# EFFECTS OF FERTILIZER NITROGEN MANAGEMENT ON BIOMASS, OIL, AND NITROUS OXIDE EMISSIONS IN PEPPERMINT IN NEBRASKA PANHANDLE

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## ABSTRACT

Peppermint (*Mentha pipperita*) is an aromatic perennial herb that contains aromatic oil, primarily menthol. Irrigated peppermint production requires large nitrogen (N) input, which is often higher than for irrigated corn. Therefore, if not managed properly, mint production has a high potential for N loss, including emissions of nitrous oxide ($N_2O$). Nitrous oxide is a major greenhouse gas and also the single most important ozone-depleting emission. Increasing $N_2O$ emissions from agriculture are linked to soil management and the application of N fertilizers. The objective of this research was to assess the effects of different N fertilizer sources and rates on peppermint biomass, oil (menthol and carvone) concentrations, and $N_2O$ emission. The experiment was conducted in 2022-2023 at the University of Nebraska Research Station in Scottsbluff, NE. The experimental design is a randomized complete block with four replicates. The main factor is N treatment, which included the control, urea, and polymer-coated urea (Duration®, Allied Nutrien, Ohio) surface applied at different rates. Biomass yield ranged 3.33-3.98 Mg $ha^{-1}$ and 7.56-14.11 Mg $ha^{-1}$ in 2022 and 2023, respectively. The 2022 biomass yield was lower than in 2023 due to lower soil available N and crop establishment issues in the first year. In 2022, there was no significant difference in dry biomass across the N source and soil available N (spring soil test N + applied N). In 2023, there was an increment of biomass with increasing soil available N and the biomass was similar for both urea and Duration, except at the applied rate of 120 kg N $ha^{-1}$, where Duration had a higher yield than urea. In both years, menthol content (>90% of total oil) was significantly higher than carvone (<10%). The greater the soil N levels, the higher the oil concentrations were. In both years, the urea treatments had higher $N_2O$ emissions than Duration across all N levels, except for the lowest N rate in 2022 and 2023. Nitrous oxide emission differed by soil N levels in the urea treatments but not in Duration. These results show that fertilizer N can be optimized for sustainable peppermint production in NE using advanced fertilizer technology such as polymer-coated N.

## INTRODUCTION

Peppermint is used in the food, pharmaceutical, and perfume industries for various purposes. Peppermint oil is the end product and primarily consists of menthol (Zheljazkov et al., 2009). The US is the world's largest producer of peppermint oil. Most peppermint is grown in the Northwest Pacific region (Idaho, Oregon, Washington), which accounts for 91% of US peppermint production (Brown et al., 2003). The Peppermint oil market shows steady growth, and Western NE has peppermint growing conditions, such as long days (>15 hours) and cool nights during the summer, like in the Northwest Pacific region (Okwany, 2012). A few local farmers have started growing peppermint in Western NE and found it profitable. Those farmers have been using the fertilizer nitrogen (N) recommendation from other peppermint growing states, especially from Idaho. Based on Idaho N recommendation, peppermint requires more N (280-325 kg $ha^{-1}$) (Brown et al., 2003) than irrigated corn (224-280 kg $ha^{-1}$) for optimal yield (Gumz, 2007). Therefore, in such a high N-input system, a considerable amount of applied N can be lost to the environment, including emission of nitrous oxide ($N_2O$) if managed improperly. $N_2O$ is a significant greenhouse gas (GHG) and the most important ozone-depleting emission. Increasing $N_2O$ emissions from agriculture are linked to soil management and the application of N fertilizers (Maharjan et al., 2014). Therefore, proper N management practice is required for commercial peppermint production in Western NE. However there hasn't been any published report on $N_2O$ emission in peppermint, which is essential for inventorying GHG emissions from agriculture and informing our mitigation efforts.

The objective of this study is to assess the effects of different N fertilizer sources and rates on peppermint yield, oil and $N_2O$ emission in the Western NE.

## MATERIALS AND METHODS

Field experiment was conducted at the Panhandle Research Extension and Education Center (PREEC) in Scottsbluff, NE (41°03'39" N, 103°40'54" W; elevation 1198 m), in 2022 and 2023. The experiment was in a randomized complete block design with four replicates. The N sources used were conventional Urea (46-0-0) and controlled-release fertilizer, Duration (43-0-0), with application rates of 0,140, 210, 280, and 350 kg N $ha^{-1}$), which corresponded to 0, 50, 75, 100, and 125% of the recommended N rate for commercially grown mint in the pacific northwest region. Peppermint biomass was collected at fully flowering stage and reported as dry matter. Oil concentration in leaves was measured using a Gas Chromatography-Mass Spectrometer (GCMS). $N_2O$ Gas fluxes were measured twice a week using LI-COR 7820 $N_2O/H_2O$ trace gas analyzer (LI-COR Biosciences, Lincoln, NE, U.S.). Cumulative $N_2O$ emission from fluxes were calculated using trapezoidal integration of flux over time. The treatment effects on measured variables were determined by the ANOVA test in SAS.

**Table 1.** Treatments used in the field experiment.

| **Treatment*** | **Spring test N (kg N $ha^{-1}$) (2022/2023)** | **Applied N (kg N $ha^{-1}$) (2022/2023)** | **$ Soil Available N (kg N $ha^{-1}$) (2022/2023)** |
|---|---|---|---|
| Control | 96/18 | 0/0 | 96/18 |
| 1 | 96/18 | 30/102 | 126/120 |
| 2 | 96/18 | 45/146 | 141/164 |
| 3 | 96/18 | 60/189 | 156/207 |
| 4 | 96/18 | 75/230 | 171/248 |

*Treatment included N applied as urea or Duration at different rates.
* Soil available N is the summation of applied N and residual N (spring soil test N).

## RESULTS AND DISCUSSION

### Peppermint Dry Matter Biomass

Year 1 (2022) received less than half of N in year 2 (2023) and had plant establishment issues. Therefore, peppermint yield was greater in year 2 (2023) than in year 1 (2022). In year 1, peppermint yield did not vary by N source or rate. In year 2, fertilized plots had higher yields than the control in the cases of both urea and Duration. The lowest N rate treatment yielded less than the two highest N rates in the case of urea and the highest N rate in Duration. In 2023, between N sources, Duration had a greater yield than urea at the lowest applied N rate. The results of the year 2 (2023) related to N rates of urea treatments were similar with Alsafar and Al-Hassan, (2009) and Shormin et al. (1970) who reported fertilized plots has yield increment trend when increasing N rates. Year 2 (2023) results related to the N source (urea and Polymer-coated urea (PCU), Duration®) was similar with Kiran & Patra, (2003) who reported significant yield increment of mint in the controlled release fertilizer than urea.

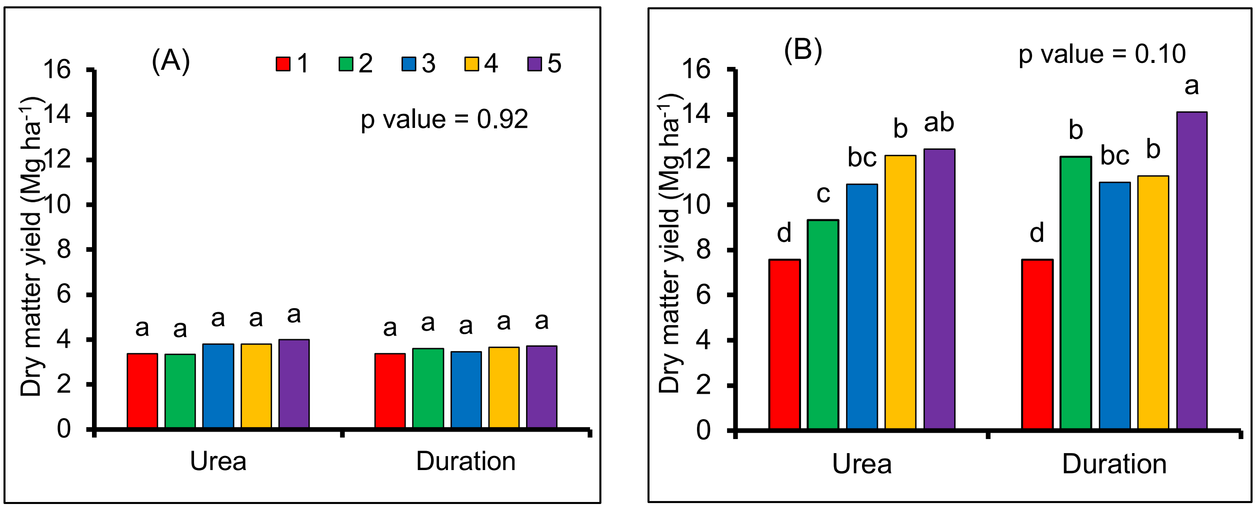


**Figure 1.** Interaction effect of N source and N rates on peppermint dry matter yield 2022 (A) and 2023 (B).
Different small case letters above bars indicate significant treatment differences at given p value.

### Nitrous Oxide ($N_2O$) Emission

In year 1, among urea treatments, emissions were in the order of treatments 4=3=2>1=control. In year 2, they were in the order 4=3>2>1>control. All Duration treatments had similar emissions as the control in both years. $N_2O$ emissions were greater in urea than in Duration in both years, except for the lowest applied N rate in year 1 (2022).

It's well-established in previous studies that applying N fertilizers leads to increased $N_2O$ emissions from agricultural cropping systems, and this increase is directly proportional to the higher N application rates (Dusenbury et al., 2008; Hoben et al., 2011).

Nitrous oxide emissions in Duration did not increase with different N rates. Several studies have shown that the N source can affect soil $N_2O$ emission (Drury et al., 2012). Polymer-coated urea (Duration®) reduces the $N_2O$ emission since durable polymer coated technology to gradually and efficiently releases nutrients (the nutrients releasing process is diffusion) by improving N use efficiency and reducing environmental N losses. Halvorson et al. (2010), and Sistani et al. (2011) have reported that PCU (Duration®) reduces $N_2O$ emissions compared to urea in different cropping systems (corn and potato), by confirming the results of this study for peppermint.

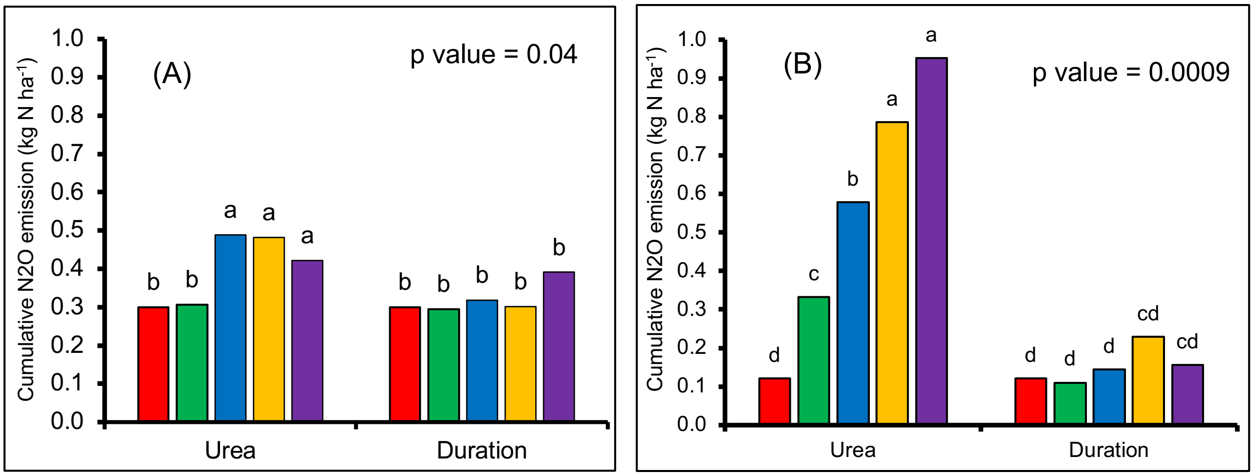


**Figure 2.** Interaction effect of N source and N rates on cumulative $N_2O$ emission in 2022 (A) and 2023 (B).
Different small case letters above bars indicate significant treatment differences at given p value.

**Peppermint oil**

The menthol and carvone concentrations in peppermint leaves were significantly affected by the different N rates irrespective of the different N sources in both years. However, fertilizer application increases the menthol and carvone concentration in leaves. Those results contrast with Kothari et al. (1987) and Poshtdar et al. (2016) who found that when increasing N levels oil concentration get reduce due to dilution or increase the concentration of other oil types. But Marotti et al. (1994) have found that when increasing N mineral fertilizer rates increase the menthol concentration when compared to control, this finding has been proved in this study.

**Table 1.** Menthol and carvone concentrations in peppermint leaves affected by N sources and N rates in year 1 (2022).

| Factors | Menthol (mg $g^{-1}$) | Carvone ( mg $g^{-1}$) |
|---|---|---|
| **N source (N)** | | |
| Urea | 6.51 | 0.91 |
| Duration | 7.14 | 1.01 |
| ***Significance level (p value)*** | 0.50 | 0.69 |
| **Applied N (R) (kg $ha^{-1}$)** | | |
| 0 | 4.07 **b** | 0.22 **b** |
| 30 | 7.73 **a** | 1.17 **a** |
| 45 | 6.34 **ab** | 1.26 **a** |
| 60 | 7.31 **a** | 1.12 **a** |
| 75 | 8.67 **a** | 1.03 **ab** |
| ***Significance level (p value)*** | 0.05 | 0.09 |
| **Interaction effect (N X R)** | | |
| ***Significance level (p value)*** | 0.78 | 0.78 |

*Different letters behind mean values indicate significant treatment differences at given p value.

## CONCLUSIONS

There was no significant yield response across N rates and sources due to the establishment issue in 2022. Across N rates, Duration increased peppermint dry matter yield and reduced emissions compared to urea in 2023. Fertilizer application increased menthol and carvone concentrations. Fertilizer N can be optimized for sustainable peppermint production in NE using advanced fertilizer technology such as PCN (here, Duration). More site-year data would be necessary to determine the optimum N rates for greater dry matter yield and oil concentration (menthol and carvone).

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