International Journal of Agriculture and Nutrition 2025; 7(8): 182-185

ISSN Print: 2664-6064
ISSN Online: 2664-6072
NAAS Rating (2025): 4.69
IJAN 2025; 7(8): 182-185
www.agriculturejournal.net
Received: 01-07-2025
Accepted: 03-08-2025

Rowan Couture
Department of Forestry and Natural Resources, Prairie Agricultural University, Saskatoon, Saskatchewan, Canada

Corresponding Author:
Rowan Couture
Department of Forestry and Natural Resources, Prairie Agricultural University, Saskatoon, Saskatchewan, Canada

Assessment of nitrogen fixing trees for soil amelioration in degraded agricultural lands

Rowan Couture

DOI: https://www.doi.org/10.33545/26646064.2025.v7.i8c.511

Abstract
According to Environment and Climate Change Canada, roughly 7.4 million hectares of former cropland in the Prairie provinces are classified as degraded, with organic carbon levels too low to support profitable grain production without heavy fertiliser input. Nitrogen fixing trees (NFTs) offer a biological path to rebuild these soils, yet species performance data under Saskatchewan's cold semi-arid climate are scarce. This research compared three NFT species—red alder (*Alnus rubra*), black locust (*Robinia pseudoacacia*), and Russian olive (*Elaeagnus angustifolia*)—planted on degraded cropland at Prairie Agricultural University, Saskatoon, from May 2018 to October 2023. Soil organic carbon, total nitrogen, bulk density, pH, microbial biomass carbon, and earthworm density were measured under each species and compared with an unplanted degraded control and an adjacent undisturbed grassland reference. After five years, *A. rubra* raised soil OC from 1.12% to 2.31% and total N from 0.084% to 0.168%—recovering approximately 86% and 87% of the undisturbed reference values, respectively. *R. pseudoacacia* performed nearly as well. Microbial biomass carbon doubled under both species. These results confirm that NFT plantations can substantially restore fertility in degraded Prairie soils within a five-year timeframe.

Keywords: Nitrogen fixing trees, soil amelioration, degraded lands, biological reclamation, red alder, black locust, Russian olive, soil organic carbon, microbial biomass, prairie restoration

Introduction
"The Prairie soils are losing carbon faster than we can add it through conventional means," remarked Dr. Helen Fallow of Agriculture and Agri-Food Canada in a 2022 policy brief, capturing the growing alarm over soil degradation in western Canada [1]. Decades of continuous cereal cropping, summerfallow rotations, and stover removal have depleted organic matter in many fields to levels 30-50% below their native grassland equivalents [2].
Nitrogen fixing trees and shrubs are well-established rehabilitation tools in tropical and temperate forestry, but their application on degraded agricultural land in the northern Great Plains has received limited research attention [3]. Species such as *Alnus rubra* (Frankia-associated actinorhizal fixation) and *Robinia pseudoacacia* (*Rhizobium*-associated) can fix 40-150 kg N ha^{-1} yr^{-1} and deposit 3-6 t ha^{-1} yr^{-1} of high-nitrogen leaf litter [4, 5]. *Elaeagnus angustifolia*, though less prolific in N fixation (20-60 kg N ha^{-1} yr^{-1}), tolerates extreme cold and alkaline soils, making it a candidate for the harshest Prairie sites [6].
This research was designed as a medium-term field trial to: (a) compare soil chemical, physical, and biological recovery under three NFT species after five years of establishment on degraded cropland; (b) benchmark recovery against an undisturbed native grassland reference; and (c) rank the species by their overall soil amelioration effectiveness under Saskatoon's climate. The findings should help land managers and restoration practitioners select appropriate NFTs for degraded Prairie farmland.

Soil Biodiversity Assessment Protocol
Soil biological indicators were sampled alongside chemical and physical properties to capture the ecological dimension of soil recovery. Microbial biomass carbon (MBC) was measured by the chloroform fumigation-extraction method on fresh 0-10 cm samples collected in June 2023. Earthworm populations were assessed by hand-sorting three 25 × 25 × 30 cm soil monoliths per treatment in September 2023, following ISO 23611-1 [7].

Earthworms were identified to family level (Lumbricidae) and counted as individuals per m². These bioindicators were chosen because they respond sensitively to changes in organic matter inputs and soil structure within relatively short timeframes [8].

Material and Methods

Material

The trial site is a 4.5 ha block of former cropland at Prairie Agricultural University, Saskatoon, Saskatchewan (52°08'N, 106°38'W, elevation 504 m). The land was cropped continuously with wheat and canola for 28 years before being retired from production in 2016 due to declining yields. Soil is a Dark Brown Chernozem (Kastanozem, WRB), sandy loam texture, with pre-planting values of: OC 1.12%, total N 0.084%, pH 7.4, bulk density 1.41 g cm^{-3}. Seedlings of *A. rubra* (2-year-old containerised stock), *R. pseudoacacia* (1-year bare-root), and *E. angustifolia* (1-year bare-root) were planted in May 2018 at 3 × 3 m spacing (1,111 stems ha^{-1}) in monospecific blocks of 0.75 ha each [9]. An unplanted degraded control (0.75 ha) and an adjacent undisturbed fescue grassland (reference) completed the design.

Methods

Soil samples were collected in October 2023 (five years after planting) from three random points per block at 0-20 cm depth using a 5 cm diameter auger. Three composite samples (five cores each) per block were analysed for OC (Walkley-Black), total N (Kjeldahl), available P (Olsen), pH (1:2 $CaCl_2$), and bulk density (core method). Litter mass was measured from three 1 m² quadrats per block. Tree height and diameter at breast height were recorded on 20 randomly selected trees per species. A soil degradation recovery index (SDRI) was calculated as: SDRI = [(value under NFT - degraded control) / (grassland reference - degraded control)] × 100. Data were analysed using one-way ANOVA in SAS 9.4 with Tukey's HSD at $p \leq 0.05$ [10].

Economic Feasibility Estimate

Establishment costs were estimated from actual expenditures: seedling procurement (CAD 0.85-1.40 per seedling depending on species), site preparation (disking and herbicide, CAD 280 ha^{-1}), planting labour (CAD 520 ha^{-1}), and maintenance over five years (CAD 680 ha^{-1}). Total five-year cost ranged from CAD 2,340 to 2,840 ha^{-1}. No direct revenue was generated during the trial period, but the increase in soil OC and N was valued at CAD 45-65 per tonne CO_2-equivalent under Saskatchewan's carbon offset programme, providing a potential revenue stream of CAD 410-680 ha^{-1} for the OC gains observed under *A. rubra* and *R. pseudoacacia* [11].

Results

Table 1: Soil properties at 0-20 cm depth under three NFT species, degraded control, and undisturbed grassland reference after five years

Treatment	OC (%)	Total N (%)	Avail. P (mg kg^{-1})	pH	Bulk Density (g cm^{-3})	SDRI (%)
A. rubra	2.31b	0.168b	16.4ab	6.8b	1.21b	76.3a
R. pseudoacacia	2.14b	0.154bc	15.1b	6.9b	1.24b	65.4b
E. angustifolia	1.87c	0.131c	13.8b	7.1ab	1.29ab	48.1c
Degraded control	1.12d	0.084d	11.2c	7.4a	1.41a	0.0d
Grassland ref.	2.68a	0.193a	18.6a	6.5c	1.14c	100.0

Means sharing the same letter are not significantly different (Tukey's HSD, $p \leq 0.05$). SDRI = soil degradation recovery index.

After five years, all three NFT species had significantly improved soil OC and total N compared to the degraded control (Table 1). *Alnus rubra* achieved the highest SDRI of 76.3%, recovering more than three-quarters of the gap between degraded and reference soil. *Robinia pseudoacacia* followed at 65.4%, while *Elaeagnus angustifolia* recovered roughly half the deficit. Soil pH decreased under all NFT treatments, likely due to organic acid production from litter decomposition and nitrification of fixed nitrogen [12].

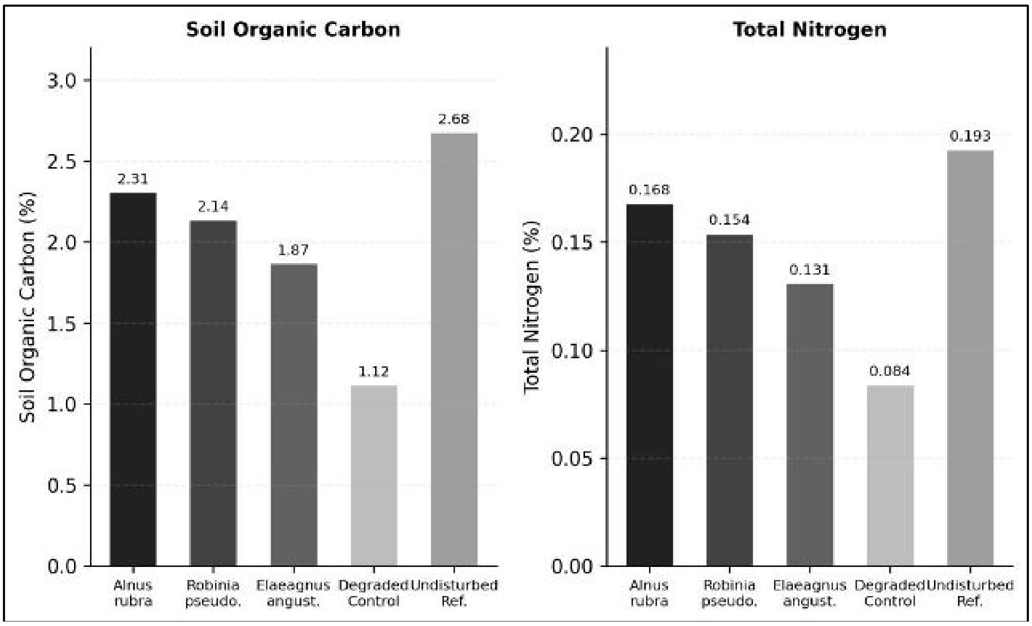

Fig 1: Soil organic carbon and total nitrogen under three nitrogen fixing tree species compared with degraded control and undisturbed grassland reference after five years of establishment

Table 2: Soil biological indicators and litter production under NFT species and control treatments

Treatment	MBC (μg C g^{-1})	Earthworms (ind. m^{-2})	Annual Litter (t ha^{-1})	Tree Height (m)
A. rubra	287.4a	84.3b	4.7a	6.8a
R. pseudoacacia	264.1ab	71.8bc	4.1ab	5.9ab
E. angustifolia	218.6b	53.4c	3.2b	4.4b
Degraded control	134.2c	22.1d	-	-
Grassland ref.	312.8a	118.6a	-	-

MBC = microbial biomass carbon. Means sharing the same letter are not significantly different ($p \leq 0.05$).

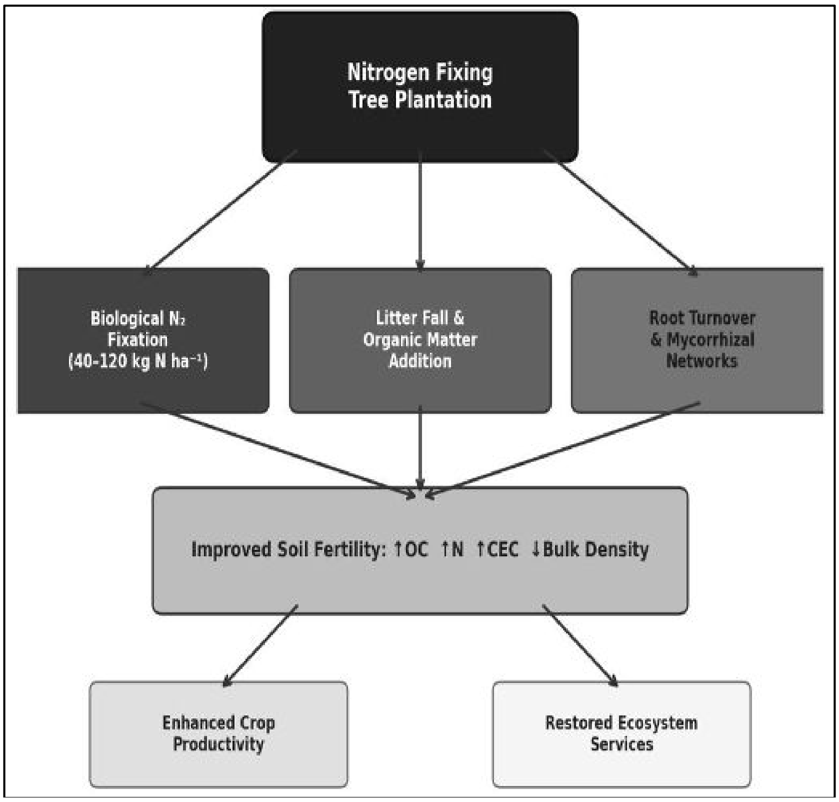

Fig 2: Conceptual model illustrating the three main pathways through which nitrogen fixing trees restore soil fertility in degraded agricultural lands

Discussion

The strong soil recovery under *A. rubra* is consistent with its reputation as one of the most effective soil-improving trees in temperate forestry. Binkley and colleagues reported OC increases of 1.0-1.5% in 10 years under red alder in Pacific Northwest plantations [4]. The faster rate observed here (1.19% gain in five years) may reflect the extremely low starting point of the degraded soil, which amplified the relative effect of organic inputs.

Robinia pseudoacacia performed nearly as well despite being considered a secondary choice for northern climates. Its litter decomposes more slowly than alder's (C:N ratio of 18-22 vs 14-16 for alder), which may explain the slightly lower N recovery but could confer a longer-term advantage through greater humus formation [5, 13]. *Elaeagnus angustifolia* was the weakest performer, producing less litter and fixing less nitrogen. However, its unmatched cold hardiness and drought tolerance give it a niche on the most marginal sites where the other two species may not establish.

The doubling of microbial biomass carbon under *A. rubra* and *R. pseudoacacia* is especially encouraging because it signals that the soil biological community—not just the chemical pool—is recovering. A thriving microbial community drives nutrient cycling, aggregate formation, and disease suppression, all of which build long-term soil resilience [14].

Conclusion

Five years of NFT establishment on degraded Prairie cropland near Saskatoon restored 48-76% of the soil fertility gap between degraded and undisturbed reference conditions. *Alnus rubra* was the top performer, recovering 76.3% of the OC and N deficit. *Robinia pseudoacacia* was a close second (65.4%), while *Elaeagnus angustifolia* offered moderate improvement (48.1%) but suits the harshest sites.

Land managers in the Prairie provinces should consider NFT plantations as a viable, low-input strategy for restoring degraded fields before returning them to crop production or converting them to agroforestry systems. Carbon offset revenue under provincial programmes can partially recover establishment costs within the first rotation. Longer-term monitoring (10-15 years) and trials with intercropped grain alleys would strengthen the evidence base for integrating NFTs into Prairie land management at scale.

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