Annual Carbon Accumulations
in
Agroforestry Plantations

An AgriFood Innovation Fund Project

by: J. Kort and R. Turnock

Agriculture and AgriFood Canada
PFRA Shelterbelt Centre
Indian Head, SK
S0G 2K0

AGRI-FOOD
INNOVATION
FUND

Canada
Saskatchewan

Agriculture and
Agri-Food Canada
Agriculture et
Agroalimentaire Canada

Canada

SUMMARY

The objective of this project was to determine the annual rate at which trees and shrubs in shelterbelts fix carbon so that their value as a carbon sink could be known. A previous study had determined the total carbon contained in trees older than 20 years. Shelterbelt trees of various ages were sampled throughout Saskatchewan to determine their biomass

Sampling consisted of tree ring measurements and weighing of biomass. The accumulation rate increased with age for all species. As the trees got bigger, they developed more leaf area and grew faster. At the age of 40 years, the annual aboveground accumulation rate (in the Black soil zone) varied from 3.4 kg/tree/yr for green ash to 27.0 kg/tree/yr for poplar. In general, trees growing in the Black soil zone grew the fastest while trees in the Dark Brown and Brown soil zones produced 69% and 62% as much aboveground biomass, respectively. Caragana shelterbelts added biomass at a rate of 5.3 kg/10 m/year, approximately 0.37 kg/shrub/year assuming an average spacing of 0.7 m.

TECHNICAL REPORT

Background and Objectives

Shelterbelts on the Canadian prairies are a form of "afforestation", a term used in the Kyoto Protocol on greenhouse gases as one acceptable practice of removing carbon dioxide from the atmosphere (ie. a carbon "sink"). In this project, we measured the rate of carbon fixed in actively growing shelterbelts in Saskatchewan. This information will be useful to those involved in the decision-making process, and will provide a basis for the measurement of carbon in shelterbelts if they become an accredited carbon sink.

A tree's growth rate depends on its leaf area but is divided between aboveground and belowground growth. In the early years of a tree's life, because of the small leaf area, the absolute rate of biomass and carbon accumulation is not very great. When a tree is old, size and disease start to detrimentally affect it so that growth is slowed. However, in its healthy, vigorously growing, stage, the annual biomass accumulation of a tree increases with age. It was the objective of this study to determine for different shelterbelt tree and shrub species, and for different regions of Saskatchewan, the annual aboveground carbon accumulation rate at different tree ages. Measurement of belowground biomass was not a part of this project and would need to be estimated as a percentage of the aboveground biomass. Literature indicates that the biomass in roots is 30% to 50% of the aboveground biomass.

Project Activities

In 1997, the aboveground biomass of trees was sampled in 63 shelterbelts and, in 1998, the aboveground biomass of caragana was sampled in 59 shelterbelts. The tree species investigated were green ash (*Fraxinus pennsylvanica* Marsh), Manitoba maple (*Acer negundo* L.), poplar (*Populus spp.*), Siberian elm (*Ulmus pumila* L.), white spruce (*Picea glauca* Moench Voss), Colorado spruce (*Picea pungens* Englem.) and Scots pine (*Pinus sylvestris* L.). Caragana (*Caragana arborescens* Lam.) is the main shrub used in prairie shelterbelts and was the only shrub species investigated.

In 1997, sampling consisted of the collection of trees cores or tree discs from trees in mature shelterbelts (ie. 40 years of age or older) and annual carbon fixation rates were calculated by measuring the annual increase in stem diameter of trees at breast height (1.4 metres). The percentage of bark in the total diameter of the studied tree species was determined. One tree of each species was felled and the primary stem cut into 15 cm bolts from stump to top. The top of each bolt was measured twice each for diameter inside bark and diameter outside bark, and an average was calculated for each. The total number of measurements depended on the height of the tree. The percentage of bark was determined for each bolt. Bark contributed between 6% and 18% of total diameter, depending on species (Table 1). Coniferous species had proportionally less bark (6% to 9%) than the deciduous species (11% to 18%). These bark constants were factored into the tree-ring diameter measurements so that the total cross-sectional area could be determined at all ages representing the tree-rings.

Table 1. Bark as a percentage of total diameter for seven shelterbelt species

Species	Percent bark	N[1]
Green ash	14.0	30
Manitoba maple	16.0	23
Poplar	11.0	26
Siberian elm	18.0	31
White spruce	7.0	41
Scots pine	6.0	37
Colorado spruce	9.0	26

[1] N = Number of measurements.

Equations developed in a previous project (Kort and Turnock, 1996) were used to convert stem diameter into aboveground biomass. These equations are shown in Table 2. In the previous project, trees had actually been cut down, weighed and their carbon contents determined. Stem diameter was found to be the best predictor of aboveground biomass

For the tree species, three mature shelterbelts of the seven species were located in each of the Brown, Dark Brown and Black soil zones of Saskatchewan (Table 3). At each location, for each species, three representative trees of each shelterbelt were sampled. For the deciduous species and the conifers at Indian Head, sampling involved the felling of the trees and the collection of a disc from the stem(s) of each tree at breast height (1.4 metres). For the coniferous species at the other locations, two core samples were taken with an increment borer from each tree at breast height. The tree-ring diameter for each year was measured to the nearest millimetre for each tree over its life span.

Table 2. Aboveground biomass equations for eleven shelterbelt species.

Species	Biomass Equation	R^2 Value[1]
Green ash	ABG[2] = 0.439 * X1[3]	0.839
Manitoba maple	ABG = 0.278 * X1	0.506
Hybrid poplar	ABG = 0.432 * X1	0.883
Siberian elm	ABG = 0.318 * X1	0.782
White spruce	ABG = 0.514 * X1	0.921
Scots pine	ABG = 0.346 * X1	0.895
Colorado spruce	ABG = 0.525 * X1	0.864
Caragana	ABG = 2.337 * X2[4]	0.462
Choke cherry	ABG = 1.934 * X2	0.722
Villosa lilac	ABG = 2.889 * X2	0.618
Buffaloberry	ABG = 1.639 * X2	0.865
Sea buckthorn	ABG = 1.470 * X2	[5]

[1] Indicates the accuracy of the equation, the closer it is to 1.0 the more accurate.

[2] ABG - Above ground biomass (kg/tree).

[3] X1 = Total stem cross-sectional area at breast height (cm2/tree).

[4] X2 = Shelterbelt volume (m3) (Shelterbelt length(m) x width(m) x height(m)).

[5] Only two sample points therefore little confidence in this value.

For the two core sub-samples from each tree, an average stem diameter for each year was calculated from the measurement of the distance from the tree centre (year zero) to the outside edge of each ring. This resulted in two calculated diameter values which were used to determine the average diameter at breast height (dbh) for every year in the tree's life. The rings on the disc samples were measured along two transects running perpendicular to each other through the centre of the discs (Figure 1). Same-year values were averaged to give a ring diameter for each year. These values, combined with the corresponding bark constants, give a total dbh value for each year in a tree's life. With these values, the rate of annual carbon accumulation and the total carbon content for all the trees was calculated for each year according to the previously determined relationships between diameter and aboveground biomass (Table 2).

To determine the rate of carbon accumulation for each species, linear regressions were conducted on the logarithm of the annual accumulation vs. the logarithm of the age was determined. The first six to eleven rings (depending on species) were omitted from regression analysis because they represented the establishment period of the trees.

Table 3. Shelterbelt sampling locations by Ecoregion, Soil Zone and Rural Municipality

Location	Ecoregion	Soil zone	Rural municipality(s)
Indian Head	Aspen Parkland	Black	156
Melfort	Boreal Transition	Black	428, 458
Lyleton (Manitoba)	Aspen Parkland	Black	122
Kenaston	Moist Mixed Grassland	Dark Brown	281, 282, 283
Swift Current	Mixed Grassland	Dark Brown	107, 136, 137
Weyburn	Moist Mixed Grassland	Dark Brown	66, 67
Aneroid	Mixed Grassland	Brown	17, 45, 46
Kyle	Mixed Grassland	Brown	228, 259
Mortlach	Mixed Grassland	Brown	133, 162

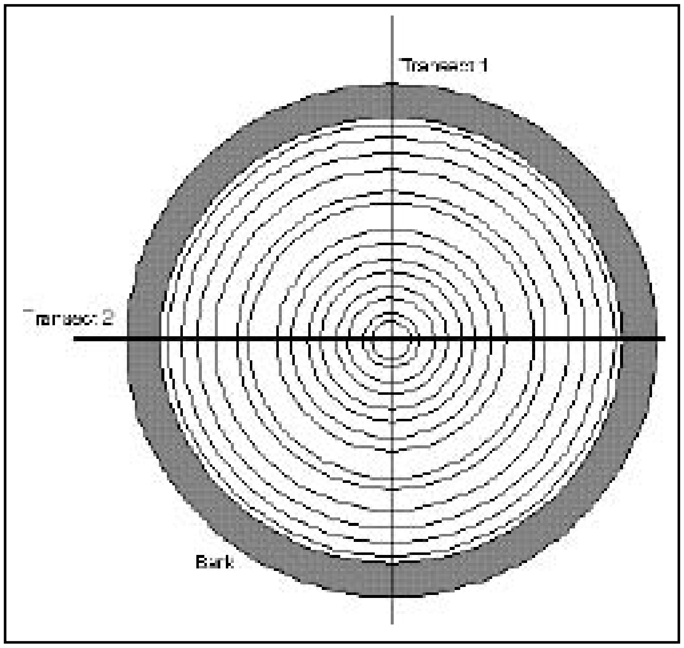


***Figure 1**. Tree disc showing the method used to measure tree-rings.*

Caragana sampling consisted of cutting and weighing samples in shelterbelts of different ages. This was done since ring analysis of caragana (and other shelterbelt shrubs) was not well related to aboveground biomass as determined in the previous study (Kort and Turnock, 1996). The 59 shelterbelts sampled were equally distributed in the Brown, Dark Brown and Black soil zones of Saskatchewan and varied in age from 5 to 61 years.

Based on the conclusions of this study, we projected the annual carbon accumulations in shelterbelts for the 2008 - 2012 verification window specified in the Kyoto Protocol for mitigative measures undertaken from 1990 onwards.

Results and Conclusions

The relationship between annual carbon accumulation and age at breast height for established trees was best described by the model $Y=aX^b$, where X is the age of a tree at breast height. The *"b"* exponent is the average slope of the line for each species on the logarithmically transformed data and is shown in Table 4. Average values for "b" ranged from a low of 0.2551 (Siberian elm) to a high of 1.0568 (Manitoba maple). Linear regression analysis was then performed on the annual carbon accumulation data and the age (X^b) data to determine the *"a"* coefficients of the equations for each tree in each soil zone. For each species the median value of the nine trees sampled in each soil zone was selected as the *"a"* coefficient for that soil zone (Table 4).

Table 4. Coefficients for annual carbon accumulation (kg) equations for seven shelterbelt species[1]

Species	Black soil zone		Dark Brown soil zone		Brown soil zone	
	a	b	a	b	a	b
Green ash	1.1391	0.2932	0.7284	0.2932	0.5218	0.2932
Manitoba maple	0.1177	1.0568	0.0654	1.0568	0.0916	1.0568
Poplar	0.7679	0.9651	0.3232	0.9651	0.2089	0.9651
Siberian elm	2.6801	0.2551	2.0672	0.2551	1.6595	0.2551
Colorado spruce	1.0394	0.4560	0.9950	0.4560	0.8193	0.4560
White spruce	0.2318	0.8960	0.1345	0.8970	0.1633	0.8970
Scots pine	0.3159	0.6716	0.2895	0.6716	0.2266	0.6716
Caragana[2]	0.5987	0.6446	0.4511	0.6446	0.4017	0.6446

[1] For equation in the form: $Y = aX^b$, where: Y = annual carbon accumulation (kg), X = age at breast height (yrs).
[2] Annual carbon accumulation for caragana is expressed in kg/10m for a linear shelterbelt.

Figure 2 shows the relationships between annual carbon accumulation and age at breast height based on the developed equations for the seven species in the three soil zones. The curves cover the characteristic lifespan of the species beginning after the trees are established (6-11 years). It should be noted that the curves represent the growth rate of healthy, intact trees and do not account for any loss of vigour resulting from physical damage, disease, pest attack, climate or general decline. This results in very steep annual accumulation curves for the faster growing and more water-responsive species such as poplar. As trees age, they deteriorate and the rate of carbon accumulation is eventually outpaced by decay.

The graphs in Figure 2 show two forms. The first type is characterized by "b" exponents less than 1.0 and has curves whose slopes decrease with age. This group includes green ash, Siberian elm, Colorado spruce and Scots pine. The remaining species (Manitoba maple, poplar and white spruce) have curves defined by "b" exponents that are closer to, or greater than 1.0 whose slopes are constant with age. These relationships may be the result of the moisture requirements of the individual species. Manitoba maple, poplar and white spruce are species that are adapted to environments where moisture is not a limiting factor. The other species are known to be more drought-tolerant and generally have slower growth rates.

When carbon accumulation is compared among soil zones, rates were greatest in the Black and least in the Brown soil zone, as expected. The exceptions to this were Manitoba maple and white spruce. For these native species, the amount of carbon accumulated was greater in the Brown soil zone than in the Dark Brown soil zone. These species are moisture dependent and normally do not thrive in the more arid Brown soil zone. However, they may do very well if they are planted around farmyards or in locations with high water tables, where they can benefit from the longer growing season and milder winters common to this soil zone.

The equations were then used to create total carbon accumulation curves for each of the species in the three soil zones (Figure 3). These graphs can be used to predict the size of the carbon sink that any future shelterbelt planting would represent. The large carbon contents obtained for poplar and Siberian elm stand out because of their fast growth rate and relatively short lifespans. In dry areas, these species may have an expected lifespan as short as twenty to twenty-five years.

The total carbon held in shelterbelt trees at forty years of age illustrates differences among species as carbon sinks (Table 5). Forty years was chosen as a point of comparison because it falls within the mature range of the expected lifespans of

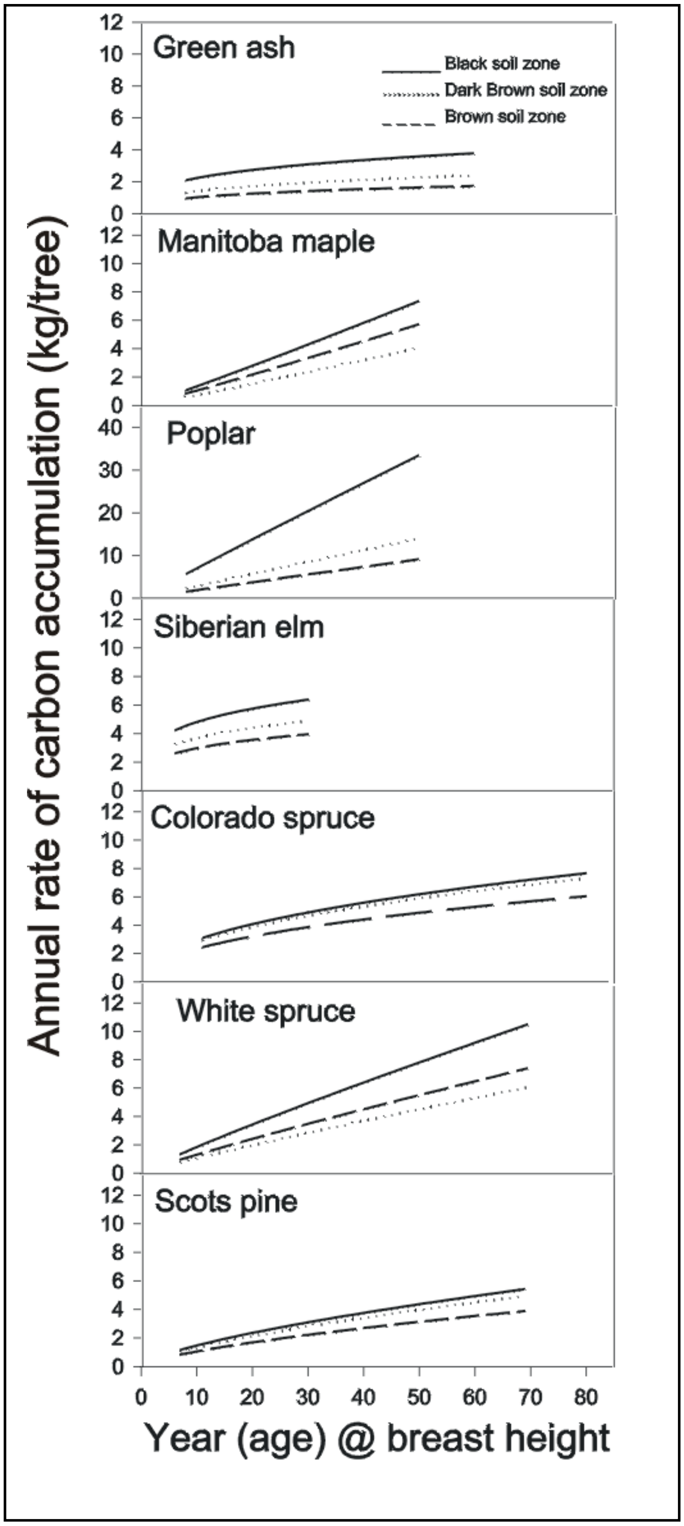


Figure 2. *Annual carbon accumulation curves for seven shelterbelt species.* **Note: Y-axis expanded for poplar.**

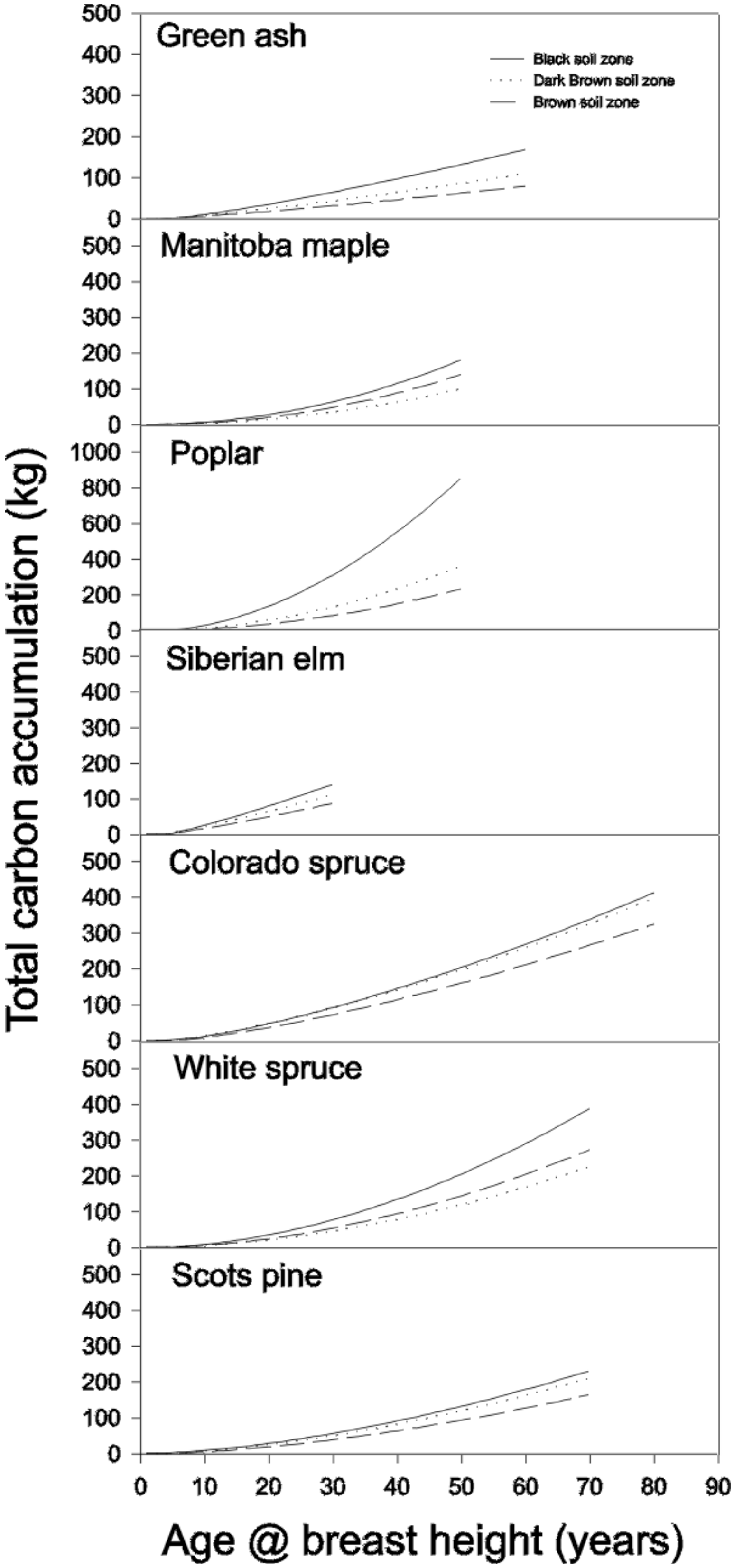


Figure 3. *Total carbon accumulation curves for seven shelterbelt species.* **Note: Y-axis expanded for poplar.**

most of the species. A forty-year-old shelterbelt of green ash in the Black soil zone 1.0 km in length, can be expected to contain 39.0 tonnes of carbon. A similar shelterbelt in the Brown soil zone would hold 18.6 tonnes of carbon. Caragana carbon accumulation rates were considerably lower than those of any of the tree species both on a kg/tree basis and a t/km basis (Figure 4 and Table 5). Carbon accumulation rate was up to 50% greater in the Black soil zone than in the Dark Brown or Brown soil zones (Figure 4). Average annual accumulation rate for established caragana shelterbelts ranged from 2 to 8 kg/10m/year. This data may be used to aid in planning site specific agroforestry plantings that maximize the traditional agricultural benefits of shelterbelts, the size of the carbon sinks they represent, and the other environmental benefits of prairie tree planting programs.

REFERENCES

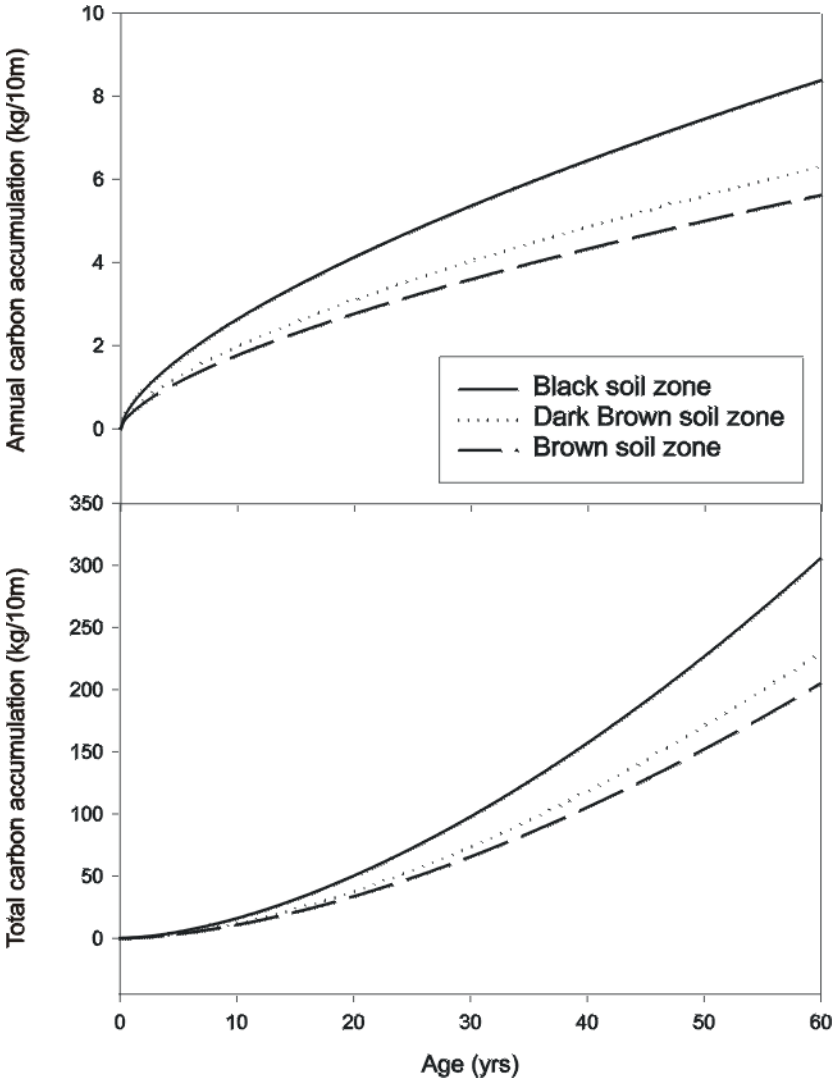
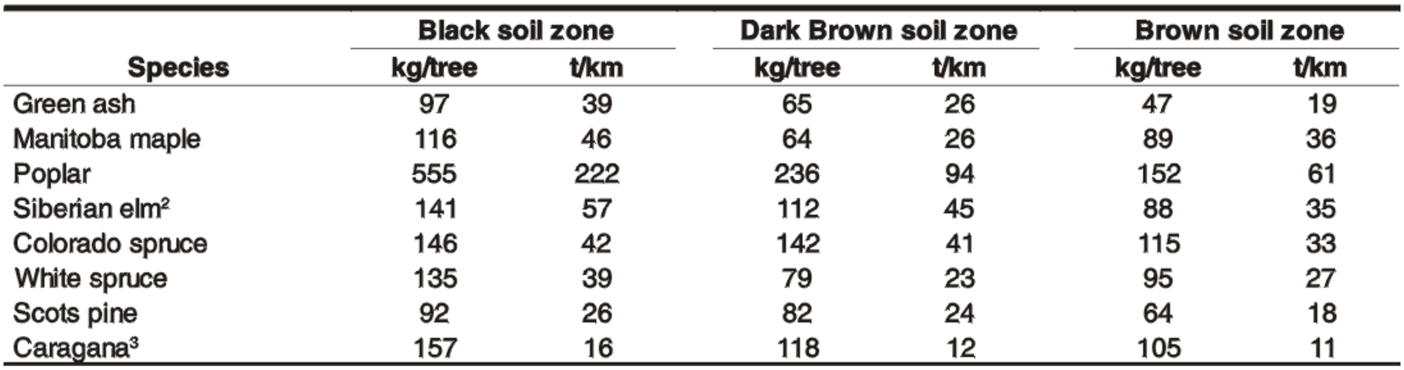


Figure 4*. Annual and total aboveground carbon accumulation rates for caragana in three soil zones.*

Table 5. Predicted aboveground carbon contents for seven shelterbelt species after 40 years[1]



Species	Black soil zone		Dark Brown soil zone		Brown soil zone	
	kg/tree	t/km	kg/tree	t/km	kg/tree	t/km
Green ash	97	39	65	26	47	19
Manitoba maple	116	46	64	26	89	36
Poplar	555	222	236	94	152	61
Siberian elm[2]	141	57	112	45	88	35
Colorado spruce	146	42	142	41	115	33
White spruce	135	39	79	23	95	27
Scots pine	92	26	82	24	64	18
Caragana[3]	157	16	118	12	105	11

[1] Assumes 100% survival, 2.5 m spacing between hardwoods and 3.5 m spacing between softwoods.

[2] Predicted lifespan of this species is only 30 years.

[3] Carbon content for caragana is expressed in kg/10m and t/km.

Kort, J. and Turnock, B. 1996. Biomass production and carbon fixation by prairie shelterbelts. PFRA Shelterbelt Centre Supplementary Report 96-5. 14 pp.

INDICATIONS FOR FURTHER DEVELOPMENT

The results above describe the rate and amount of biomass accumulation in shelterbelt plantings. This information will be important in the development of a transparent methodology for measuring and verifying the carbon actually fixed in shelterbelt trees. Although the lifespan of any trees successfully established from 1990 onwards will extend beyond the verification window of 2008-2012, it will be necessary, eventually, to determine longer-term contributions of agroforestry plantings (ie a comparison of growth rates and deterioration rates). This should also include considerations of the fate of mature trees. The use of wood in long-term wood products extends the duration of the carbon reservoir while replacement of fossil fuels with renewable fuel such as firewood reduces net emissions.

COMMUNICATIONS AND INFORMATION SHARING

The basic results of the study, as described above, have been summarized in the PFRA Shelterbelt Centre's 1997 and 1998 Annual Reports. Although the information has been circulated to those interested in it, it has been particularly sent to the national round tables dealing with Agriculture, Forestry and Greenhouse Gas Sinks. It was also verbally presented to a meeting of the Agriculture Round Table. Reports were sent to several consultants who had been contracted by the Sinks and Forestry Round Tables to determine the scope and feasibility for afforestation on the prairies. The results of the study were also used in projections, for the round tables, to estimate the effect of tree plantings since 1990 in the current shelterbelt program on the carbon fixed during the 2008-2012 verification window. Currently, shelterbelt tree growth is being factored into the Century (CRAM) model to estimate carbon balances under a variety of land management practices.

IMPACT OF THE RESULTS

This work may have an impact on Canada's international negotiations regarding greenhouse gases as a significant and verifiable means of reducing Canada's net carbon emissions. As carbon emitted into the atmosphere is likely, eventually, to represent an economic, as well as an environmental cost, viable carbon sinks in shelterbelts will represent an economic benefit to Canada in addition to their already recognized conservation benefits.