Department of Soil Science, University of Manitoba
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PROJECT REPORT (Executive Summary)

1. Project Title: Soil productivity and soil health status following the restoration of pipeline rights-of-way on Agricultural Land Reserve cropland in northeastern British Columbia

2. Team

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3. Project Objectives

The overall objective of this project was to assess the recovery of productivity on reclaimed natural gas pipeline rights-of-way (ROWs) with increasing time since reclamation. Specific objectives were to:

1. Assess the recovery of soil productivity and crop yields as a function of time elapsed since completion of reclamation (TSR)
2. Evaluate temporal changes in soil health and soil physical, chemical, and biological properties following reclamation of ROWs
3. Identify fertilizer application rates that optimize crop yields on reclaimed ROWs of different TSR.

4. Limitations of the study

The project was impacted by COVID-19-related travel restrictions (Table S1). This greatly reduced the number of study site visits and sampling events. The number of study sites, hence pipeline ROW ages, was reduced to a manageable size, which in turn reduced (1) the number of fields (sample size) included in the study; (2) the number of seasons of testing; (3) the range of pipeline ROW ages tested (4-12 years since reclamation); and (4) the number of variables and associated measurements completed. These adjustments impacted the statistical power for some of the variables. Retrospective statistical power analysis showed that replications were insufficient to detect significant differences among treatments for soil variables such as aggregate stability. Critical factors, such as soil temperature and soil moisture dynamics during the growing season, which could have provided insights into processes limiting crop yields, were not included among the measurements. It is therefore crucial that further studies are performed, which should include a larger number of sites to capture the variability in inherent soil properties across the region, different timings of pipeline installation, and pipelines installed under frozen versus non-frozen soil conditions. Despite these limitations, results from the study provide scientific insights into the equivalent land use capability of reclaimed underground pipeline ROWs on cropland.

5. Methodology

This research project was conducted on three farms in Farmington, BC. In addition to field experiments, the project also included laboratory and controlled environment experiments. Soil and crop samples were collected from ten reclaimed underground pipeline ROWs in August – September of each year for four years (2019-2022). Samples were also collected from adjacent undisturbed locations (off-ROW) to serve as benchmark samples for comparison with the reclaimed ROWs. The differentiating feature of the ROWs was time elapsed since the completion of reclamation (TSR) or ROW age. ROW ages ranged from 4 to 13 years.

After collection, soil samples were processed by air-drying for 72 hours at 60 °C followed by sieving. The samples were subsequently analyzed for soil health indicators (permanganate oxidizable C (POXC), autoclaved citrate-extractable (ACE) protein, and soil respiration) and soil chemical properties (pH, electrical conductivity (EC), soil organic matter (SOM), cation exchange capacity (CEC), total carbon (C), inorganic C, total organic C (TOC), total nitrogen (N), nitrate nitrogen (NO_3-N), total phosphorus (P), available P, and extractable K, Ca, and Mg).

Crop samples were air dried for 5 d at 60 °C, threshed, and weighed for grain and straw yield. Soil and crop samples were processed at the University of Manitoba during the fall and winter months each year. Soil samples were analyzed for some of the attributes in a soil science laboratory at the University of Manitoba while other measurements were carried out at a commercial laboratory (Agvise Laboratories, Northwood, ND, USA). Grain and straw samples were ground and sent to Agvise Laboratories for determination of N and P concentrations. At the end of the four years, soil and crop measurements were combined across years and sites before statistical analysis to determine TSR effects.

Field measurements for soil physical properties (penetration resistance (PR), saturated hydraulic conductivity, and near-saturated hydraulic conductivity) were taken in August – September of 2021 and 2022. These measurements were taken at the same locations where soil and crop samples were collected. Near-saturated hydraulic conductivity data were used to determine changes to soil macroporosity (that is, the large pores through which much of the waterflow through the soil profile takes place). In addition to field measurements, soil particle size distribution (a measure of texture) and wet aggregate stability were also determined in the laboratory. Aggregate stability was determined in the Soil Science laboratory at the University of Manitoba while soil texture was determined at Agvise Laboratories. Metagenomic analysis was also conducted to assess microbial (bacterial and fungal) community diversity and composition on the reclaimed ROWs and the off-ROW using soil samples collected in 2022. The soil samples for metagenomics were specially collected using procedures appropriate for microbial analysis. Metagenomic analysis was performed at Psomagen (Rockville, MD, USA).

In addition to the field and laboratory experiments, an eight month (November 2022 – June 2023) long growth room bioassay was also conducted at the University of Manitoba using bulk soil samples collected in 2022 from one of the collaborating farms in Farmington. The bioassay was in lieu of the previously planned field plot study, which could not be done due to the COVID-19 pandemic. The objective of the bioassay was to determine fertilizer application rates that optimize crop productivity on reclaimed ROWs.

Throughout the project, relevant literature was reviewed on a continuing basis to stay updated on research being published on the topic and related topics. In addition, data were also analyzed throughout the study.

6. Findings

6.1 Soil physical properties

ROW age had a significant effect on penetration resistance (an indicator of compaction) and saturated and near-saturated hydraulic conductivity but not on soil aggregate stability. Penetration resistance influences root growth and development and therefore crop uptake of nutrients and water from the soil. As a general guideline, 3 MPa is considered the threshold penetration resistance above which root growth is restricted for most crops. However, penetration resistance was greater on the 4 – 5-yr ROWs (3.5 – 5.5 MPa) than on the off-ROW. The penetration resistance values on the 6- to 7- and 12- to 13-yr ROWs were similar to the off-ROW.

Soil hydraulic conductivity under saturated and near-saturated conditions showed a similar trend to penetration resistance and was lower on the younger ROWs than on the off-ROW while the older (12- to 13-yr) ROWs showed similar conductivities to the off-ROW. Our results also showed a significant reduction in the proportion of large, conductive soil pores (macroporosity) in ROWs relative to the off-ROW. Soil pores are crucial for water transport, water storage, and soil aeration. Therefore, the reduction in water transport (hydraulic conductivity) observed on the ROWs could have been due to a decrease in soil macroporosity. Nonetheless, our findings showed a steady improvement in the measured soil physical properties with increasing TSR.

6.2 Soil health indicators

Our study is one of the few studies to evaluate the recovery of ROWs using soil health indicators. The soil health indicators used in the study are among the most sensitive to changes in land use, hence their suitability to evaluate recovery of ROWs over time. Soil health indicator values were lower on the younger ROWs (4- to 9-yr) than on the off-ROW, indicating the reduced soil productivity on the ROW. Soil health indicator on the older ROWs (11- to 12-yr) were similar to those on the off-ROWs. A similar pattern was observed for soil organic matter content and available N (NO_3-N) concentration, although the latter also likely reflected current fertilizer management practices and N removal by crops. For the same reason, plant available nutrients, soil pH and EC were generally similar for reclaimed ROWs and off-ROWs.

We also assessed the diversity and composition of bacterial and fungal communities on the ROWs vs. off-ROWs. Our results showed lower bacterial and fungal community diversity on the 5- to 6-yr ROWs than on the off-ROWs whereas diversity on the 11- to 12-yr ROWs was similar to the off-ROWs. Overall, these results showed that pipeline construction could have caused deleterious impacts on some bacterial and fungal species. Similar to soil physical properties, soil health indicators and soil chemical and biological properties also improved with increasing TSR.

6.3 Crop yield

Crop yield is a general reflection of the status of the soil ecosystem. Crop samples were collected from five crops (canola, wheat, pea, barley, and oats) grown in rotation by the landowners. To analyze across the crops, yield on the ROWs was expressed as a fraction of the yield on the adjacent off-ROWs. We observed a decrease in crop yields on all ROWs relative to the off-ROW, with crop yield on the 11- to 13-yr ROWs still 42% lower than yield on the off-ROW. Similar to soil properties, crop yields also improved with increasing TSR. However, unlike soil properties, the impacts of pipeline construction on crop yield persisted beyond 13 yr post-reclamation, indicating longer-term impacts on crop yield compared to soil properties. These results suggest that, beyond 13 yr, crop yield on reclaimed ROWs was likely limited by soil factors not measured in this study. Individually, crops showed varied responses to increasing TSR. Eight to 10 yr after reclamation, oat and barley grain yields on reclaimed ROWs were similar to the off-ROWs while wheat grain yields were still lower. Canola grain yield on ROWs statistically matched those on the off-ROWs 11- to 13-yr after reclamation while pea grain yields were inconsistent across the years.

6.4 Growth room bioassay

In the growth room bioassay, the recommended fertilizer rate for wheat and canola biomass yield produced lower biomass yields on the 4- and 10-yr ROWs than on the off-ROW, indicating that the recommended rate could not optimize yield on the ROWs. However, increasing the fertilizer rate by 1.5 times the recommended rate increased canola and wheat biomass yields on the 4- and 10-yr ROWs to the same level as that on the off-ROW. These results show the potential for optimizing crop yield on reclaimed ROWs by increasing fertilizer application rate. However, the fact that this was not the case in the study fields where some farmers applied 1.5 times the recommended fertilizer suggest that there are other yield-limiting factors on the off-ROWs. In the growth room experiment, temperature was maintained at optimum levels and moisture was kept close to field capacity throughout the experiment. It is expected that temperature in and around the pipeline trench area would be at least slightly elevated due to the presence of the active natural gas pipeline below. The elevated temperature could enhance soil moisture loss, leading to moisture deficits and yield reductions. Field plot studies are needed to investigate this possibility.

6.5 Summary of findings

Overall, results from this study showed that (1) the construction of underground natural gas pipelines on the tested croplands had detrimental effects on the soil ecosystem, which was reflected by the observed reduction in crop yields; (2) the impacts of pipeline construction on soil properties and crop productivity were becoming less pronounced with increasing TSR; and (3) pipeline construction impacts on crop productivity persisted longer than impacts on the soil properties measured in this study.

7. Conclusion

Notwithstanding the limitations due to the COVID-19 pandemic, the objectives of this project were achieved. Using data collected over 4 years from 10 pipeline ROWs across three farms, this study showed that soil and crop attributes impacted by pipeline construction were steadily recovering with increasing time since reclamation. Relative crop yields remained significantly lower on the ROWs than on the undisturbed off-ROWs even 13 years after completion of reclamation. Although this was the general observed trend, it is noteworthy that individual crops responded differently to increasing TSR, with canola yield losses persisting longer than the other crops.

8. Suggested next steps

We recommend a next phase of this project that would include 10-15 sites located on cultivated land under annual crops. The study would include ALR lands with pipeline footprints varying widely in recovery periods based on time of 'Leave to Open' filing. The sites would capture a cross section of ROWs constructed during frozen and unfrozen soil conditions. The selected pipelines would be sampled along a minimum of 800 m. We suggest three functional age categories: (1) pre-2013 (3 ages ranging from 11 to 25 years will be selected), (2) 2013-2017 (one age), (3) post 2017 (one age). Soil and crop samples would be taken from the ROW working side, trench line, and soil storage side, and from the off-ROW withing each field. In addition to measurements from the first phase, we suggest (1) assessing the critical effects of potentially elevated ROW temperatures on soil moisture dynamics and availability to plants, (2) measuring coupled heat and soil moisture transfer on the ROWs, (3) using model simulation to extend the estimation to incremental distances from the pipeline centerline towards the off-ROW, and (4) exploring practical approaches to mitigate temperature elevation effects on the ROWs.

9. Financial

All funds provided by the British Columbia Oil and Gas Research and Innovation Society (BC OGRIS) were solely used to finance different aspects of this project. The financial statement has been sent separately but is also included with this report.

Supplemental information

Table S1. Activities which were proposed but not started/completed

Proposed activity	Report
Conduct a 2-year field plot study to test effect of TSR and fertilizer rate on crop productivity	Field plot study was not started because of the Covid public health restrictions. In lieu of the plot study, a growth room bioassay was conducted at the University of Manitoba.
Collect soil and crop samples from at least 12 ALR land properties (sites)	Sites were reduced to a manageable 3 study sites
Installation of automated weather stations to collect site specific weather data and soil temperature	Weather stations and soil temperature sensors were not installed due to pandemic restrictions