Study on Japanese Cornmint in Mississippi

Valcho D. Zheljazkov, Charles L. Cantrell, and Tess Astatkie

ABSTRACT

Japanese cornmint (Mentha canadensis L.) is a subtropical essential oil crop grown in Asia and South America. The essential oil of Japanese cornmint is the source for production of crystal (–)-menthol, which is an important aromatic agent used in various industries. The United States is a major importer and consumer of (–)-menthol and de-mentholized oil. Currently there is no production of Japanese cornmint in the United States. A 2-yr study was conducted in Mississippi to evaluate the effect of N application rates (0, 80, and 160 kg ha−1) and cut (harvest time, with a first cut in July, and a second cut in October) on herbage yields, essential oil content, and composition of two Japanese cornmint genotypes (‘Arvensis 2’ and ‘Arvensis 3’). Both cultivars provided two cuts and comparable herbage and oil yields to literature reports. Generally, N application increased fresh herbage and oil yields relative to the untreated control. Herbage, essential oil, (–)-menthol, and (–)-menthone yields were greater from the first cut than from the second for both cultivars. The concentration of (–)-menthol in the oil of both cultivars was approximately 50% in 2007; however, in 2008 the (–)-menthol concentration was 67% to 76% in ‘Arvensis 2’ and 73 to 78% in ‘Arvensis 3’. This study demonstrates that Japanese cornmint could be successfully grown in Mississippi and possibly other areas in the southeastern United States with similar environmental conditions.

Japanese cornmint is grown for production of essential oil, from which (–)-menthol (a cyclic terpene alcohol, with three asymmetric carbon atoms) is extracted. Both (–)-menthol and the de-mentholized oil are widely used as flavor and fragrance vectors in pharmaceutical, food, flavor, and fragrance industries (Clark, 1998; Chand et al., 2004; Galeotti et al., 2002; Shrivastava et al., 2002; Topalov, 1962; Topalov, 1989). Japanese cornmint oil and (–)-menthol have been shown to possess antimicrobial (Duarte et al., 2005; Ozkan et al., 2002) and antioxidant (Shan et al., 2005) properties, making them usable as constituents in modified atmosphere packaging (MAP) to preserve fruit or vegetable quality and to extend their shelf life (Serrano et al., 2008). The wide application of (–)-menthol is due to its cooling sensation, which makes it a preferred flavor agent in topical antipruritic, antiseptic and cooling formulations (Clark, 1998; Galeotti et al., 2002). The cooling and tingling sensation are caused by effects on biological membranes; menthol stimulates cold receptors by inhibiting the Ca cation current in neuronal membranes (Eccles, 1994; Galeotti et al., 2002; Schafer et al., 1982). (–)-menthol is only found in usable quantities in the oil of two species: peppermint (Mentha × piperita) and Japanese cornmint (Mentha canadensis L.). However, (–)-menthol crystallization from peppermint oil is both cost and technically prohibitive, making Japanese cornmint the only suitable species for production of crystalline (–)-menthol (Clark, 1998). (–)-menthol and other compounds found in Japanese cornmint oil such as L-menthyl lactate (Gassenmeier, 2006) could be synthesized artificially. However, current regulations prohibit the use of non-natural compounds in many areas of food and flavor industries (Hiserodt et al., 2004; Gassenmeier, 2006). Furthermore, synthetic (–)-menthol has off-odors (due to the matrix material used for its production) that often contain impurities that may cause severe nose and throat irritation (Clark, 1998). Additionally, Japanese cornmint has a high concentration of (–)-menthol in its...
oil. (60–80% (−)-menthol concentration in Japanese cornmint essential oil vs. 40–45% in peppermint oil). Hence, the production of (−)-menthol is based exclusively on Japanese cornmint, which is also known as the “menthol mint.”

Japanese cornmint is a subtropical plant that is widely grown in India, China, Vietnam, Brazil, (Chand et al., 2004; Clark, 1998; Kumar et al., 2000; Singh and Saini, 2008) and, to a limited extent, in some eastern-European countries. Some authors (Pandey et al., 2003; Singh and Saini, 2008) have incorrectly indicated that Japanese cornmint is produced in the US as well. There is no commercial production of Japanese cornmint in the United States, although the United States is a major market for Japanese cornmint essential oil, (−)-menthol and de-mentholized oil (MIRC, personal communication, 2007). Hence, (−)-menthol and Japanese cornmint essential oil have been imported to the United States for use in various industries.

Essential oil broker companies and MIRC indicated that there is a significant market for Japanese cornmint oil in the United States. Current suppliers of Japanese cornmint essential oil and (−)-menthol are India, China and other countries in Asia. However, historically and currently there have been significant issues with the consistency of supply and quality of both Japanese cornmint essential oil and crystal (−)-menthol (Clark, 1998; MIRC, 2007). Issues with consistency in supply and quality could be solved through domestic production of Japanese cornmint. Furthermore, the introduction of Japanese cornmint in the United States would provide a cash crop for primary producers and may foster the development of value-added processing. The objectives of this study were to evaluate the effect of N application rate and cut (harvest time) on herbage yields, essential oil content, oil composition, and on the yields of individual oil constituent [(−)-menthol, (−)-menthone, and (±)-menthofuran] of two Japanese cornmint genotypes.

MATERIALS AND METHODS

Field Experiments

A field experiment was performed in 2007 and 2008 at the North Mississippi Research and Extension Center (NMREC) in Verona, Mississippi (34°43’22˝ N and –88°43’22˝ W). Following a suggestion from the Mint Industry Research Council, and to curtail pest and disease pressure, transplants (certified and virus-free planting material) of Japanese cornmint (Mentha canadensis L.) ‘Arvensis 2’ and ‘Arvensis 3,’ two cultivars of dissimilar morphology (Fig. 1), were purchased from The Summit Plant Laboratories, Inc. (Fort Collins, CO). The transplants, 10 to 11 cm in height and with well-developed root systems, were placed individually in 52 cell trays. Before transplanting, the transplants were hardened for a week.

For each year, the experimental design was a two-factor factorial in four blocks, and had responses measured repeatedly on two occasions (cuts). The individual research plots were 6.1 m long, and the harvested area in each plot was 4.1 m².

The soil at Verona was Quitman sandy loam (fine-loamy, siliceous, semiactive, thermic, Aquic Paleudult). The experimental site was previously under perennial grass. Site land preparation included the application of total herbicide (glyphosate at 2 kg ha⁻¹), as well as plowing and disking 2 wk after the application of the herbicide. Selected soil properties and the concentration of the extractable nutrients at the end of the second growing season (0–15 cm deep, 4 cores per plot) are provided in Table 1. Before land preparation, soil samples (0–15 cm deep, 3 composite samples made of 24 soil cores) were analyzed for extractable nutrients. The concentration of available soil nutrients was determined following the Lancaster soil test method (Cox, 2001) and was measured on an inductively coupled argon plasma

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>N Trt kg N h⁻¹</th>
<th>OM %</th>
<th>pH</th>
<th>Nitrate-N</th>
<th>P kg ha⁻¹</th>
<th>K kg ha⁻¹</th>
<th>Ca kg ha⁻¹</th>
<th>Mg kg ha⁻¹</th>
<th>Zn kg ha⁻¹</th>
<th>S kg ha⁻¹</th>
<th>Na kg ha⁻¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>‘Arvensis 2’</td>
<td>0</td>
<td>1.27</td>
<td>5.87</td>
<td>3.4</td>
<td>133</td>
<td>149</td>
<td>2037</td>
<td>140</td>
<td>2.2</td>
<td>205</td>
<td>123</td>
</tr>
<tr>
<td>‘Arvensis 2’</td>
<td>80</td>
<td>1.66</td>
<td>5.57</td>
<td>3.4</td>
<td>145</td>
<td>168</td>
<td>2291</td>
<td>139</td>
<td>1.5</td>
<td>268</td>
<td>120</td>
</tr>
<tr>
<td>‘Arvensis 3’</td>
<td>160</td>
<td>1.39</td>
<td>5.50</td>
<td>35.8</td>
<td>96</td>
<td>120</td>
<td>2027</td>
<td>97</td>
<td>1.5</td>
<td>224</td>
<td>111</td>
</tr>
<tr>
<td>‘Arvensis 3’</td>
<td>0</td>
<td>1.27</td>
<td>6.17</td>
<td>3.4</td>
<td>131</td>
<td>139</td>
<td>2404</td>
<td>118</td>
<td>2.0</td>
<td>205</td>
<td>164</td>
</tr>
<tr>
<td>‘Arvensis 3’</td>
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<td>1.46</td>
<td>5.90</td>
<td>3.4</td>
<td>133</td>
<td>143</td>
<td>2402</td>
<td>133</td>
<td>1.5</td>
<td>225</td>
<td>127</td>
</tr>
<tr>
<td>‘Arvensis 3’</td>
<td>160</td>
<td>1.26</td>
<td>5.77</td>
<td>25.4</td>
<td>99</td>
<td>111</td>
<td>2292</td>
<td>128</td>
<td>1.7</td>
<td>203</td>
<td>132</td>
</tr>
</tbody>
</table>
The field was treated with Quadris twice at a rate of 2957 mL ha⁻¹.

Powdery mildew (Erysiphe cichoracearum) was observed, and the treatment was effective in controlling the disease. The plots were free of pests and diseases in 2007. However, in 2008, a minor disease incidence was observed.

All of the plots of the Japanese cornmint were transplanted in the field on 4 and 5 May 2007. The transplants were spaced in two rows on each bed in an offset pattern, with 30 cm in-row and 30 cm between-row spacing; every plot had 40 plants. All of the plots of the Japanese cornmint were free of pests and diseases in 2007. However, in 2008, powdery mildew (Erysiphe cichoracearum) was observed, and the field was treated with Quadris twice at a rate of 2 kg ha⁻¹ for weed control.

Rounded beds (12 cm high and 77 cm wide across the top) were prepared, after disking, by using a press-pan-type bed shaper machine, which also placed a drip tape irrigation tube at 2 to 3 cm soil depth below the soil surface, in the middle of the bed. Raised beds are quite common in the southern United States; they help with surface drainage and ensure that no areas in the field are under water after heavy rains. After bed formation and before planting, Sinbar was incorporated at a rate of 2 kg ha⁻¹ for weed control. Sinbar is the most traditional soil herbicide used in mint production in the United States and abroad (MIRC, 2007; Topalov, 1989; Zheljazkov, 1998). Both cultivars of Japanese cornmint were transplanted in the field on 4 and 5 May 2007. The transplants were spaced in two rows on each bed in an offset pattern, with 30 cm in-row and 30 cm between-row spacing; every plot had 40 plants. All of the plots of the Japanese cornmint were free of pests and diseases in 2007. However, in 2008, powdery mildew (Erysiphe cichoracearum) was observed, and the field was treated with Quadris twice at a rate of 2957 mL ha⁻¹.

Plants from all plots were harvested at flowering, which was when the content and the composition of the essential oil were considered optimal (Topalov, 1989). Aboveground (5–6 cm above the soil surface) fresh herbage yields were recorded, and then the plants were dried at temperatures of 35 to 40ºC to avoid essential oil loss (Topalov, 1989). Finally, the dry weight was also recorded. Subsamples from every plot were steam-distilled for 60 min using a 2-L Clevenger type steam distillation unit (Clevenger, 1928; Furnis et al., 1989) as described previously (Gawde et al., 2009). The essential oil was measured on an analytical scale and the essential oil content was calculated as the amount (g) of oil per weight (g) of dry plant tissue, and then the oil yield per area was calculated for every plot.

### Gas Chromatography–Mass Spectrophotometer Analysis of the Essential Oil

Qualitative and quantitative analysis of the essential oil from all of the plots was performed. Generally, the gas chromatography–mass spectrophotometer (GC–MS) methods and conditions for analysis were identical to those previously described (Zheljazkov et al., 2008, 2010a). The amount of the essential oil was expressed as the ratio of oil/fresh (w/w) raw material. Individual concentration gradients for reference standards were prepared for (−)-menthol, (−)-menthone, and (+)-menthofuran to obtain a standard curve for each.

### Quantitative Analysis

Commercial standards of (−)-menthol, (−)-menthone, and (+)-menthofuran were purchased from Fluka (Buchs, Switzerland). With five concentration points, an external standard least squares regression was performed for quantification. All analytes were used to formulate separate calibration curves. Linearity was imposed by using response factors and regression coefficients independently. Response factors were calculated using the equation RF = DR/C, where DR was the detector response in peak area (PA) and C was the analyte concentration.

The chromatograms of each of the essential oil samples from the field experiments and the commercial mint oil samples were compared with the chromatograms from standard injections. The target peaks were confirmed by both retention time and mass spectra. Confirmed integrated peaks were then used to determine the percentage of each chemical constituent in the essential oil. The RF of the target chemical constituent was used to determine the “percent of oil” for each sample using the equation: PA/RF/C = % (peak area/response factor/concentration) in the oil.

### Statistical Methods

The nine response measurements (fresh herbage yield, percent oil content from fresh herbage, fresh herbage oil yield, (−)-menthol concentration, (−)-menthone concentration, (+)-menthofuran concentration, (−)-menthol oil yield, (−)-menthone oil yield, and (−)-menthofuran oil yield) were analyzed as repeated measures of a two-factor factorial design in four blocks. The two factors of interest whose levels were completely randomized in each block were Cultivar (‘Arvensis 2’ and ‘Arvensis 3’) and N Treatment rate (0 and 80 kg ha⁻¹ for Cut 1 and a third level of 160 kg ha⁻¹ for Cut 2). The data were analyzed as repeated measures with two occasions (Cut 1 and Cut 2) nested in Year (2007 and 2008) because the measurements were taken in the same experimental unit (plot) on two dates, and nested because the plants in the two years had different plant and canopy architecture. These differences were due to different plant densities between the first and second cut in 2007 and also between the 2007 and 2008 cuts. Year effect was accounted by adding year and associated interaction effects in the model. The analysis of variance (ANOVA) was completed using the mixed procedure of SAS (SAS Institute, 2003), and further multiple means comparison was completed for significant (p value < 0.05) and marginally significant (p value between 0.05 and 0.1) effects by comparing the least squares means of the corresponding treatment combinations using the lsmeans statement of Proc Mixed with the pdiff option to produce p values for all pairwise differences. Letter groupings were generated using a 5% level of significance. For each response, the validity of model assumptions on the error terms was verified by examining the residuals as described by Montgomery (2009).

### RESULTS

The main effects of (but not interactions with) cultivar and N treatment were significant on the concentration of (+)-menthofuran and (−)-menthone yields respectively (Table 2). The interaction effect of cultivar and N treatment was significant for (−)-menthone concentration. The interaction of cultivar and cut(year) was significant for oil content and yield, and for (−)-menthol and (−)-menthone concentrations and yields. The interaction effect of N treatment and cut(year) was significant on oil content and yield, the concentrations of (−)-menthol and (−)-menthone in the oils and on (−)-menthol yields (Table 2). The 3-way interaction effect of cultivar, N treatment, and cut(year) was significant on fresh herbage yield and (−)-menthofuran yield (Table 2).
In both cropping seasons, oil content in the biomass from both cuts of ‘Arvensis 2’ was higher than the oil content in the biomass from the first or second cut of ‘Arvensis 3’. Generally, within a cultivar, oil yields were higher from the first cut than from the second cut. The highest oil yields (approximately 140–143 kg ha$^{-1}$) were achieved from the first cut of ‘Arvensis 3’ in 2007 and from the first cut of ‘Arvensis 2’ in 2008.

(–)-Menthol concentration in the oil of both cultivars was higher in the 2008 than in the 2007 cropping season (Table 3). In the 2008 cropping season, (–)-menthol concentration in the biomass of ‘Arvensis 2’ was higher from the second cut (76%) than from the first cut (67%), whereas cut did not significantly affect this index (73% and 78%) in the other cultivar. Generally, (–)-menthone concentration in the oil and (–)-menthone yield were higher in the first cut as compared with the second cut. Also, (–)-menthone concentration in most instances was higher in the oil of ‘Arvensis 3’. Because of differences in (–)-menthol concentrations in the oils between the two cropping season, greater (–)-menthol yields were achieved in 2008. The highest (–)-menthol yields were achieved in 2008 cropping season from the first cut of both cultivars and the lowest, from the second cut of ‘Arvensis 3’ in the same cropping season (Table 3).

In the 2008 cropping season, (–)-menthol concentration in the oil and (–)-menthol yield concentration was higher in the oil from ‘Arvensis 2’ (7.2%) than from ‘Arvensis 3’ (5.8%).

The three-way interaction effect of cultivar, N treatment and cut(year) on fresh herbage yield shown in Fig. 2 indicates increased yield due to the first addition of 80 kg N ha$^{-1}$ in cut 1 of both cultivars in the 2008 cropping season, but not in the 2007 cropping season. This increase was more pronounced in ‘Arvensis 2’ than in ‘Arvensis 3’. However, in cut 2, the first addition of 80 kg N ha$^{-1}$ did not increase fresh herbage yield of ‘Arvensis 2’, but considerably increased the yield of ‘Arvensis 3’. The second addition of 80 kg N ha$^{-1}$ increased the yield of ‘Arvensis 2’ in 2008, but decreased that of ‘Arvensis 3’ in both years. These results suggest that while ‘Arvensis 2’ may benefit from a second addition of 80 kg N ha$^{-1}$, the optimum for ‘Arvensis 3’ is just one application of 80 kg N ha$^{-1}$.

<table>
<thead>
<tr>
<th>Source of variation</th>
<th>FrHYld</th>
<th>OilYld</th>
<th>M-olC</th>
<th>M-oneC</th>
<th>M-onfuC</th>
<th>M-olYld</th>
<th>M-oneYld</th>
<th>M-onfuYld</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cult</td>
<td>0.001</td>
<td>0.001</td>
<td>1.000</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
</tr>
<tr>
<td>Trt</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
</tr>
<tr>
<td>Cult × Trt</td>
<td>0.024</td>
<td>0.012</td>
<td>0.980</td>
<td>0.202</td>
<td>0.046</td>
<td>0.615</td>
<td>0.749</td>
<td>0.254</td>
</tr>
<tr>
<td>Cut(Year)</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
<td>0.576</td>
<td>0.001</td>
<td>0.340</td>
<td>0.001</td>
<td>0.001</td>
</tr>
<tr>
<td>Cult × Cut(Year)</td>
<td>0.001</td>
<td>0.001</td>
<td>0.001</td>
<td>0.003</td>
<td>0.001</td>
<td>0.956</td>
<td>0.001</td>
<td>0.004</td>
</tr>
<tr>
<td>Trt × Cut(Year)</td>
<td>0.005†</td>
<td>0.429</td>
<td>0.219</td>
<td>0.852</td>
<td>0.866</td>
<td>0.525</td>
<td>0.405</td>
<td>0.394</td>
</tr>
<tr>
<td>Cult × Trt × Cut(Year)</td>
<td>0.005†</td>
<td>0.429</td>
<td>0.219</td>
<td>0.852</td>
<td>0.866</td>
<td>0.525</td>
<td>0.405</td>
<td>0.394</td>
</tr>
</tbody>
</table>

† F values that suggest significance of the effects requiring multiple means comparison are underlined.
**Table 4.** Means together with letter groupings of percent oil content from fresh herbage (OilFH), Fresh herbage oil yield (OilYld in kg ha⁻¹), Menthol concentration (M-olC), (−)-Menthone concentration (M-oneC), and Menthol oil yield (M-olYld in kg ha⁻¹) for the five combinations of N treatment and Cut in 2007 and 2008.

<table>
<thead>
<tr>
<th>N Treatment Year Cut</th>
<th>OilFH</th>
<th>OilYld</th>
<th>M-oneC</th>
<th>M-oneYld</th>
<th>M-olC</th>
<th>M-olYld</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>kg N ha⁻¹</td>
<td>% kg ha⁻¹</td>
<td>% kg ha⁻¹</td>
<td>kg ha⁻¹</td>
<td></td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>0.00</td>
<td>10.00</td>
<td>11.00</td>
<td>12.00</td>
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<td>0</td>
<td>0.00</td>
<td>10.00</td>
<td>11.00</td>
<td>12.00</td>
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<td>80</td>
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<td>11.00</td>
<td>12.00</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

† Means followed by the same letter within a column are not significantly different at the 5% level.

**DISCUSSION**

The (−)-menthol concentration in the two cultivars in this study was similar to that in literature reports. For example, Pandey et al. (2003) reported 71% (−)-menthol in *M. arvensis* in central India. In a study with one cultivar of *M. arvensis*, Murray et al. (1972) reported 64 to 73% menthol in 1970 in Indiana (41º39’ N lat) and 48 to 58% menthol in 1972 in Michigan (42º36’ N lat). Zheljazkov and Margina (1996) reported 61 to 67% menthol in a single cultivar of *M. arvensis*, whereas Zheljazkov et al. (1996a, 1996b) reported 57 to 64% (−)-menthol in two cultivars of Japanese cornmint in Plovdiv, Bulgaria (42º08’ N lat). Comparison with the literature is complicated by the fact that most papers report (−)-menthol concentration as the area under the curve, whereas we did an absolute quantification of (−)-menthol in this study.

(−)-Menthone is an important component of Japanese cornmint essential oil because it is a precursor for (−)-menthol, whereas (−)-menthofuran is a side product of (−)-menthone biosynthesis (Burbott and Loomis, 1967; Mahmoud and Croteau, 2003; Rios-Estepa et al., 2008). Environmental and agronomic factors that promote the conversion of (−)-menthone into (−)-menthol are desirable, whereas factors that lead to an accumulation of (−)-menthofuran in the oil are undesirable. The final concentration of (−)-menthol in the essential oil of Japanese cornmint is a function of the environment, genotype, N application rate, harvest stage and timing, and plantation density (Topalov, 1989; Saxena and Singh, 1996; Saxena and Singh, 1998; Zheljazkov and Nielsen, 1996). A higher plant density after the first cut results in a different plant architecture, a different ratio of older leaves, but the infl orescences are a relatively small portion of the total aboveground biomass. It is important to keep the older leaves, which are often lost before harvest as a result of disease infestations, water stress, or high plant density.

Overall, the N response of the two cultivars of Japanese cornmint in this experiment was similar to literature reports (Anwar et al., 2002; Chandra et al., 1983; Singh et al., 1989a, 1989b; Singh and Saini, 2008; Zheljazkov and Margina, 1996). For example, Chandra et al. (1983) reported increased biomass yields with increased N rates of up to 160 kg ha⁻¹. Anwar et al. (2002) reported the highest biomass and oil yields when Japanese cornmint was provided with S at 50 kg ha⁻¹ and N at 200 kg ha⁻¹. Singh et al. (1989b) reported optimal economic yields of *M. arvensis* at N application rate of 167 kg ha⁻¹. Singh and Saini (2008) reported biomass yield variation of *M. arvensis* between 7,363 and 14,570 kg ha⁻¹, except...
in the weedy check and depending on planting date, mulching, and weed control.

The essential oil yields in this study were either similar to or greater than yields reported in the literature (Ram et al., 2006; Singh and Saini, 2008; Singh et al., 1989a, 1989b; Zheljazkov and Margina, 1996; Zheljazkov et al., 1996a, 1996b). For example, Singh and Saini (2008) reported oil yields between 57 and 102 L ha\(^{-1}\) that depended on planting date, mulching and herbicide treatments. In a 2-yr fertilizer study of Japanese cornmint (\(M.\ arvensis\), Zheljazkov and Margina (1996) reported oil yields of 67 kg ha\(^{-1}\) (N at 0 kg ha\(^{-1}\)) and 111 kg ha\(^{-1}\) (N at 151 kg ha\(^{-1}\)). Ram et al. (2006) reported total oil yields from two harvests ranging from 158 to 373 kg ha\(^{-1}\) that depended on irrigation and N regimes. However, the higher yields in the latter study were obtained from very high N application rates (Ram et al., 2006). Some of the above studies were conducted in the subtropical part of India, at latitudes 30º5´ N and 26º5´ N, respectively. Zheljazkov et al. (1996a) and Zheljazkov and Margina (1996) reported oil yields (from a single harvest/year) of 108 to 176 kg ha\(^{-1}\) in Bulgaria, at 42º08´ N lat.

This study demonstrated that two full cuts could be obtained from Japanese cornmint in Mississippi. The introduction of Japanese cornmint into the United States will provide another cash crop for southern growers. In addition, the local production of Japanese cornmint oil could promote local value-added processing, and an overall improvement to the sustainability and profitability of cropping systems in the southeastern United States. Moreover, crystallization of (–)-menthol has been previously done by manufacturers in the southern United States using imported Japanese cornmint oil (Clark, 1998). Departments of agriculture in the southeastern United States may therefore consider programs for the development of a steam-distillation infrastructure that is needed for essential oil extraction. Such measures by state governments would certainly encourage the development of Japanese cornmint, peppermint, and spearmints (Zheljazkov et al., 2010a,b) as cash crops in the southeastern United States. Further research may be needed to evaluate higher N application rates, the means for weed and disease control, and feasible methods for propagation and establishment of new Japanese cornmint production plantations in the southeastern United States.

Fig. 3. Interaction plot of (+)-menthofuran yield (kg ha\(^{-1}\)) vs. N treatment for the two cultivars and the two cuts. Means sharing the same letter are not significantly different at the 5% level of significance.

CONCLUSIONS

Both cultivars, 'Arvensis 2' and 'Arvensis 3', provided two full cuts, and produced high herbage and oil yields. An N application rate with 80-kg ha\(^{-1}\) increments increased fresh herbage and oil yields relative to the untreated control. Herbage, essential oil, (–)-menthol, and (–)-menthone yields were greater from the first cut than from the second within both cultivars. The average oil content in the biomass of 'Arvensis 2' varied from 0.35 to 0.38%, and the oil content in the biomass of 'Arvensis 3' varied from 0.15 to 0.32%. In 2007, the (–)-menthol concentration in the oil from both cultivars was approximately 50%; however, in 2008 the (–)-menthol concentration was 67% to 76% in 'Arvensis 2', and 73 to 78% in 'Arvensis 3'. This is the first report on Japanese cornmint essential oil productivity with absolute quantification of the oil constituents as a function of genotype, harvest and N application rate in the United States. This study demonstrates that Japanese cornmint could be successfully grown in Mississippi and possibly other areas in the southeastern United States with similar environmental conditions.

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