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Source: Canadian Journal of Soil Science, 102(4) : 1000-1004

Published By: Canadian Science Publishing

URL: https://doi.org/10.1139/cjss-2022-0032

Canadian Journal of
Soil Science

Nitrous oxide emissions from productive and degraded potato fields in the Fraser Valley delta of British Columbia

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Abstract

Soil nitrous oxide (N_2O) emissions and potato yield were evaluated under 0, 90, and 120 kg N ha^{-1} fertilizer rates and two planting dates, at productive and degraded fields in the Fraser Valley delta. During the growing season, N_2O emissions were comparable among N fertilizer rates. Following November rainfall, N_2O emissions increased by three times with 120 kg N ha^{-1}. In the degraded field, yield did not respond to the increasing N fertilizer rates. These findings suggest that lower N fertilizer rates, especially in fields with degraded soils, can lower N_2O emissions from British Columbia potato production.

Key words: crop production, soil mineral nitrogen, agronomic efficiency

Résumé

Les auteurs ont évalué les émissions de protoxyde d'azote (N_2O) du sol et le rendement de la pomme de terre après l'application de 0, de 90 ou de 120 kg d'engrais N par hectare et deux dates de repiquage, dans des champs en production ou dégradés du delta de la vallée du Fraser. Pendant la période végétative, ils ont relevé des dégagements similaires de N_2O pour tous les taux d'application de l'engrais. Après une précipitation en novembre, les émissions de N_2O ont triplé avec le traitement de 120 kg de N par hectare. Le rendement du champ dégradé a mal réagi à la hausse des applications d'engrais. Ces résultats laissent croire que l'application d'une moins grande quantité d'engrais N, surtout sur les sols dégradés, pourrait réduire les dégagements de N_2O résultant de la culture de la pomme de terre en Colombie-Britannique. [Traduction par la Rédaction]

Mots-clés : production végétale, azote minéral du sol, rendement agronomique

Introduction

Decades of extensive cultivation in the Fraser Valley delta of British Columbia (BC) has degraded numerous fields in this region, especially those located on fine-textured soils. With the limited availability of arable land in the region, these degraded fields are actively cultivated, and N fertilizer inputs are often increased to compensate for the poor soil quality, which could contribute to nitrous oxide (N_2O) emissions. This is particularly relevant for potato production, typically associated with intensive tillage. Potatoes are an important crop in BC, contributing to one-third of the province's total field vegetable farm gate value in 2013–2017 (Statistics Canada 2020*a*), so it is important to evaluate the impacts of N fertilizer rates on not only yield but also N_2O emissions at a regional scale.

Most research on N_2O emissions from Canadian potato production has occurred in the Atlantic and Prairie provinces where potato production is more prevalent than in BC. There are significant differences between these major Canadian potato producing regions and the Fraser Valley delta. For example, Atlantic Canada typically receives twice as much precipitation during the growing season and the recommended N fertilizer rate for potato production is two times greater than the Fraser Valley delta (British Columbia Ministry of Agriculture 2012). The recommended rate in the Fraser Valley delta is 70 kg N ha^{-1}, though higher rates are used, especially on degraded fields (Brisbin and Runka 1995). It is not clear whether higher N fertilizer rates improve the potato yield in the degraded fields, or how this practice affects N_2O emissions. This regional understanding is necessary to develop best management strategies that can mitigate soil N_2O emissions from crop production.

The objective of this preliminary study was to compare the effects of urea fertilizer rates (0, 90, and 120 kg N ha^{-1}) and planting date (regular and late) on N_2O emissions, soil nitrate content, and potato tuber yield in a productive and a degraded field in the Fraser Valley delta.

Materials and methods

Study sites

The experiment was conducted from May to November 2018 on two operational farm fields in the Municipality of Delta, BC. One field was categorized as productive (Rego Gleysol and Orthic Gleysol) and the other as degraded (Humic Luvic Gleysol) based on electrical conductivity and exchangeable sodium percentage (Lussier et al. 2019; Chizen 2020). Both fields have a nearly level slope (<3%), average elevation of 2 m above sea level, and a silt loam soil texture with poor to very poor drainage. Annual precipitation in the region is 1180 mm, of which 75% occurs from October to April. In 2018, the 10.7 °C mean annual temperature was comparable to the climate normal (Vancouver International Airport), with April, September, and November being wetter, and May–August being drier than the long-term average.

The experiment was established in both fields as a split-plot design with fertilizer rate (0, 90, 120 kg N ha^{-1}) in the form of granular urea (46-0-0) at the whole-plot level and planting date (May 31, regular; June 18, late) at the split-plot level; there were three replicates of each treatment combination arranged in randomized blocks for a total of 18 plots per field. Fertilizer was banded at the time of planting; 85 kg P ha^{-1} and 162 kg K ha^{-1} were also applied to all plots.

In the spring, the fields were tilled, and Kennebec seed potatoes (*Solanum tuberosum* L. cv. 'Kennebec') were planted by hand at a 10 cm depth at a rate of 1800 kg ha^{-1} and then harvested 107 days after planting; crops were drip irrigated every two weeks (June 21–August 14).

Sampling and analysis

N_2O emissions

The dynamic closed-chamber technique with a Gasmet DX-4040 portable FTIR gas analyser (Gasmet Technologies Oy, Finland) was used to measure N_2O fluxes. The chamber collars were positioned between plants in the hill with a 10 cm headspace. They were constructed from 15 cm long PVC pipe with a 20 cm inner diameter and 0.6 cm thick walls. N_2O fluxes were measured over a six minute enclosure time followed by a two minute ambient air flush. A linear regression goodness-of-fit (R^2) of mixing ratio versus time verified that the enclosure time was long enough to effectively capture the flux. At each sampling time, ancillary data were collected for air and soil temperature, chamber headspace height, and volumetric water content.

From late May to October 2018, N_2O fluxes were measured every two weeks, with an additional sampling in the productive field on November 11 to quantify the emissions after a heavy rainfall event, typical for the region in late fall. The degraded field was not accessible in November due to poor field conditions. N_2O fluxes were calculated using the following equation:

$$F = \rho SV/A$$

where F is the flux (μmol m^{-2} s^{-1}), ρ is the molar density (mol m^{-3}) of dry air, S is the mixing ratio versus time slope as determined by a linear regression using five minutes of measurements (μmol mol^{-1} s^{-1}), V is the volume of the headspace (m^3), and A is the soil surface area (m^2).

The cumulative flux during the sampling period was calculated using piecewise linear interpolation between the days of N_2O flux measurements.

Soil nitrates

Soil samples for NO_3-N analysis were collected seven times from May to October 2018, from 0–15 and 15–30 cm depths. At each plot, samples were composited from three points in the potato rows and analysed colorimetrically.

Yield, agronomic efficiency, and cost efficiency

The crop was manually harvested from the middle rows and yield was calculated as fresh weight in Mg ha^{-1}. The effect of N fertilizer rate on yield was assessed by calculating agronomic efficiency (AE_N) and cost efficiency (CE) as follows:

$$AE_N = (Y_i - Y_0)/N$$

where AE_N is in units of kg potatoes (kg N)$^{-1}$, Y_i is the potato yield (kg ha^{-1}) for a given N fertilizer treatment, Y_0 is the potato yield (kg ha^{-1}) in the control treatment, and N is the fertilizer rate (kg N ha^{-1}).

$$CE = [(Y_i - Y_0)P]/FC$$

where CE is given in units of \$ crop (\$ N fertilizer)$^{-1}$, P is the potato price (\$ kg^{-1}), and FC is the N fertilizer cost (\$ kg^{-1}). In fall 2018, the BC average price of fresh potatoes was \$0.64 kg^{-1} (Statistics Canada 2020*b*) and urea (46% N) was locally purchased for \$0.79 kg^{-1}. All prices are in Canadian dollars.

Statistical analysis

Linear mixed effects models were used to evaluate differences in N_2O emissions, soil nitrate, yield, AE_N, and CE using R software (R Core Team 2020), with N fertilizer rate and planting date as fixed effects. The productive and degraded fields were analysed separately due to known differences in the soil properties. N_2O emissions and soil nitrate were statistically analysed separately for each sampling date and nitrate was also analysed separately by soil depth. A likelihood ratio test was performed to assess for interactions between fertilizer rate and planting date, and when there was no interaction, a partial F test was used to test for main effects on the simplified model. A Tukey's test was conducted when factors were significant to assess differences between treatments.

Results and discussion

Soil nitrate and N_2O emissions

During the growing season, N_2O emissions tended to be higher from 120 kg N ha^{-1} relative to 90 kg N ha^{-1} and con-

Fig. 1. Cumulative N_2O emissions and soil nitrate concentration at 0–15 and 15–30 cm depths with nitrogen fertilizer rate in the productive field (A and B, respectively) and degraded field (C and D, respectively). Error bars represent the standard error of the mean ($n = 3$). For each day, significant differences between treatments are denoted by an asterisk ($\alpha = 0.05$). The vertical lines indicate the time of planting/fertilization (day 0), harvest (day 107), and a major precipitation event (day 145). Note the different ranges of the *y* axes of panels (A) and (C).

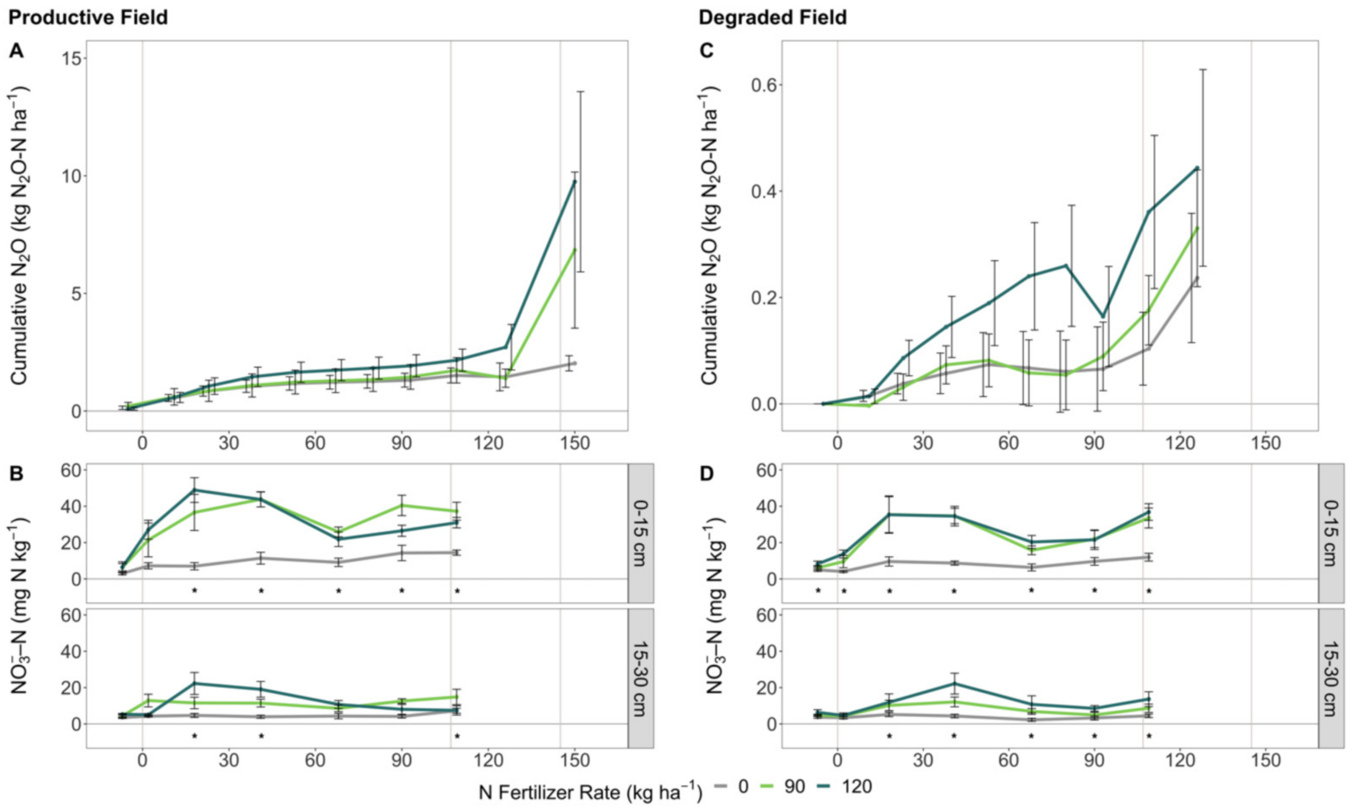

Table 1. Potato tuber yield, agronomic efficiency (AE_N), and cost efficiency (CE) for the productive and degraded fields for the potato growing season (from May to October 2018).

Field	N fertilizer rate (kg N ha^{-1})	Yield (Mg fresh weight ha^{-1})	AE_N (kg yield (kg N fertilizer)$^{-1}$)	CE (crop \$ revenue (\$ N fertilizer)$^{-1}$)
Productive	0	19.5 (2.87)a	-	-
	90	31.9 (2.13)ab	137.6 (19.10)	51.3 (7.12)
	120	36.1 (3.24)b	138.8 (39.17)	51.7 (14.60)
Degraded	0	20.2 (3.02)	-	-
	90	23.7 (2.08)	38.8 (41.21)	14.5 (15.36)
	120	24.6 (2.86)	36.6 (19.39)	13.6 (7.23)

Note: Standard error of the mean is shown in brackets ($n = 3$). In the productive field, there was a significant difference between fertilizer treatments as indicated by different letters ($\alpha = 0.05$). There were no significant differences in yield at the degraded field, AE_N, or CE ($\alpha = 0.05$).

trol, yet neither N fertilizer rate nor planting date had a significant effect on N_2O emissions (Fig. 1A and 1C). The lack of differences among N fertilizer treatments was possibly due to the limited number of measurements and inherently high spatial and temporal variability in N_2O fluxes. The low soil water content during the growing season (Chizen 2020) may have contributed to limited N_2O emissions, regardless of N fertilizer application rate.

N_2O emissions observed in November from the productive field showed a clear spike from the treatments with N fertilization relative to the control (Fig. 1A). The spike was associated with the presence of substantial residual soil nitrate at the end of the growing season (Fig. 1B) combined with a major rainfall event and soil temperature above 10 °C (Chizen 2020). The cumulative N_2O emissions for the 90 and 120 kg N ha^{-1} rates were 4 and 3.6 times higher than the control, respectively, when the November sampling date was included compared to when it was not. These preliminary findings indicate that measurements of the N_2O emissions from potato fields in the Fraser Valley delta should include the post-harvest shoulder season (October–November) that is characterized by abundant rainfall and relatively mild temperatures. More frequent measurements around rainfall events during the growing season should also be considered to improve detection of seasonal spikes in N_2O emissions.

Cumulative N_2O emissions were notably lower in the degraded field (Fig. 1B) than the productive field during the growing season. The lower emissions were associated with three measurements of negative N_2O fluxes observed 53–80 days after planting. Further measurements from the shoulder seasons are needed to determine whether the N_2O production induced by increased soil moisture and residual soil nitrate (Fig. 1D) offsets these negative fluxes at the degraded field.

Potato yield and agronomic efficiency

In the productive field, potato tuber yield increased with N fertilizer rate, while planting date had no significant effect. The yield obtained with the 120 kg N ha^{-1} was 12% greater than the 90 kg N ha^{-1} rate, yet this was not significantly different. Unexpectedly, yield in the degraded field did not differ among the three N fertilizer rates, most likely due to the site's soil degradation and soil salinity issue. The Kennebec potato variety has a poor salinity tolerance (Khrais et al. 1998) and it ended up having a relatively low yield even with the high N fertilizer rate.

The AE_N and CE for both fields showed that the yield and revenue relative to the amount of fertilizer applied did not significantly differ between the 90 and 120 kg N ha^{-1} rates (Table 1). The lack of difference in CE from 90 kg N ha^{-1} versus 120 kg N ha^{-1} supports lower N fertilizer application and future research should assess the BC recommended rate of 70 kg N ha^{-1}. Considering the wet conditions that occur in the spring and fall, lowering the N fertilizer application rate to reduce residual soil N is a strategy to mitigate N_2O emissions. While this strategy may reduce yields in productive fields, the CE calculation showed that the additional cost of N fertilizer input does not outweigh the increase in yield. Our results suggest that higher fertilizer rates in degraded fields are not likely to improve yields unless other yield limiting factors such as salinity are addressed. Hence, reducing N application rates is a more cost-effective climate change mitigating strategy.

Conclusions

Use of manual chambers to measure N_2O emissions did not result in clear differences among the N fertilizer rates on the productive or the degraded field, although N_2O emissions for the 120 kg N ha^{-1} rate were somewhat higher relative to 90 kg N ha^{-1} rate. N_2O emissions observed in November on the productive field showed a spike for both rates of N application relative to the control, most likely due to the presence of a substantial amount of residual soil nitrates at the end of the growing season. Yield and the revenue relative to the amount of fertilizer applied did not significantly differ between 90 and 120 kg N ha^{-1} rates indicating that there is no need to use a higher rate, which showed potential to increase N_2O emissions. Overall, our findings support lowering N fertilizer rates to mitigate N_2O emissions and reduce fertilizer costs in the Fraser Valley delta.

Acknowledgements

We acknowledge that this research was conducted on the traditional and ancestral territory of the xwməθkwəyəm (Musqueam), S'ólh Téméxw (Stó:lō), scəwaθenaʔɬ təməx (Tsawwassen), and Tsleil-Waututh. We appreciate the field and laboratory help from Lewis Fausak, Hannah Friesen, Skylar Kylstra, Alex Kramer, and Isabelle Philpott. Thank you to Ken Montgomery and Blake Lundstrum for hosting our field experiments. This work was supported by funding from Agriculture and Agri-Food Canada (grant number AGGP2-036_CA, 2017).

Article information

History dates

Received: 2 March 2022
Accepted: 27 April 2022
Accepted manuscript online: 11 May 2022
Version of record online: 19 September 2022

Data availability

The data from this study are available from the corresponding author upon request.

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Author Maja Krzic served as a Associate Editor at the time of manuscript review and acceptance; peer review and editorial decisions regarding this manuscript were handled by David Pelster.

Competing interests

The authors declare no conflict of interest.

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