield of oil was obtained in both 1970 and 1971 with the 350 pound nitrogen rate.

Oil yields increased with maturity (Table 8). The 1971 measurements at Corvallis showed an increase in oil yield between 50% and 100% bloom. Results obtained in 1971 showed that a decrease in oil yield resulted with maturity beyond 50% bloom; however, rain which occurred between the 50% and 100% bloom harvests may have decreased oil yields.

Table 8. Effects of maturity on oil yields at the Corvallis and Madras locations.

		Oil Yield (lb oil/acre)				
Location	Year	Bud Stage	15% Bloom	50% Bloom	Full Bloom	LSD (.05)
Corvallis	1970	44	--	52	63	5
Corvallis	1971	55	--	73	62*	9
Madras	1970	--	57	83	--	9
Madras	1971	99	--	107	--	-

*Rain occurred between 50% and 100% bloom harvests.

These results are in general agreement with similar studies on oil yields. Baird (1959), Heuttig (1969) and Nelson et al. (1971c) have demonstrated that nitrogen fertilizer plays an important role in the production of maximum oil yields in Oregon and Washington. Plant maturity is also an important factor which affects oil yields. Bullis et al. (1948) and Watson and St. John (1955) observed that maximum oil yields coincided with the full bloom maturity stage.

These data suggest that the optimum rate of nitrogen fertilizer lies in the range of 200-250 lb N/A. For the central Oregon mint areas, the optimum nitrogen rate may be closer to 300 lb N/A. The various times of nitrogen application used in these experiments did not significantly affect oil yields.

Maturity did have a significant effect on oil yield with oil production increasing as the plants become more mature. The one exception to this occurred at Corvallis in 1971, where a decrease in yield of oil after the 50% bloom stage was associated with rain between these two harvest dates. Growers regularly observe a decrease in oil yield on peppermint that is in the field during a rainy period.

EFFECTS OF NITROGEN TREATMENTS AND PLANT MATURITY ON OIL COMPOSITION

Peppermint oil composition is often characterized by the amounts of menthone, menthol, menthyl acetate, menthofuran and terpene hydrocarbons it contains. The latter term is frequently used by commercial processors with reference to the light boiling fractions which include primarily α-pinene, β-pinene, limonene and 1-8 cineol. Although technically all of the mint oil is terpenes, the term terpene hydrocarbons used in this thesis refers to the light boiling fractions mentioned and does not include menthol, menthyl acetate, or menthofuran.

Concentrations of these components vary with environmental conditions of the growing regions (Smith and Levi, 1961). Contents of various peppermint oil constituents considered desirable for Oregon are presented in Table 9.

Table 9. Desirable composition of Oregon peppermint oil.[1]

Oil Component	Range, %
Terpene hydrocarbons	9.5-13.0
Menthone	20.0-30.0
Menthol	50.0-60.0
Menthyl acetate	5.0- 7.5
Menthofuran	less than 3.0

[1] R.E. Hughes Jr., Technical Director. A.M. Todd Co., Kalamazoo, Michigan. Personal communication, October 20, 1970.

Terpene Hydrocarbon Content

Contents of terpene hydrocarbons in peppermint oil obtained at the Corvallis and Madras locations are given in Tables 10 and 11, respectively. The nitrogen treatments had little effect on the terpene hydrocarbon content of the oil.

The Corvallis experiment in 1970 showed higher levels of terpene hydrocarbons present at bud stage over the 50% bloom or full bloom stages (Table 10). The data from the Madras experiment in 1971 showed similar results. This suggests that the light boiling fraction (α and β pinene, limonene and 1-8 cineol) may decrease in concentration with increase in plant maturity. Acceptable levels (9.5%-13.5%) of terpene hydrocarbons were obtained for all samples taken at and beyond the 50% bloom stage.

Table 10. Effect of nitrogen treatments and maturity on the terpene hydrocarbon content of peppermint oil at Corvallis.

Nitrogen Treatments lb N/A	Terpene Hydrocarbons, %					
	1970*			1971		
	Bud	50% Bloom	Full Bloom	Bud	50% Bloom	Full Bloom
50	14.5	11.7	11.4	10.9	11.1	12.5
100A**	15.9	11.8	11.7	10.9	11.2	9.6
100B	16.6	11.0	11.5	10.8	11.2	9.8
200A	14.9	11.2	11.4	11.2	9.6	10.7
200B	14.4	11.2	12.2	11.0	10.5	10.2
200C	13.1	11.3	11.2	9.8	10.0	10.2
300A	14.4	12.2	11.6	10.5	10.2	9.6
Average	14.8	11.5	11.6	10.7	10.5	10.3

* LSD (.05) = 2.1%.

** Codes A, B and C refer to time of N application as outlined in Table 3.

Table 11. Effect of nitrogen treatments and maturity on the terpene hydrocarbon content of peppermint oil at Madras.

Nitrogen Treatments lb N/A	Terpene Hydrocarbons, %			
	1970*		1971	
	15% Bloom	50% Bloom	Bud Stage	50% Bloom
0	--	--	15.7	13.4
40	14.2	12.7	--	--
100A**	11.8	11.9	--	--
150A	13.4	12.6	13.4	11.3
150B	--	--	15.1	11.5
200A	16.4	12.7	14.1	11.5
200B	--	--	12.8	10.9
250A	12.4	12.1	14.4	11.3
250B	--	--	14.2	12.3
350A	11.6	12.2	13.2	11.8
Average	13.3	12.4	14.1	10.5

* LSD (.05) = 2.2%.

** Codes A, B and C refer to time of N application as outlined in Table 4.

Menthone Content

The menthone contents of mint oil at Corvallis (Figures 3 and 4) and at Madras (Table 12) increased with higher rates of nitrogen fertilization. Generally, nitrogen applied at 15 day intervals (time of application A) resulted in higher methone contents than nitrogen applied entirely on June 1 or July 1 (times of application B and C, respectively).

Increases in maturity resulted in a decline in menthone contents at both locations. Nelson et al. (1971b) reported decreases in

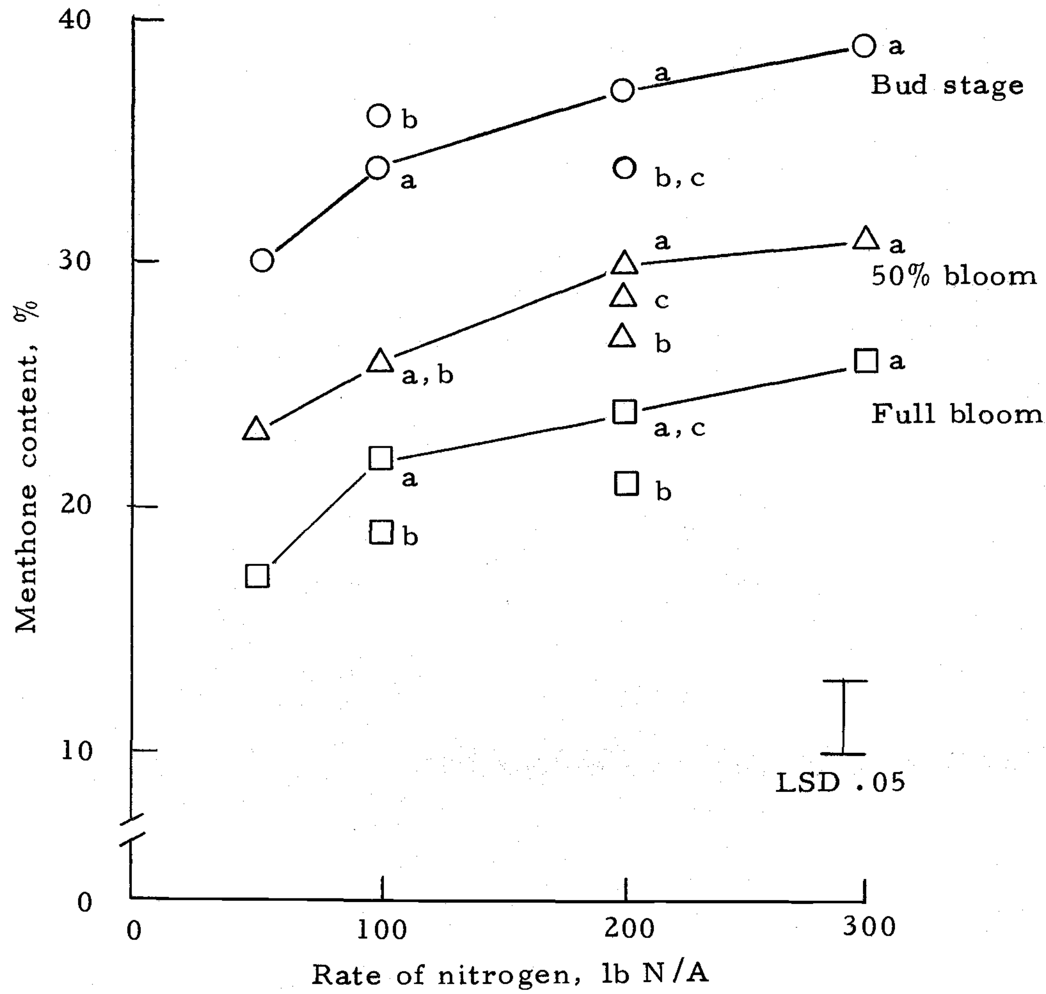

Figure 3. Effect of nitrogen treatments and maturity on the menthone content of peppermint oil at the Corvallis location, 1970. (a, b and c refer to time of N application as described in Table 3.)

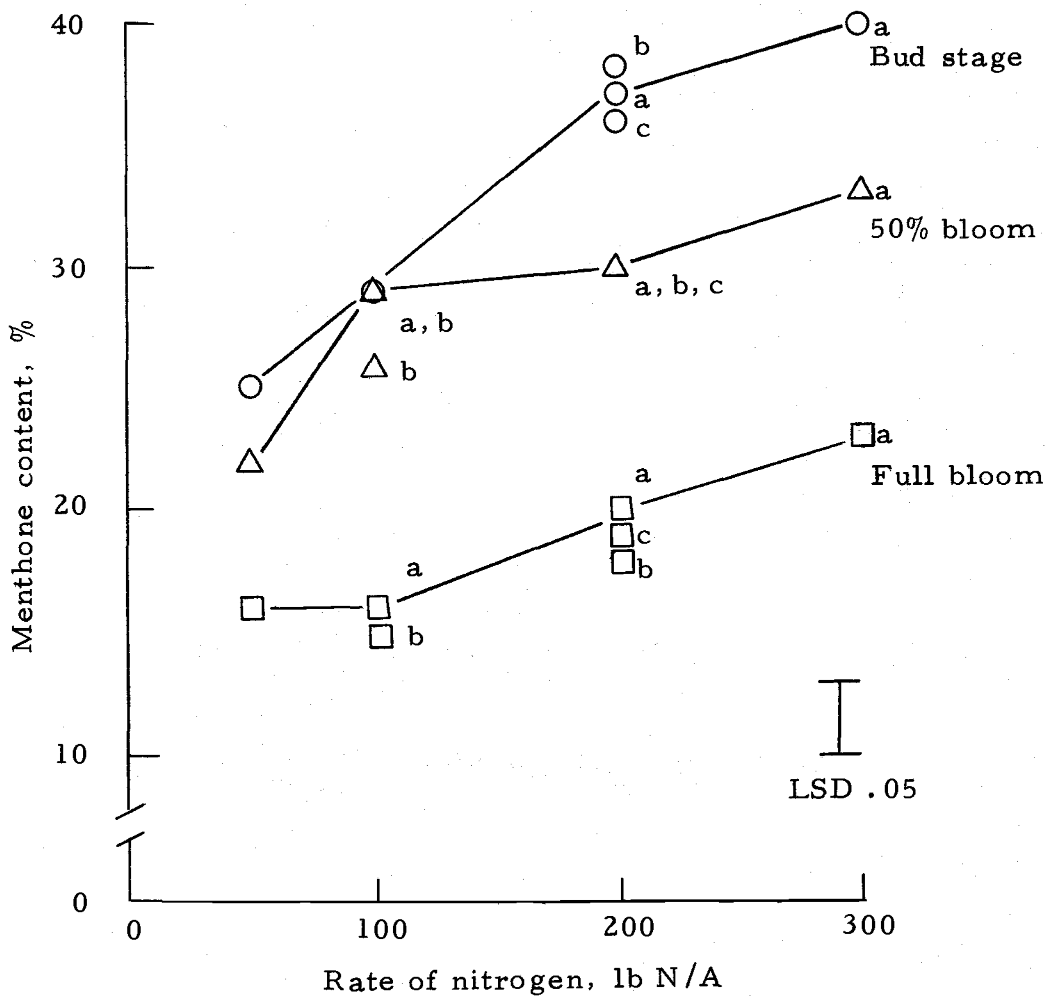

Figure 4. Effect of nitrogen treatments and maturity on the menthone content of peppermint oil at the Corvallis location, 1971. (a, b and c refer to time of N application as described in Table 3.)

menthone contents with maturation for eastern Washington mint. Radioactive tracer experiments (Battaile and Loomis, 1961) have indicated that younger leaves contain oil with more unsaturated ketones as compared to that in older leaves. These data apparently are in agreement with those findings.

Table 12. Effect of nitrogen treatments and maturity on the menthone contents of peppermint oil at Madras.

Nitrogen Treatments lb N/A	Menthone Content, %			
	15% Bloom 1970	40% Bloom 1970	Bud 1971	50% Bloom 1971
0	--	--	23.6	18.0
40	21.3	15.7	--	--
100A*	23.6	17.0	--	--
150A	24.6	18.8	27.7	22.7
150B	--	--	28.1	22.1
200A	26.8	20.4	27.4	24.5
200B	--	--	28.0	24.5
250A	26.9	21.9	27.2	24.7
250B	--	--	28.0	26.9
350A	27.9	22.1	29.0	26.3
LSD (.05)	1.9	1.9	2.2	2.2

* A, B and C refer to time of N application as described in Table 3.

Methone contents of 20% to 30% are considered normal for Oregon mint oils. Samples taken during 50% bloom appeared to best satisfy this criterion. The bud stage samples were generally beyond the 30% upper limit except where low rates of nitrogen were applied. Samples taken at full bloom were at the lower limit of the prescribed range. Those plots which had received high rates of nitrogen, however, still appeared normal. Menthone contents of oil from the Madras experiment were generally in the normal category with the exception of lower nitrogen rates (less than 100 lb N/A) harvested at 50% bloom.

Menthol Content

Decreases in menthol contents due to increases in the rates of nitrogen fertilization were observed at the Corvallis (Figures 5 and 6) and Madras locations (Table 13). Apparently, the effect of nitrogen on menthol content varies with the stage of maturity of the mint plants at harvest. Differences in menthol contents due to nitrogen were significant ($P = .05$) when mint was harvested in the bud stage and at 50% bloom (Figure 6). Decreases in menthol measured at full bloom were not significant. The nitrogen fertilizer-maturity relationship evidently does not hold for row mint (Figure 5). Although both nitrogen fertilization and maturity had an influence on the menthol content, these effects appeared to be independent of each other.

The time of nitrogen application seemed to have little effect on the menthol content of mint oil. The differences observed were usually non-significant and inconsistent for both locations.

Maturity differences account for large variations in the menthol contents measured both at Corvallis and Madras. The differences resulting from harvesting at different stages of maturity usually were

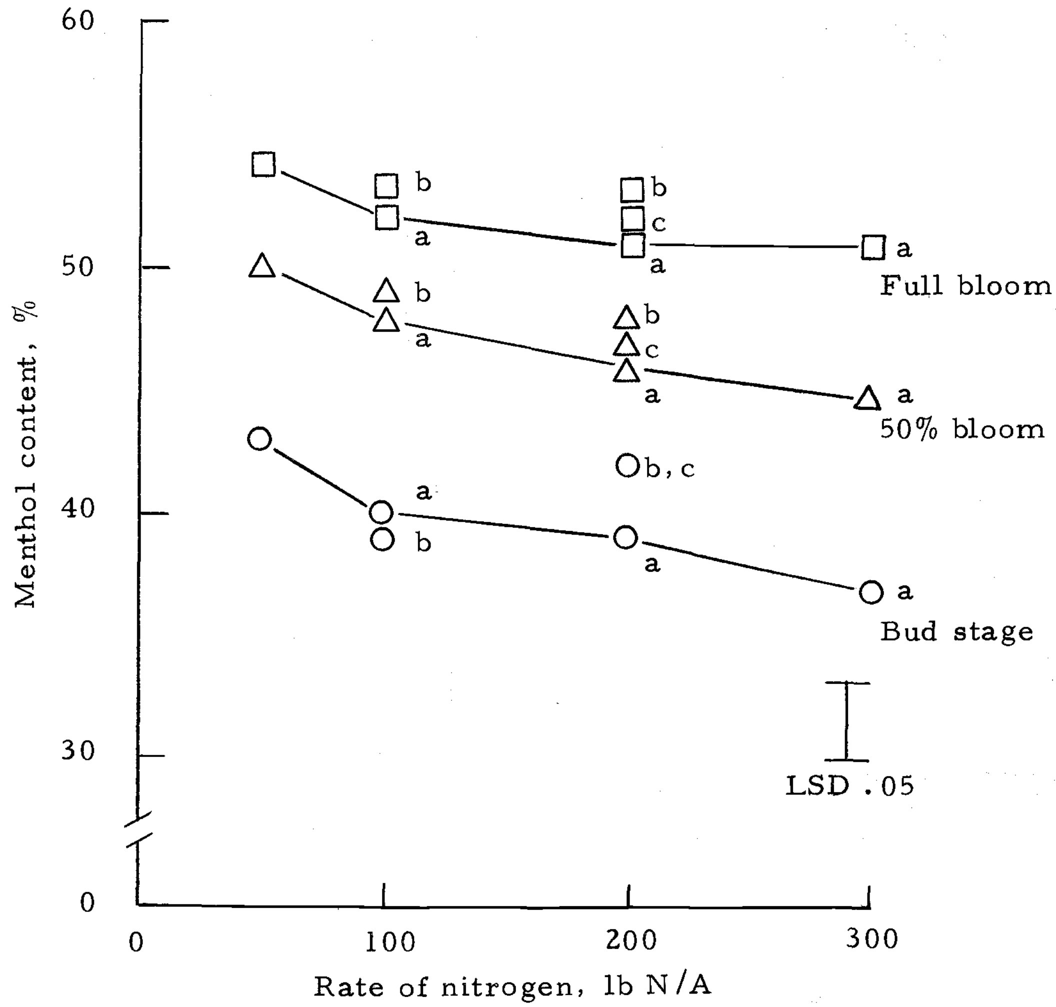

Figure 5. Effect of nitrogen treatments and maturity on the menthol content of peppermint oil at the Corvallis location, 1970. (a, b and c refer to the time of N application as described in Table 3.)

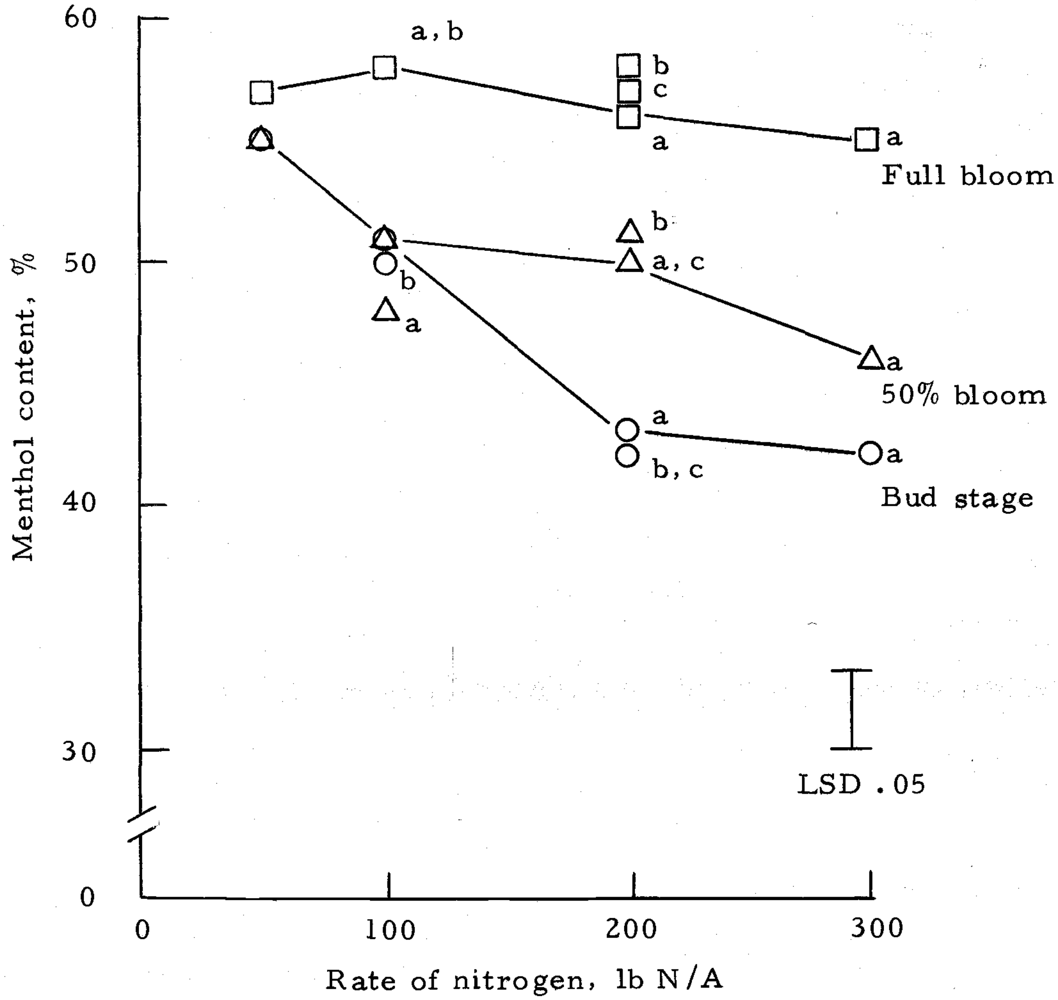

Figure 6. Effect of nitrogen treatments and maturity on the menthol content of peppermint oil at the Corvallis location, 1971. (a, b, and c refer to time of N application as described in Table 3.)

of larger magnitude than those differences resulting from various rates of nitrogen fertilization (Figures 5 and 6).

Table 13. Effects of nitrogen treatments and maturity on the menthol contents of peppermint oil at Madras.

Nitrogen Treatments lb N/A	Menthol Content, %			
	15% Bloom 1970	50% Bloom 1970	Bud 1971	50% Bloom 1971
0	--	--	50.9	55.4
40	51.7	55.2	--	--
100A*	52.2	55.7	--	--
150A	50.8	54.7	48.4	52.7
150B	--	--	48.2	53.6
200A	47.2	53.3	49.7	50.8
200B	--	--	49.6	50.8
250A	49.5	53.1	48.1	51.6
250B	--	--	48.3	48.4
350A	49.0	52.6	47.7	50.1
LSD (.05)	2.5	2.5	2.2	2.2

* A, B and C refer to time of N application as described in Table 3.

The data for both experimental locations suggest that on established fields (meadow mint) a rate of 200-250 lb N/A appears optimum for mint harvested at 50% bloom or later. This should result in oil having approximately 50-60% menthol which is desirable for Oregon mint oils (Table 9).

Menthyl Acetate

Differences in maturity accounted for the greatest differences in menthyl acetate at both locations. Generally, menthyl acetate contents increase as maturation progresses.

Slight increases in menthyl acetate were measured with rates of nitrogen up to 200 lb N/A on row mint at the Corvallis location in 1970 (Figure 7). The 300 lb N/A rate did not show differences in menthyl acetate when compared to the 200 lb N/A rate for mint harvested in the bud stage or 50% bloom. At full bloom, 300 lb N/A resulted in less menthyl acetate than obtained with 200 lb N/A.

Menthyl acetate contents measured at the same location in 1971 (Figure 8) on meadow mint decreased when nitrogen in excess of 100 lb N/A was applied to mint which was harvested in the bud stage. The same rates, however, produced increases in menthyl acetate for mint harvested at 50% bloom. Menthyl acetate contents for mint harvested at full bloom remained relatively constant with nitrogen applications over 100 lb N/A. The inconsistency in the trends of menthyl acetate contents observed at bud and 50 bloom cannot be explained without further study. Nitrogen treatments at the Madras location (Table 14) did not have a significant effect on menthyl acetate contents.

Some differences in menthyl acetate due to the time of nitrogen application were observed at Corvallis. These differences were usually inconsistent with the exception of 200 lb N/A applied to row

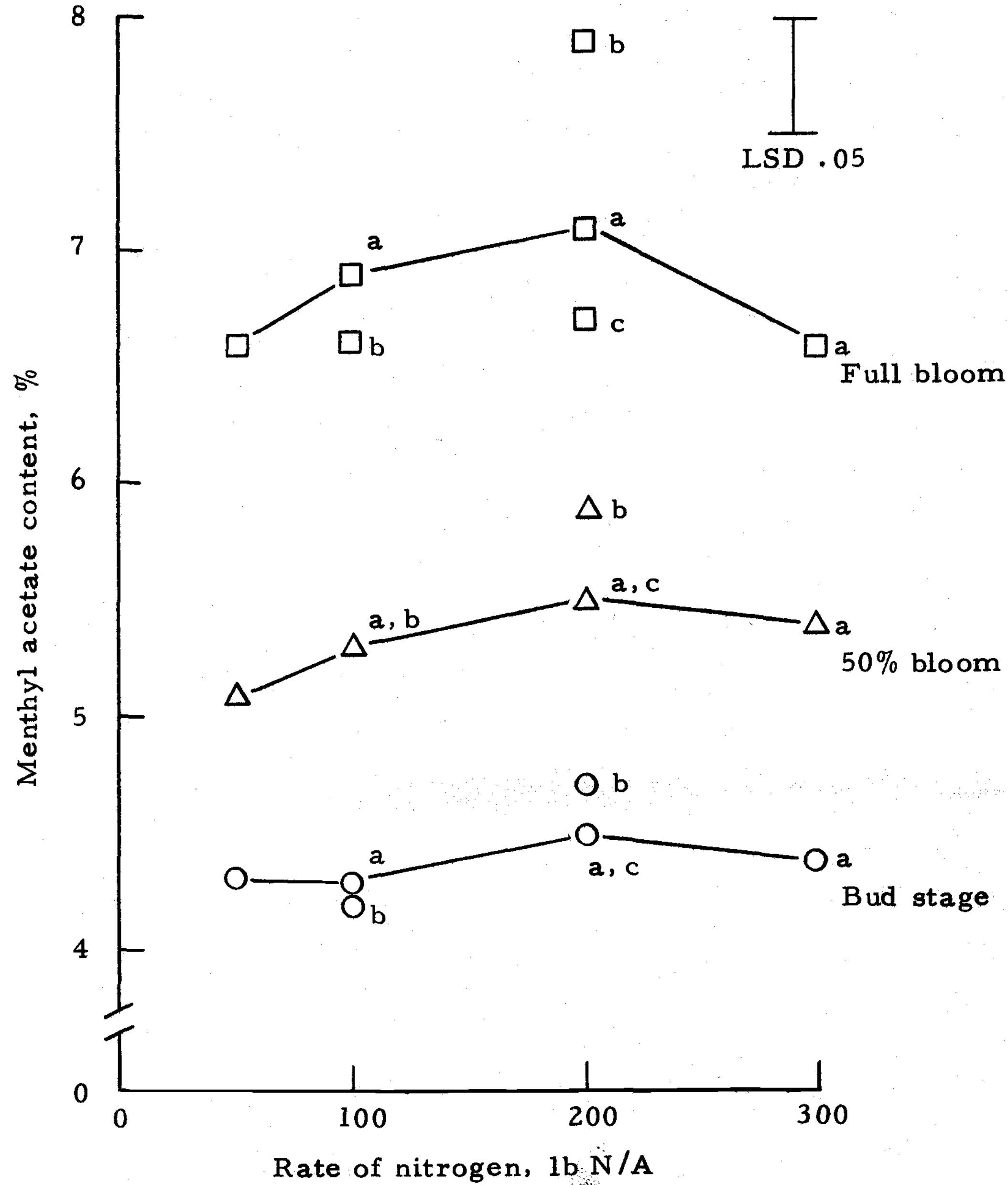

Figure 7. Effect of nitrogen treatments and maturity on the menthyl acetate content of peppermint oil at the Corvallis location, 1970. (a, b, and c refer to time of N application as described in Table 3.)

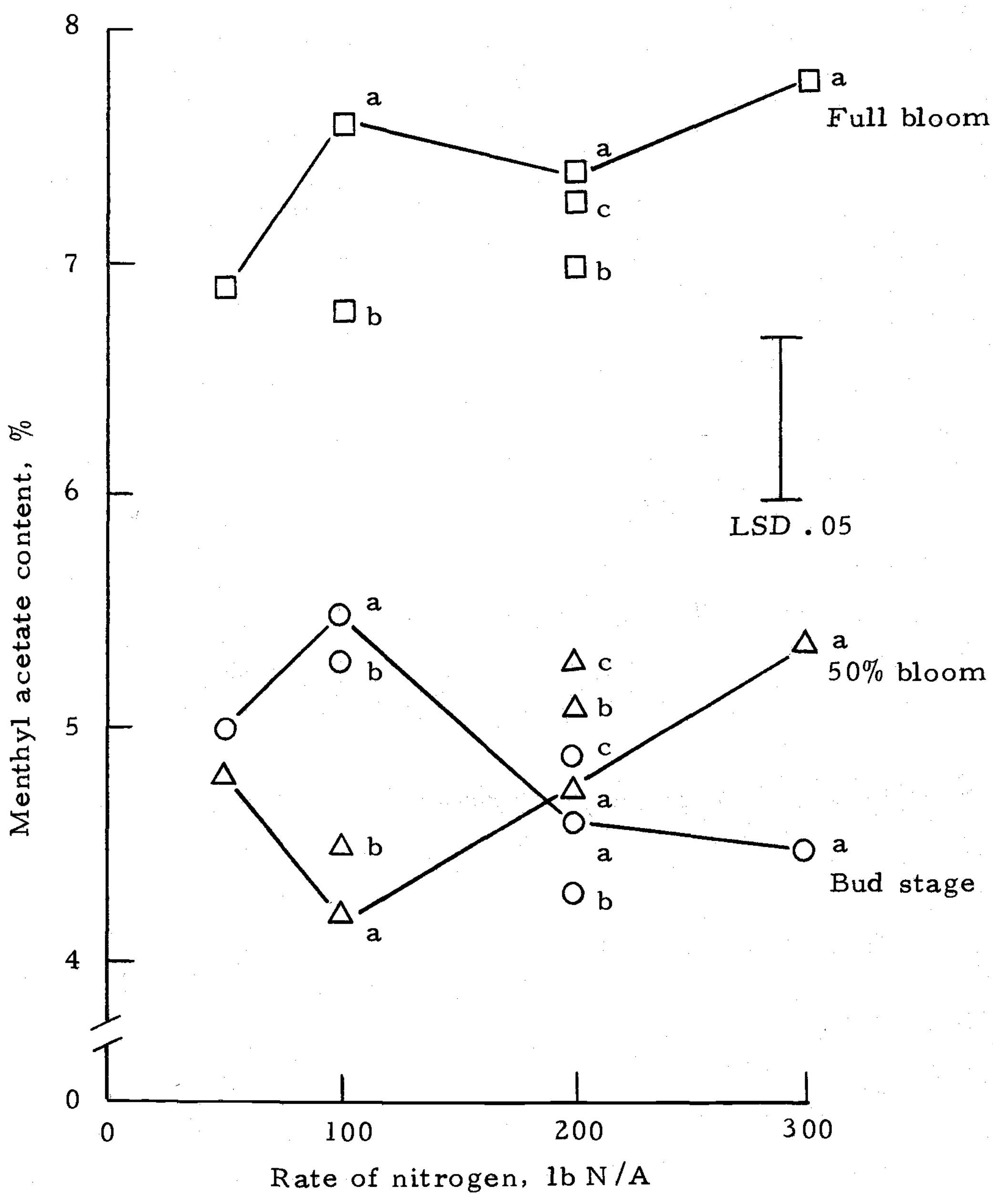

Figure 8. Effect of nitrogen treatments and maturity on the menthyl acetate content of peppermint oil at the Corvallis location, 1971. (a, b, and c refer to time of N application as described in Table 3.)

mint on June 1 (B treatment). In this case, the June 1 applications were always higher in menthyl acetate than either the 15-day applications (A treatments) or the July 1 (C treatments) applications regardless of the time of harvest (Figure 7).

Table 14. Effects of nitrogen treatments and maturity on the menthyl acetate content of peppermint oil at Madras.

Nitrogen Treatments lb N/A	Menthyl Acetate Content, %			
	15% Bloom 1970	50% Bloom 1970	Bud 1971	50% Bloom 1971
0	-	-	8.7	8.9
40	5.9	7.5	-	-
100A*	6.4	7.4	-	-
150A	6.6	8.0	7.7	9.0
150B	-	-	8.4	9.3
200A	6.3	8.3	8.6	8.8
200B	-	-	8.0	8.6
250A	6.5	7.8	8.8	9.2
250B	-	-	7.8	8.2
350A	6.3	7.7	8.2	9.0
LSD (.05)	1.0	1.0	-	-

* A, B and C refer to time of N application as outlined in Table 3.

Oregon peppermint oil should contain 5.0-7.5% methyl acetate (Table 9). Approximately 250 lb N/A to 300 lb N/A is optimum with harvests made at 50% bloom for Willamette Valley mint and just prior to 50% bloom for Central Oregon mint.

Menthofuran Content

Measurements of menthofuran content made at Corvallis in 1970 and 1971 showed that a reduction in menthofuran levels occurred with higher rates of nitrogen fertilizer for mint harvested during 50% and full bloom (Figures 9 and 10). This trend, however, was not the same for mint which was harvested while in the bud stage. In this case, menthofuran contents remained relatively constant (Figure 9) or increased (Figure 10) with higher rates of nitrogen fertilizer.

Growth chamber studies by Battaile and Loomis (1966) indicate that younger leaves are abundant in unsaturated ketones and menthofuran whereas older leaves have relatively more menthol and menthyl acetate. Later work by Burbott and Loomis (1967) indicate that the oil obtained from the flowers contained high levels of menthofuran. The differences in menthofuran contents in oil from young versus older leaves and the higher menthofuran contents of the flowers could possibly account for the interaction between the nitrogen fertilizer treatments and maturity on menthofuran content.

Mint which received high rates of nitrogen fertilizer responded with vigorous vegetative growth. The oil from these plots contained relatively more menthofuran when harvested in the bud stage as compared to plots receiving low nitrogen rates due to the greater amount of new foliage. When harvested at 50% and full bloom, however, the

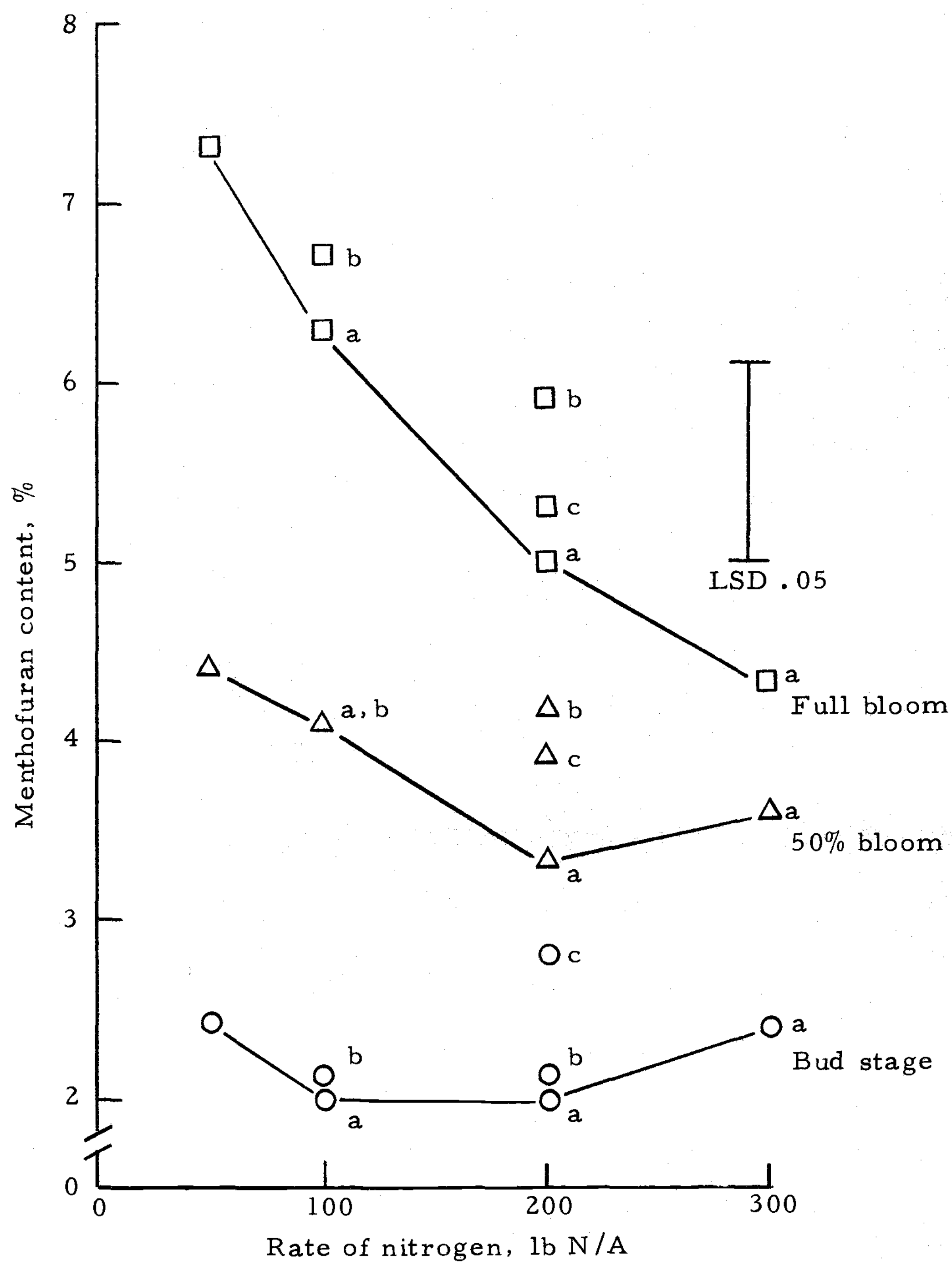

Figure 9. Effect of nitrogen treatments and maturity on the menthofuran content of peppermint oil at the Corvallis location, 1970. (a, b, and c refer to time of N application as described in Table 3.)

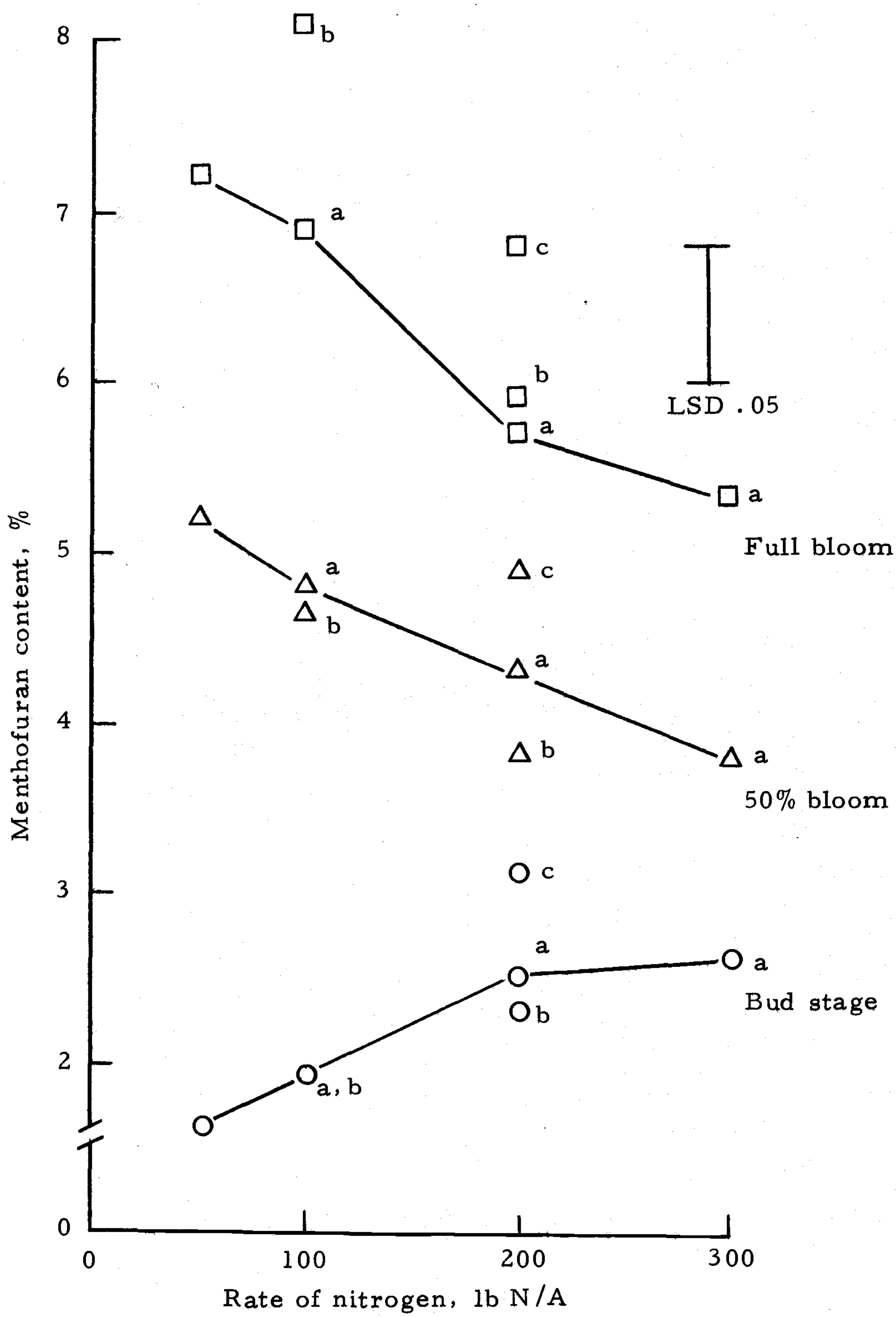

Figure 10. Effect of nitrogen treatments and maturity on the menthofuran content of peppermint oil at the Corvallis location, 1971. (a, b, and c refer to time of N application as described in Table 3.)

plots receiving the higher nitrogen rates yielded relatively lower menthofuran contents. This suggests, perhaps, a dilution of the flower oil, which is high in menthofuran, by leaf oil from more mature leaves that have lower menthofuran concentration.

The effects of nitrogen on menthofuran contents at Madras were not consistent (Table 15). The 1970 measurements made at 50% bloom stage did, however, show slightly lower menthofuran contents for plots which received 250 and 350 lb N/A.

Table 15. Effect of nitrogen treatments and maturity on menthofuran contents of peppermint oil at the Madras location.

Nitrogen Treatments lb N/A	Menthofuran Content, %			
	15% Bloom 1970	50% Bloom 1970	Bud 1971	50% Bloom 1971
0	-	-	2.0	4.3
40	1.9	4.5	-	-
100A*	1.3	3.9	-	-
150A	1.5	3.3	2.7	5.1
150B	-	-	2.0	4.1
200A	1.5	3.4	2.2	3.9
200B	-	-	2.6	4.4
250A	1.6	2.9	2.7	4.2
250B	-	-	2.6	4.2
350A	1.7	3.2	2.8	4.2
LSD (.05)	0.6	0.6	0.6	0.6

* A, B and C refer to time of N application as outlined in Table 3.

The differences in menthofuran due to time of nitrogen application were relatively small and not consistent. Delaying nitrogen fertilization until July 1 (C treatment) at Corvallis did tend to result in higher menthofuran contents in comparison with 15-day nitrogen applications (A treatments). These differences, however, were not statistically significant (P = .05).

High concentrations of menthofuran in mint oil are an indication of inferior quality. Menthofuran contents of less than 3% are desired for mint oil produced in Oregon (Table 9). Results from both experimental locations indicate that Oregon mint should be harvested prior to 50% bloom in order to obtain menthofuran contents less than 3%. Heavy nitrogen rates (200 lb N/A or greater) can reduce menthofuran contents for mint harvested at 50% bloom or later.

EFFECTS OF NITROGEN TREATMENTS AND PLANT MATURITY ON OIL ODOR

Subjective evaluations of mint oil odor were performed by odor specialists of A. M. Todd Company in Kalamazoo, Michigan. Each sample was compared with a standard and assigned a numerical grade which ranged from one to five. Each grade is defined in Table 16.

Sampling at different stages of maturity produced only slight differences in oil odor (Table 17). These differences were not consistent from one year to the next.

Table 16. Definitions of oil odor grades.

Odor Grade	Definition
1	Equal to or better than control (a good quality western Oregon oil).
2	Not quite equal to control, but probably o.k. for most uses.
3	Not equal to control; not good.
4	Poor quality.
5	Very poor quality or weedy.

Table 17. Effect of maturity on the odor of peppermint oil at the Corvallis and Madras locations.

		Odor Grade				
Location	Year	Bud	15% Bloom	50% Bloom	Full Bloom	LSD (.05)
Corvallis	1970	1.8	-	2.1	2.3	N.S.
Corvallis	1971	2.9	-	2.7	2.3	N.S.
Madras	1970	-	1.9	2.5	-	0.4
Madras	1971	-	2.8	2.0	-	-

At Corvallis, data taken in 1970 showed a deterioration in oil odor with maturation. Measurements made in 1971, however, showed a contradictory trend; oil odor improved with increasing maturity. The differences in oil odor attributed to differences in maturity were not statistically significant (P = .05) for the Corvallis location. The 1970 odor analysis at Madras indicated a significant (P = .05) decrease in oil odor quality between mint harvested at 15 and 50 percent bloom.

Increasing rates of nitrogen fertilizer generally did not establish any consistent trends with respect to either the improvement or detriment of oil odor quality (Tables 18 and 19). Differences in odor grades due to nitrogen treatments were not significant with the exception of the 1970 data from Corvallis (Table 18). These results showed that the 200B and 300A nitrogen treatments produced oil having relatively good odor compared to the other treatments. Relatively high rates of nitrogen fertilizer (200-300 lb N/A) were not detrimental to odor quality.

Table 18. Effect of nitrogen treatments on peppermint oil odor at the Corvallis location.

Nitrogen Treatments lb N/A	Odor Grade 1970	Odor Grade 1971
50	2.7	1.7
100A	1.9	2.7
100B	2.1	3.5
200A	2.2	3.1
200B	1.6	2.3
200C	2.3	3.0
300A	1.7	2.3
LSD (.05)	0.6	N.S.

Table 19. Effect of nitrogen treatments and maturity on peppermint oil odor at the Madras location.

Nitrogen Treatments lb N/A	Odor Grade			
	15% Bloom 1970	50% Bloom 1970	Bud 1971	50% Bloom 1971
0	-	-	3.0	2.8
40	2.0	2.2	-	1.0
100A	1.4	1.8	-	2.2
150A	1.8	3.2	3.0	2.2
150B	-	-	2.4	1.6
200A	2.4	2.6	3.8	1.8
200B	-	-	3.0	1.4
250A	1.6	2.6	3.0	2.4
250B	-	-	2.2	3.4
350A	2.2	2.6	2.0	1.2
LSD (.05)	N.S.	N.S.	N.S.	N.S.

EFFECTS OF NITROGEN TREATMENTS AND PLANT MATURITY ON NUTRIENT CONTENT

The effects of nitrogen treatments and maturity on the nutrient content of mint was evaluated in 1970 at the Corvallis location. Nitrogen fertilizer treatments had a marked effect on the NO_3-N content of mint at harvest time (Table 20). Significant differences in NO_3-N were obtained with increases in nitrogen fertilizer rates. Differences in NO_3-N resulting from different times of nitrogen application were negligible. Although increases in NO_3-N were apparent with increases in nitrogen fertilizer rates, oil yields were unaffected (Table 7). This could be due to the row mint status of the experiment in 1970.

Substantial variations in NO_3-N were found with differences in maturity. Increases in maturity were accompanied by decreases in NO_3-N contents in the stems (Table 21). This emphasizes the importance of defining critical NO_3-N levels at a specified stage of development for mint.

Contents of phosphorus and potassium appeared unaffected by the nitrogen treatments applied. Generally, these values were in agreement with those reported by Heuttig (1969) for mint in western Oregon.

Table 20. Nutrient contents of peppermint stems at the Corvallis location on June 30, 1970, 23 days before bud stage.

Nitrogen Treatment lb N/A	Nutrient Contents						
	Percent					ppm	
	P	K	Ca	Mg	Na	Zn	Mn
50	.38	5.01	1.54	.35	.03	34	41
100A	.41	4.99	1.55	.37	.04	34	35
100B	.37	4.76	1.56	.41	.04	35	35
200A	.34	4.81	1.60	.44	.04	36	35
200B	.35	4.92	1.56	.41	.04	36	38
200C	.36	4.81	1.58	.39	.04	35	38
300A	.35	4.75	1.57	.42	.04	36	38

Table 21. NO_3-N contents of peppermint stems sampled at three different stages of maturity at the Corvallis location, 1970.

Nitrogen Treatments lb N/A	NO_3-N Content, Percent*		
	Bud Stage	50% Bloom	Full Bloom
50	.03	.05	.05
100A	.40	.26	.24
100B	.48	.22	.16
200A	.61	.51	.33
200B	.67	.50	.38
200C	.62	.55	.43
300A	.80	.59	.43

*$LSD_{.05}$ = .02%, $LSD_{.01}$ = .27%

SUMMARY AND CONCLUSIONS

Oil Yield

Greater oil yields were obtained with higher nitrogen applications. For Willamette valley peppermint, rates of 200 to 250 pounds of nitrogen per acre appeared optimum. This corresponds well with Heuttig's findings in 1969. Slightly higher rates of 250 to 300 pounds of nitrogen per acre seem optimum for higher oil yields in the central Oregon production areas. Apparently, higher oil yields are possible in central Oregon over the Willamette valley area, hence the response to heavier nitrogen application. The warmer day temperatures and larger diurnal temperature differentials in the central Oregon area may contribute to the higher yield potential. Varying the time of nitrogen application provided no noticeable effect on oil yields.

Oil yields increase with crop maturation. Statistically greater oil yields were obtained for mint harvested at 50 percent bloom over mint harvested while in the bud stage. In order to obtain optimum yields, Oregon mint should be harvested when the crop is near 50 percent bloom. Although even higher yields may be attainable past this point, late harvests should be avoided as oil quality deteriorates as full bloom approaches.

Oil Quality

Plant maturity has a most profound effect on peppermint oil quality. In general, the following trends in oil composition and odor were observed with increasing inflorecence. The level of terpene hydrocarbons, the light boiling fractions of mint oil constituents, and menthone levels decreased progressively with subsequent sampling at 50 percent bloom and full bloom. Menthol, menthyl acetate and menthofuran contents increased as the degree of crop inflorecence progressed. These observations are in general agreement with the findings of Nelson et al. (1971c) and Burbott (1963).

Subjective odor grade evaluations made with respect to different levels of bloom produced contradictory trends from one year to the next. These effects cannot be explained without further investigation.

Of the various bloom stages evaluated, it appears that peppermint oil with well balanced composition can be best obtained when the crop is near 50 percent bloom. If harvests are timed accordingly both high yields and good quality oil may be achieved. Mint harvested beyond 50 percent bloom may produce oil with higher menthofuran composition. The menthofuran measurements made during this study showed levels of less than three percent menthofuran persisted only at bud stage sample. Should bud stage harvests be made, however, other oil components such as menthone, menthol and menthyl acetate may not be within acceptable limits. Furthermore, oil yield per acre would be reduced.

Nitrogen application rates and to a lesser extent the time nitrogen is applied has some influence on mint oil composition with the exception of terpene hydrocarbon levels. The influences, however, were secondary to the effects of crop maturation.

Higher menthone levels were measured in response to higher nitrogen rates. In addition, nitrogen applied at 15 day intervals produced higher menthone levels than large nitrogen applications made either early (June 1) or late (July 1) in the season. In general, acceptable menthone contents of 20 to 30 percent may be obtained with 200 to 300 pounds of nitrogen per acre provided the crop is harvested at 50 percent to full bloom.

Lower menthol contents were obtained with higher rates of nitrogen. Time of nitrogen application, however, had little effect on menthol levels. For established mint fields (meadow mint) 200 to 300 pounds of nitrogen per acre may produce oil bearing the acceptable 50 to 60 percent menthol if harvested in excess of 50 percent bloom.

Two hundred fifty to 300 pounds of nitrogen per acre is probably optimum for Willamette Valley peppermint harvested at 50 percent bloom with 5.0 to 7.5 percent menthyl acetate. Central Oregon mint receiving these rates of nitrogen should be harvested just prior to 50 percent bloom. In most cases, menthyl acetate levels were not sensitive to differences in nitrogen application times.

Menthofuran content exhibited decreases in response to higher rates of nitrogen except for mint harvested while in the bud stage. For harvests made just prior to 50 percent bloom, 200 to 250 pounds of nitrogen may be appropriate for Willamette Valley mint. Higher rates, up to 300 pounds of nitrogen per acre appear acceptable for the central Oregon mint areas. Time of nitrogen application did not affect menthofuran contents within statistical limits, however, delaying nitrogen fertilization until July 1 did tend to result in higher levels than the incremental 15 day application.

Conclusions

Based on the results of this study the following conclusions with respect to peppermint oil yields, quality and composition are made.

1. Rates of 200 to 250 pounds of nitrogen per acre appear optimum for maximum oil yields on Willamette Valley mint. For central Oregon mint areas, 250 to 300 pounds of nitrogen per acre seem appropriate.
2. Oil yields increase with crop maturity, however, because of oil quality constraints, mint should be harvested when the crop is near 50 percent bloom. The additional yield gained by delaying harvests past this point is made at the sacrifice of high quality oil.

3. Oil quality and composition are highly dependent on crop maturity. Terpene hydrocarbons (the light boiling oil fractions) and menthone levels decrease with increase in crop maturity and inflorecence. Menthol, menthyl acetate and menthofuran contents increased with crop maturation. In order to obtain a reasonable balance of oil chemical constituents as defined by commercial standards, both Willamette Valley and central Oregon peppermint should be harvested when crop inflorecence is near 50 percent.
4. Nitrogen fertilization may influence oil composition within given harvest times, though these effects are largely secondary to crop maturation influences. The higher nitrogen applications (200-300 pounds of nitrogen per acre) tend to produce oil higher in menthone levels and lower in menthol and menthofuran. Peppermint oil with a reasonable balance in chemical constitution can be achieved with 200 to 250 pounds of nitrogen per acre rates in the Willamette Valley and 250 to 300 pounds of nitrogen per acre in central Oregon. These rates of nitrogen per acre should be distributed in approximately equal increments over the growing season.

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