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 losses, including nitrous oxide (N_2O) emissions. 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 is to assess the effects of different N fertilizer sources and rates on peppermint biomass, oil (menthol and carvone) concentration, 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 Nutrients, 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 (spring soil test N + applied 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. 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, 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 (N2O) if managed improperly. N2O is a significant greenhouse gas (GHG) and the most important ozone-depleting emission. Increasing N2O 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 N2O emission in peppermint, which is essential for inventorying GHG emissions from agriculture and informing our mitigation efforts.

The objective of this study was to assess the effects of different N fertilizer sources and rates on peppermint yield, oil quality, and N2O 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 140, 210, 280, and 350 kg N ha-1), which corresponded to 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 Chromatography-Mass Spectrometer (GCMS). N2O Gas fluxes were measured twice a week using LI-COR 7820 N2O/H2O trace gas analyzer (LI-COR Biosciences, Lincoln, NE, U.S.). Cumulative N2O emission from flux was 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.

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 & Al-Hassan, (2009) and Shormin et al. (1970) who reported fertilized plots had yield increment trend with increasing N rates. Year 2 (2023) results related to the N source (urea and controlled release fertilizer, Duration®) aligned with Kiran and Patra (2003) who reported significant yield increment of mint in the controlled release fertilizer than urea.

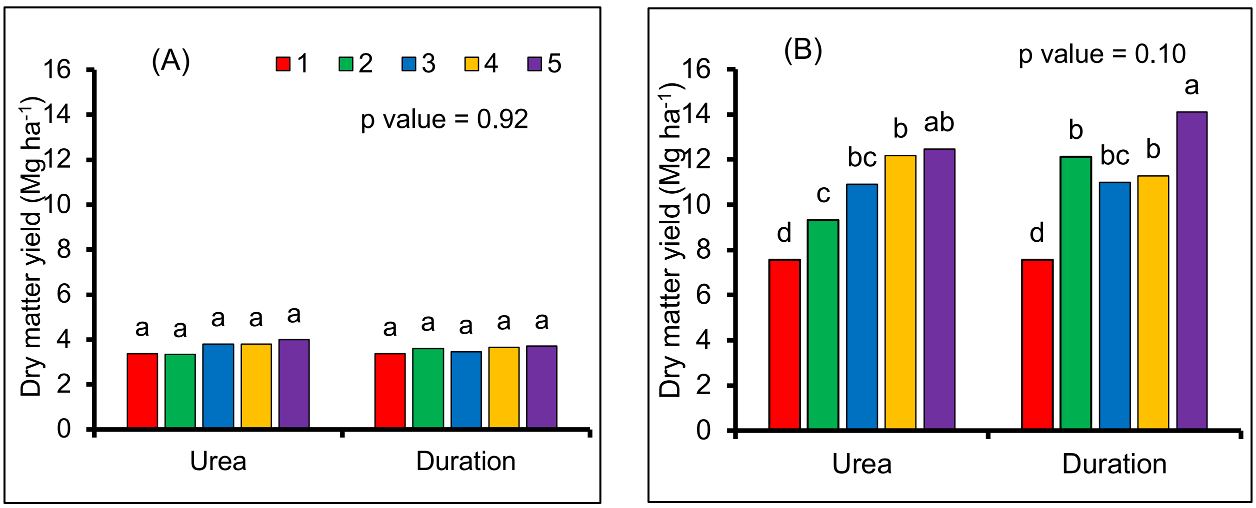

Figure 1. Interaction effect of N source and N rates on peppermint dry matter yield in 2022 (A) and 2023 (B). Different small case letters above bars indicate significant treatment differences at the given p values.

Cumulative 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. Nitrous oxide 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 fertilizer N leads to increased N_2O emissions from agricultural systems, and this increase is directly proportional to the N application rates (Dusenbury et al., 2008; Hoben et al., 2011). Nitrous oxide emissions in Duration did not increase with N rates. Several studies have shown that the N source can affect soil N_2O emission (Drury et al., 2012). Polymer-coated urea such as Duration® reduces N_2O emission since durable polymer coated technology releases nutrients gradually and efficiently (the nutrient's releasing process is diffusion), thereby improving N use efficiency and reducing environmental N losses. Halvorson et al. (2010), and Sistani et al. (2011) also reported reduced N_2O emissions with polymer coated urea compared to urea in different cropping systems (corn and potato), as was the case in this experiment.

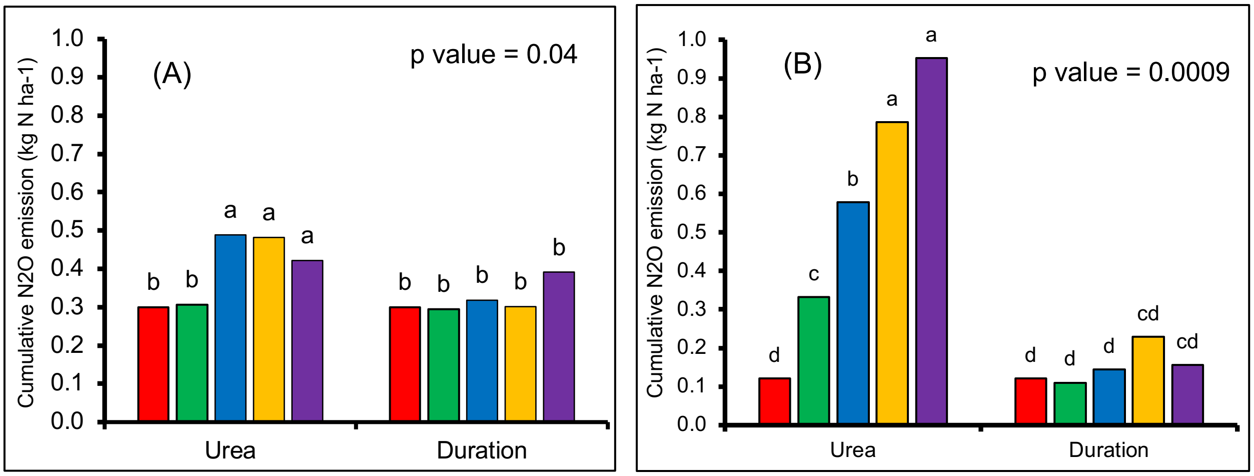

Figure 2. Interaction effect of N source and N rates on cumulative N_2O emission in 2022 (A) and 2023 (B). Different small case letters above bars indicate significant treatment differences at the given p values.

Peppermint oil

The menthol and carvone concentrations in peppermint leaves were significantly affected by N rates irrespective of N sources in both years. Fertilizer application increased the menthol and carvone concentrations in leaves. Our results aligned with Marotti et al. (1994), who also found that fertilizer N increased menthol concentration compared to control. In contrast, Kothari et al. (1987) and Poshtdar et al. (2016) reported reduced oil concentrations with higher N levels due to dilution effect as higher N increased biomass production.

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 small case letters behind mean values indicate significant treatment differences at given p values.

CONCLUSIONS

There were no significant yield differences by N rates or sources due to the establishment issue in year 1. Across N rates, Duration increased peppermint dry matter yield and reduced emissions compared to urea in year 2. Fertilizer application increased menthol and carvone concentrations. Fertilizer N can be optimized for sustainable peppermint production in NE using advanced fertilizer technology such as polymer-coated N (here, Duration). Maximum yield was obtained at 280 kg N ha^{-1} rate among Duration treatments. More site-year data would be necessary to determine the optimum N rates.

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