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Authors: Nyiraneza, Judith, Jiang, Yefang, and Fraser, Tandra D.

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Shrub willow chips incorporated after potato harvest enhance soil properties in Prince Edward Island, Canada

Judith Nyiraneza, **Yefang Jiang, and Tandra D. Fraser**

Charlottetown Research and Development Centre, Agriculture and Agri-Food Canada (AAFC), 440 University Avenue, Charlottetown, PE C1A 4N6, Canada

Corresponding author: **Judith Nyiraneza** (email: judith.nyiraneza@agr.gc.ca)

Abstract

Willow (Salix viminalis spp.) shrubs are being planted along riverbanks, on erodible and marginal farmland. Wood chips made from the woody biomass could improve the properties of light-textured soils with low organic matter content in potato-based systems. Willow chips were applied at 0, 20, 40, and 60 mg ha^{-1} (fresh weight) as a soil amendment. Soil health parameters were evaluated after 12 months, followed by C and N contents in whole soil, particulate, and mineral-associated organic matter fractions after 18 months. Willow chip application increased soil aggregation, respiration, C and N contents in whole soil, and plant-available K.

Key words: shrub willow, soil aggregation, soil respiration, soil nutrients, organic matter fractions

Résumé

On plante l'osier blanc (Salix viminalis spp.) le long des berges ainsi que sur les terres agricoles sujettes à l'érosion ou peu rentables. Des copeaux de bois tirés de la biomasse ligneuse pourraient améliorer les propriétés des sols à texture légère pauvres en matière organique, comme ceux servant à la culture de la pomme de terre. Les auteurs ont appliqué un amendement correspondant à 0, 20, 40 ou 60 Mg (poids frais) de copeaux d'osier par hectare. Douze mois plus tard, ils ont évalué la vitalité du sol puis, au bout de dix-huit mois, la teneur en C et en N du sol complet ainsi que les fractions de matière organique associées aux particules et aux minéraux. Les copeaux d'osier améliorent l'agrégation et la respiration du sol, la concentration de C et de N dans le sol complet, de même que le K assimilable par les plantes. [Traduit par la Rédaction]

Mots-clés : osier blanc, agrégation du sol, respiration du sol, éléments nutritifs du sol, fractions de matière organique

Introduction

Shrub willow plantations offer environmental and societal benefits, by (*i*) retaining nutrients and pesticides so that they do not enter water bodies (Prosser et al. 2020), (*ii*) acting as windbreaks and controlling soil erosion (Wilkinson 1999), offsetting greenhouse gas emissions through C sequestration (Amichev et al. 2014), (*iii*) and enhancing biodiversity (Weil et al. 2019) and phytoremediation (Granel et al. 2002). Their fast growth produces extensive root systems and a large amount of biomass in a short period of time. Shrub willows may be effective for revitalizing marginal and under-utilized cropland (Keoleian and Volk 2005). They are easy to propagate from cuttings (Amichev et al. 2014) and re-sprout readily following human-induced coppicing or pruning (Keoleian and Volk 2005). Shrub willows have a lifespan of around 30 years and are harvested on a 3-year cycle to stimulate root biomass, for up to 7–8 cycles (Keoleian and Volk 2005). Harvested shrub willow chips can be used as fuel wood, biofuel, biochar, animal bedding, and mulch. However, few studies have been conducted on the use of willow chips as a soil amendment.

N'Dayegamiye and Angers (1993) reported increases of 16%–37% in whole-soil C content relative to the control following 9 years of biennial application of wood residues (tree clippings) at rates of 25–100 mg ha^{-1} to a sandy loam soil in QC. The authors did not find any effect on water-stable aggregate stability but reported average increases of 68% and 17% in light and heavy fractions of organic matter, respectively, compared with the control. Carter et al. (2003) found that soil organic matter accumulation and retention dynamics can be evaluated by looking at soil C stored in particulate soil organic matter fractions (POM, unprotected) and in mineral-associated organic matter (MAOM, protected). C and N in POM fractions are considered more labile and are influenced by management practices, while C and N in MAOM are more stable and less responsive to management practices as they are linked to soil texture. Lalande et al. (1998) observed a significant increase in wet aggregate stability in the second year following application of chipped wood from twigs at a rate of 600 m^3 ha^{-1} to a loamy soil in QC. Wood chips can also enhance soil macro- and micronutrients (Holtz et al. 2004).

In 2017, as a part of the Canadian government's commitment to addressing climate change, close to 1 million CAD in funding was allocated for willow tree planting in Prince Edward Island (PE) under the federal Agricultural Greenhouse Gases Program. In earlier years, funds were allocated to PEI farmers to enable them to plant shrub willows to enhance soil and water conservation (PEI Soil and Crop Improvement Association 2013). The chip biomass from shrub willows grown along riverbanks on erodible farmland could be applied to fields to improve the soil properties of intensively farmed land with low soil organic matter content. To our knowledge, benefits of using willow chips as a soil amendment on PE farmlands have been rarely studied.

The objective of this study was to evaluate the effect of willow chip application on selected soil properties 12 months after incorporation as well as on C and N in whole soil and in protected (MAOM) and non-protected soil organic matter fractions (POM) 18 months after incorporation.

Materials and methods

The experimental site was established at Agriculture and Agri-Food Canada's Harrington Research Farm in PE on a loam sandy soil with 51% sand, 7% clay, and 42% silt content. During summer 2019, the trial plot was seeded to potato (*Solanum tubersum* L., CV Russet Burbank), and one week after potato harvest, willow chips were applied at varying rates (0, 20, 40, and 60 mg ha^{-1}; wet basis). Rates were replicated nine times in the experimental unit that measured 8 m × 6 m. Willow chips were surface-applied in plots and then disked in at a depth of approximately 10–15 cm. Willow chips (Viminalis 5027 and SV1 Salix Viminalis) were supplied from a 3-year willow chip plantation (1st coppiced cycle), and stems were cut into small pieces using a wood chipper. Around 15 subsamples were taken for C and N analyses and moisture content calculation. Averaged across the subsamples, willow chips had a moisture content of 52%, total N concentration of 9.7 g kg^{-1}, total C of 469.8 g kg^{-1}, and a C:N ratio of 48. In spring 2020, barley (*Hordeum vulgare* L.) was planted and underseeded with red clover (*Trifolium pratense* L.), and in 2021, the red clover was allowed to regrow.

One year after the first application of willow chips, in fall 2020, soil (3–4 randomly selected points) was sampled at 0–15 cm depth using a Dutch auger within each plot and composited into one sample per plot. The soil were air-dried and sieved through 2 mm mesh, and 500 g of soil was sent to the Cornell Soil Health Laboratory. Samples were analyzed for aggregate stability, soil respiration, available water capacity, permanganate extractible C (active C), and autoclaved extractible protein (protein index) following the protocol outlined in the Cornell Soil Health Laboratory manual (Moebius-Clune et al. 2016). Briefly, wet aggregate stability was assessed using the Cornell rainfall simulator on 30 g of soil sieved under 2 mm and placed on stacked sieve (2.0 and 0.25 mm). The soil respiration is the CO_2 flush released from a rewetted sample of air-dried soil held in airtight jar for 4 days. Available water capacity was measured using ceramic plates with known porosity and wetted to saturation. Autocalved extractible protein was obtained using sodium citrate buffer, and the active C was measured by mixing soil with potassium permanganate solution, which oxidizes the active C, and the color change was measured with a spectrophotometer. The soil was also extracted with the Mehlich-3 extraction solution to quantify soil macronutrients (P, K, Ca, and Mg; Mehlich 1984). Eighteen months after willow chip application, in spring 2021, during the second year of red clover growth, soil samples were again taken as described above, and POM C and N were analyzed following the protocol described by Carter et al. (2003). Briefly, 25 g of air-dried soil sieved through 2 mm mesh was dispersed using deionized water (100 mL) mixed with 5 mm (diameter) glass beads, shaken for 12 h on a reciprocal shaker and wet-sieved using deionized water through a 53 mm sieve into a 600 mL beaker. The fraction smaller than 53 mm is the slurry (MAOM), and the fraction retained in the sieve is the POM. The fractions were dried at 50 °C until constant mass. The difference between the whole-soil C and N concentrations and the C and N concentrations in the slurry fraction was used to determine the C and N concentrations in the POM fraction. Dry combustion with an Elementar analyzer (vario Max Elemental Analyzer, Hanau, Germany) was used to analyze C and N concentrations in the whole soil and the POM and MAOM fractions.

Statistical analysis

Statistical analyses were performed using the MIXED procedure of SAS (SAS Institute 2016) for a randomized complete block design with willow rate as a fixed factor and replicate as a random factor, with four rates replicated nine times for a total of 36 experimental units. The Shapiro–Wilk test was used to test for normality, and logarithm transformation was performed when needed. We also assessed the significance of linear, quadratic, and cubic responses of shrub willow application rate on measured soil properties. The DIFF function of SAS was used to compare treatment means at the 0.05 probability level.

Results

One year after incorporation, willow chips applied at increasing rates did not affect available water capacity, protein index, active C, soil pH, and Mehlich-3 extractible P, Ca, and Mg compared with the control (Table 1). However, willow chip application significantly increased aggregate stability, soil respiration, and Mehlich-3 extractible K. Linear effect was significant on aggregate stability, protein index, soil respiration, and Mehlich-3 extractible K. Quadratic and cubic effects were also significant for soil respiration. At rates of 40 and 60 mg ha^{-1}, willow chips increased aggregate stability by 67% and 84%, respectively, compared with the control, whereas soil respiration increased by 45% and 71%, respectively. Mehlich-3 extractible K increased by 22% at 40 mg ha^{-1} and by 38% at 60 mg ha^{-1}, relative to the control. Eighteen months after willow chip incorporation, C and N in the whole soil were significantly higher (40 and 60 mg ha$^{-1)}$ than in the control, whereas C and N levels in POM and MAOM fractions were comparable among treatments. Linear effect of willow chip application was observed on C and N content in the whole soil (Table 2).

Table 1. Effects of willow chip application on the soil properties at 0–15 cm soil depth 12 months (September 2020) after the first application.

Treatment (mg ha^{-1})	Available water (g g^{-1})	Aggregate stability (%)	Protein index (mg kg^{-1})	Soil respiration (mg CO_2 g^{-1})	Active carbon (ppm)	Soil pH	M_3-P (mg kg^{-1})	M_3-K (mg kg^{-1})	M_3-Ca (mg kg^{-1})	M_3-Mg (mg kg^{-1})
0	0.217	21.9b	7.39	0.367c	564	5.7	155	107b	718	64
20	0.218	20.9b	7.54	0.349c	560	5.7	158	105	700	58
40	0.218	36.6a	7.64	0.534b	560	5.7	167	131	718	65
60	0.214	40.33a	7.87	0.627a	570	5.8	157	148a	684	64
Analysis of variance (ANOVA) (*p* values)										
Treatment effects	NS	***	NS	***	NS	NS	NS	***	NS	NS
Linear	NS	***	*	***	NS	NS	NS	***	NS	NS
Quadratic	NS	NS	NS	*	NS	NS	NS	NS	NS	NS
Cubic	NS	**	NS	**	NS	NS	NS	NS	NS	NS

Note: M_3-P, M_3-K, M_3-Ca, M_3-Mg, and Mehlich-3 are extractable phosphorus, potassium, calcium and magnesium, respectively. Values followed by different letters within a column are statistically different at 0.05 probability level. NS, not significant at 0.05 probability level.
*Significant at 0.05 probability level.
**Significant at 0.01 probability level.
***Significant at 0.001 probability level.

Table 2. Effects of willow chip application on C and N contents in the 0–15 cm layer in the whole soil, in particulate organic matter (POM), and in mineral-associated organic matter (MAOM) 18 months (spring 2021) after the first application.

	Whole soil (g kg^{-1})		POM (g kg^{-1})		MAOM (g kg^{-1})		Proportion of C and N in POM over C and N in the whole soil (%)		Proportion of C and N in MAOM over the C and N in the whole soil (%)	
Treatments (mg ha^{-1})	C	N	C	N	C	N	C	N	C	N
0	15.34c	1.77b	5.92	0.63	27.90	3.27	18.8	17.5	81.2	82.4
20	15.52bc	1.76b	4.74	0.44	29.34	3.43	15.2	12.6	84.8	87.4
40	16.30a	1.84a	5.73	0.62	30.58	3.49	17.6	16.77	82.4	83.3
60	16.18ab	1.84a	5.15	0.57	30.12	3.44	15.7	15.4	84.3	84.6
Analysis of variance (ANOVA) (*p* values)										
Treatment effects	*	**	NS	NS	NS	NS	NS	NS	NS	NS
Linear	**	***	NS	NS	NS	NS	NS	NS	NS	NS
Quadratic	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Cubic	NS	*	NS	NS	NS	NS	NS	NS	NS	NS

Note: Values within a column followed by different letters are statistically different at 0.05 probability level. NS, not significant at 0.05 probability level.
*Significant at 0.05 probability level.
**Significant at 0.01 probability level.

Discussion

Growers interested in planting shrub willows want to know whether it is more beneficial to apply willow chips than to use them as an energy source. Our study showed that willow chips can enhance soil structure as demonstrated previously (Lalande et al. 1998; Holtz et al. 2004). Willow chip application also enhanced soil respiration, which suggests that the material provides a food source for soil microbes. Willow chips were found to increase soil total C 18 months after application, which corroborates the results of a study by N'Dayegamiye and Angers (1993), who reported increased C content following wood residue application. A similar trend was observed for total N. Potato-based systems have been shown to experience declines in soil organic matter and soil aggregation. Willow chips are a good source of C and N, and they have been found to stimulate microbial populations as evidenced by increased soil respiration. Lalande et al. (1998) reported an increase in fungi biomass following the addition of chipped wood from twigs and linked the observed increase in soil aggregation to the role that fungi play in enmeshing soil particles. Polysaccharides and lipids produced by microbial populations also help to stabilize soil aggregates (Abiven et al. 2009). The effect of wood residues on soil properties, including soil aggregation, may depend on the properties of the wood residues. N'Dayegamiye and Angers (1993) did not observe significant effects of wood residues (C:N ratio of 96) on soil aggregation compared with the results of the present study in which wood chips had a C:N ratio of 48. The species of willow tree/shrub used and the growth stage involved affect wood chip attributes and thus the effect this material has on soil properties. To stimulate and accelerate resprouting, shrub willows are generally harvested through coppicing every 3–4 years, and they have a lifespan of over

20 years (Keoleian and Volk 2005). Willow chips with a C:N ratio higher than 25 may also help to immobilize N, thereby reducing nitrate leaching, if applied after the harvest of a high-N crop demand is harvested.

Slightly increasing trends in macronutrients were observed, significant for K only, a finding that is in agreement with previous studies (Holtz et al. 2004). The proportion of C and N in POM compared with whole soil ranged from 15% to 19% for C and from 13% to 17% for N in this study. The latter values are in the lower range than the results reported by Carter et al. (2003), who found mean values of 22% and 27% in a study conducted at 14 different sites in eastern Canada. The C and N levels in POM and MAOM were very close and comparable among the treatments as opposed to the results obtained by N'Dayegamiye and Angers (1993), who reported 68% and 17% C in the light fraction of organic matter (unprotected) and the heavy fraction of organic matter (protected), respectively. It may take more time, higher willow chip rates, or repeated applications to see significant changes in C and N in organic matter fractions. In the latter study, the effects of wood residues (tree clippings) were analyzed after 9 years of biennial application at a rate up to 100 mg ha^{-1}. Greater willow chip rates than those considered in this study may be beneficial for aggregate stability, protein index, Mehlich-3 extractible K, and C and N in the whole soil. The significance of the linear response of willow chip rates on C, N, K, and aggregate stability implies that higher rates than those in this study could enhance the latter soil properties.

Conclusion

Our study evaluated the potential of using willow chips as a soil amendment in potato-based systems. In the first year following application, willow chips' application significantly increased soil aggregation, soil respiration, and soil Mehlich-3 extractible K. Soil total C and N were also significantly increased 18 months after application, while C and N in POM and MAOM were not affected. Our study demonstrated that using willow chips as a soil amendment is a good alternative to burning them for energy. This study used wood chips from shrub willows cut three years after establishment. This study evaluated the effect of willow chips after only one application. Future studies could focus on assessing impact on soil health of willow chips harvested at different growth stages and at rates higher than in this study, as well as effects of repeated applications over years. Our results show that willow chips replenish the soil in C, N, and K, enhance soil structure, stimulate soil microbial respiration, and provide many other ecological and environmental benefits.

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Data availability

Data generated or analyzed during this study are available from the corresponding author upon reasonable request.

Author information

Author ORCIDs

Judith Nyiraneza https://orcid.org/0000-0003-2516-5381

Author notes

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Competing interests

The authors declare that there are no competing interests.

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