PASCUZZO PLANNING INC.

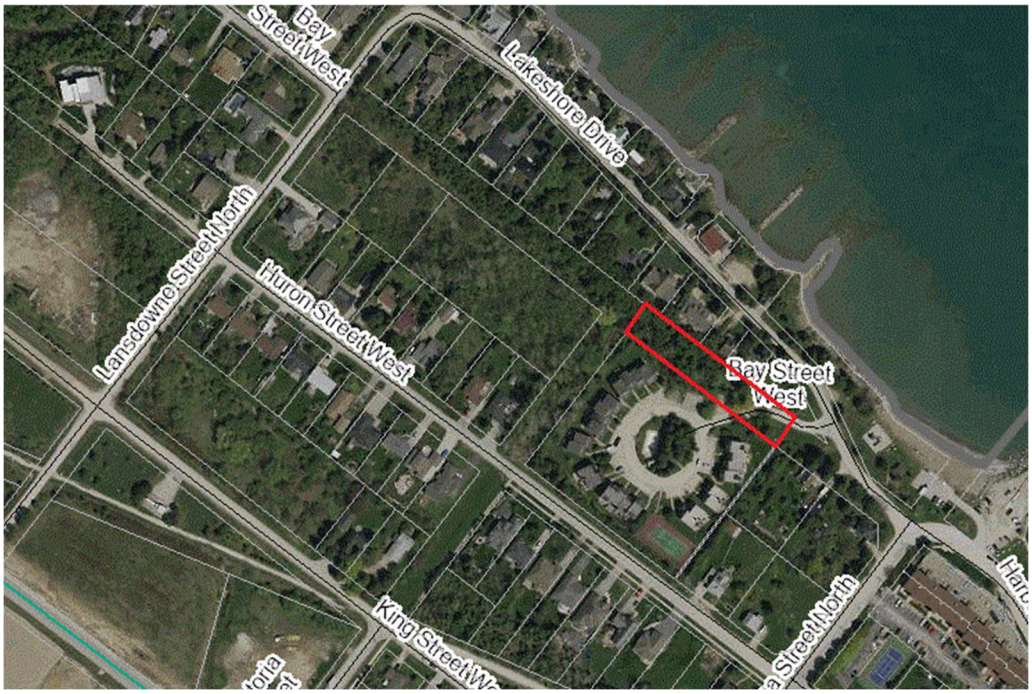
January 10, 2020

The Town of The Blue Mountains
Clerk, Corrina Giles
32 Mill Street
PO Box 310
Thornbury, ON
N0H 2P0

RE: **Potential Purchase of Unopened Road Allowance**
Bay Street West
The Town of The Blue Mountains, County of Grey

Dear Corrina:

On behalf of Grey County Condominium Corporation #11 (Bayside Villas), Pascuzzo Planning Inc. seeks Council's consideration of the potential sale of a portion of the unopened road allowance known as Bay Street West. Specifically, the portion of Bay Street West that is shown below in red.



I understand that this parcel of land would be approximately 20 m wide (66 feet) and 110 m (360 feet) deep. GCC#11 currently owns the property directly adjacent (south) of the subject lands.

I would ask that staff please advise Council of this request and advise my client and I on next steps.

PASCUZZO PLANNING INC.

Andrew Pascuzzo, MCIP, RPP

COUNCIL RESOLUTION

22

Res: 2020.01. 23

Wednesday, January 15, 2020

Moved by: [redacted]

Seconded by: [redacted]

THAT Conservation Authorities have been protecting people and conserving and restoring watersheds with local communities for over 50 years; and

THAT Municipalities must work together to ensure resilient and healthy watersheds for residents; and

THAT Conservation Authorities will be important partners in concrete and cost-effective initiatives to address climate change.

THEREFORE IT BE RESOLVED THAT the Council of the Municipality of Dutton Dunwich supports the important role Conservation Authorities provide to local communities in delivering watershed management programs

AND THAT this resolution be circulated to all upper and lower-tier municipalities, Conservation Authorities and the Provincial Government (Minister of Environment, Conservation and Parks) in Ontario

Recorded Vote	**Yeas**	**Nays**
P. Corneil	____	____
A. Drouillard	____	____
K. Loveland	____	____
M. Hentz	____	____
B. Purcell – Mayor	____	____

CARRIED: [redacted]

Mayor

DEFEATED:

Mayor

EMAIL RECEIVED – January 7, 2020
----- Forwarded Message -----
From: Alex Maxwell <[redacted]>
To: Corrina Giles <[redacted]>
Cc: Krista Royal <[redacted]>
Sent: Tuesday, January 7, 2020, 05:22:46 p.m. EST
Subject: Fw: Roads / winter maintenance and carbon sequestration

To: Mayor and Council
Transportation Advisory Committee
Sustainability Advisory Committee
Shawn Everitt, CAO

From: Alex Maxwell

Date: Jan 7th/ 2020

I ask that Council, the Transportation Advisory Committee and the Sustainability Advisory Committee consider the attached article by Dr. F. Theakson for potential inclusion in both the overall Transportation Master Plan and the Integrated Community Sustainability Plan. The article speaks to the benefits of tree planting on wind and carbon sequestration.

Please consider budgeting for and implementing a multi-year community tree planting initiative in a method recommended by Dr F. Theakston and many other experts which is based on proven scientific fact. By doing so the Town of The Blue Mountains can potentially reduce overall snow removal, reduce erosion, reduce climate change and cool our environment, increase health and safety by reducing flood risks and strengthening storm water management and enhance our natural local landscape. This is a low-cost option to accomplish a number of objectives. At the same time our municipality can reduce our carbon foot print through the planting appropriate trees that increase our tree canopy

These actions, in my humble option, speak to many sensible and practical things that can be done with positive outcomes for all residents and visitors. A multi-year plan that begins with budget inclusions for 2020 would show Council's commitment to this initiative increasing overall public good and accomplishing many of the goals identified by Council, Advisory Committees and local interest groups.

Sincerely yours,
Alex Maxwell
Town Of The Blue Mountains
Clarksburg Ontario

Climate Change at arborday.org

NCR-191 Dr. F Theakston

NRC Research Press

ARTICLE

Greenhouse gas mitigation potential of shelterbelts: Estimating farm-scale emission reductions using the Holos model[1]

Chukwudi C. Amadi, Ken C.J. Van Rees, and Richard E. Farrell

Abstract: Shelterbelts provide an opportunity for carbon (C) sequestration and have the potential to mitigate agricultural greenhouse gas (GHG) emissions. However, the influence of shelterbelts on GHG emissions at the farm scale is poorly understood. We estimated the potential of three shelterbelt tree species: hybrid poplar, white spruce, and caragana at five planting densities, to reduce GHG emissions in a model farm (cereal–pulse rotation). The Holos model, a Canadian farm-level GHG calculator developed by Agriculture and Agri-Food Canada, was used to estimate shelterbelt effects on farm GHG emissions over a 60 yr time frame. The planting densities of the shelterbelts represented 0%, 0.5%, 1.0%, 3.0%, and 5.0% of the total area of an average (688 ha) Saskatchewan farm. The greatest reduction in farm GHG emissions was estimated for hybrid poplar (23.0%) followed by white spruce (17.5%) and caragana (8.2%) — all at the highest planting density. The GHG mitigation by the shelterbelts was attributable primarily (90%–95% of GHG reduction) to C sequestration in tree biomass and in soil organic carbon (SOC) pools, with the remainder due to lower N_2O, CH_4 emissions, and a reduction in farm energy use. The GHG estimates from Holos agree with field measurements and suggests that species selection will be important for maximizing C sequestration and GHG mitigation potential of shelterbelt systems; conversely, shelterbelt removal from the agricultural landscape suggests an increase of on-farm GHG emissions.

Key words: shelterbelts, greenhouse gas, carbon, model farm, Holos model.

Résumé : Les brise-vents séquestrent le carbone (C) et peuvent réduire les émissions de gaz à effet de serre (GES) attribuables aux activités agricoles. Toutefois, on comprend mal l'influence de telles cultures sur les dégagements de GES de cette origine. Les auteurs ont estimé la capacité de réduction des émissions de GES de trois essences employées comme brise-vent (peuplier hybride, épinette blanche et caragana) à cinq densités de peuplement grâce à un modèle agricole (culture de céréales et de légumineuses en assolement). Le modèle Holos, élaboré par Agriculture et Agroalimentaire Canada pour calculer les émissions de GES des exploitations agricoles, a servi à estimer les effets des brise-vents sur les dégagements de GES au cours d'une période de 60 ans. La densité des peuplements de brise-vents correspondait respectivement à 0 %, 0,5 %, 1,0 %, 3,0 % et 5,0 % de la superficie d'une ferme moyenne (688 ha) en Saskatchewan. On estime que la plus forte réduction des émissions agricoles de GES résulte de la plantation de peupliers hybrides (23,0 %), puis d'épinettes blanches (17,5 %) et de caraganas (8,2 %), à la densité la plus élevée. On attribue essentiellement la baisse des émissions de GES (de 90 à 95 %) à la séquestration du C dans la biomasse des arbres et les réserves de carbone organique du sol, le reste venant de la diminution des émissions de N_2O et de CH_4, ainsi que d'une moins grande consommation d'énergie à la ferme. L'estimation des émissions de GES par le modèle Holos concorde avec les relevés effectués sur le terrain et laisse croire qu'il est important de bien choisir l'essence des arbres si l'on veut optimiser la séquestration du C et la baisse des émissions de GES par les brise-vents. Inversement, l'élimination des brise-vents sur les terres arables pourrait donner lieu à une hausse des dégagements de GES. [Traduit par la Rédaction]

Mots-clés : brise-vent, gaz à effet de serre, carbone, exploitation modèle, modèle Holos.

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C.C. Amadi, K.C.J. Van Rees, and R.E. Farrell. Department of Soil Science, University of Saskatchewan, Saskatoon, SK S7N 5A8, Canada.

Corresponding author: Chukwudi C. Amadi (email: chukwudi.amadi@usask.ca).

Abbreviations: **C**, carbon; **CH_4**, methane; **CO_2**, carbon dioxide; **GHG**, greenhouse gas; **NPP**, net primary productivity; **N_2O**, nitrous oxide; **SOC**, soil organic carbon.

[1]This paper is part of a Special issue entitled Greenhouse Gas Emissions: Sources and Sinks in Canadian Agro-Ecosystem.

Introduction

The removal of atmospheric carbon (CO_2) and its storage in the terrestrial biosphere is an option for reducing GHG emissions (Intergovernmental Panel on Climate Change (IPCC) 2006). Arable lands, therefore, present an opportunity for removing large amounts of atmospheric GHG if trees are incorporated into farming systems (Evers et al. 2010). Shelterbelts, linear arrays of trees and shrubs have been planted in Canada for more than a century, mainly to protect crops from wind damage, reduce soil erosion, and provide a myriad of other ecological functions such as wildlife habitats, improved biodiversity, and water quality (Amichev et al. 2016). Moreover, for the past two decades, shelterbelts have been recognized as a strategy for reducing atmospheric C concentrations through C storage in tree biomass (Kort and Turnock 1999) and in soil organic carbon (SOC) pools (Sauer et al. 2007). Yet the integrated role of shelterbelts in terms of C storage and trace gas mitigation in cropped fields remains poorly understood, particularly at the farm scale.

Despite the relatively small land area that they occupy on the agricultural landscape, shelterbelts can sequester large amounts of C per unit area. For example, potential C sequestration rates in above- and belowground components in shelterbelt systems were estimated at 6.4 Mg C ha^{-1} yr^{-1}, compared with 2.6, 3.4, and 6.1 Mg C ha^{-1} yr^{-1} for riparian forest buffers, alley cropping, and silvopasture system, respectively (Udawatta and Jose 2011). In Saskatchewan, Canada, Kort and Turnock (1999) estimated C sequestration in aboveground biomass of 17–90 yr old, single-row shelterbelts at 105, 24–41, and 11 Mg C km^{-1} for hybrid poplar, conifer, and shrub shelterbelts, respectively. In a study that predicted C accumulation in 60 yr old white spruce shelterbelts using 3PG model, Amichev et al. (2016) reported total aboveground C content of 120 Mg C km^{-1} representing a mean annual C increment of 2 Mg C km^{-1} yr^{-1}.

Shelterbelts also increase C sequestration in stabilized SOC pools (Udawatta and Jose 2011). In Nebraska, USA, Sauer et al. (2007) reported that SOC concentrations in the 0–7.5 cm soil layer under a red cedar (*Juniperus virginiana*)–Scots pine (*Pinus sylvestris*) shelterbelt (3.04%) were 55% greater than in the adjacent cultivated field (1.96%), with 12% greater SOC in the 7.5–15 cm soil depth. Thus, during a period of 35 yr, SOC sequestration in the shelterbelts within the 0–15 cm soil depth was 3.71 Mg greater than that in the cropped field, representing an annual increase of 0.11 Mg ha^{-1} yr^{-1}. The greater SOC content in the shelterbelts was attributed to the increased inputs from tree litter and wind-blown sediments, reduced soil disturbance from agronomic practices, and reduced soil erosion. Using the CENTURY model, Campbell et al. (2005) predicted annual SOC storage in cropped field in Southern Saskatchewan at 0.16 Mg ha^{-1} yr^{-1}, but the authors did not estimate C storage in shelterbelts or other agroforestry systems. However, Janzen et al. (2001) suggested that annual C storage in agroforestry systems could range from 0.2 to 1.0 Mg ha^{-1} yr^{-1}.

The potential for atmospheric C reduction by agroforestry systems occurs not only through C accumulations in tree biomass and soil but also through various indirect benefits associated with agroforestry. For example, planting shelterbelts reduces farm energy because the areas occupied by trees are exempt from fertilizer application and other agronomic practices such as tillage and pesticide applications. This implies not only a reduction in N_2O emissions but also a reduction in CO_2 emissions from diesel use and during the manufacture of fertilizers and pesticides (Brandle et al. 1992; Little et al. 2008). Other indirect benefits include C storage in long lasting wood products (e.g., wooden furniture and houses) and the use of wood as a fuel source instead of fossil C which reduces the need for increased use of fossil C and unsustainable deforestation (Roy 1999).

Integrating trees into the agricultural landscape reduced soil N_2O emissions and increased CH_4 oxidation (Evers et al. 2010). Trees are deep rooting and can inhibit the denitrification process by absorbing residual NO_3 and excess soil water that would otherwise be susceptible to N_2O emission or NO_3 leaching. Whereas some of this N is retained in the tree biomass, most is returned to the soil through litterfall. This process is recognized as the safety-net role of tree roots (Allen et al. 2004), and the result is more efficient N cycling, decreased fertilizer N demand by surrounding soils, and thus, reduced N_2O emissions from N fertilization (Amadi et al. 2016). However, the ability of tree roots to take up excess moisture and N in surrounding soils can create favorable conditions for CH_4 oxidation, which in turn, increases the size of CH_4 sink in soils under treed systems (Amadi et al. 2016).

To date, research into the GHG mitigation potential of shelterbelts has focused on single components within the farm system, i.e., either C storage in biomass and soil, or trace gas emissions in shelterbelts and cropped fields, without taking into account the complexity of interrelationships in these systems. Thus, there is a need for an integrated model of shelterbelts that considers the C balance and GHG reductions in the tree–soil system. The Holos model is a farm-level GHG emission assessment tool specific for Canadian conditions (Little et al. 2008). It was conceptualized as a farm-level "Virtual Farm" model that links descriptors (farm characterization) and algorithms (e.g., IPCC Tier 2 emission factors) to generate whole-farm greenhouse gas (GHG) emission estimates (Little et al. 2008). In addition to estimate GHG emissions, Holos allows users to contemplate GHG mitigation strategies, making it an exploratory tool (Little et al. 2008).

Although there are more than 60 000 km of shelterbelts in Saskatchewan, farm managers and regional

planners lack integrative farm-scale estimates of GHG reduction by shelterbelts. This information is needed to quantify the environmental benefits of shelterbelts and support management and policy decisions regarding the use of trees in agricultural systems. The previous work (Amadi et al. 2016) demonstrated that established (19–41 yr old) shelterbelts generate a net GHG mitigation benefit but did not describe the temporal changes in C sequestration and GHG emissions following establishment or as the shelterbelt aged. The present study provides those missing details using the Holos model to estimate the long-term potential for reducing GHG emissions of three common shelterbelt tree species (hybrid poplar (*Populus* spp.), white spruce (*Picea glauca*), and caragana (*Caragana arborescens*)), at five planting densities.

Materials and Methods

Holos model

Holos is a farm-scale empirical model based on IPCC (2006) methodology, modified for Canadian conditions, which uses a yearly time step to test and compare the GHG mitigation potential of different management scenarios (Little et al. 2008). Based on 30 yr climate norms, Holos considers all significant emissions and removals on the farm, taking into account CO_2, N_2O, and CH_4 emissions, as well as C sequestration from tree plantings and changes in land use and management. It also calculates emissions from on-farm energy use and the manufacture of fertilizers and herbicides. This systems' approach allows net whole-farm emissions to be calculated from management changes on any part of the farm (Beauchemin et al. 2010).

Model scenarios

The total area of the model farm was 688 ha, representing the average farm size in Saskatchewan (Saskatchewan Ministry of Agriculture 2015). Three commonly cultivated crops: wheat (*Triticum aestivum*), field pea (*Pisum sativum*), and oat (*Avena sativa*) were selected using a continuous wheat–pea–oat rotation, with reduced tillage (i.e., few tillage passes with most residue retained on the surface) and moderate fertilizer inputs (i.e., based on crop requirements).

The most common trees planted in shelterbelts in Saskatchewan are white spruce (2% of total shelterbelt length), hybrid popular (8.2% of shelterbelts), and caragana (70% of shelterbelts) (Amichev et al. 2015, 2016). Consequently, these three species were used to simulate GHG emissions over a period of 60 yr (i.e., from the first year of tree planting to 60 yr after planting). At the farm scale, the area occupied by shelterbelts within an individual farm unit can vary considerably ranging from 0% (no shelterbelt planting) to many rows of planted trees accounting for up to 5% of the total farm area (Stoeckeler 1965; Kort 1988; Schoeneberger 2009). Thus, given the variation in shelterbelt area on a typical farm, we considered five scenarios of single-row shelterbelts [0% (baseline), 0.5%, 1.0%, 3.0%, and 5.0% of the total farm area].

Farm zones

Three major zones were identified for simulating GHG on the farm: the shelterbelt, the transition between the shelterbelt and cropped field, and the cropped field itself. The shelterbelt zone is the area under the crown width of the linear shelterbelts. Crown width values of 14.04, 7.86, and 9.49 m were used for hybrid poplar, white spruce, and caragana, respectively (Amichev et al. 2016). Shelterbelts were assumed to be in good condition (i.e., no disease present, no stress due to drought or nutrient deficiency), and the soil in the shelterbelt area was undisturbed and excluded from agronomic activities such as tillage, fertilizer application, and seeding.

The transition zone is the area that is indirectly influenced by shelterbelts, e.g., by shading, root activity, litter depositions, and microclimatic influences. The transition zone area is derived by multiplying the transition zone width (i.e., 1.5 times the shelterbelt height) by the total length of the shelterbelt. The cropped area was determined by subtracting the shelterbelt area and the transition zone area from the total farm area.

Geographical location and climatic conditions of the farm

The Holos model uses emission factors adjusted for variations in climatic and soil conditions across Canada, which are drawn from a database of ecodistricts, with soil information obtained from the Canadian Soil Information System National Ecological Framework (Marshall et al. 1999). The model farm was located in Ecodistrict 772 (i.e., within the Semiarid Prairies ecozone), and the soil type was a dark-brown Chernozem, of medium soil texture, managed using reduced/minimum tillage practices. Average growing season (May–October) precipitation for the ecodistrict was 259 mm, and potential evapotranspiration was 659 mm.

Carbon storage in tree biomass

Holos calculates C storage in aboveground tree biomass based on tree growth equations developed through destructive sampling of seven common shelterbelt species across the brown, dark-brown, and black soil zones of Saskatchewan (Kort and Turnock 1999). The age of the sampled shelterbelts ranged from 17 to 90 yr, with 72% of the shelterbelts between 30 and 60 yr of age. Based on the age range of trees sampled by Kort and Turnock (1999), we estimated C accumulation curves for hybrid poplar, white spruce, and caragana shelterbelts over a period of 60 yr. Kort and Turnock (1999) demonstrated that a tree's growth rate depends on its leaf area and that the rate of biomass accumulation increased with tree age for all tree species. Thus, during the early years of a tree's life, the rates of biomass and C accumulation were low due to small leaf area, but in later years as the tree developed more leaf area, it grew faster.

To develop a C accumulation equation for each species in a given soil zone, the authors sampled only mature trees (i.e., 40 yr of age or older) and conducted linear regressions on annual biomass accumulation vs. age data. Annual C accumulation per tree was estimated as a function of tree age and coefficients of annual C accumulation, as shown in the following equation:

$$C_{tree} = [a \times (age - 2)]^b \quad (1)$$

where C_{tree} represents the annual C accumulation per tree (kg C yr^{-1}), a and b are the coefficients of annual C accumulation which vary by soil type and tree species, respectively; age is the age of the shelterbelt (years). The model assumes that C accumulation in trees starts at least 2 yr after planting. Values for coefficient a (i.e., for the dark-brown soil zone) were 0.3232, 0.1345, and 0.4511 and values for coefficient b were 0.9651, 0.8970, and 0.6446 for hybrid poplar, white spruce, and caragana, respectively (Little et al. 2008).

The annual C accumulation of a single-row shelterbelt on the model farm was estimated as follows (Little et al. 2008):

$$C_{planting} = C_{tree} \times \frac{length}{planting\ space} \times rows \quad (2)$$

where $C_{planting}$ represents the annual C accumulation per linear planting (Mg C yr^{-1}), length is the total length of shelterbelt in each scenario (km), planting space is the spacing of individual trees (m) and rows is the number of tree rows. A planting space of 2 m was used to estimate $C_{planting}$ for hybrid poplar and white spruce. Planting space for caragana shelterbelts in the field ranged between 0.5 and 0.7 m; however, $C_{planting}$ for caragana was calculated using a spacing of 10 m harvested sections within the shelterbelt (Kort and Turnock 1999). Carbon accumulation in belowground biomass for hybrid poplar, white spruce, and caragana was estimated as 40%, 30%, and 50% of the aboveground C content as recommended by Kort and Turnock (1999) based on studies by Freedman and Keith (1995), Van Lear and Kapeluck (1995), and Young et al. (1987), respectively. Furthermore, eqs. 1 and 2 were derived from leafless trees and do not account for C storage in tree leaves, root turnover, and exudates.

SOC sequestration

Soil organic C storage in the shelterbelt area and cropped area was estimated using the net primary productivity (NPP) approach described by Bolinder et al. (2007). The NPP approach quantifies annual C storage in above- and belowground biomass by allocating C within different crop plant parts; and estimates annual plant residue input to soil from litter, root turnover, and exudates. Soil organic C sequestration was defined as the fraction of plant residue incorporated into the soil and then integrated into stable SOC pools. The NPP represents C increase in a whole plant and is made up of C associated with different plant compartments as expressed in the following relationship:

$$NPP = C_P + C_R + C_S + C_E \quad (3)$$

where C_P is the C stored in harvestable plant products, i.e., grain or tree bole; C_R is the C in plant roots; C_S is the C in the aboveground residues (i.e., crop residues, straw, or litterfall); and C_E represents the C derived in root products including root turnover and exudates (Bolinder et al. 2007). Values that were applied to tree species and crops in this study are provided in Table 1. Carbon allocation to different plant compartments was estimated as follows:

$$C_P = Yield \times C\ content \quad (4)$$

$$C_R = Yield/(shoot:root \times harvest\ index) \times C\ content \quad (5)$$

$$C_S = Yield \times (1 - harvest\ index)/harvest\ index \times C\ content \quad (6)$$

$$C_E = C_R \times Y_E \quad (7)$$

where yield is the dry matter (DM) yield of aboveground products (kg ha^{-1} yr^{-1}); harvest index is the DM yield of grain/total aboveground DM yield; and Y_E is the extra root C from root turnover and exudates relative to recoverable roots. Total annual C input to the soil from various plant components was estimated as follows:

$$C_i = [C_P \times S_P] + [C_R \times S_R] + [C_S \times S_S] + [C_E \times S_E \quad (8)$$

where C_i is the annual C input to soil from plants and S is the proportion of C in the respective plant component that enters the soil. The value of S ranges from 0 to 1 indicating 0% to 100% of a plant fraction incorporated into the soil annually (Bolinder et al. 2007).

Carbon sequestration into soil stable C pools C_{is} is the proportion of C inputs that is potentially integrated into the stable SOC pool. Because the cropped area (including the transition zone) was tilled annually exposing the soil to rapid SOC oxidation while the shelterbelt zone was relatively undisturbed, it was assumed that 12% of C_i was incorporated into stable C pools within the cropped area of the farm (Winans et al. 2015), while 30% of C_i was sequestered into stable C pools within the shelterbelt area (Thevathasan and Gordon 2004). Thus, C_{is} in the cropped and the shelterbelt areas were expressed as follows:

$$C_{is}\ (cropped\ area) = 0.12\ C_i \quad (9)$$

$$C_{is}\ (shelterbelt\ area) = 0.30\ C_i \quad (10)$$

Within the cropped area, the C in grains and other harvestable products are removed from the field and, therefore, not returned to the soil. Crop yield and C

Table 1. Values of crop yield (Mg DM ha^{-1} yr^{-1}), C content (%), harvest index, root:shoot ratio, extra root C (YE), and root turnover used for the calculation of C input to soil in a model farm (688 ha, located in Saskatchewan, Canada) with the Holos model.

	Value	Reference	Value	Reference	Value	Reference
	Spring wheat		Dry pea		Oats	
Yield (Mg DM ha^{-1} yr^{-1})[a]	1333	Little et al. (2008)	943	Little et al. (2008)	1008	Little et al. (2008)
C content (%)	0.45	Bolinder et al. (2007)	0.45	Bolinder et al. (2007)	0.45	Bolinder et al. (2007)
Harvest index	40	Bolinder et al. (2007)	42	Bolinder et al. (2007)	53	Bolinder et al. (2007)
Shoot:root	5.6	Campbell and de Jong (2001)	9.2	House et al. (1984)	2.5	Izaurralde et al. (1993)
YE	1	Bolinder et al. (1997)	1	Bolinder et al. (1997)	1	Bolinder et al. (1997)
	Hybrid poplar		White spruce		Caragana	
C content (%)	0.48	Freedman and Keith (1995)	0.50	Freedman and Keith (1995)	0.51	Freedman and Keith (1995)
Fine root turnover	1.28	Yuan and Chen (2010)	0.84	Yuan and Chen (2010)	1.15	Yuan and Chen (2010)
Coarse root turnover	0.4	Yuan and Chen (2010)	0.4	Yuan and Chen (2010)	0.4	Yuan and Chen (2010)
YE	1	Bolinder et al. (1997)	1	Bolinder et al. (1997)	1	Bolinder et al. (1997)

[a]Yields are default values in Holos estimated from McConkey et al. (2007) for the Ecodistrict of the farm location.

input within the transition zone are not uniform across the entire zone due to competition between the trees and the field crop for nutrients and water (Kort 1988). However, in the previous study (Amadi et al. 2016), we found no significant difference in SOC between the transition zone and the cropped field. This suggests that the effect of reduced biomass inputs due to root competition in the transition zone was counteracted by the effect of a shelterbelt-induced increase in biomass inputs. In the present study, it was assumed that average C input in the transition zone was the same as in the cropped field.

Within the shelterbelt area, it was assumed that all tree leaves produced per year were deposited to the soil as leaf litter (C_S) and C_E represented C in root turnover and exudates; in the case of white spruce, this assumption represents annual needle fall turnover. Leaf biomass C was calculated as 9.8% and 16% of aboveground biomass C for hybrid poplar and white spruce, respectively; and 29% of aboveground biomass C for caragana (Moukoumi et al. 2012). For all trees, the fine root biomass C was assumed to be equal to leaf biomass C (Amichev et al. 2016). Thus, coarse root biomass C was estimated as the belowground biomass minus the fine root biomass. As such, CE was estimated based on root turnover rates of coarse and fine roots reported by Yuan and Chen (2010). Coarse roots (i.e., >2 mm dia.) had a turnover rate of 0.4 yr^{-1} for all three tree species; whereas fine root (i.e., ≤2 mm dia.) turnover rates were 1.28, 0.84, and 1.15 yr^{-1} for hybrid poplar, white spruce, and caragana, respectively (Yuan and Chen 2010). Carbon content in root exudates did not vary significantly among tree and crop roots (Bolinder et al. 1997); thus, C content in the root exudates of all tree species was assumed to be same as in the crops (Table 1).

Carbon loss to the atmosphere

Carbon loss from the soil C_{ie} was estimated as the proportion of C inputs that were not integrated into the stable SOC pool but were released back to the atmosphere through microbial decomposition processes (Winans et al. 2015). Annual CO_2 emissions from cropped and shelterbelt areas were estimated as 88% and 70% of total C inputs to the soil and expressed as

$$C_{ie}\,(\text{cropped area}) = 0.88\,C_i \quad (11)$$

$$C_{ie}\,(\text{shelterbelt area}) = 0.70\,C_i \quad (12)$$

Soil N_2O emissions

Holos calculates direct N_2O from soils based on N inputs, modified by climate, tillage, soil texture, and topography. For the cropped area, total N additions to soil comprised synthetic N fertilizer additions and N derived from above- and belowground crop residue decompositions. Fertilizer N inputs were estimated from total N requirement by crops (McConkey et al. 2007), while N inputs from crop residues were calculated from crop yields, using coefficients derived from Janzen et al. (2003). Thus, during the 60-yr-long long crop rotation, fertilizer N application to the cropped area has default values of 45 kg N ha^{-1} yr^{-1} for spring wheat and oats and 0 kg N ha^{-1} yr^{-1} for dry peas (McConkey et al. 2007). For the shelterbelt area total N additions to soil included N in leaf litter and N in root turnover. The N content in leaf litter was estimated as 2.0% for hybrid poplar (Thevathasan and Gordon 1997), 1.17% for white spruce (Wang and Klinka 1997), and 3% for caragana (Moukoumi et al. 2012). Foliar N content of each tree species was assumed to be the same as N content in root turnover.

Holos calculates soil-derived N_2O emission from total N inputs, using Canada-specific algorithms modified from those developed for calculating the national GHG inventory (Rochette et al. 2008). The total N input was multiplied by an emission factor, adjusted for growing season precipitation and the potential evapotranspiration for the ecodistrict, using data from CanSIS averaged from 1971 to 2000 (Marshall et al. 1999). Modifiers for soil type, texture, tillage system, and topography were based on Rochette et al. (2008). The emission factor was calculated as follows:

$$EF_{eco} = 0.022 \times \frac{P}{PE} - 0.0048 \quad (13)$$

where EF_{eco} represents the ecodistrict emission factor (kg N_2O-N (kg N)$^{-1}$); P is the growing season precipitation by ecodistrict (May–October) (mm); and PE is the growing season evapotranspiration (May–October) (mm). Based on eq. 15, an emission factor of 0.0047 kg N_2O-N (kg N)$^{-1}$ was used to estimate N_2O emission in all zones of the model farm. Soil N_2O emissions from the cropped field was defined as

$$N_2O\text{-}N_{crop\ inputs} = (N_{fert} + N_{res}) \times \text{cropped area} \times EF_{eco} \quad (14)$$

where $N_2O\text{-}N_{crop\ inputs}$ represents the N emissions from cropland due to crop inputs to soil (kg N_2O-N), N_{fert} is the N input from synthetic N fertilizers (kg N), and N_{res} is the N input from crop residue returned to soil (kg N). Soil N_2O emissions from the shelterbelt area was defined as

$$N_2O\text{-}N_{tree\ inputs} = (N_{leaf\ litter} + N_{root\ turnover}) \times \text{shelterbelt area} \times EF_{eco} \quad (15)$$

where $N_2O\text{-}N_{tree\ inputs}$ represents the N emissions from the shelterbelt area due to tree inputs to the soil (kg N_2O-N), $N_{leaf\ litter}$ is the N input from tree leaf litter (kg N), and $N_{root\ turnover}$ is the N input from tree root turnover (kg N). Soil N_2O emissions in the transition zone was estimated as one half of N_2O emissions in the cropped field (Amadi 2016). This was based on more efficient N cycling reported in this zone. Tree roots extend to the transition area and take up excess soil N and moisture, which reduces the processes that result in N_2O emissions (Evers et al. 2010).

Soil CH_4 fluxes

In general, cropped fields are slight sources or sinks of soil CH_4 (Bronson and Mosier 1993); however, the incorporation of trees into cropped fields could significantly increase soil CH_4 sink size through the removal of excess soil moisture, an increase in soil organic matter (SOM), and a decrease in soil bulk density (Hütsch et al. 1994). There is evidence for increasing soil CH_4 oxidation with the increasing root biomass in soil occupied by tree roots (e.g., in temperate pine forests (Peichl et al. 2010) and a hybrid poplar–caragana shelterbelt (Amadi 2016)). Therefore, the soil CH_4 flux (CH_{4soil}) in the shelterbelt and cropped field was estimated using a regression equation between root biomass and CH_4 emission, based on data reported by Amadi (2016):

$$CH_{4(soil)} = -197.83(\text{root biomass}) + 18.1 \quad (16)$$

Soil CH_4 flux in the transition zone was estimated as one half of the CH_4 flux in the shelterbelt area. This assumption is based on reported reduction of root biomass in this zone relative to the shelterbelt zone and root competition for resources with crops (Kort 1988; Amadi 2016).

Carbon dioxide emissions from farm energy use

Holos estimates CO_2 emissions from the use of fossil fuel on the farm and categorizes them as primary or secondary emission sources (Gifford 1984). Primary sources include fossil fuel used in cropping operations; i.e., tillage, seeding/fertilizer application, and harvesting. Secondary sources of CO_2 emissions from fossil fuels include emissions related to the manufacture of fertilizers and herbicides. Carbon dioxide emissions associated with the transportation of goods to the farm or the manufacture of farm machines was not considered.

Carbon emissions related to the manufacture of N and P fertilizers was estimated at 3.59 kg CO_2 (kg N)$^{-1}$ and 0.5699 kg CO_2 (kg P_2O_5)$^{-1}$, respectively (Nagy 2000). Energy emissions related to the manufacture of herbicide production was 1.334 kg CO_2 (kg herbicide)$^{-1}$ (Little et al. 2008). Based on the above values, annual farm CO_2 emissions from energy use ($CO_{2energy}$) in the cropped area was 0.30 Mg CO_2e ha^{-1} yr^{-1} for spring wheat and oats and 0.14 Mg CO_2e ha^{-1} yr^{-1} for dry peas. The shelterbelt zone was excluded from CO_2 emissions from fossil fuel use. However, because farm machinery is usually employed during the initial planting of shelterbelts, it was assumed that CO_2 emissions associated with planting the trees was equivalent to emissions associated with seeding spring wheat for 1 yr (i.e., 0.30 Mg CO_2e ha^{-1}).

Whole-farm GHG emissions

Whole-farm GHG emissions ($GHG_{whole\ farm}$) was defined as the sum of all sources and sinks of GHG emissions across the entire farm (i.e., the shelterbelt, transition zone, and cropped field) and was expressed in Mg CO_2e to account for the global warming potential of the respective gases. Whole-farm GHG emissions per year was expressed as

Table 2. Annual greenhouse gas (GHG) emissions per hectare, including C and trace gas fluxes in the shelterbelt, transition, and cropped zones of a model farm (688 ha, located in Saskatchewan, Canada).

	C_P (Mg C ha^{-1} yr^{-1})	C_R (Mg C ha^{-1} yr^{-1})	C_S (Mg C ha^{-1} yr^{-1})	C_E (Mg C ha^{-1} yr^{-1})	C_I (Mg C ha^{-1} yr^{-1})	C_{is} (Mg C ha^{-1} yr^{-1})	C_{ie} (Mg C ha^{-1} yr^{-1})	$CO_{2energy}$ (Mg CO_2 ha^{-1} yr^{-1})	CH_{4soil} (kg CH_4-C ha^{-1} yr^{-1})	N_2O_{soil} (kg N_2O-N ha^{-1} yr^{-1})	GHG_{total} (Mg CO_2e ha^{-1} yr^{-1})
Cropped field											
Spring wheat	0.60	0.27	0.90	0.27	1.44	0.17	1.27	0.30	−0.088	0.64	4.53
Peas	0.42	0.11	0.59	0.11	0.81	0.10	0.71	0.14	−0.025	0.29	2.46
Oats	0.45	0.34	0.40	0.34	1.09	0.13	0.96	0.30	−0.117	0.61	3.53
Transition zone											
Spring wheat	0.60	0.27	0.90	0.27	1.44	0.17	1.27	0.30	−0.230	0.320	4.43
Peas	0.42	0.11	0.59	0.11	0.81	0.10	0.71	0.14	−0.115	0.145	2.42
Oats	0.45	0.34	0.40	0.34	1.09	0.13	0.96	0.30	−0.046	0.305	3.44
Shelterbelt zone											
Hybrid poplar	3.01	1.21	0.30	1.95	2.26	0.68	1.58	0.005	−0.459	0.18	−12.13
White spruce	2.08	0.62	0.33	1.02	1.35	0.41	0.94	0.005	−0.229	0.07	−7.94
Caragana	0.55	0.28	0.16	0.51	0.66	0.23	0.43	0.005	−0.091	0.10	−2.28

Note: C_I, annual soil C input; C_P, carbon in harvestable plant product; C_S, carbon in plant residues; C_R, carbon in root biomass; C_E, carbon in root turnover and root exudates; C_{is}, carbon in stable soil organic carbon (SOC) pool; C_{ie}, carbon loss to the atmosphere; $CO_{2energy}$, carbon emissions from farm energy; CH_{4soil}, methane flux; N_2O_{soil}, nitrous oxide flux; GHG_{total}, total farm greenhouse gas (GHG) emissions.

$$GHG_{whole\ farm} = \left[C_{planting} \times \left(\frac{44}{12}\right) \times (-1)\right] + \left[C_{is} \times \left(\frac{44}{12}\right) \times (-1)\right] + \left[C_{ie} \times \left(\frac{44}{12}\right) \times (1)\right] + [N_2O\text{-}N \times 298 \times (1)] + [CH_{4(soil)} \times 25 \times (1)] + [CO_{2energy} \times (1)] \quad (17)$$

where $GHG_{whole\ farm}$ represents whole-farm GHG emissions (Mg CO_2e yr^{-1}), (44/12) is the conversion factor from C to CO_2e, and 298 and 25 are the factors used to convert from N_2O and CH_4 to CO_2e, respectively (Forster et al. 2007).

Results

Carbon storage in tree biomass

Carbon fixation in above- and belowground biomasses was 4.22, 2.70, and 0.83 Mg C ha^{-1} yr^{-1} for hybrid poplar, white spruce, and caragana shelterbelts, respectively (Table 2). For all three tree species, simulated C storage in tree biomass to age 60 increased with an increasing farm area planted to shelterbelts; however, C storage in tree biomass varied between the three tree species (Fig. 1). At the end of 60 yr of growth, the maximum estimated C accumulation was 8712, 5581, and 1705 Mg C for the 5.0% scenario for hybrid poplar, white spruce, and caragana, respectively (Fig. 2; Table 3).

SOC inputs, sequestration, and loss

Within the cropped zone, average C input into the soil from crop residues (i.e., straw, roots, and root exudates from the wheat–peas–oats rotation) was 1.11 Mg C ha^{-1} yr^{-1}; resulting in C sequestration of 0.13 Mg C ha^{-1} yr^{-1} into soil stable C pools and C loss of 0.98 Mg C ha^{-1} yr^{-1} into the atmosphere from microbial decomposition processes (Table 2). However, within the shelterbelt zone, C inputs to soil (i.e., leaf litter, root turnover, and exudates) were 2.26, 1.35, and 0.66 Mg C ha^{-1} yr^{-1} for hybrid poplar, white spruce, and caragana, respectively. As a result, the C sequestered into stable SOC pools was 0.68, 0.41, and 0.23 Mg C ha^{-1} yr^{-1}; while C loss to the atmosphere was 1.58, 0.94, and 0.43 Mg C ha^{-1} yr^{-1} for the hybrid poplar, white spruce, and caragana shelterbelts, respectively (Table 2).

The C sequestered in stable SOC pools increased with the increasing shelterbelt area, but the increase in SOC sequestration varied with tree species (Fig. 3). For example, at the baseline scenario (i.e., scenario 0%), total SOC within the farm after 60 yr was 5495 Mg C. Incorporating shelterbelts into the farm increased the amount of C storage in the soil relative to baseline levels, reaching a maximum SOC storage of 6617, 6058, and 5701 Mg C for hybrid poplar, white spruce, and caragana, respectively (Table 3).

Fig. 1. Aboveground C content for hybrid poplar, white spruce, and caragana derived using the Holos model (small circles), compared with measured values from destructive sampling (Kort and Turnock 1999; inverted triangles) and predicted values using the 3PG model (Amichev et al. 2016; three-point stars).

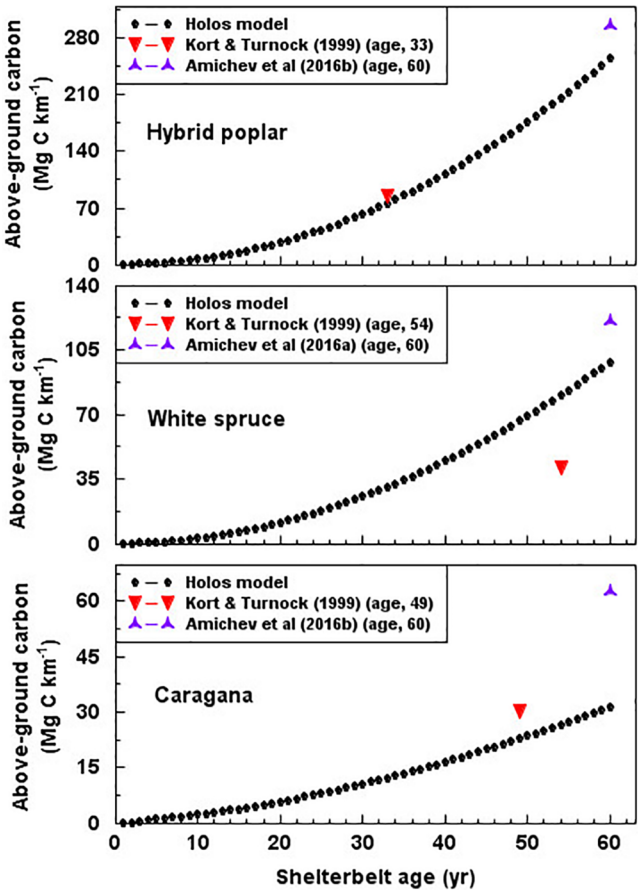
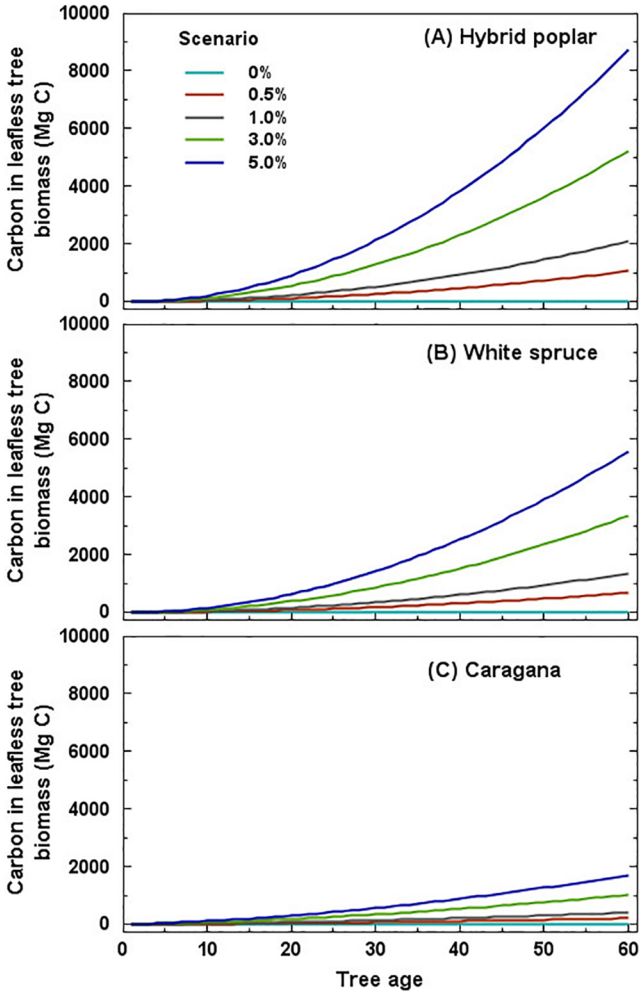


Fig. 2. Carbon storage in the above- and belowground tree biomasses of (A) hybrid poplar, (B) white spruce, and (C) caragana during a 60 yr period. Each tree species was established at five planting densities in shelterbelts on a model farm (688 ha, located in Saskatchewan, Canada). Simulations were generated with the Holos model.



Total C loss to the atmosphere from microbial decomposition processes over 60 yr of farming was 40 297 Mg C at the baseline scenario (i.e., no shelterbelts). However, with the increasing shelterbelt area, C loss from the soil increased with hybrid poplar and decreased with caragana shelterbelts but appeared to be comparatively constant with white spruce species reflecting differences in amounts of tree litter inputs and root respiration among these tree species (Table 3).

Soil CH_4 and N_2O exchange

Within the cropped field zone, average soil CH_4 exchange (i.e., after 60 yr of wheat–peas–oats rotation) was estimated at −0.077 kg CH_4-C ha^{-1} yr^{-1} (a net sink); while average soil N_2O emissions was 0.51 kg N_2O-N ha^{-1} yr^{-1} (Table 2). In the shelterbelt zone, the estimated soil CH_4 consumption rate was greatest under hybrid poplar (−0.46 kg CH_4-C ha^{-1} yr^{-1}), followed by white spruce (−0.23 kg CH_4-C ha^{-1} yr^{-1}) and caragana (−0.09 kg CH_4-C ha^{-1} yr^{-1}). In contrast, the lowest rate of soil N_2O emission was estimated for white spruce (0.07 kg N_2O-N ha^{-1} yr^{-1}), followed by caragana (0.10 kg N_2O-N ha^{-1} yr^{-1}) and hybrid poplar (0.18 kg N_2O-N ha^{-1} yr^{-1}).

For the baseline scenario (i.e., scenario 0), total soil CH_4 oxidation and N_2O emissions for the farm after 60 yr were −1.0 Mg CH_4-C and 21.2 Mg N_2O-N, respectively. The incorporation of various amounts of shelterbelts into the cropped field resulted in the increased soil CH_4 uptake and reduced N_2O emissions, although the changes in both gases varied with tree species (Figs. 4 and 5). Maximum whole-farm CH_4 uptake (−2.8 Mg CH_4-C, at scenario 5) was achieved when the shelterbelt species in the farm was hybrid poplar, followed by white spruce (−2.1 Mg CH_4-C) and caragana (−1.1 Mg CH_4-C). However, the lowest farm soil N_2O emissions (14.8 Mg N_2O-N) was reached with white spruce, followed by hybrid poplar (17.3 Mg N_2O-N) and caragana (20.3 Mg N_2O-N) (Table 3).

Table 3. Farm-scale carbon (C) and trace gas emissions in a model farm (688 ha, located in Saskatchewan, Canada) planted with hybrid poplar, white spruce, and caragana during a 60 yr period.

	Scenario (proportion of farm planted to shelterbelt)				
Parameter/shelterbelt species considered	0%	0.5%	1.0%	3%	5%
C in tree biomass (Mg C)					
Hybrid poplar	0	871	1742	5227	8712
White spruce	0	558	1116	3348	5581
Caragana	0	171	341	1023	1705
Soil organic carbon (SOC) sequestration (Mg C)					
Hybrid poplar	5495	5607	5719	6168	6617
White spruce	5495	5551	5608	5833	6058
Caragana	5495	5516	5536	5618	5701
Soil CO_2 emissions (Mg C)					
Hybrid poplar	40 297	40 421	40 546	41 043	41 541
White spruce	40 297	40 291	40 285	40 261	40 237
Caragana	40 297	40 185	40 072	39 624	39 174
Soil CH_4 exchange (Mg CH_4-C)					
Hybrid poplar	−1.0	−1.2	−1.4	−2.1	−2.8
White spruce	−1.0	−1.1	−1.2	−1.7	−2.1
Caragana	−1.0	−1.0	−1.0	−1.0	−1.0
Soil N_2O emissions (Mg N_2O-N)					
Hybrid poplar	21.2	20.8	20.4	18.8	17.3
White spruce	21.2	20.6	19.9	17.3	14.8
Caragana	21.2	21.1	21.0	20.7	20.3
Farm energy CO_2 emissions (Mg C)					
Hybrid poplar	2788	2774	2761	2706	2652
White spruce	2788	2774	2761	2706	2652
Caragana	2788	2774	2761	2706	2652
Whole-farm greenhouse gas (GHG) emissions (Mg CO_2e)					
Hybrid poplar	144 205	140 882	137 560	124 269	110 979
White spruce	144 205	141 686	139 166	129 089	119 011
Caragana	144 205	143 015	141 826	137 067	132 309

Note: Each tree species was established at five planting densities. Simulations were generated with the Holos model.

Farm energy CO_2 emissions

The emissions of CO_2 due to fuel use (i.e., from running farm machines and the manufacture of fertilizers and herbicides) averaged 0.25 Mg CO_2 ha^{-1} yr^{-1} in the cropped zone and 0.005 Mg CO_2 ha^{-1} yr^{-1} in the shelterbelt zone (Table 2). Total farm energy use after 60 yr was 2788 Mg C without shelterbelts; however, total farm energy declined by 136 Mg C for the largest ratio of shelterbelt area (scenario 5) (Table 3).

Whole-farm GHG emissions

Crop production (i.e., wheat–peas–oats rotation) in the cropped field zone resulted in an annual GHG emission of 3.51 Mg CO_2e ha^{-1} yr^{-1}; however, the shelterbelt area was an annual net sink of atmospheric GHG over the 60 yr period irrespective of the shelterbelt species (Table 2). The largest sink (−12.1 Mg CO_2e ha^{-1} yr^{-1}) was achieved with hybrid poplar, followed by white spruce (−7.9 Mg CO_2e ha^{-1} yr^{-1}) and caragana (−2.3 Mg CO_2e ha^{-1} yr^{-1}). Total farm GHG emissions over 60 yr was 144 205 Mg CO_2e for the baseline scenario and decreased with the increasing shelterbelt area planted (Fig. 6). The greatest reduction in total farm GHG emissions (110 979 Mg CO_2e, at scenario 5) was simulated for hybrid poplar shelterbelts representing a 23.0% decrease in cumulative farm emissions. Planting white spruce shelterbelts decreased overall farm emissions by 17.5% (119 011 Mg CO_2e), while caragana shelterbelts reduced farm emissions by 8.2% (132 309 Mg CO_2e) at the largest planting (Table 3).

Discussion

Carbon sequestration in tree biomass and stable SOC pools

The Holos model simulations showed that tree species selection is important for maximizing C sequestration. For example, greater C accumulation was estimated for faster growing trees such as hybrid poplar, followed by white spruce and caragana. The estimated C accumulation curves obtained using the Holos model were compared with C in tree biomass derived through

Fig. 3. Farm-scale total soil C content in a model farm planted with (A) hybrid poplar, (B) white spruce, and (C) caragana during a 60 yr period. Each tree species was established at five planting densities on a model farm (688 ha, located in Saskatchewan, Canada). Simulations were generated with the Holos model.

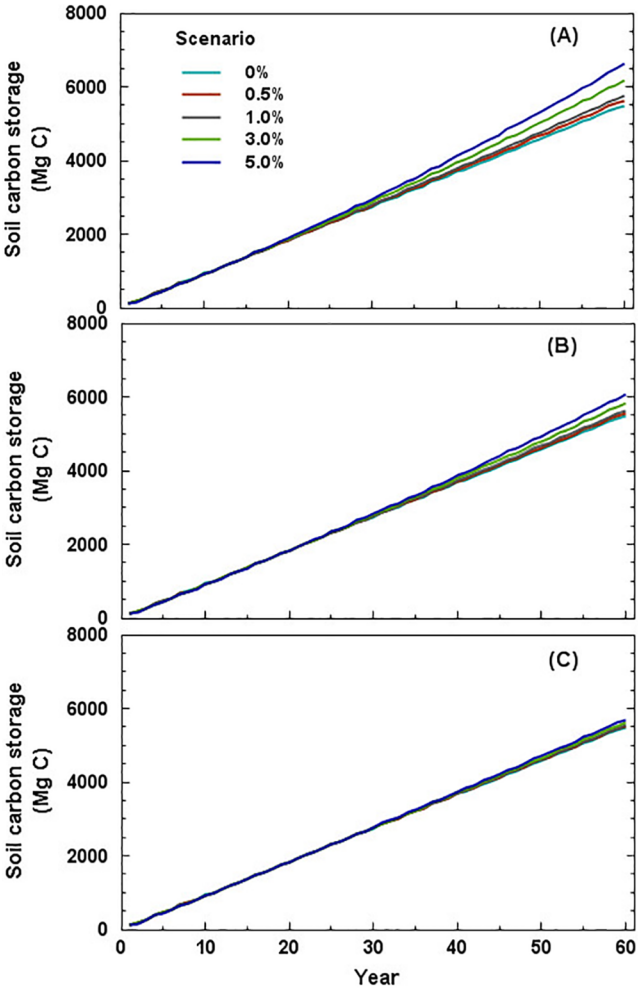
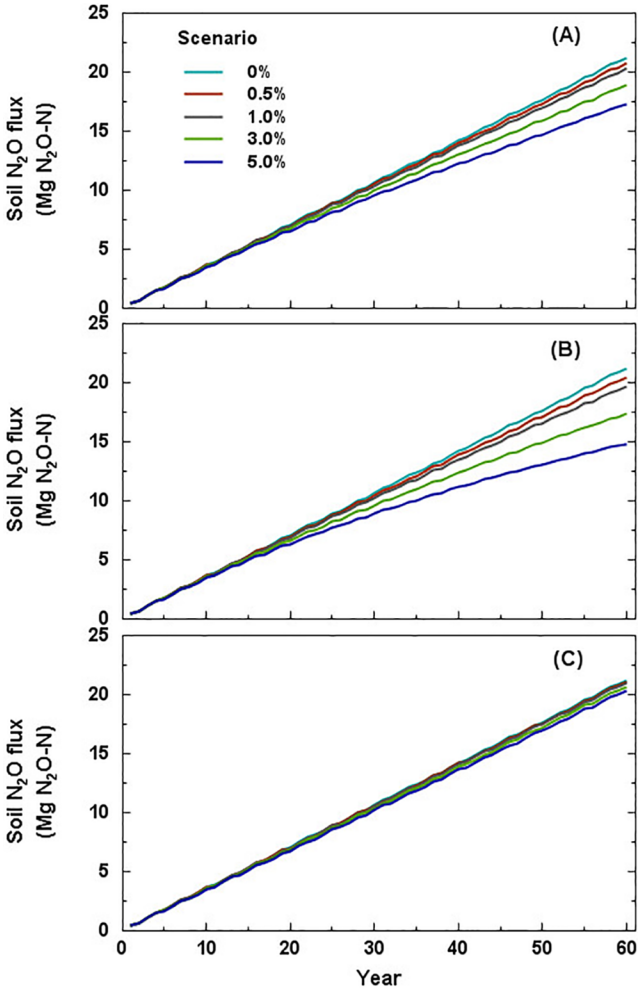


Fig. 4. Farm-scale total N_2O emissions in a model farm planted with (A) hybrid poplar, (B) white spruce, and (C) caragana during a 60 yr period. Each tree species was established at five planting densities on a model farm (688 ha, located in Saskatchewan, Canada). Simulations were generated with the Holos model.



destructive sampling of trees in the dark-brown soil zone of Saskatchewan (Kort and Turnock 1999) and those obtained using the 3PG model under Saskatchewan conditions (Amichev et al. 2016) (Fig. 1). Estimated C content in aboveground biomass for hybrid poplar in the Holos model was comparable with values derived from destructive sampling at an average tree age of 33 yr (i.e., 75.2 vs. 83.0 Mg C km^{-1} yr^{-1} for Holos and measured values, respectively) and to those derived with the 3PG model at a tree age of 60 yr (i.e., 254 vs. 295 Mg C km^{-1} yr^{-1} for Holos and 3PG values, respectively). For white spruce species, C in the aboveground biomass was greater than those derived from destructive tree sampling at an average tree age of 54 yr (i.e., 72.9 vs. 41.0 Mg C km^{-1} yr^{-1} for Holos and measured values, respectively) but was lower than those derived using the 3PG model at a tree age of 60 yr (i.e., 98.1 vs. 120.7 Mg C km^{-1} yr^{-1} for Holos and 3PG values, respectively). For caragana shelterbelts, Holos model estimates of C content in aboveground biomass were comparable with those derived from destructive tree sampling at an average tree age of 49 yr (i.e., 23.0 vs. 30.0 Mg C km^{-1} yr^{-1} for Holos and measured values, respectively) but were lower than C values derived using the 3PG model at 60 yr of tree age (i.e., 31.3 vs. 62.5 Mg C km^{-1} yr^{-1} for Holos and 3PG values, respectively).

In general, the growth equation used in the Holos model was capable of estimating C in aboveground tree biomass, and the estimated values were comparable with actual values derived through destructive tree sampling and earlier values derived using the 3PG model (Fig. 1). However, further work is still needed to improve the C accumulation equations for various tree species in the Holos model, such that they more accurately capture C content at different phases throughout the life cycle of a tree.

Fig. 5. Farm-scale total CH_4 oxidation in a model farm planted with (A) hybrid poplar, (B) white spruce, and (C) caragana during a 60 yr period. Each tree species was established at five planting densities on a model farm (688 ha, located in Saskatchewan, Canada). Simulations were generated with the Holos model.

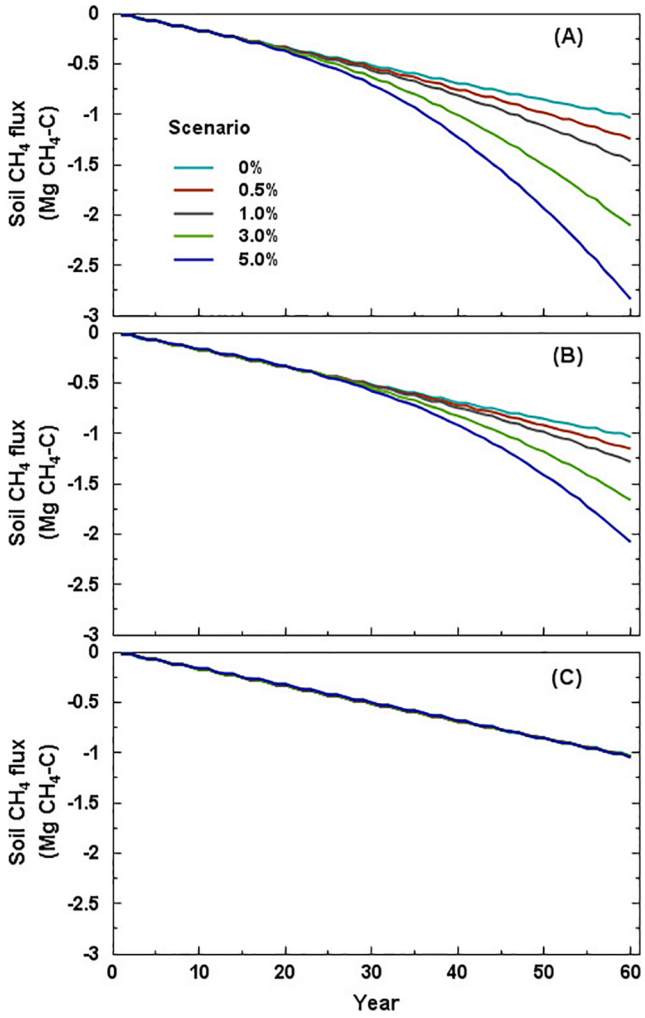
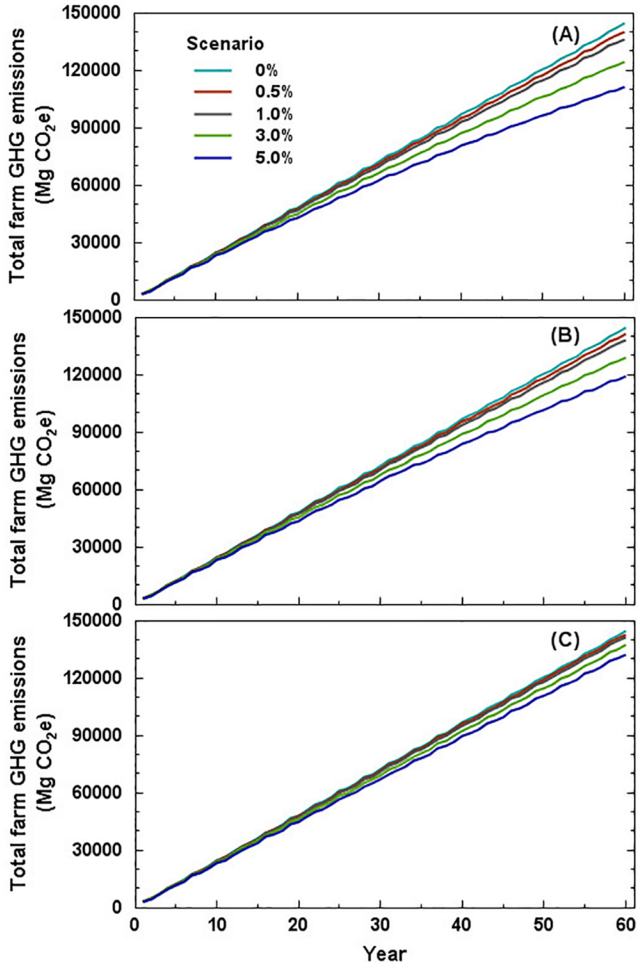


Fig. 6. Farm-scale total greenhouse gas (GHG) emissions in a model farm planted with (A) hybrid poplar, (B) white spruce, and (C) caragana during a 60 yr period. Each tree species was established at five planting densities on a model farm (688 ha, located in Saskatchewan, Canada). Simulations were generated with the Holos model.



The estimated annual gain in SOC in the cropped zone (i.e., the wheat–peas–oats rotation) of the present study (0.10–0.17 Mg C ha^{-1} yr^{-1}) was comparable with the C sequestration value of 0.16 Mg C ha^{-1} yr^{-1} estimated for a continuous wheat rotation in Southern Saskatchewan using the CENTURY model (Campbell et al. 2005) and was within the range obtained through field measurement (i.e., 0.09–0.29 Mg C ha^{-1} yr^{-1}) (Campbell et al. 2001). Likewise, in this study, annual SOC sequestration within the shelterbelt (0.23–0.68 Mg C ha^{-1} yr^{-1}) was within the range of SOC sequestration values reported for agroforestry practices in Canada (0.2–1.0 Mg C ha^{-1} yr^{-1}) (Janzen et al. 2001) and in the United States (0.23–1.15 Mg C ha^{-1} yr^{-1}) (Eagle et al. 2011). The greater annual SOC sequestration in the shelterbelt zone relative to the cropped zone was attributed to the role of trees in enhancing the quantity and quality of shoot and root litter C inputs and in modifying microclimatic conditions such as soil moisture and temperature regimes (Laganière et al. 2010). Correspondingly, the greater SOC sequestration in hybrid poplar shelterbelts was attributed to greater biomass production and consequently, more rapid C input to soil through litter fall and root turnover compared with the white spruce and caragana shelterbelts.

The estimation of annual C sequestration in the soil depends on several crop- and tree-specific values, as well as site-specific factors such as soil zone, tillage practices, fertilizer application rates, and weather regime. While the Holos model can factor indirect emissions related to agronomic practices and site-specific conditions, in this study, the NPP method used in estimating SOC sequestration did not consider the finite capacity of soils to store C. Soil organic C levels are assumed to stabilize at a new steady state after 20 yr of management (IPCC

2006); however, a longer period of 45 yr has been reported for agroforestry systems (Hernandez-Ramirez et al. 2011).

Methane and nitrous oxide fluxes

The greater annual CH_4 oxidation observed in the shelterbelt zone compared with the cropped zone reflects the greater root biomass of planted trees within the shelterbelt zone. Among the tree species compared, the greatest CH_4 oxidation was estimated for hybrid poplar shelterbelts, and this was related to the greater root biomass in hybrid poplar compared with white spruce and caragana shelterbelts (Table 2). Estimated annual CH_4 oxidation within the shelterbelt zone in the present study (−0.09 to −0.46 kg CH_4-C ha^{-1} yr^{-1}) was within the range of CH_4 oxidation (−0.14 to −0.99 kg CH_4-C ha^{-1} yr^{-1}) measured in shelterbelts within the dark-brown soil zone in Saskatchewan, Canada (Amadi et al. 2016) and that (−0.43 to −3.0 kg CH_4-C ha^{-1} yr^{-1}) measured in a 67 yr old pine forest in Eastern Canada (Peichl et al. 2010). Annual CH_4 oxidation within the cropped field in the present study (−0.088 to −0.117 kg CH_4-C ha^{-1} yr^{-1}) was comparable with a slight CH_4 sink (−0.019 kg CH_4-C ha^{-1} yr^{-1}) reported in Amadi et al. (2016). In a 3 yr study of GHG intensity in irrigated cropping systems in Northeastern Colorado, Mosier et al. (2006) reported a much wider range of CH_4 fluxes (0.392 to −0.151 kg CH_4-C ha^{-1} yr^{-1}) across various tillage, N fertilization and crop rotation regimes.

The greater annual N_2O emissions estimated in the cropped zone relative to the shelterbelt zone (Table 2) was reflective of the greater N inputs in the cropped field (i.e., 45 kg N ha^{-1} yr^{-1} plus N in the crop residue) relative to the shelterbelt zone in which N input was mainly a function of N concentration in leaf litter and root turnover. This result is in agreement with Amadi et al. (2016) who reported significantly greater N_2O emissions from cropped fields compared with shelterbelts within the Boreal and Prairie Ecozones of Saskatchewan. The greatest reduction in N_2O emissions was estimated for white spruce which is attributed to lower N concentrations in the needles (1.17%) compared with hybrid poplar (2%) and caragana leaves (3%). However, the greater annual N_2O estimated for caragana compared with white spruce was not unexpected as caragana trees are N-fixing — acquiring more than 80% of their N requirement through N-fixation (Moukoumi et al. 2012). This result is consistent with Amadi (2016) who reported significantly greater N_2O emissions in caragana shelterbelts compared with Scots pine shelterbelts, suggesting that trees with relatively low foliar N concentrations (such as conifers) may be more efficient in reducing soil N_2O emissions compared with tree species with comparatively greater foliar N concentrations.

Planting shelterbelts composed of pure stands of N-fixing trees (e.g., caragana) may be beneficial in terms of C sequestration; however, they may be significant sources of atmospheric N_2O emissions, which may constitute an even greater environmental hazard (Amadi et al. 2016). During shelterbelt establishment, it may be more effective to interplant N-fixing trees with non-N-fixing trees, as this would not only improve the N nutrition of the non-N-fixing trees but also decrease N_2O loses by reducing the amount of fixed N in the soil. Mixing tree plantings with N-fixing trees has been reported to increase biomass production, thus C sequestration, and result in greater retention of relatively stable SOC (Resh et al. 2002). However, more research is needed to elucidate the role of N-fixing tree species on GHG dynamics in tree-based systems. Clearly, the success of agroforestry systems in tackling issues of climate change will depend on adequate understanding of trade-offs between C sequestration and the emission of trace gases such as CH_4 and N_2O.

Total farm emissions

The Holos model was useful in estimating the impact of three shelterbelts species under five planting scenarios on GHG mitigation for a model farm for a 60 yr period. Our data indicate that despite the relatively small proportion of the farm occupied by shelterbelts, the mitigation potential of the shelterbelts (over a 60 yr timeframe) ranges from 11 896 to 33 226 Mg CO_2e depending on the species and planting density of the shelterbelts. The model simulations from Holos demonstrate the importance of tree species selection in maximizing the C sequestration and GHG mitigation potential from shelterbelt systems. The previous studies have attributed the mitigation of atmospheric GHG in agroforestry systems to the fixation of C in above- and belowground biomasses, increased C sequestration in the soil, enhanced CH_4 oxidation and reduced N_2O, and energy emissions due to the exclusion of N fertilization on areas occupied by trees (Evers et al. 2010). However, these studies did not report the relative contributions of these components to the overall GHG mitigation in agroforestry systems. Modelling simulations from this study indicate that 90%–95% of GHG mitigation by shelterbelts was through C sequestration in tree biomass and in stable SOC pools, while the reduction in N_2O emissions contributed 5.1%–9.6% of the total GHG mitigation by shelterbelts. Increased CH_4 oxidation contributed only 0.002%–0.12%, while a reduction in CO_2 emissions associated with reduced farm energy consumption contributed 1.5%–4.2% of the total GHG mitigation by shelterbelts.

The major appeal of shelterbelt systems as a GHG mitigation strategy is based on its ability to sequester large amounts of C on a relatively small land unit (i.e., ≤5%) while leaving the bulk of the land for agricultural production (Ruark et al. 2003). Based on our modelling data, the incorporation of trees on the farm — be it in the form of shelterbelts, riparian buffers, or other

agroforestry systems has potentials for reducing GHG emissions in the agricultural landscape. In addition, marginal agricultural lands or parcels that are not farmed due to land degradation could be targeted for tree plantings without jeopardizing food production. Older shelterbelts in the province should also be rehabilitated to maintain or enhance the mitigating potential of shelterbelts on agricultural landscapes.

Conclusion

The Holos model indicates that shelterbelts can capture a substantial amount of atmospheric CO_2 and store it in tree biomass and soil, reduce N_2O emissions, and improve soil CH_4 oxidation. Of the three species tested in the model, hybrid poplar was the most effective species for maximizing C sequestration and mitigating GHG, followed by white spruce and caragana. Additional research is needed to determine that tree species would be most effective at mitigating GHG with future changing climates. Moreover, the potential benefits of mixed species shelterbelts should be considered; e.g., combining white spruce and caragana. Nevertheless, the models show that shelterbelts are 2–4 times more effective than cropland in mitigating GHG emissions and could reduce total farm emissions by 8.2%–23% during a 60 yr period, depending on the tree species (and assuming that the trees occupy 5% of the total farm area). Thus, future policy should ensure that trees are planted in agricultural landscapes, and that existing established shelterbelts are maintained or rehabilitated to fully exploit their GHG mitigation capabilities.

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BC Farm Practices & Climate Change Adaptation

Shelterbelts

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project manager
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author & photographer
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Climate Action Initiative
BC AGRICULTURE & FOOD

Farm Practices & Climate Change Adaptation Series

This series of six reports evaluates selected farm practices for their potential to reduce risk or increase resilience in a changing climate.

The practices selected are well known in contemporary and conservation-based agriculture. While they are not new practices, better understanding of their potential relationship to climate change may expand or alter the roles these practices play in various farming systems.

Climate change will not only shift average temperatures across the province, it will alter precipitation and hydrology patterns and increase the frequency and intensity of extreme weather events. The projected changes and anticipated impacts for agricultural systems are considered in the practice evaluations. More details regarding climate change and impacts for various production systems in five BC regions may be found in the *BC Agriculture Risk & Opportunity Assessment* at: *www.bcagclimateaction.ca/adapt/risk-opportunity*

Farming systems are dynamic, complex, and specific to the local environments in which they operate. This makes the analysis of farm practices on a provincial level particularly challenging. The approach taken for this series, is to explore the application of practices regionally and across a range of cropping systems and farm-scales. While the ratings are subjective and may not reflect suitability for a particular farm, the ratings and associated discussion help to identify both the potential, and the limitations, of selected practices on a broader scale. In some cases, the numerical ratings are expressed as a range, to reflect variation in conditions across regions and cropping systems.

The practice evaluations are informed by background research and input from agriculture producers around the province about their current use of practices. Each document includes: a practice introduction, key findings, an evaluation of suitability to help to address climate change risks, and technical practice background related to adaptation. The documents conclude with practice application examples from various regions of the province. More detailed information about the overall project may be found at: *www.bcagclimateaction.ca/adapt/farm-practices*

Like farming systems, practice applications are location specific and change over time. Continued adaptation and holistic integrated practice implementation will be required as climate conditions change. The effectiveness of most practices for mitigating climate and weather related risks will vary over a range of conditions. Ultimately, if practice adoption can reduce vulnerability and risk overall, it has some effectiveness in supporting adaptation.

This document is not intended to serve as a stand-alone technical guide. Rather, it is hoped that this evaluation supports dialogue—among producers, agricultural organizations and key government agencies—about how these and other practices may apply in a changing climate, and how to address information or resource gaps to support further adoption and adaptation.

Contents

Introduction

Shelterbelts offer British Columbia's farmers and ranchers a way to directly moderate some of the impacts of climate change in their fields, orchards and pastures. Shelterbelts are created by planting adapted species of trees or shrubs, or in some cases, allowing natural plant communities to establish by protecting selected areas from grazing or cropping. Shelterbelts can also be created during land clearing and forestry operations by retaining treed areas.[1] These can be referred to as timberbelts if timber production is an objective for the producer. When actively managed, treed shelterbelts are integral parts of agroforestry and silvopasture systems, and can provide additional harvestable products.[2]

Shelterbelt applications and uses

- Crop protection
- Livestock shelter
- Energy conservation
- Wildlife habitat and bio-diversity retention
- Fence-line erosion control
- Water storage evaporation reduction
- Soil moisture retention

How Do Shelterbelts Work?

Shelterbelts, or windbreaks, modify the micro-climate mainly by changing wind speed and turbulence. They are most effective when planted or created in rows at right angles to the prevailing wind. They also modify air and ground temperatures, humidity and CO_2 concentration, mostly in the leeward zone.[3] They can affect how snow accumulates and melts, contribute to soil and water conservation, prevent erosion, and provide habitat for wildlife and beneficial insects.

Shelterbelts are a barrier to wind flow, deflecting it over the top and compressing it above. This causes an increase in wind velocity above shelterbelts, a decrease in wind velocity on the leeward side, and energy release and turbulence further out in the

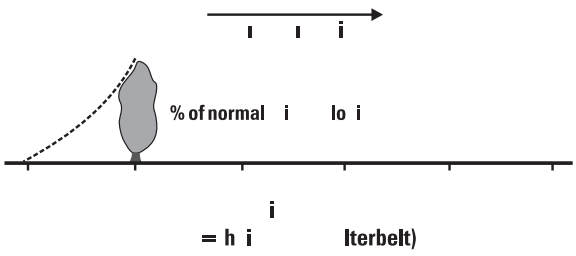


FIGURE 1 Approximate reduction of wind velocity by a single row shelterbelt

Source: Casement and Timmermans, 2007.[4]

field (Figure 1). The density and species selected for windbreaks can change these characteristics.[5] The type of species—whether tree, shrub, deciduous or coniferous—can dramatically impact how air flows through or over the shelterbelt, depending on the porosity that is created.

Shelterbelts can have positive effects on crop production by moderating plant water use, reducing physical damage, changing air and soil temperature, as well as impacting CO_2 levels and relative humidity. In some situations, a single row of trees can provide adequate shelter for crop production. The main disadvantages of the single row are the limitations that are imposed on the structural design of the shelterbelt, and the potential for interruption in the shelterbelt effectiveness with the loss of individual trees.

Current Adoption in BC

Just fewer than 20% of all farms in BC reported having natural or planted windbreaks or shelterbelts in the Statistics Canada, 2011 Census of Agriculture. However, the purpose of shelterbelts—whether for farmstead, crop or livestock protection—is not indicated in the census data, suggesting potential for further shelterbelt implementation across a broad range of applications (Figure 2).

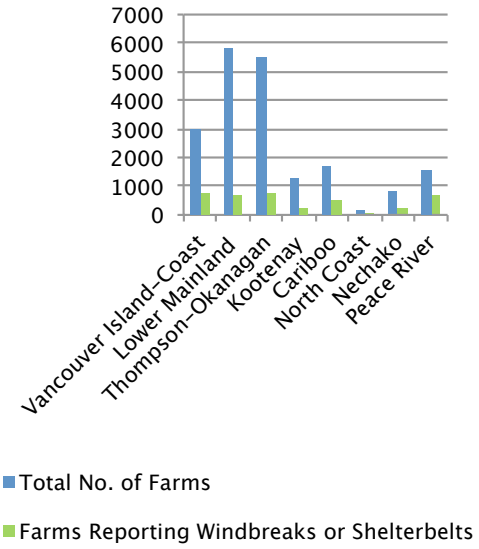


FIGURE 2 Total number of farms, and number of farms reporting windbreaks or shelterbelts, natural or planted, by region

Source: Statistics Canada, 2011 Census of Agriculture, Farm and Farm Operator Data, catalogue no. 95-640-XWE.

Key Findings

- With greater frequency of extreme weather events projected for the entire province, changes in wind frequency and intensity are likely to affect production in all regions. Properly designed shelterbelts have potential to reduce associated risks or vulnerabilities (particularly on farms where they are not already in use).
- The effectiveness and overall suitability of shelterbelts depends on the region, individual farm location and farming system.
- Shelterbelts have been shown to produce benefits for almost all crops, whether or not they are wind tolerant.
- There is a range of other conditions related to climate change that shelterbelts can help to moderate (e.g., extended dry periods, and extreme precipitation events).
- Retained shelterbelts in pastures could provide additional late season forage, and help to moderate losses in forage quality and quantity during drought periods.
- Continued management over the life of the shelterbelt is necessary to maintain shelterbelt effectiveness.
- There is likely potential for increased management of shelterbelts on farms where they are already in use.
- There is relatively low adoption of shelterbelts in Canada, which may be attributed to a number of factors including:
  - → A need for more demonstration and assessment of shelterbelt benefits on a regional and farming system basis; and
  - → A need for further development of shelterbelt design and management within various farming systems.
- Shelterbelts have potential to be highly adaptable when they are managed as part of agroforestry systems.
- The use of shelterbelts and planned retention areas is compatible with existing institutional and legal structures.
- Site specific planning and cost-benefit analysis are necessary to fully assess the suitability of shelterbelt establishment on farms and ranches.

Areas for Further Adaptation Research & Support

- Identification of regions, production systems and sites where there is potential for effective shelterbelt implementation.
- Research and demonstration that support development of shelterbelt establishment and management practices for different farming systems.
- Assessment of the costs and benefits of shelterbelt applications in different farming systems.
- Continuation of research on integrated land use management and agroforestry systems.
- Inclusion of wind measurements and wind related-parameters in climate information. Where possible, include wind parameter measurements in baseline and "new normal" weather descriptions, and on individual weather station reports.
- Identify the relative importance of wind in weather station estimates of evapotranspiration, and link to existing farm production models and calculators.

Evaluation: Adaptation & Shelterbelts

Multi-Criteria Evaluation

Agricultural research is typically undertaken to establish the efficacy of a product or practice under specific conditions. Similarly, cost-benefit analysis is valuable for assessing whether an investment is economically efficient (whether it pays to invest in a particular practice or asset). An evaluation of adaptation options for climate change needs to consider more than just effectiveness and economic efficiency to be useful for both farmers and those interested in supporting climate change adaptation. Multi-criteria evaluation provides a framework for this evaluation—enabling a set of decision-making criteria to be examined simultaneously.

Multi-criteria evaluation (MCE) can be highly structured, or, as it is applied here, more subjective and exploratory. To have value, the evaluation has to have the decision makers it aims to serve in mind. Often when MCE is employed, considerable time is spent gathering input on decision-making criteria and the needs of users. Given the limited scope of this project, it was not possible to gather user-specific input, and instead the criteria were developed by looking at other studies in the field of adaptation to climate change.[6] However, producers did provide input on the relative importance of the selected decision making criteria in a ranking exercise (27 of 29 participants). Perhaps not surprisingly, economic efficiency and effectiveness were the top ranked criteria followed by adoptability, adaptability, flexibility and independent benefits. Institutional compatibility was ranked last by the majority of farmers.

Often MCE is used to select the most desirable option from various alternatives. Ratings for each criterion are determined, and then added together to provide a total score for each alternative. The relative importance, or weight, given to a single criterion can affect the overall suitability rating for a practice. However, for this evaluation, it is the scores for individual criteria that provide insight into how a practice might be suitable for adapting to climate change, and what might need to change to make it even more suitable. The purpose of the evaluation is not to aggregate ratings and compare practices, but rather to improve understanding of how the individual practices relate to adaptation to climate change.

The evaluation takes a broad view (coarse-scale) across areas and farming systems in the regions (and production systems) where the practice might be applied or considered. The ratings were determined under the assumption that there is some basis for the application of a practice within certain farm types. For example, management-intensive grazing does not have application on a farm without livestock, and therefore it would be ineffective as an adaptive practice for that farm when compared to other alternatives.[7] If carried out at a fine-scale (individual farm level), the suitability rating of any practice could

be quite different because the specific circumstances of the farm would be considered for each criterion. Likewise, ratings could vary depending on the purpose (e.g., policy formulation vs. farmer adoption), and the perspective of the individual(s) carrying out the evaluation. Even though, a broad view is taken in the evaluation, the criteria in this series are considered from an on-farm perspective.

The evaluation below assesses a farm practice through the following set of decision-making criteria: *Effectiveness*, *Economic Efficiency*, *Flexibility*, *Adaptability*, *Institutional Compatibility*, *Adoptability* and *Independent Benefits*. Each of the criteria are defined and a numerical rating (in some cases a range) has been assigned across a scale from 1–5 to reflect its potential value in adapting to climate change. The discussion that accompanies the rating captures some of the issues contemplated in determining the rating, as well as some of the variation and complexity of practice application across the province and farm systems.

Effectiveness

Whether the adaptation option reduces the risk or vulnerability, and/or enhances opportunity to respond to the effects of climate change.

RATING: 4
moderately effective

Properly designed shelterbelts are likely to be moderately effective in reducing the risk or vulnerability to climate change on farms where they are not already in use. In addition, there is the potential for increased use or management of shelterbelts on farms where they are already in place.

Surface winds that affect agricultural production are a highly localized weather phenomenon dependent on topography, air temperature and pressure differences. The effectiveness of shelterbelts will vary by region and farm location within each region. With predicted increases in average temperatures and greater frequency of extreme weather events for the entire province, changes in wind frequency and intensity are likely to become an increasingly important factor affecting production in all regions.

Shelterbelts have been shown to produce benefits for almost all crops, whether or not they are wind tolerant. Improvements in crop production have been associated with shelterbelts where moisture is a yield limiting factor. Though total precipitation is predicted to increase across BC, summer precipitation and precipitation falling as snow are expected to decrease. With corresponding increases in temperature, growing season moisture deficits are expected to increase. Shelterbelts should help moderate these effects.

Yield differences between sheltered and unsheltered crops can be used to estimate the amount of water conservation for each type of crop. Yield differences reflect increased water application efficiency, increased infiltration and storage from snow or rainfall, reduced evaporation from the soil surface and the ability of plants to use the stored moisture more efficiently.[8] Planned and managed retention areas in pastures could provide additional late season forage, and help moderate losses in forage quality and quantity during drought periods.

Economic Efficiency

The economic benefits relative to the economic costs that are assumed in implementing the adaptation option.

RATING: 3–4
neutral to moderately efficient

The economic efficiency of shelterbelts for on-farm adaptation is highly variable depending on what is being sheltered (crop type, livestock, etc.), the shelterbelt design, and the discount rate used in the analysis. Additional farm benefits that may not be fully captured by estimating crop yields (e.g., reduced soil erosion, evaporation from water storage, and energy efficiency) should be considered along with any harvestable products from the shelterbelt. Similarly, both establishment and on-going maintenance should be included in the determination of cost estimates. Future benefits may be affected by climate change and accompanying uncertainty. An on-site risk assessment should be done to weight future management considerations, and establish appropriate risk factors for the analysis. Some of the factors in determining shelterbelt costs are outlined in more detail in Table 4 (page 12).

Shelterbelts also have social and environmental (public, downstream or external) benefits, and some governments have provided subsidies to help farmers establish shelterbelts.[9] On the Great Plains, studies have shown shelterbelts to be efficient investments without subsidy. Winter wheat yields averaged 15% higher under sheltered conditions in Nebraska, resulting in a 15 year payback period and a positive net present value for a shelter belt investment.[10] Another study that considered future climate scenarios, found that yield benefits increased as more stressful climate change scenarios were introduced.[11] In this study, unsubsidized shelterbelts were profitable with discount rates over 8%, but producers would have a long period of negative returns without government cost-sharing. In southwest Saskatchewan, tall wheatgrass barriers spaced at 15 metre intervals only marginally improved net returns over conventional open-field production, but reduced risks associated with continuous cropping by increasing yields and net returns in dry years.[12] The public benefits (such as reduced soil erosion, and carbon sequestration) of trees distributed from the Agriculture and Agri-Food Canada Shelterbelt Centre in the Canadian Prairie Provinces for the period 1981–2001, were estimated at $140 million (2001 CND$).[13]

Flexibility

The ability of an option to function under a wide range of climate change conditions. An option that reduces income loss under specific conditions, and has no effect under other conditions, would be considered inflexible.

RATING: 5
very flexible

Shelterbelts effectively change micro-climates and decouple the climates of sheltered areas from those that are unsheltered. Thus it is expected shelterbelts would be effective and function under a wide range of climate change conditions.[14] A crop modelling study in in eastern Nebraska found that sheltered maize production continued to perform better than unsheltered crops under a wide range of projected conditions. The scenarios considered included temperature increases of up to 5°, precipitation levels 70-130% of normal, and wind speed changes of plus or minus 30%.

Adaptability

Whether a practice can be built upon to suit future conditions and allows further adaptation.

RATING: 4–5
moderately adaptable to very adaptable

Shelterbelts have the potential to be very adaptable when they are managed as part of agroforestry, systems. In this type of system, production risks are distributed over a number of harvestable products, and management emphasis can also be shifted among products. Small-scale vegetative shelterbelts would be a very adaptable practice, as these can be installed and managed on a shorter-term basis. Treed shelterbelts planted for a specific crop may be less adaptable for a range of conditions. However, if they are well designed, they may be managed or modified to suit future production systems and conditions.

Institutional compatibility

Compatibility of the adaptation option with existing institutional and legal structures.

RATING: 5
very compatible

The use of shelterbelts and planned retention areas is compatible with existing government and legal structures. Until recently, shelterbelt establishment was supported by the federal Prairie Shelterbelt Program in the Peace River region, so there is a long history of this type of institutional support. The *BC Environmental Farm Plan Program* has supported and provided funding for the establishment of shelterbelts and buffers in all regions. Shelterbelt design recommendations may need to be modified to comply with various road rights-of-way or infrastructure specifications.

Adoptability

The ease with which farms can implement the practice under existing management practices, values and resource conditions.

RATING: 2
moderately low adoptability

Although there is long history of shelterbelt promotion in Canada for conservation purposes, there is still a relatively low level of adoption. There are likely several contributing factors including:[15]

- Poor shelterbelt design—including taking too much land out of production—and the resulting marginal benefits;
- The up-front capital and management investment required (with delayed benefits while shelterbelts are being established);
- Yield decreases in the competitive zone immediately near shelterbelts;
- Inadequate quantification of the benefits on a regional and farming system basis;
- A history of land clearing in BC (for both logging and agriculture) may have led to negative perceptions about the value of retaining or planting trees in cropland and pasture;
- Increases in equipment size, especially for grain farming operations, mean that shelterbelts interfere with operational efficiency, increasing fuel and labour costs;
- Limited active management of existing shelterbelts, and lack of fully integrated production (agroforestry), and demonstration;
- The substantial level of knowledge and planning capacity required for adoption; and
- Potential for shelterbelts to become sources of harmful pests, weeds or wildlife impacts.

Independent Benefits

The potential for a practice to produce benefits independent of climate change. For example, a practice that reduces income loss regardless of climate change effects, would be rated high.

RATING: 4–5
moderate to high independent benefits

The ability of shelterbelts to produce benefits independent of climate change is moderate to high. The economic efficiency of shelterbelts is variable, but benefits including reduced soil erosion loss, soil moisture retention, and increased crop quality and yield have been demonstrated under normal conditions.

TABLE 1 Shelterbelts evaluation summary

Evaluation Criteria	Rating	Meaning
Effectiveness	4	Moderately effective
Economic Efficiency	3–4	Neutral to moderately efficient
Flexibility	5	Very flexible
Adaptability	4–5	Moderately adaptable to very adaptable
Institutional Compatibility	5	Very compatible
Adoptability	2	Moderately low adoptability
Independent Benefits	4–5	Moderate to high independent benefits

Shelterbelts Background Information

Shelterbelt Benefits for Crop Production

When shelterbelts are suggested to land owners, the negative effects observed immediately adjacent to windbreaks and shelterbelts are generally thought of first. The overall effect of improved crop yields further into the field are not always appreciated.[16] Nearly all crops have been shown to benefit from protection by shelterbelts. The crop response may be caused by wind protection, resultant changes in the micro-climate or both. Though all crops may respond to shelter with yield increases, some crops are more tolerant to wind and wind-blown soil than others:

- **Tolerant crops**—cereals and forages
- **Moderate tolerance crops**—corn and sorghum
- **Low tolerance crops**—orchard and vineyard crops
- **Very low tolerance crops**—vegetable and specialty crops, and new alfalfa seedlings

Tolerant & Moderate Tolerance Crops

Since the early 20th century, research has demonstrated that field shelterbelts have positive benefits for crops growing within their shelter.[17] Table 2 provides a summary of research since 1932 from around the world, on the yield response of some wind tolerant crops in temperate climates. Unfortunately, the shelterbelts designs in these studies were not always adequately described. It is possible that with appropriately designed shelterbelts, greater yield increases might be demonstrated. Nonetheless, the response is quite strong across a variety of crops. Alfalfa showed a particularly positive response to shelter in this summary, but there were comparatively few field years of data for this crop.

Table 2 Relative responsiveness of various crops to shelter

Crop	Number of field years	Weighted mean yield increase (%)
Spring wheat	190	8
Winter wheat	131	23
Barley	30	25
Oats	48	6
Rye	39	19
Millet	18	44
Corn	209	12
Alfalfa	3	99
Hay (mixed grass and legumes)	14	20

Source: Kort, 1988[17].

Where substantial annual moisture falls as snow, and moisture is a yield limiting factor, snow trapping and retention by shelterbelts has been shown to increase crop yields (Table 3). In addition, snow provides an insulating layer to prevent winterkill of sensitive crops like winter wheat and forage legumes. Treed shelterbelts designed for snow control may need thinning or pruning to create shallow and wide snowdrifts. Deep snow drifts can delay spring fieldwork in annual cropping systems (Figure 3).

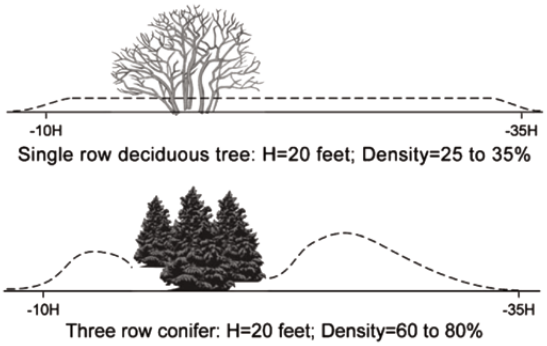


FIGURE 3 Effect of shelterbelt density on snow accumulation

Source: Brandle et al. 2004.[14]

TABLE 3 The effect of persistent snow on crop yields[18]

Winter precipitation	Number of field-years	Weighted mean yield increase (%)
Snow	377	20.8
No snow	313	12.5

Low Tolerance & Very Low Tolerance Crops

Numerous benefits are associated with the creation of tall windbreaks to protect orchard and vineyard crops:[19]

- Improvements in pollination and fruit set, resulting in higher yields;
- Less mechanical damage from whipping of leaves, branches, buds and flowers, and bruising of fruit;
- Less root breakage and tree deformation;
- Less transpiration, and greater irrigation efficiency;
- Efficient use of pesticides due to better water distribution and reduced evaporation; and
- Reduced spray drift to non-target species.

Vegetable crops are highly vulnerable to wind and wind abrasion. Improved crop quality and yield increases are the major benefit of shelterbelt protection systems. Most benefits occur within a zone that is 10 x the shelter height on the leeward side, or within 0–3 x the shelter height of the wind break on the windward side.[20] Windbreaks do not have to be tall to be effective, if they are placed in a sequence to create protected zones. Vegetation strips of lupine, oats and fall rye, were shown to be highly effective in melon production in the southeast U.S.

Shelterbelt Benefits for Livestock Production

Forage production in fields and pastures can be improved with the use of shelterbelts, but shelterbelts can also benefit livestock directly. Shelterbelts moderate temperatures and this directly affects animal performance:

- In winter, shelterbelts reduce wind-chill and the amount of nutritional energy animals need for body maintenance, thus reducing feed costs.
- In summer shelterbelts and buffers provide shade for animals, which reduces stress and improves animal performance.
- The temperature of confined livestock facilities can be affected in much the same way with the use of planned shelterbelts, reducing energy costs for building heating and cooling.
- As well as providing shelter, managed retention areas in developed pasture—especially aspen types—can be used to moderate seasonal declines in forage quality.

Shelterbelts Costs

The cost of shelterbelt establishment depends on the objectives, type, application and plant species (or structures) involved. Costs can generally be divided into three categories: 1) planning and site preparation; 2) planting and/or establishment; and 3) on-going maintenance. However, the primary cost consideration, especially for field shelterbelts, is the amount of land taken out of production. In integrated and planned agroforestry situations, shelterbelts can provide revenue from wood, wood fibre or other products. The retention of existing trees, or other native vegetation, will reduce establishment costs in some situations.

Farm specific planning and a cost-benefit analysis are necessary to fully assess the suitability of shelterbelt establishment. Some of the areas of potential cost are outlined for two shelterbelt applications in Table 4. The first scenario outlines on-farm costs that might be associated with establishing a planted shelterbelt. The second scenario identifies potential costs for planned retention areas in a pasture development situation.

Some Considerations for Shelterbelt Planning

Shelterbelts need to be properly designed and integrated into the farming system to be effective, and there are a number of considerations for planning.

- Vegetative shelterbelts can be competitive and use up available resources needed for crop plant growth. Treed shelterbelts may need to be crown or root pruned to maintain effectiveness, or minimize competitive effects.
- Plant species need to be adapted to soil and site conditions and carefully selected to obtain the desired protection, while minimizing the use of resources like irrigation water. Some species may produce alleopathic effects on crops.[21]

TABLE 4 Potential cost considerations for two shelterbelt applications

Costs	Planted field tree-shrub shelterbelt	Planned retention areas in improved pasture development
Planning and site preparation	▪ Planning, time and/or specialist services ▪ Land taken out of production for shelterbelt ▪ Opportunity cost based on crops grown, expected prices, delay in benefits ▪ Site preparation including: cultivation, weed control, mulching, cover crop	▪ Planning time and/or specialist services ▪ Land taken out of improved forage production for shelterbelt ▪ Opportunity cost based on expected forage yield differences in open vs. timbered areas ▪ Reduced equipment and site development costs
Planting and establishment	▪ Planting costs, i.e., shrub and tree costs by species, seedling size, planting method—mechanical vs. hand planting, number of rows* ▪ Understory seed costs, i.e., grass seed mix ▪ Irrigation and weed control ▪ Fencing or cages for protection from wildlife and livestock	▪ Fencing costs for grazing management
Maintenance	▪ Top-pruning, root pruning ▪ Irrigation (some situations) ▪ Fence maintenance (some situations)	▪ Fence maintenance

* *Total plant cost will vary with species and planting density. The following example is provided to give a rough measure for estimating plant material costs. Species with a recommended planting density of 3 metres, at $2.50/seedling would cost $837.50/km/row.*

- Yield responses can be highly variable, and are sensitive to shelterbelt design, location and the kind and variety of crop grown. Conditions vary widely across the province.
- Primary objectives should be considered in the design for example, a more porous design for good snow distribution may conflict with a design for maximum wind protection of sensitive crops.
- Shelterbelts may attract wildlife that can damage crops.
- Shelterbelts may increase fencing requirements in some situations.
- Shelterbelts may make certain equipment operations more difficult, and restrict the scale of equipment that can be used in some cropping situations.

Characteristics to consider in planning effective shelterbelts

- Height and density
- Orientation
- Length and width
- Continuity/uniformity, cross-sectional shape or structure
- Tree or shrub species
- Maintenance
- Harvestable products
- Grazing management if applicable

Shelterbelt Examples

Field Vegetable Shelterbelt *(Thompson-Okanagan region)*

Originally established in 1997, the value of this poplar and pine windbreak shelterbelt for improving the quality and production of field peppers has been recognized on this farm in the Thompson-Okanagan region. Peppers are vulnerable to wind in the spring immediately after planting, and spring winds are common at this site:

> *"We love windbreaks… because we can block ourselves from wind we can get two weeks extra on a crop. Think about what that means economically…*

Management of the windbreak has changed over time to suit the conditions, minimize water use and meet the needs of the sheltered crops. Some disease issues indicated there was not enough air movement later in the season:

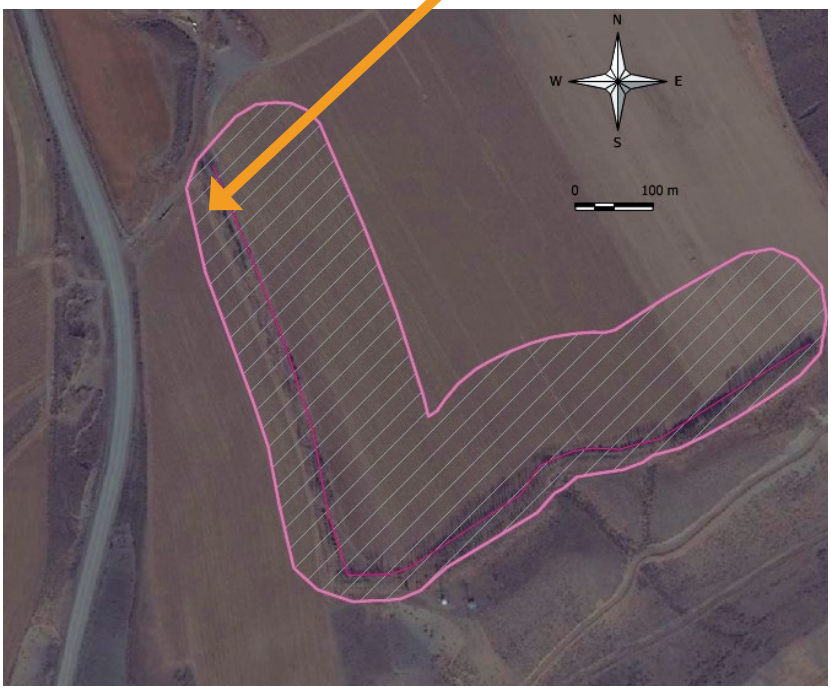
> *"Where there was no air movement we had more Phytophthora and Pythium problems on the peppers. So we don't have the wind, but without the wind we have those problems. Later in the year we didn't have the air movement in there. So [we] went along, and took all the branches off the bottom 12 feet [and] we let a certain amount of air come in.*

The shelterbelt also uses some of the irrigation licence and the water is turned off in the mid to late summer, allowing the trees go dormant to minimize water use. With benefits clearly identified, this producer is establishing more windbreaks, looking at species that require less water, and experimenting with mechanical shading systems.

Highlights

- → Extended growing season for wind intolerant crop
- → Increased production
- → Shelterbelt management for crop disease control and water conservation

Shelterbelt at the north end, with peppers in the foreground.



The planted shelterbelt from above, and an estimate of the quiet area created by protection from winds from the west and south (area estimate = 10 x height on the leeward side, and 3 x height on the windward side; windbreak is the dark pink line and the quiet area is in light pink). The shelterbelt is approximately 15 metres high, and is about 1.2 km in length.

Integrated Pasture & Shelterbelts *(Cariboo region)*

The value of shelterbelts in rangeland and pasture contexts is not always appreciated, especially in areas with substantial annual precipitation, like the east-central Cariboo region. This forage-based organic livestock producer knows that annual growing season moisture is a limiting factor, and that natural shelterbelts and forested buffers retained in earlier land clearing operations are highly beneficial.

> *"You get more snow [referring to snow capture] and you have more snow on the shady side [of the shelterbelt] and I have pictures where you can see the shelterbelt and the really green grass for a distance and it tapers out and [then] it's brown… because this all here [forage production] is dependent on the moisture we get.*

Windrows, which contained dead woody debris and have regrown, would have ordinarily been re-piled and burned in conventional land clearing practice. Management of these retained shelterbelts is fully integrated with management intensive grazing, pasture rejuvenation and forage harvest rotation (alternate haying, grazing and rejuvenation). Grazing in the shelterbelts themselves is timed to be beneficial for wildlife, and some work has been done to create openings and laneways to improve the efficiency of machinery operations. Some aspen harvest is integrated in this system. Other benefits in this holistically managed operation are also recognized.

> *"I learned about the research they are doing with the mycorrhizae and that grass depends on mycorrhizae from trees and the tree mycorrhiza depends on mycorrhiza from grass, and the ideal distance is maximum 150 metres from shelterbelt to shelterbelt and that's what I have here. I wish I had some money to plant some shelterbelts again. Even this [referring to open area] is a more wind protected site, but this here [referring to another site] is on top of the hill, and also here it's really windy so that it's really important have [shelterbelts].*

Highlights

- → Natural and retained shelterbelts
- → Shelterbelt management
- → Moisture conservation
- → Increased forage production
- → Improved fertility
- → Integrated agroforestry with aspen harvest
- → Wildlife benefits

The arrangement of shelterbelts forested buffers, and timberbelts on a forage-based organic livestock operation in the east-central Cariboo.

Cattle grazing in the pasture in the very southeast corner of the aerial photo, with a forested buffer in the background.

Mixed-Farm Shelterbelts *(Peace River region)*

In traditional land clearing practice in the Peace River region, trees were knocked down, piled in windrows, and then burned, re-piled and burned again. The land between windrows was cultivated, and often these windrows were left to be dealt with later. This allowed crop production to begin without additional expense. In some areas, these brush piles were left intentionally and have revegetated to form natural shelterbelts. These shelterbelts have been retained on this mixed grain, oilseed and beef cattle farm just north of the Peace River.

> *We don't want to take out any of our bush strips either. We leave them on purpose. Instead of farming a quarter section in one field, it's chopped into 3 or 4 pieces.*
>
> *Well for hay, pasture and cattle… cattle need shelter. So you tend to leave bush pieces, partially for erosion control, partially for cattle shelter, partially to hold snow for grazing [and] for hayland.*

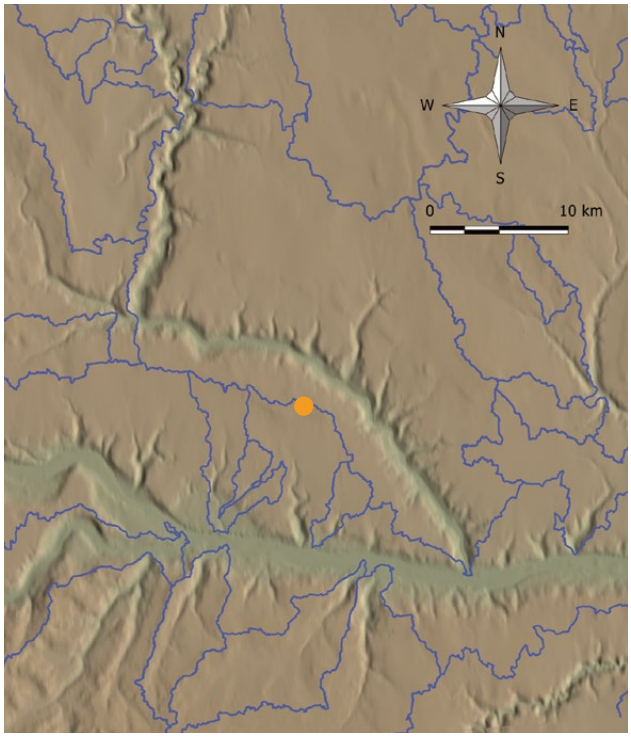
Orientation to the prevailing wind is a major factor for shelterbelt effectiveness. The prevailing winds in this area are from the northwest, with harder storms coming from the southwest. The variations in shelterbelt direction produce different micro-climate effects.

> *It's a pain. If you are trying to use the land north of the bush you lose the first 30-40 feet the hay doesn't dry out.*
>
> *On a dry year it holds moisture.*

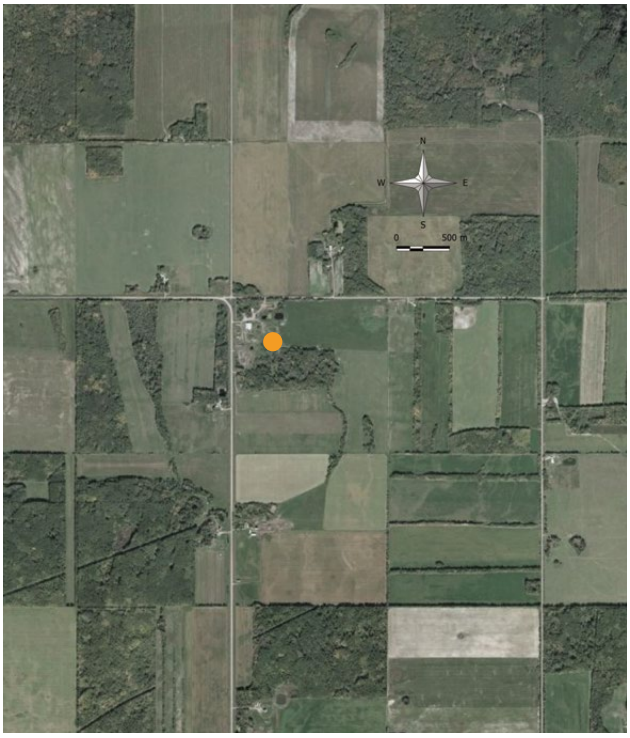
The value for erosion control can also vary, depending on the direction of the slope and the natural drainage patterns. Narrow fields oriented in the direction of the slope may tend to work against contour farming practices, because it is less efficient for large-scale equipment to work and turn over short distances. In turn, the gridded land survey and property boundaries have influenced the land clearing practice, as property lines were usually followed. In this location, which slopes to the south-southwest, these natural shelterbelts are beneficial, but with mixed effects for erosion control, depending on their orientation in relation to the slope.

Highlights

- → Natural retained shelterbelts
- → Moisture conservation
- → Erosion control
- → Livestock protection
- → Mixed farm enterprise allows integration



Hill-shaded map (above) shows the relief and sub watersheds around this mixed farm. The farm is located at the top of the watershed (orange point) with lands sloping to the southwest and toward the Peace River.



The orientation of shelterbelts around this farm (orange point marks the same location from the map above).

Endnotes

1 Physical structures like slat fences can also be used to create positive mico-climatic effects to shelter and shade crops. Shelterbelts may also be called windbreaks, timberbelts or buffers, depending on how they function and how their purpose is viewed within the production system.

2 Lisa Zabek and Dave Trotter, *Agroforestry Factsheet - Windbreaks/shelterbelts, timberbelts, buffers* (BC Ministry of Agriculture, 2010), *http://www.agf.gov.bc.ca/resmgmt/publist/0-100Series/100100-3_Shelterbelts.pdf*

3 K. G. McNaughton, "Effects of windbreaks on turbulent transport and microclimate," *Agriculture, Ecosystems & Environment* 22 (1988): 17–39.

4 Brendan Casement and John Timmermans, *Field Shelterbelts for Soil Conservation Agri-facts* (Alberta Agriculture and Food, 2007), *http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/agdex2073/$file/277_20-3.pdf?OpenElement*

5 G. M. Heisler and D. R. Dewalle, "Effects of windbreak structure on wind flow," *Agriculture, ecosystems & environment* 22 (1988): 41–69.

6 A.H. Dolan et al., *Adaptation to Climate Change in Agriculture: Evaluation of Options* (University of Guelph, Department of Geography, 2001), *http://www.uoguelph.ca/gecg/images/userimages/Dolan%20et%20al.%20(2001).pdf*

7 Enterprise diversification, may in fact be suitable adaptive strategy to minimize the effects of climate change, however it is not among the practices evaluated in this series.

8 Gylan L. Dickey, "Crop water use and water conservation benefits from windbreaks," *Agriculture, Ecosystems & Environment* 22–23, no. 0 (August 1988): 381–392.

9 In Canada, shelterbelt establishment has been supported by the federal PFRA Prairie Shelterbelt Program, the Canada – Provincial Environmental Farm Plan and Greencover programs, and provincial programs in Quebec and Ontario.

10 J. R. Brandle, B. B. Johnson, and D. D. Dearmont, "Windbreak economics: The case of winter wheat production in eastern Nebraska," *Journal of soil and water conservation* 39, no. 5 (1984): 339–343.

11 M. L. Marsh, "The value of shelterbelts to agricultural production in the northern Great Plains: An economic assessment in a changing climate" (1999), *http://digitalcommons.unl.edu/dissertations/AAI9947124/*

12 B. G. McConkey, R. P. Zentner, and W. Nicholaichuk, "Perennial grass windbreaks for continuous wheat production on the Canadian prairies," *Journal of Soil and Water Conservation* 45, no. 4 (July 1, 1990): 482–485.

13 Surendra Kulshreshtha and John Kort, "External economic benefits and social goods from prairie shelterbelts," *Agroforestry Systems* 75, no. 1 (2009): 39–47.

14 J. R. Brandle, L. Hodges, and X. H. Zhou, "Windbreaks in North American agricultural systems," *Agroforestry systems* 61, no. 1 (2004): 65–78. *http://digitalcommons.unl.edu/agronomyfacpub/389/*

15 J.W. Sturrock, "Shelter: Its management and promotion," *Agriculture, Ecosystems & Environment* 22–23, (August 1988): 1–13.

16 University of Missouri--Columbia Center for Agroforestry, *Training Manual for Applied Agroforestry Practices* (University of Missouri Center for Agroforestry, 2006), *http://www.centerforagroforestry.org/pubs/training/*

17 J. Kort, "Benefits of windbreaks to field and forage crops," *Agriculture, Ecosystems & Environment* 23 (1988): 165–190.

18 Ibid.

19 Richard L. Norton, "Windbreaks: Benefits to orchard and vineyard crops," *Agriculture, Ecosystems & Environment* 22–23, (August 1988): 205–213.

20 Charles S. Baldwin, "The influence of field windbreaks on vegetable and specialty crops," *Agriculture, Ecosystems & Environment* 22–23, (August 1988): 191–203.

21 Allelopathy, refers to the biochemical inhibition of growth, survival or reproduction of one species by another.

EXTENSION NOTES

Ontario

DESIGNING AND CARING FOR WINDBREAKS

Windbreaks perform a variety of jobs. They reduce soil erosion, increase crop yield and protect livestock. They shield buildings and help reduce heating costs. They can also add beauty to landscapes and provide habitat for wildlife. Getting the results you want from a windbreak can depend on factors as obvious as its location and size, or as subtle as the kind of trees you use and the spacing between them. One of the most important factors when designing a windbreak is knowing exactly what you want your windbreak to achieve.

This Extension Note provides information about designing and caring for windbreaks that perform different functions.

DESIGN FACTORS

Before you begin to design your windbreak, you should consider the following factors that determine how a windbreak works.

DENSITY

Density is the most important characteristic of a windbreak. It determines how much a windbreak slows the speed of the wind and the size of the area it shelters.

While density is defined as the amount of space in a windbreak through which air can travel, it is easily judged by the amount of light that can be seen through the leaves, twigs and branches along a windbreak's face. If light appears to be spread evenly throughout half of the face, the density is medium. If light can be seen through more or less than half of the face, its density is low or high.

A windbreak with medium density will protect the largest area of land. By reducing wind speed over the greatest distance, it can improve crop yield and quality, reduce soil erosion and provide shelter for buildings and greenhouses.

A high-density windbreak, where light can be seen through about 20 per cent of the face, acts more like a wall. Used in the wrong place it can create wind turbulence which can damage crops and erode soil. High density windbreaks should be used primarily to protect livestock from heat and cold, as well as to prevent snow from drifting on driveways or yards.

A low-density windbreak, where light can be seen through about 70 per cent of the face, is often used to spread snow evenly over crops and fields, thereby protecting crops, reducing soil erosion and improving the moisture content of the soil as the snow melts.

The density of a windbreak is determined, for the most part, by the species of trees.

WINDBREAK DENSITY BY SPECIES

SPECIES	DENSITY	
	SUMMER	WINTER
Norway Spruce	Medium	Medium
White Spruce	Medium	Medium
Blue Spruce	Medium to High	Medium to High
Austrian Pine	Low to Medium	Low to Medium
Scots Pine	Low to Medium	Low to Medium
Red Pine	Low to Medium	Low to Medium
White Cedar	Very High	Very High
Black Locust	Low to Medium	Very Low
Poplar*	Medium	Very Low
Silver Maple*	Medium	Low
Green Ash*	Medium	Low
Shrubs	Medium to High	Low to Medium

* hardwood shrubs, which are naturally pruned, should be planted at the base to fill in the bottom area.

HEIGHT

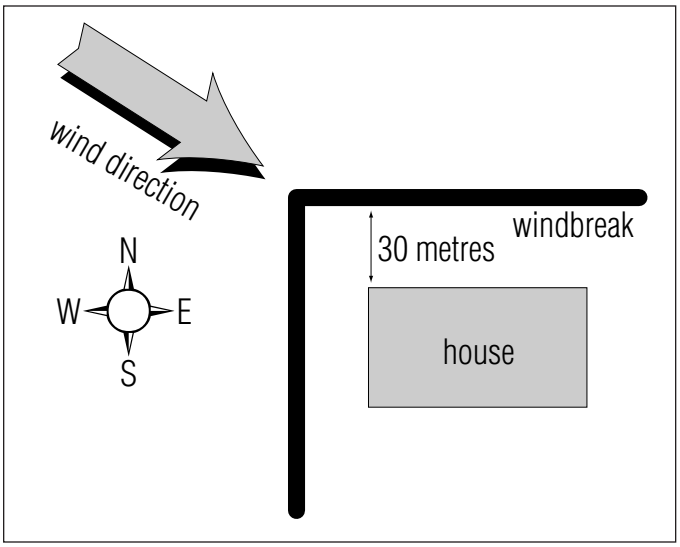
The height of a windbreak is governed by the species used, the growing conditions and the age of the trees. It influences the distance over which wind speeds are reduced. For example, a windbreak of medium density will reduce the wind speed by at least 20 per cent for a distance of 15 to 20 times the height of the windbreak. That means when a 50-kilometre-per-hour wind hits a 10-metre-high, medium-density windbreak, wind speed is reduced by at least 10 kilometres an hour for a distance of up to 200 metres. Although it may not sound like much, a wind speed reduction of this kind is enough to significantly decrease soil erosion and improve crop yield and quality. The area of greatest protection is found at a distance from the windbreak of eight to 10 times the height of the windbreak.

WIDTH

The width of a windbreak affects its density. As a general rule, the more rows of trees you plant, the higher the density of your windbreak. For most applications, a windbreak made from a single row of trees is sufficient and the required density can be achieved by selecting the correct tree species. In fact, for most species of conifers, more than a single row results in a very dense windbreak, which may not be appropriate for the objective you have in mind.

LENGTH

Because winds tend to bend in around the ends of a barrier, a windbreak should extend as far as possible beyond the area it is intended to shelter.



Farmstead windbreaks provide the most protection when they are planted on the north and west sides and 20 to 30 metres from a building.

SPACING

To ensure that the trees in your windbreak develop and keep a full crown and remain healthy for a long time, they must be allowed to grow with as little competition from other plants as possible. The best way to achieve this is to plant the trees close together and to remove some of the trees as they mature. As a rule of thumb, plant trees about one metre apart along a row. This ensures that you have enough trees to allow for some natural mortality.

TREE SPECIES

Each tree and shrub species has its own characteristic height, density, width, growth rate and life expectancy. The species you choose, therefore, is an important factor in designing a windbreak to perform a particular function. When choosing a species, you will need to consider local soil and climatic conditions. Evergreens are the most common kind of tree used in windbreaks in Ontario, but deciduous trees are popular in other parts of the world.

SUITABILITY OF TREE SPECIES TO ONTARIO SOIL TYPES

SURFACE TEXTURE	NATURAL DRAINAGE GOOD	FAIR (IMPERFECT)	POOR
Coarse (Sandy)	Austrian Pine Norway Spruce Red Pine White Spruce Black Locust White Cedar Windbreak Poplar	Norway Spruce Red Pine Austrian Pine White Cedar Windbreak Poplar Silver Maple Black Locust	Norway Spruce Silver Maple Green Ash White Cedar White Spruce
Medium (Coarse Loamy)	Norway Spruce Austrian Pine Red Pine White Cedar White Spruce Windbreak Poplar Black Locust	Norway Spruce Austrian Pine Red Pine White Cedar Windbreak Poplar Green Ash Silver Maple Black Locust	Silver Maple Green Ash Norway Spruce White Cedar White Spruce
Fine (Fine Loamy)	Norway Spruce White Spruce White Cedar Windbreak Poplar Green Ash Black Locust	Norway Spruce Silver Maple White Spruce Green Ash White Cedar Black Locust Windbreak Poplar	Silver Maple Green Ash Norway Spruce White Spruce
Very Fine (Clayey)	Norway Spruce White Spruce Green Ash Black Locust White Cedar	Green Ash Silver Maple Norway Spruce White Spruce Windbreak Poplar	Silver Maple Green Ash White Spruce

Note: for each texture-drainage combination, the most suitable species is listed first. The next most suitable is second and so on. White pine is not recommended for a single or two-row field windbreak but may be used in multiple-row windbreaks around farmsteads.

Source: Best Management Practices Farm Forestry and Habitat Management

DESIGNING WINDBREAKS TO WORK FOR YOU

There are three main kinds of windbreaks, farmstead windbreaks that protect buildings, field windbreaks that protect crops and soils and living snow fences that protect roads by trapping drifting snow.


farmstead windbreak

FARMSTEAD WINDBREAKS

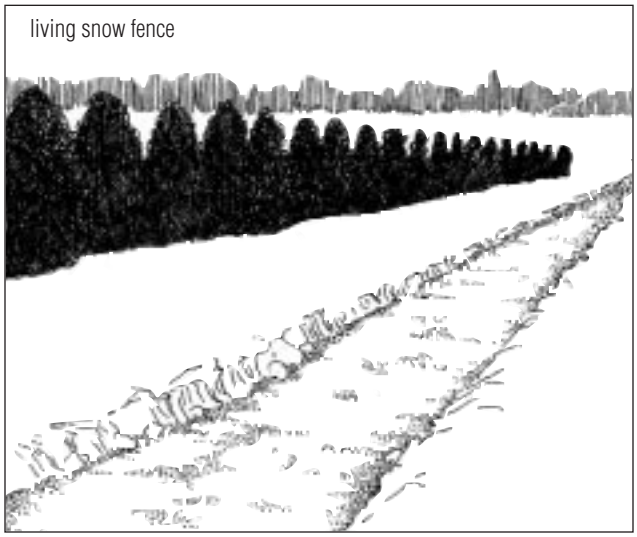
Farmstead windbreaks protect homes, barns and greenhouses from wind, resulting in reduced heating costs and more comfortable living environments. The most effective farmstead windbreaks are of medium density. They protect buildings and their surrounding areas, while allowing some air to filter through to prevent the build-up of cold air in the spring and fall and to provide some air circulation in the summer. A single row of white spruce or Norway spruce has the ideal density for this purpose. To be most effective, the windbreak should be planted on the north and west sides of a house or barn, at a distance of about 30 metres from the building it is intended to protect.


field windbreak

FIELD WINDBREAKS

Medium density windbreaks are most effective for controlling erosion and protecting crops. As with farmstead windbreaks, a single row of spruce or pine planted at least on the north and west sides of the field is best. Planting on all sides gives even greater protection.

If, on the other hand, you want to ensure that snow is distributed evenly over your fields, a single row of hardwoods is best. This type of windbreak also gives you good protection during the summer when the leaves are present. Silver maple, green ash and some poplars are among the hardwood species that should be considered. Remember that you should plant a row of shrubs along with the hardwood trees to fill in the gaps that will occur as the trees get bigger and lose their bottom branches. Highbush cranberry, nannyberry, ninebark or alternate-leaved dogwood are good shrub species to consider. These should be planted in a row parallel to the windbreak at a distance of about three metres from the windbreak on the upwind side.


living snow fence

LIVING SNOW FENCES

High density windbreaks are the best choices for trapping snow before it drifts onto lane ways or farmyards. A single row of white cedar or two rows of spruces (with three metres between the rows) makes a good snow fence. Most of the snow piles up within 10 to 15 metres of such a windbreak. Therefore, the trees should be planted about 20 metres from the nearest building, roadway or farmyard.

PLANTING AND CARING FOR WINDBREAKS

PLANTING

A windbreak is an important long-term investment. Careful site preparation the year before planting, the use of good planting stock and care in planting will ensure that you have an effective windbreak for a long time. For specific instructions on site preparation, the care of planting stock, planting techniques and weed control, please consult other Extension Notes in this series.

THINNING

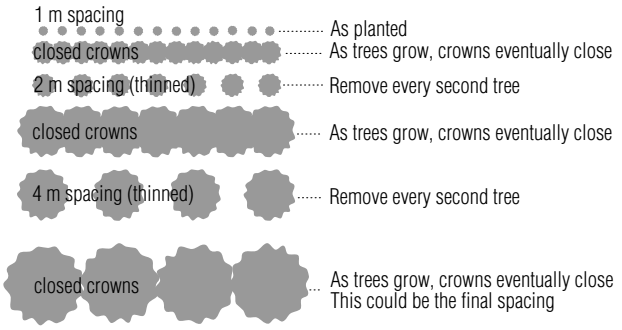
Thinning a windbreak is an essential part of its maintenance. After a number of years, the crowns of the trees will begin to touch. By removing every second tree, you'll be able to prevent the branches on the remaining trees from dying. After a number of years the crowns will again begin to touch. As before, remove every second tree, taking into consideration the trees lost through natural mortality and avoiding the creation of excessively large gaps. The key is to thin a windbreak before the lower branches on adjacent trees begin to die.

PLANTING AND REPLACEMENT

A field windbreak has to be continuous. If there are gaps in it, weather damage to crops and soil will increase in the areas behind the gaps. Replant the gaps left by dead trees as soon as possible.

Even the healthiest windbreak will not last forever. Make plans to replace your windbreak well in advance of its decline.

For more information on designing, planting and caring for a windbreak, contact a representative of your local conservation authority, Ontario Ministry of Agriculture, Food and Rural Affairs or Ministry of Natural Resources.



THINNING A WINDBREAK

Begin by planting trees one metre apart. Remove every other tree when the trees have grown to the point that the crowns are touching. Thin the trees once more after several years when the crowns begin to tough again.

The high density of white cedar makes this species ideal as a living snow fence that traps snow in a deep narrow drift close to the windbreak.

NATIVE SHRUBS FOR WILDLIFE FOOD

NAME	SOILS/MOISTURE	GROWTH FORM	WILDLIFE USE
Highbush Cranberry	Fertile soil/well-drained	Tall shrub, two to four metres wet to moist sites (not dry)	Song/game birds use this, although mainly as winter nourishment
Red-osier Dogwood	Fertile soils/moist to wet sites	Small shrub, less than two metres, forms thickets	Song birds eat berries; rabbits, hare and deer browse twigs; cover for game birds
Alternate-leaved Dogwood	Most soils/moist best, tolerates dry	Shrub or small tree	Song/game birds, eat berries
Nannyberry	Moderately fertile/average to wet sites	Tall shrub, seven to ten metres	Many birds eat berries; rabbit and deer browse twigs; nesting
Elderberry	Well drained loam or sandy soil/well-drained to moist sites	Shrub, one to five metres	Song/game birds, red squirrels, chipmunks and mice eat berries; deer and rabbits browse
Staghorn Sumac	Can grow in very poor soil/well-drained to dry sites	Groups of shrubs, two to five metres	Song birds eat fruit; winter food for deer and rabbits
Serviceberry	Sandy loam/dry-average	Small tree, seven to thirteen metres	Many birds and mammals eat berries; deer browse twigs
Ninebark	Rich, well-drained/flood plain	Shrub, two to three metres	Many birds eat seeds
Wild Apple	Well-drained loam/clay loam/moist	Low spreading tree, eight metres	Deer, rabbits and grouse eat fruit; good for nesting
American Hazelnut	Most soils/well-drained	To three metres	Song/game birds and mammals eat nuts

Source: Best Management Practices Farm Forestry and Habitat Management

Produced by the LandOwner Resource Centre and the University of Toronto's Faculty of Forestry

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EXTENSION NOTES

Ontario

THE BENEFITS OF WINDBREAKS

Windbreaks are rows of trees or shrubs that reduce the force of the wind. They can reduce soil erosion, increase crop yields and protect livestock from heat and cold. Windbreaks can shield buildings and roads from drifting snow. They beautify the landscape and provide travel routes and habitat for wildlife. Windbreaks can also be sources of wood and food.

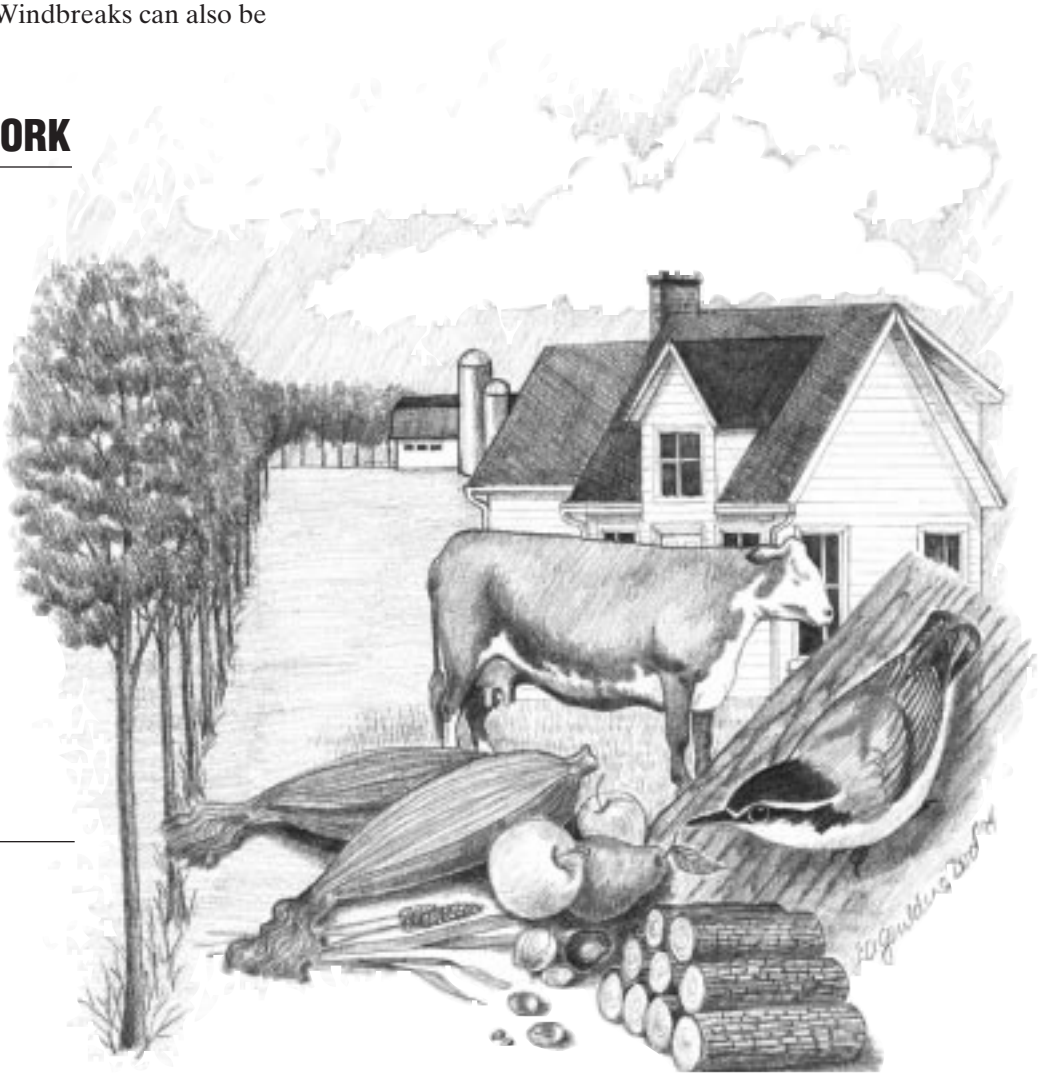
This extension note provides information on some of the many benefits of windbreaks, as well as factors to consider when designing a windbreak for your property.

HOW WINDBREAKS WORK

By reducing wind speed, windbreaks modify the climate in the areas they shelter. The effects of reduced wind speed are:

- Moderated soil and air temperatures
- Increased relative humidity
- Reduced evaporation and increased soil moisture
- Changes in the distribution of snow

These effects are determined by a windbreak's height, length, density, location and species of trees or shrubs.



EROSION CONTROL

The trend toward larger fields has helped to increase soil erosion in Ontario. The removal of windbreaks, natural fence rows and other barriers to wind exposes soil to wind.

Illustration by M.C. Rodrick

Windbreaks can reduce soil erosion by:

- Reducing the occurrence of winds that are strong enough to carry soil away
- Reducing the loss of soil moisture, which binds soil particles together and makes them less likely to be blown by wind

IMPROVED CROP QUALITY AND YIELD

Windbreaks increase crop quality and yield in sheltered areas by:

- Providing lower temperatures in the day and warmer temperatures in the night
- Increasing relative humidity and helping to retain soil moisture
- Reducing physical damage caused by high wind

The amount a crop will benefit from a windbreak depends on the site, windbreak design and crop variety. In studies of field crops, soybean yields in southwestern Ontario were 25 per cent higher when grown in areas sheltered by windbreaks. Corn yields were six to eight per cent higher. Winter wheat, barley, rye, alfalfa and hay yields increased when fields were sheltered, while spring wheat and oats responded to a lesser degree. Vegetable and specialty crops improved in both yield and quality.

In studies of orchards, windbreaks improved pollination and fruit set. Physical damage caused by whipping leaves, branches and fruit was also reduced.

IMPROVED LIVESTOCK PRODUCTIVITY

Windbreaks increase the health of livestock and the survival rates of young animals by protecting livestock from heat in summer and cold and wind in winter. Protection from extreme cold also increases productivity by allowing food energy to be used for growth and milk production, rather than for maintaining body heat. In this way, windbreaks can reduce the amount of food animals require to keep warm in winter.

Because animals graze less when exposed to heat, the shade provided by windbreaks also helps to increase productivity in summer.

The best windbreaks for animals are designed to reduce the speed of the wind without creating drafts or turbulence.

REDUCED HEATING AND COOLING COSTS

Windbreaks help to save energy and to reduce the cost of heating and cooling by protecting buildings from winter wind and summer sun. Windbreaks can reduce winter heating costs up to 25 per cent. The reduction in summer air conditioning costs from windbreaks can be quite dramatic. The cooling effect of one mature deciduous tree is equal to 10 room-sized air conditioners.

Windbreaks can also protect greenhouses from heat loss in winter. Studies suggest that heat loss from greenhouses doubles as wind speed increases from zero to 24 kilometres an hour. Windbreak protection can decrease heat loss by 10 to 15 per cent.

IMPROVED SNOW DISTRIBUTION

Windbreaks can be designed to control snow in different ways.

Dense windbreaks are useful for protecting roads and farm yards from drifting snow. They retain snow and shape it into deep, narrow drifts.

Windbreaks of open structure, which distribute snow evenly over fields, are useful for protecting crops, reducing soil erosion and increasing soil moisture. Studies suggest that a layer of snow 20 centimetres deep completely protects the soil from freezing. A single row of trees is most effective because it allows air to flow through the gaps between trees. This type of windbreak can distribute snow evenly over a distance 25 times the height of the trees.

FOOD AND WOOD PRODUCTION

In addition to their role in providing shelter, windbreaks can be designed to provide both food and wood. They can produce fruit, nuts, maple syrup, firewood, posts, poles, veneer and sawlogs.

WILDLIFE HABITAT AND OTHER BENEFITS

Windbreaks can provide shelter and food for wildlife, as well as safe travel corridors between woodlots. They can also provide nectar and pollen for bees.

Windbreaks can act as sound barriers. They also filter dust from the air and improve the appearance of the rural landscape.

Illustration by M.C. Rodrick

FACTORS TO CONSIDER WHEN DESIGNING WINDBREAKS

Windbreaks are designed to perform specific jobs. The best tree or shrub species to use, the spacing between trees, the size of the windbreak and its location are determined by the characteristics of the land and the job you want the windbreak to do.

When planning a windbreak, you need to consider the shape and orientation of the property, wind speed and direction, and the way snow accumulates. The positions of buildings, roads, power lines, property lines, ditches, trees and wooded areas are important factors. The growing period and the amount of care required by different tree species should also be considered.

For additional information on designing, planting and caring for windbreaks, contact a representative of your local conservation authority, the Ontario Ministry of Natural Resources, or the Ontario Ministry of Agriculture, Food and Rural Affairs.

Produced in the spirit of co-operation by the LandOwner Resource Centre and the University of Toronto's Faculty of Forestry.

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Ministry of the Environment, Conservation and Parks

Office of the Minister

777 Bay Street, 5th Floor
Toronto ON M7A 2J3
Tel.: 416-314-6790

Ministère de l'Environnement, de la Protection de la nature et des Parcs

Bureau du ministre

777, rue Bay, 5e étage
Toronto (Ontario) M7A 2J3
Tél. : 416.314.6790

Ontario

JAN 0 9 2020

357-2019-3279

Ms. Krista Royal, Dipl., MA
Deputy Clerk
Town of The Blue Mountains
Email: kroyal@thebluemountains.ca

Dear Ms. Royal:

I received a copy of your email and Town of The Blue Mountains' resolution regarding climate change from MPP Jim Wilson. I am pleased to share the following information with you.

Our government is committed to protecting the Ontario we know and love and ensuring that its clean air, pristine landscapes and strong communities can thrive now and in the future.

On November 29, 2018, our government released for consultation a living document, our Made-in-Ontario Environment Plan (https://www.ontario.ca/page/made-in-ontario-environment-plan). We continue to work on it so we protect our air, land and water, address litter and reduce waste, support Ontarians to continue to do their share to reduce greenhouse-gas (GHG) emissions, and help communities and families prepare for the impacts of climate change.

As committed to in our Environment Plan, on November 28, 2019, I announced that Ontario has established an advisory panel on climate change to provide expert advice on the implementation of the province's climate change actions, especially on how Ontario can prepare for the costs and impacts of climate change.

We are committed to addressing Ontario's environmental challenges – including climate change – in a way that considers our province's unique challenges and opportunities, and respects Ontario's hardworking taxpayers. We continue to find effective and affordable ways to slow down climate change and build more resilient communities to prepare for its effects.

Ontario already leads the country in reducing Canada's GHG emissions. We will continue to address climate change through a balanced approach to GHG emissions.

Polluters will be held accountable with stronger enforcement and tougher penalties for breaking environmental laws. We will do this in a transparent way, making real-time information about monitoring, incidents and enforcement available to the public.

...2

We will enable others to be environmental leaders and do their part in developing environmental solutions. This includes tapping into the resourcefulness and creativity of our diverse and thriving private sector by helping them invest in and develop clean solutions to today's environmental challenges.

A key element of this approach is the proposed Emission Reduction Fund to support and encourage investments across the province for initiatives that reduce GHG emissions. The fund would leverage a limited initial investment from the government to attract funds from the private sector in order to drive investment in clean technologies.

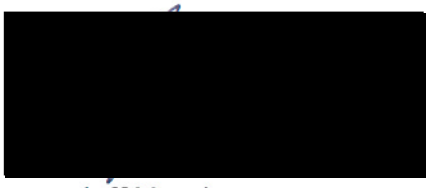
Regulating large polluters through emission performance standards is a key part of our government's approach to reducing GHG emissions and meeting Ontario's share of Canada's 2030 target. Once the federal government removes their carbon pricing program from Ontario industry, these new standards will ensure polluters are accountable for their GHG emissions while addressing the unique circumstances of Ontario's industrial sectors. They also do not create an administratively burdensome system for business and industry, like the former government's cap and trade program.

Recently, our government finalized the Greenhouse Gas Emissions Performance Standards (EPS) Regulation (O. Reg. 241/19) which can be found at https://www.ontario.ca/laws/regulation/r19241 – as an alternative to replace the federal government's carbon pricing program for industry. We have also amended the Greenhouse Gas Emissions: Quantification, Reporting and Verification Regulation (O. Reg. 390/18) – which can be found at https://www.ontario.ca/laws/regulation/180390 – to support the EPS program. My ministry posted a decision notice to the Environmental Registry providing additional details. You can view the notice (Registry #013-4551) at https://ero.ontario.ca/notice/013-4551.

Our government is committed to promoting integrated, tangible environmental solutions that save people and businesses money, address local priorities, and support our communities in doing their part for the environment.

Thank you, again, for writing to share your views.

Sincerely,



Jeff Yurek
Minister of the Environment, Conservation and Parks

c: Mr. Jim Wilson, MPP
Simcoe-Grey

January 8, 2020

Dear Mayor Soever and Council,

Odette Bartnicki's resignation as Deputy Mayor is regrettable and a huge loss to the Blue Mountains community. Constituents have lost a champion.

Odette sacrificed a full, productive but balanced lifestyle to run for Deputy Mayor in order to serve "in the best interests of all people of The Town of the Blue Mountains." Equipped with strong leadership skills and the rare values of integrity and transparency, Odette hoped to positively influence the long-term sustainability of The Town of the Blue Mountains.

From the onset, Odette worked collaboratively to build strong community, economic and political partnerships and relationships within the Town of The Blue Mountains and across Grey County. With enthusiastic commitment and unfailing energy, the new Deputy Mayor worked to procure the people and resources needed to successfully implement the shared priorities and goals of the community. She tackled difficult and challenging community issues head-on and helped resolve them through communication and outstanding advocacy. She accomplished much in her short time in this role. In less than a year, Odette affected positive change and made a significant impact in key areas such as the environment, long-term care, protection of parkland and building strong relationships across Grey County and the Province that would afford the Town of Blue Mountains new and competitive advantages to pave the way for future success and prosperity.

Odette sets the gold standard when it comes to leadership and I have personally come to know that she has a positive and passionate propensity to pursue and to stand up for what is right. Always the professional, she will, without a doubt, continue to bring and advocate for excellence in whatever future roles she aspires to. It's truly unfortunate that it's no longer in the role of Deputy Mayor in The Town of The Blue Mountains.

Sincerely,

Maria Rowles

ONTARIO ENERGY BOARD NOTICE
TO CUSTOMERS OF ENBRIDGE GAS INC.

Enbridge Gas Inc. has applied to raise its natural gas rates effective April 1, 2020, to recover costs associated with the federal government's *Greenhouse Gas Pollution Pricing Act,* and to recover certain related account balances.

Learn more. Have your say.

Enbridge Gas Inc. (Enbridge Gas) has applied to the Ontario Energy Board for approval to increase its rates effective April 1, 2020, to recover the costs associated with meeting its obligations under the federal government's *Greenhouse Gas Pollution Pricing Act.* Enbridge Gas has also applied to recover from customers the balances in the related deferral and variance accounts.

The *Greenhouse Gas Pollution Pricing Act* establishes a carbon pricing program under which a natural gas utility in Ontario, such as Enbridge Gas, is required to pay a carbon charge for the natural gas that it delivers to its customers. The carbon charge came into effect on April 1, 2019, and will increase on April 1, 2020. The costs related to emissions from the operation of Enbridge Gas' natural gas distribution system are also increasing.

Enbridge Gas says that if its application is approved as filed, it will have the following bill impacts:

- **A typical residential customer in the EGD rate zone (former customers of Enbridge Gas Distribution Inc.) will see a bill increase of $68.75. This is composed of a $47.16 yearly bill increase arising from the 2020 carbon charges, plus a one-time charge of $21.59, to recover the balances in the related deferral and variance accounts.**
- **A typical residential customer in the Union South rate zone (former customers of Union Gas Limited), will see a bill increase of $61.32. This is composed of a $43.15 yearly bill increase from the 2020 carbon charges, plus a one-time charge of $18.17, to recover the balances in the related deferral and variance accounts.**
- **A typical residential customer in the Union North rate zone (former customers of Union Gas Limited), will see a bill increase of $61.97. This is composed of a $43.15 yearly bill increase arising from the 2020 carbon charges, plus a one-time charge of $18.82, to recover the balances in the related deferral and variance accounts.**

Other customers, including businesses, will also be affected. It is important to review the application carefully to determine whether you will be affected by the changes.

THE ONTARIO ENERGY BOARD IS HOLDING A PUBLIC HEARING

The Ontario Energy Board (OEB) will hold a public hearing to consider the application filed by Enbridge Gas. During the hearing, the OEB will question Enbridge Gas on its application and will hear questions and arguments from participants (called intervenors) that have registered to actively participate in the hearing.

The OEB is an independent and impartial public agency. We make decisions that serve the public interest. Our goal is to promote a financially viable and efficient energy sector that provides you with reliable energy services at a reasonable cost.

BE INFORMED AND HAVE YOUR SAY

You have the right to information regarding this application and to be involved in the process.

- You can review the application filed by Enbridge Gas on the OEB's website now.
- You can file a letter with your comments, which will be considered during the hearing.
- You can become an active participant (called an intervenor). As an intervenor, you can ask questions and make arguments about Enbridge Gas' application. Apply by **January 27, 2020** or the hearing will go ahead without you and you will not receive any further notice of the proceeding.
- At the end of the process, you can review the OEB's decision and its reasons on our website.

LEARN MORE

Our file number for this case is **EB-2019-0247.** To learn more about this hearing, find instructions on how to file letters or become an intervenor, or to access any document related to this case, please enter the file number **EB-2019-0247** on the OEB website: **www.oeb.ca/notice.** You can also phone our Consumer Relations Centre at 1-877-632-2727 with any questions.

ORAL VS. WRITTEN HEARINGS

There are two types of OEB hearings – oral and written. Enbridge Gas has applied for a written hearing. The OEB is considering this request. If you think an oral hearing is needed, you can write to the OEB to explain why by **January 27, 2020.**

PRIVACY

If you write a letter of comment, your name and the content of your letter will be put on the public record and the OEB website. However, your personal telephone number, home address and e-mail address will be removed. If you are a business, all your information will remain public. If you apply to become an intervenor, all information will be public.

This rate hearing will be held under section 36 of the Ontario Energy Board Act, S.O. 1998 c.15 (Schedule B).

December 31, 2019

The Town of the Blue Mountains
C.Giles, Clerk
32 Mill Street P.O. Box 310
Thornbury, Ontario
N0H 2P0

Dear Ms. Giles:

RE: NVCA BOARD MEMBER'S PER DIEM AND EXPENSES

I have been asked to supply municipalities with remuneration expenses paid to our NVCA Board members over the 2019 year in accordance with the Municipal Act, Section 284(3).

Your council's appointee for the 2019 term to the Nottawasaga Valley Conservation Authority was Andrea Matrosovs.

The Authority held 11 Board of Directors meetings from January 1 to December 31, 2019.

The total number attended by your member was 10 Authority meetings.

The total mileage expense paid was $928.00 and the total per diem paid was $820.30

If you have any questions relating to the above, please do not hesitate to contact the undersigned at 705-424-1379 ext.228.

Sincerely,

[redacted]

Sheryl Flannagan
Director, Corporate Services
SF/ds

Nottawasaga Valley Conservation Authority
8195 8th Line, Utopia, ON L0M 1T0
T: 705-424-1479 **F**: 705-424-2115
admin@nvca.on.ca ● nvca.on.ca

TOWNSHIP OF NAIRN AND HYMAN

64 McIntyre Street • Nairn Centre, Ontario • P0M 2L0 ☎ 705-869-4232 🖷 705-869-5248
Established: March 7, 1896 Office of the Clerk Treasurer, CAO E-mail: nairncentre@personainternet.com

January 3, 2020

The Honourable Steve Clark
Minister of Municipal Affairs and Housing
777 Bay Street, 17th Floor
Toronto, ON M5G 2E5

Dear Minister Clark:

Re: Support Resolution Re: Integrity Commission Matters

Please be advised our Council adopted the following resolution at their meeting of December 16, 2019:

SUPPORT RESOLUTION RE INTEGRITY COMMISSION MATTERS

RESOLUTION # 2019-16-312

MOVED BY: Katherine Bourrier
SECONDED BY: Rod MacDonald

RESOLVED: that the Corporation of the Township of Nairn and Hyman endorse and supports the resolution of the Town of The Blue Mountains requesting that the Ontario Ministry of Municipal Affairs and Housing create a searchable database of all matters placed before all Integrity Commissioners within the province and the resolution of such matters.

AND FURTHER THAT: a copy of this motion be sent to the Association of Municipalities of Ontario (AMO); and the Town of The Blue Mountains.

CARRIED

Sincerely Yours,

[redacted]

Belinda Ketchabaw
CAO Clerk - Treasurer

BK/mb

Cc: AMO
Town of The Blue Mountains

Town of The Blue Mountains
32 Mill Street, Box 310
THORNBURY, ON N0H 2P0
https://www.thebluemountains.ca

OFFICE OF: Mayor Alar Soever
Email: asoever@thebluemountains.ca
Phone: 519-599-3131 Ext 400

Sent via E-mail

October 4, 2019

Ministry of Municipal Affairs and Housing
Hon. Steve Clark | Minister | minister.mah@ontario.ca
777 Bay Street, 17th Floor
Toronto, ON M5G 2E5

Dear Minister Clark,

RE: Integrity Commission Matters

Since the Province required all municipalities to have Integrity Commissioners ("ICs"), we have noted that although this is a quasi-judicial role, few if any decisions by Integrity Commissioners refer to British Common Law precedents, or any precedents for that matter.

In addition, there seems to be quite a difference of opinion on matters between Integrity Commissioners. As an example, our IC takes the position that in all cases the Complainant should never be named in a report, even when they are another member of Council, while at the County level, our County IC, states that she would almost always name the complainant in these circumstances, unless it was a personal matter. Her test would be whether it was a matter of public interest.

As a result of this confusion on behalf of the Town of The Blue Mountains, please note the following resolution passed by Council on September 30, 2019:

> Moved by: Rob Potter Seconded by: Peter Bordignon
>
> WHEREAS the system of justice in Ontario is based on the British system of Common Law which bases decisions on legal precedents;
>
> AND WHEREAS the decisions of Integrity Commissioners in settled cases could provide guidance to all involved in Municipal Government in Ontario as well as to the people they serve;
>
> BE IT THEREFORE RESOLVED that the Code of Conduct Sub-Committee recommends that the Council of the Town of The Blue Mountains requests that the Ontario Ministry of Municipal Affairs and Housing create a searchable database of all matters placed before all Integrity Commissioners within the province and the resolution of such matters;
>
> AND FURTHER BE IT RESOLVED THAT this resolution be circulated to all municipalities in Ontario via the Association of Municipalities of Ontario, Carried.

Please do not hesitate to contact me if you have any questions or comments.

Yours Truly,

[redacted]

Mayor Alar Soever
Town of The Blue Mountains

CC: Mayor and Council, Town of The Blue Mountains (via e-mail)
Shawn Everitt, CAO, Town of The Blue Mountains (via email)
Municipalities in Ontario (via-email)