Tree-Based Intercropping in Southern Ontario, Canada

Article *in* Canadian Journal of Agricultural Economics/Revue canadienne d agroeconomie · June 2012

DOI: 10.1111/j.1744-7976.2012.01245.x

Joann K. Whalen
McGill University

Anwar Naseem
Rutgers, The State University of …

Tree-Based Intercropping in Southern Ontario, Canada

Imran A. Toor,[1] Elwin G. Smith,[2] Joann K. Whalen[3]
and Anwar Naseem[4]

[1] *Former Graduate Student, Department of Natural Resource Sciences, McGill University, Macdonald Campus, 21, 111 Lakeshore Road, Ste. Anne de Bellevue, Quebec, Canada H9X 3V9 (phone: 403-402-5358; e-mail: imrantoor@gmail.com).*
[2] *Bioeconomist, Agriculture and Agri-Food Canada, PO Box 3000, Lethbridge, Alberta, Canada T1J 4B1 (corresponding author: phone: 403-317-2339; fax: 403-317-2187; e-mail: elwin.smith@agr.gc.ca).*
[3] *Associate Professor, Department of Natural Resource Sciences, McGill University, Macdonald Campus, 21, 111 Lakeshore Road, Ste. Anne de Bellevue, Quebec, Canada H9X 3V9 (phone: 514-398-7943; fax: 514-398-7990; e-mail: joann.whalen@mcgill.ca).*
[4] *Assistant Professor, Department of Natural Resource Sciences, McGill University, Macdonald Campus, 21, 111 Lakeshore Road, Ste. Anne de Bellevue, Quebec, Canada H9X 3V9 (phone: 514-398-7825; fax: 514-398-7990; e-mail: anwar.naseem@mcgill.ca).*

Tree-based intercropping (TBI) integrates tree production within annual grain cropping. The system is widely used in tropical regions, but is not common in temperate regions. This study evaluates the annualized return from TBI systems in southern Ontario, Canada against annual grain crop production. The TBI systems include hybrid poplar, Norway spruce, and red oak. The annualized return for all TBI systems is less than for annual cropping using the base prices; however, when tree prices are high and grain prices low the hybrid poplar TBI system has a higher return than annual cropping. Grants for planting trees, technologies to reduce the cost of establishing and maintaining trees, and improving the returns from tree production will be required for producers in temperate regions to adopt TBI systems.

Un système de cultures intercalaires (SCI) intègre la production d'arbres dans la culture annuelle de céréales. Ce système est largement utilisé dans les régions tropicales, mais peu courant dans les régions tempérées. La présente étude évalue le rendement annualisé des SCI dans le sud de l'Ontario, au Canada, par rapport à celui de la production annuelle de céréales. Les SCI intègrent le peuplier hybride, l'épinette de Norvège et le chêne rouge. Le rendement annualisé des SCI est inférieur à celui des cultures annuelles si l'on utilise les prix de référence. Toutefois, lorsque les prix des arbres sont élevés et que les prix des céréales sont faibles, le SCI qui intègre le peuplier hybride obtient un rendement supérieur à celui des cultures annuelles. Pour que les agriculteurs des régions tempérées adoptent les SCI, il faudra offrir des subventions à la plantation d'arbres, offrir des technologies qui permettront de réduire les coûts de plantation et d'entretien des arbres et améliorer les rendements/revenus de la production d'arbres.

INTRODUCTION

Deciduous tree plantations are common throughout Canada; hybrid poplar plantations have been implemented on logged forested land since the 1980s in eastern Canada to produce pulpwood (Zsuffa et al 1977) and poplar plantations are being evaluated in the Parkland region of western Canada (Centre for Northern Agroforestry and

Canadian Journal of Agricultural Economics 60 (2012) 141–154
DOI: 10.1111/j.1744-7976.2012.01245.x

Afforestation [CNAA] 2011). Growing conditions are favorable across Canada for hybrid poplar and other deciduous species, which could be grown commercially to alleviate potential hardwood shortages for industry (Toyne et al 2002), supply biofuel to combust for energy production (Ontario Ministry of Agriculture, Food and Rural Affair [OMAFRA] 2011), and provide a range of ecological services (CNAA 2011). Despite the experience with plantations and the perceived benefits of tree production to meet wood and ecological demands, few agricultural producers have integrated agroforestry systems on their land base, especially using higher quality hardwoods. Agroforestry in this study refers to integrating tree production with the production of conventional annual crops, a system known as tree-based intercropping (TBI).

The TBI system is an integrated system of growing trees and annual crops together, with trees planted in rows that allows annual crop production between the rows (Lelle and Gold 1994). Unlike a tree plantation, there is cash flow from the annual crops while the trees grow, and fewer trees are planted than in a plantation because most of the land remains in crop production. The financial risk of allocating a small portion of land to tree production might also be less compared to a plantation. The layout of a TBI system would be comparable to shelterbelts in western Canada with a single row of trees, though shelterbelt trees are not harvested. As with shelterbelts, field efficiencies could be reduced because the effective field size is reduced.

Stated benefits of TBI systems have emphasized physical and environmental factors, such as increased diversity of output, increased soil quality characteristics, cycling of leached nutrients, providing a litter layer to reduced soil erosion, increased biodiversity, reduced leaching, and reduced agrochemical inputs (Gordon et al 1997; Young 1997; Nair 2007; Palma et al 2007). The crop can also benefit tree production as Rivest et al (2010) report soybean intercrop resulted in greater biomass of hybrid poplar. Despite potential physical and environmental benefits of TBI systems, the benefits might not translate into improved returns to the land owner. For example, the profitability of black walnut and corn intercropping in southern Ontario was found to be lower than conventional corn (Dyack et al 1999). Even though black walnut is a highly valued tree, the TBI system had lower financial returns than a conventional corn agroecosystem because black walnut production removes some cropland and requires many decades of growth to reach marketable size, reducing the net present value (NPV) of the tree at harvest.

Examples of successful TBI systems exist. They are common in developing counties because they provide a steady and diversified source of income (e.g., firewood and grain), and can be managed as low-input systems requiring few off-farm purchases (Mathews et al 1993; Ellis 1998). The price and cost structure for subsistence farming in developing countries results in TBI being an economical system. A meta-analysis of TBI adoption found factors that influence adoption, primarily in tropical regions, are biophysical (soil, slope, plot size), resource endowments (income, assets), and risk (tenure, experience, extension) (Pattanayak et al 2003). A maize-leucaena (shrub planted in hedges) intercropping system increased maize yield in Kenya because of a reduction in corn stem-borers (Callistus et al 1999). An alley cropping study with leucaena cropped with maize and beans showed economic potential but the result was based on simulated yield and subsidized tree cost (Hoekstra 1983). Scherr (1995) reports that most of the 56 agroforestry systems examined in Central America and the Caribbean are financially profitable for the farmers, with 75% of the agroforestry systems having a positive NPV. However, Scherr (1995) does not compare the NPV of agroforestry systems to that of conventional systems. In Africa and South Asia, where environmental stress is common, intercropping offers greater stability and is an insurance against total income failure (Horwith 1985).

The TBI system could be appealing to producers looking for alternative agricultural practices that can potentially provide improved economic and environmental sustainability (Kurtz et al 1991). Yet in many cases, financial assistance may be required to establish and maintain TBI systems. Gold and Hanover (1987) review agroforestry systems in temperate zones and report annual cropping with intensively managed high-value hardwood plantations appears to be feasible; however, the potential gains relative to conventional cropping systems are not provided. Graves et al (2005) found tree-related subsidies are critical for TBI profitability in Europe, when compared to annual crop production. Dyack et al (1999) estimate the return from corn intercropped with black walnut in southern Ontario is $42/ha/year less than the conventional corn agroecosystem, due to the low NPV of harvested timber from this slow growing tree. TBI systems are proposed as being profitable when used as an erosion control practice on lower quality soil that is susceptible to erosion (Campbell et al 1989; Countryman and Murrow 2000). Under these conditions there are additional private benefits, other than commercial timber, and the annual foregone crop production due to tree production is less on lower quality soil.

Many of the TBI system benefits proposed are societal rather than private benefits, and if society wants these benefits there will be a need for society to provide payment to producers to adopt TBI systems. Graves et al (2005) conclude that grants are required in Europe for TBI systems to be profitable. The grants could cover costs of establishing trees, and tree maintenance costs over time including weed control and pruning. The certainty of future outcomes from a long-term investment in a TBI system is less than for annual cropping including the future value for trees and ecological services, and tree revenue might never be realized by the current land owner.

The evidence for profitable TBI systems in developed northern climate countries is limited. The objective of this study is to evaluate the profitability of selected TBI systems for southern Ontario, Canada relative to conventional annual crop production, and to evaluate factors that impact the profitability of TBI systems. Southern Ontario is selected because it has a long growing season, high-valued hardwoods can be grown, and there is provincial interest in using forestry products for energy generation. Annual cropping agroecosystem and TBI systems are compared using NPV because of differing period lengths from planting to harvest for different tree species and for annual crops. The NPV is converted to an annual annuity since there are annual crops produced and comparisons of yearly values are more intuitive. Three tree types for TBI systems are evaluated—hybrid poplar for fast-growing trees, Norway spruce for moderately fast-growing softwood trees, and red oak for slow-growing hardwood trees. Crop and tree prices will be major factors of profitability and their prices vary over time, so a range of prices is considered for trees and crops. The tree price range in the analysis is also used to evaluate whether higher prices or additional payments based on tree mass, such as a payment for carbon, would alter the profitability of TBI systems. Other factors that could influence the NPV include the discount rate, the growth in crop yields over time due to better cropping technologies, tree spacing within a row, row spacing of trees, and a policy that provides grants or subsidizes a portion of the tree planting and maintenance costs assuming trees are deemed to provide ecological services to society.

MODEL

To compare the net economic benefits of annual cropping only and TBI systems, the flows of returns and costs are converted to NPV. The NPV is computed with a set discount factor, considered to be the opportunity cost of an investment. The NPV for a unit area of land with only annual cropping and with a TBI system are expressed, respectively, as

$$NPV_{crop} = \sum_{t=0}^{T} (1+r)^{-t}(R_{ct} - C_t) \tag{1}$$

$$NPV_{TBI} = \sum_{t=0}^{T} (1+r)^{-t}(R_{ft} - C_t) \cdot AC + \sum_{t=0}^{T} (1+r)^{-t}(H_t - E_t) \cdot (1 - AC) \tag{2}$$

where t is the time period, T is the end of the time period considered, R is the revenue from crop production (price times yield), C is the cost of crop production, AC is the proportion of area in crop production with $(1-AC)$ being the area used for the trees, H is the revenue from tree harvest, E is the cost of establishing and maintaining trees, and the crop revenue subscripts are c for annual crop and f for TBI. Annual crop yield and revenue for the TBI system will be depressed near tree rows because of competition from trees for nutrients and light. Crop revenue and cropping costs will occur each year, but for trees there will only be revenue when the trees are harvested or if pruned branches have firewood value. Tree establishment costs include site preparation, planting and tree purchase, plus annual maintenance costs such as weeding and pruning. In this analysis the on-going maintenance costs are discounted back to the establishment period. For most years, H and E will be zero.

This model is applied in an agroforestry model, Farm-SAFE, that was developed to evaluate agroforestry systems in Europe (Graves et al 2005). Farm-SAFE is a spreadsheet model that facilitates the computation of NPV. The user is required to provide their own input data of prices, costs, crop yield, tree growth and harvest, and the discount rate. Production data are yearly. The model does not determine the optimal harvest age, which is specified and differs by tree species. Harvest age is based on that reported by Van Kooten and Folmer (2004) for hybrid poplar and spruce. The authors report rotation ages of 17 and 33 years, respectively, for hybrid poplar and spruce using the Fisher criterion, and 11 and 23 years when using the Faustmann criterion.[1] Slow growing hardwoods are not considered by these authors, but would require a longer rotation length. The impact of harvest age on the quality of the tree is not considered. The price of hardwoods can relate to size and form, which could be important for determining the harvest age of hardwoods as the quality and use for the tree moves from pulp (lowest price) to narrow boards to wider boards to veneer (highest price). If tree value per unit volume increases with volume, the optimal rotation age will increase.

---

[1] The Fisher criteria maximize benefits from a single cut, and trees are left standing as long as the rate of growth in the value of the tree value exceeds the discount rate. The Faustmann criteria consider that trees are replaced at harvest with like trees and this will result in a shorter rotation age to avoid delaying the replacement of trees.

Data and Model Application

The model is used to evaluate and compare the profitability of arable cropping and TBI systems in southern Ontario. The NPV of the systems is converted to an annualized value using the appropriate annuity factor. The TBI systems are based on a study at the University of Guelph Agroforestry Research Station, Guelph, Ontario. The study was initiated in 1987 and is operated by the University of Guelph and the Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA). The TBI study covers 30 hectares (ha) of agricultural land containing 10 different tree species planted in rows spaced either 12.5 m or 15 m, with annual crops grown between the tree rows. Tree rows are oriented in the N–S direction. The tree species are in groups along the rows with four replications. An adjoining field planted to annual crop is used to determine the annual crop yield without the influence of trees. Further details of the experimental design and site management are in Peichl et al (2006).

Corn and soybean, and to a lesser extent winter wheat or barley, are planted between the tree rows using common production practices. There is no specific rotation of these crops so the crop sequencing in this study follows that of the actual field study. The frequency of crops is corn (50%), soybean (35%), barley (10%), and wheat (5%). Initially, the tree strip itself was 1 m in width (6% of land area), but by 1997 was about 2 m because of the larger tree size. In this analysis the tree strip width is set at 2 m. A test of the impact of using 2 m instead of 1 m for young trees was less than 0.5% of the return. As the trees are evenly spaced intra-row and the tree canopy is relatively uniform within each species, only a few tree canopies overlap within the rows (Gordon et al 1997).

For this study three tree species *Populus sp*. (poplar–hybrid), *Picea abies* (Norway spruce), and *Quercus rubra* (red oak) are used to represent fast growth trees, moderately fast growth softwoods, and slow growth hardwoods. Because the trees at the University of Guelph are only about 20 years of age, tree growth for subsequent years is projected by modeling with the Ecosys model.[2] The projected growth from the Ecosys model is consistent with growth of red oak reported by Johnson et al (2002, p. 426), of Norway spruce by Ge (2011), and of hybrid poplar by van Oosten (2006, Appendix O). Red oak uses 60 years of projected growth until harvest, the hybrid poplar is harvested at 20 years, and the Norway spruce at 30 years. The 20 year harvest age for hybrid poplar is slightly older and 30 years for Norway spruce is consistent with the Fisher criterion harvest ages reported by Van Kooten and Folmer (2004). Over 60 years, there will be three plantings and harvests of hybrid poplar, two for Norway spruce, and one for red oak.

In this study, tree row spacing is set at 100 m to accommodate larger machine sizes and to minimize losses in field efficiency for the crop produced between the tree rows. Because the TBI annual crop yields from the Guelph experiment are based on narrower tree row spacing, crop yields for the TBI systems are adjusted for wider row spacing. Crop yield is reduced in a band near the tree row, and no impact is observed at further distances. The reduction of crop yield should depend on tree size, but these data are available only for established trees (Reynolds et al 2007). The response with distance in this study is consistent with other studies examining the impact of distance from trees on crop yield

---

[2] Ecosys (Grant 2011) models the increase in tree carbon over time, which is then converted to tree biomass. The model is calibrated using the first 20 years of tree growth for 10 randomly selected trees for each species.

Table 1. Output prices for trees and crops in southern Ontario

Product	Lowest	Low	Base	High	Highest
	Tree price ($/m^3)[a]				
Tree					
Hybrid poplar	10	25	40	55	70
Norway spruce	10	35	60	85	110
Red oak	10	70	130	190	250
	Crop price ($/metric ton)				
Crop					
Winter wheat	112	136	160	192	224
Feed barley	98	119	140	168	196
Corn	105	127.5	150	180	210
Soybean	224	272	320	384	448
Crop price index	70	85	100	120	140

[a] Tree price is the standing (stumpage) price.

(Akbar et al 1990; Khybri et al 1992; Puri and Bangarwa 1992; Khan and Ehrenreich 1994; Singh et al 1998). The crop yield for the TBI system with 100 m tree row spacing, not including the land reduction for the trees, is 1.4% less than arable production without trees. Annual average crop yields for the arable crop only system for corn, soybean, winter wheat, and barley are, respectively, 6.36, 2.08, 4.10, and 2.94 metric ton/ha. Crop yields on the cropped land for the TBI systems are 1.4% lower than these yields.

A range of crop and tree prices are used in the analysis because these prices can vary over time, but tree prices will also vary due to quality. The relative prices of trees and crops impact the profitability of TBI versus annual cropping. Tree prices are obtained from stumpage prices in states adjoining Ontario (Michigan Department of Natural Resources 2009; New York State Department of Environmental Conservation 2009; Maine Forest Service 2010). Stumpage prices for southern Ontario are not readily available, but because trees can be shipped between the two countries, the prices in the United States should closely reflect those in Canada. The base tree prices are the prices most representative of the reported prices for each species. Tree prices can range from pulpwood (lowest) to high quality veneering wood (highest) and because of the range of prices higher and lower tree prices are specified for each species to determine the impact of tree price on profitability (Table 1). Branches (collected at pruning and at harvest) of firewood quality are priced at \$5.24/m^3. Base crop prices are a five-year average of Ontario prices (OMAFRA 2010). The relative prices of corn, soybean, wheat, and barley will vary over time, but for this analysis the relative crop prices are fixed and indexed (Table 1). The lowest price is 70% of the base, the low price 85% of the base, the high price is 120% of the base, and the highest price is 140% of the base. Crop prices are indexed to be able to determine the effect of changes to general crop prices rather than a specific crop.

Crop production costs for the four annual crops are from OMAFRA (2008) crop budgets. These costs include operating (seed, fertilizer, pesticide, machine operation costs, insurance, drying, trucking, storage, labor, and operating interest) and overhead costs (machine depreciation and interest, and other overhead). Because the annualized return is determined over a time period that exceeds the life of most machines, machinery investment and other overhead costs are included. Production costs are $1,134/ha for corn, $544/ha for soybean, $683/ha for winter wheat, and $616/ha for barley. Land costs are not included. The cost of establishing trees for the TBI systems is estimated and includes site preparation, the tree seedling, planting, weed control, and pruning. The costs of weed control and pruning are discounted to a net present cost and recorded in the year of establishment. Costs in the year of establishing TBI systems are site preparation and planting ($1.50/tree) and the tree ($1.25/tree for Norway spruce and red oak and $1.45/tree for hybrid poplar). Yearly costs are weed control for the first 10 years of $0.90/tree for labor and herbicides, and pruning every second year for the first 20 years at a cost of $1.80/tree when pruned. The net present cost per tree (tree seedling plus maintenance) is $22.75 for Norway spruce and red oak, and $22.95 for the hybrid poplar. Most of the tree cost for the TBI system is labor for pruning, which is essential to produce a straight quality tree without knots. Unpruned trees would be pulpwood quality and priced low. The cost of establishing and maintaining trees could deter adoption of TBI. If the return for the TBI system is lower than for annual cropping, we determine the reduction in the cost of tree establishment required for the two systems to have equal return. A policy to encourage adoption of TBI could use this estimate to determine the grant, or subsidy, required for producers to adopt TBI.

In addition to the prices of annual crops and trees impacting the annualized return, tree spacing within the row, row width spacing, the discount rate, and technology yield growth of crops will affect the return of TBI systems. Tree spacing within row is reduced to 3 m to increase the harvested trees per unit area without reducing crop area. Row spacing of 15 m is examined to determine the impact of allocating more land area to tree production. The base discount rate used in the analysis is 4%, a rate that could be viewed as including minimal risk premium. A lower rate of 1% is used to determine whether the results would be different for an individual who places a high value on future outcomes, and 8% is used to include a rate with some risk premium. Finally, annual crop yields have trended up by about 1%/year (a bit more for corn) but tree technology is fixed once the tree is planted. Annual crop yield is increased 1%/year to determine how yield technology impacts the TBI decision.

RESULTS

At the base prices for annual crops and trees, none of the production systems have a positive annualized return (Table 2). The base crop prices used in the analysis (Table 1) are not profitable, given the specified yields, prices, and costs of crop production. The annualized returns for the low and high tree prices, and the index 85 and 115 crop prices are not reported in Table 1 because the annualized return across prices is nearly linear. The return for annual cropping would be positive with crop prices 11% higher than the base prices. For TBI systems, the annualized return is negative for the crop and tree components. The tree component would have a positive annualized return if tree prices are 2.2% higher for hybrid poplar, 230% higher for Norway spruce, and 513% higher for red oak.

Of greatest interest for this study is the difference in returns between annual cropping and the TBI systems. At the base prices, the annualized return for annual cropping is greater than TBI: $9/ha for hybrid poplar, $22/ha for Norway spruce, and $21/ha for

Table 2. Annualized return ($/ha) for annual cropping and three tree-based intercropping systems, for three tree price and crop price index levels

Crop price index	Tree price level: Lowest	Base	Highest
		Annual crop	
70	−317	−317	−317
100	−86	−86	−86
140	223	223	223
		Hybrid poplar	
70	−336	−319	−302
100	−112	−95	−78
140	183	203	220
		Norway spruce	
70	−337	−332	−327
100	−113	−108	−103
140	185	190	195
		Red oak	
70	−333	−331	−329
100	−110	−107	−105
140	189	192	193

red oak (Table 2). The return for the TBI systems is dominated by the return to crop production. The difference in annualized return between cropping and the red oak TBI in this study is about one-half that reported by Dyack et al (1999) for black walnut intercropping.

For the price scenarios with the highest tree price and either crop price index 70 or 100, the hybrid poplar TBI has a higher annualized return than annual cropping. For all other price scenarios and for Norway spruce and red oak, the TBI systems are less profitable (Table 2). The annualized return for the three tree species is similar at the lowest tree price, at the base price hybrid poplar TBI is $13/ha higher and at the highest price hybrid poplar TBI is $25/ha higher than Norway spruce and red oak TBI systems. The selection of a fast growing hybrid tree that can be harvested at a younger age has a higher return. Overall, the return from the tree portion of TBI in this study is low because the present value of the harvested tree is about equal to the present cost of establishing the tree.

The profitability of TBI systems relative to annual cropping did not change appreciably with changes to the prices for trees or crops (Table 2). The difference in annual returns from the base tree price to the highest or to the lowest tree price ranges from $2/ha for red oak TBI to $17/ha for hybrid poplar TBI—a small percentage of the annualized return (Table 2). The return for Norway spruce and red oak TBI systems has limited sensitivity to tree price because harvest is many years into the future so the discounted value is low and tree revenue is a small percentage of the total return. At the base crop price, the break-even tree price for the TBI systems would need to be \$56, \$290 and \$1,265/m^3, respectively, for hybrid poplar, Norway spruce and red oak. The break-even hybrid poplar price is within a range of possible prices, but the break-even prices for Norway spruce and red oak are higher than the highest prices that could be expected for trees (Michigan Department of Natural Resources 2009; New York State Department of Environmental Conservation 2009; Maine Forest Service 2010). The value of the foregone annual crop production exceeds the annualized return from trees, especially red oak.

The presence of a carbon market for which producers of wood (trees) could receive payments for sequestering carbon would benefit the TBI systems. A carbon payment is evaluated as an increase in the price of trees, adjusting the price to a CO_2-equivalent basis. It is estimated that at the base prices for crops and trees the price of carbon would need to be \$26, \$330, and \$1,238/metric ton CO_2-equivalent, respectively, for hybrid poplar, Norway spruce, and red oak to be as profitable as annual cropping. The Norway spruce and red oak estimates are greater than those reported by Torres et al (2010) and used by Van Kooten et al (1995) for forest carbon. Carbon payments could result in hybrid poplar TBI being more profitable than annual cropping, but will not be a deciding factor for Norway spruce or red oak. At the highest tree price, carbon payment estimates are \$22, \$258 and \$1,107/metric ton CO_2-equivalent, respectively. High carbon prices will have little influence on Norway spruce and red oak TBI systems.

If society places a high value on trees in the agricultural landscape because of their ecological benefits, and is willing to pay for trees to be planted, there would be a need to develop a grant or subsidy program to encourage producers to adopt TBI systems. Without a program and with current prices, producers are unlikely to adopt TBI systems. The amount of the grant required for the TBI systems to be as profitable as annual cropping depends on the tree species and the expected prices of trees and crops. At the base prices for trees and crops, the estimated one-time grant at establishment required for TBI systems to break even is \$9, \$26, and \$32 per tree, respectively, for hybrid poplar, Norway spruce, and red oak (Table 3). The subsidy is less with higher tree prices and greater with higher crop prices. The subsidy would off-set the costs of establishment and maintenance, but if tree prices are low and crop prices high the grant would need to be greater than the cost of tree establishment and maintenance. The grant estimates do not include premiums that might be required because of greater uncertainty or operational changes required for TBI systems.

Sensitivity Analysis

In addition to price impacts, the sensitivity of the base price results are evaluated relative to tree spacing, row width, the discount rate, and technology growth in crop yield (Table 4). Spacing the trees within a row closer together to have more trees per unit land area reduces the annualized return for the TBI system (\$1 to \$16/ha). The annualized return for hybrid poplar TBI is about the same, but is lower for Norway spruce and red oak TBI systems because the present cost per tree exceeds the present value of the tree revenue, and with more trees the monetary loss increases. Planting trees closer together within the row did lower the per tree weed control cost, but pruning is a per tree cost that needs to be maintained. Reducing tree spacing within rows to harvest more trees per unit land area will have little impact.

Table 3. Grant required at establishment ($/tree) for the tree-based intercropping systems to break even with annual cropping, for three tree price and crop price index levels

Crop price index	Tree price level		
	Lowest	Base	Highest
		Hybrid poplar	
70	17	1	−14
100	24	9	−7
140	34	18	2
		Norway spruce	
70	23	17	11
100	32	26	20
140	43	38	33
		Red oak	
70	24	21	17
100	36	32	29
140	51	48	45

Table 4. Annualized return ($/ha) for changes in tree and row spacing, discount rate, and technology of crop yield, for annual crop production and three tree-based intercropping systems

Production system	Base	3m	15m	1%	8%	Tech
Annual crop	−86	−86	−86	−74	−96	96
Hybrid poplar	−95	−96	−158	−69	−123	81
Norway spruce	−108	−124	−245	−87	−132	68
Red oak	−107	−122	−239	−84	−132	69

3m, trees spaced at 3 m within row; 15m, row spacing of 15 m instead of 100 m; 1%, a lower discount rate; 8%, a higher discount rate; Tech, technology of crop yield (all crops) increases by 1% per year.

Reducing the width between rows of trees to 15 m will result in the TBI system being less profitable ($63 to $137/ha/year) than the wider row spacing (Table 4). Three factors contribute to the lower return. Reducing the row width increases the density of trees but the return from trees is negative or near zero. Second, average annual crop production is lower because there is proportionately more crop growing near tree rows and yield is lower because of competition with the trees for nutrients and sunlight, and more land is removed for tree production. Finally, field efficiency would be lower which increases crop production costs. Relatively narrow spacing of tree rows would not be an acceptable system to producers considering TBI systems.

Reducing the discount rate increases the annualized return from annual crop production ($12/ha) and the TBI systems ($21 to $26/ha) at the base crop prices (Table 4).

The low discount rate increases all annualized returns and the hybrid poplar TBI system is more profitable than annual cropping. A higher discount rate (8%) increases the gap between the annualized returns from annual cropping and TBI systems. The discount rate has limited impact on the relative annualized returns of the TBI systems, expect for hybrid poplar and a low discount rate.

During the life of the tree, the yield of the annual crops is expected to grow due to advances in cropping technology. Over a 60-year period, crop yield will nearly double when growing at 1% per year. The increased crop yield will increase the annualized return of all systems given constant crop prices, but the increase is proportionately greater for the annual cropping only system (Table 4). With increasing crop yield over time, TBI systems will need to further increase the profitability of the tree component to compete.

Tree growth rate will impact the annualized return for the TBI systems. The growth rate was not altered in the analysis, but the net effect of a change in growth would be very similar to a change in the price of trees. Assuming harvest age does not change, a change in tree growth will only change the volume of harvested wood and the revenue from wood—the same as if the tree price changed. A higher growth rate for hybrid poplar could result in the annualized return being higher for the hybrid poplar TBI than for annual cropping.

SUMMARY AND CONCLUSIONS

The profitability of cropping only and TBI systems are compared over a 60 year time horizon. Slower growing trees, especially hardwoods, require many years of growth until harvest. The annualized return from annual cropping and three TBI systems is evaluated using a grid of feasible crop and tree prices because prices and quality of marketable trees vary. The impact of the cost of establishing and maintaining trees, tree spacing, the discount rate, carbon payments, and technology are also evaluated.

The annualized return for all systems is very sensitive to crop price because crop production is the main source of revenue for all systems. The TBI systems provide cash flow and income while the trees are growing, but income is reduced because of lower crop yield, land is removed from cropping, and the net return from trees is low. There is generally a net cost of TBI systems because lost crop revenue from land allocated to produce trees plus the reduced crop yield adjacent to the tree rows is greater than the tree revenue. Higher tree prices will reduce the revenue gap, but only hybrid poplar TBI will be profitable enough at high tree prices to eliminate the gap. Payments for carbon sequestration reduce the returns gap between TBI systems and annual cropping, but would only have an impact on hybrid poplar TBI using reasonable carbon prices.

The cost of planting and maintaining trees in a TBI system is high relative to the present value of the trees at harvest. The main cost is labor for pruning, however, pruning is required otherwise trees will be low quality and priced low (e.g., pulpwood), further reducing the return from TBI systems. Since tree maintenance is required, alternative technologies for tree maintenance and pruning need to be developed to reduce these costs and to increase TBI returns. Reducing tree maintenance cost is one component of TBI systems required to increase returns, but alone will not guarantee the system will have higher returns than annual cropping.

The lower annualized return from TBI systems, when compared to annual cropping, prevails with changes to tree spacing, tree row width, and growth in annual crop yield. A low discount rate (1%) will result in the hybrid poplar TBI having a higher annualized return than annual cropping. However, most producers would not have such a low discount rate. Changes to the TBI system and the use of planting grants or subsidies will be required for the TBI systems to be competitive with annual cropping. Grants for tree establishment would be low ($9/tree) for hybrid poplar but high ($32/tree) for red oak at the base prices.

The concept of TBI systems for temperate regions must be re-evaluated for conditions such as those of southern Ontario. This study used land that was productive for annual cropping, and a major cost of TBI systems is lost crop production. Implementing the system on land that is lower quality for crop production would reduce the revenue lost from crop production, though this impact will not alter the relative profitability. The benefit of planting trees could also be expanded to include environmental benefits, including carbon payments, which would require a policy to pay for the planting of trees. Tree row location could follow the contour of the land or of creeks and gullies, instead of straight rows, providing soil conservation and water quality benefits, plus removing less land from annual cropping. Techniques to reduce tree maintenance costs need to be evaluated, from mechanical pruning to planting trees in dense multiple rows to force the trees to grow upward requiring less pruning. An integrated system needs to be developed for temperate regions that increase the benefits and reduces the costs of TBI systems before they will become widely adopted.

ACKNOWLEDGMENTS

We would like to thank Andy M. Gordon and Naresh V. Thevathasan for providing historical long-term data from the Guelph Agroforestry Research Station, Charles Beaudette for the tree growth projections, Anil Graves for assistance with the Farm-SAFE model, Jose Barbieri for additional model runs, and anonymous reviewers for their constructive comments.

REFERENCES

Akbar, G., M. Ahmad, S. Rafique and K. N. Babar. 1990. Effect of trees on the yield of wheat crop. *Agroforestry Systems* 11: 1–10.

Callistus, K. P. O. O., J. R. Spence and A. Keddie. 1999. Maize stem borer colonization, establishment and crop damage levels in a maize-leucaena agroforestry system in Kenya. *Agriculture, Ecosystems & Environment* 76: 1–15.

Campbell, G. E., G. J. Lottes and J. O. Dawson. 1989. An analysis of agroforestry systems in Illinois. University of Illinois Agricultural Experiment Station Bulletin No. 89–92.

Centre for Northern Agroforestry and Afforestation (CNAA). 2011. http://www.saskagroforestry.ca/index.php?pid = 51 (accessed July 18, 2011).

Countryman, D. W. and J. C. Murrow. 2000. Economic analysis of contour tree buffer strips using present net value. *Journal of Soil and Water Conservation* 55: 152–60.

Dyack, B., K. Rollins and A. Gordon. 1999. A model to calculate *ex ante* the threshold value of interaction effects necessary for proposed intercropping projects to be feasible to the landowner and desirable to society. *Agroforestry Systems* 44: 197–214.

Ellis, F. 1998. Household strategies and rural livelihood diversification. *Journal of Development Studies* 35 (1): 1–38.

Ge, Z.-M. 2011. Effects of climate change and management on growth of Norway spruce in boreal conditions—an approach based on ecosystem model. Ph.D. dissertation, University of Eastern Finland, Yliopistokatu. http:/www.metla.fi/dissertations/df122.htm (accessed September 19, 2011).

Gold, M. A. and J. W. Hanover. 1987. Agroforestry systems for the temperate zone. *Agroforestry Systems* 5: 109–21.

Gordon, A. M., S. M. Newman and P. A. Williams. 1997. Temperate agroforestry: an overview. In *Temperate Agroforestry Systems*, edited by A. M. Gordon and S. M. Newman, pp. 1–18. Wallingford, UK: CAB International.

Grant, R. 2011. The Ecosys Modelling Project. http://www.ales.ualberta.ca/rr/Research/EcosysModellingProject.aspx (accessed March 30, 2011).

Graves, A. R., P. J. Burgess, F. Liagre, J.-P. Terreaux and C. Dupraz. 2005. Development and use of a framework for characterising computer models of silvoarable economics. *Agroforestry Systems* 65: 53–65.

Hoekstra, D. A. 1983. An economic analysis of a simulated ally cropping system for semi-arid conditions, using micro computers. *Agroforestry Systems* 1: 335–45.

Horwith, B. 1985. A role for intercropping in modern agriculture. *BioScience* 35 (5): 286–91.

Johnson, P. S., S. R. Shifley and R. Rogers. 2002. *The Ecology and Silviculture of Oaks*. Wallingford, UK: CABI Publishing.

Khan, G. S. and J. H. Ehrenreich. 1994. Effect of increasing distance from *Acacia nilotica* trees on wheat yield. *Agroforestry Systems* 25: 23–29.

Khybri, M. L., R. K. Gupta, S. Ram and H. P. S. Tomar. 1992. Crop yields of rice and wheat grown in rotation as intercrops with three tree species in the outer hills of Western Himalaya. *Agroforestry Systems* 17: 193–204.

Kurtz, W. B., S. E. Thurman, M. J. Monson and H. E. Garrett. 1991. The use of agroforestry to control erosion—financial aspects. *The Forestry Chronicle* 67 (3): 254–57.

Lelle, M. and M. Gold. 1994. Agroforestry systems for temperate climates—lessons from roman Italy. *Forest & Conservation History* 38: 118–26.

Maine Forest Service. 2010. 2009 Stumpage prices by Maine county, all counties. http://www.maine.gov/doc/mfs/pubs/pdf/stumpage/09stump.pdf (accessed January 25, 2011).

Mathews, S., S. M. Pease, A. M. Gordon and P. A. Williams. 1993. Landowner perceptions and adoption of agroforestry in southern Ontario, Canada. *Agroforestry Systems* 21: 159–68.

Michigan Department of Natural Resources. 2009. Average stumpage price report for 01/01/2009 to 12/31/2009. http://www.michigandnr.com/ftp/forestry/tsreports/StumpagePriceReports/12_Month_Stumpage_Price_Reports/2009_Stumpage_Price_Reports/4th_Qtr_Oct_2009.pdf (accessed January 25, 2011)

Nair, P. K. R. 2007. The coming age of agroforestry. *Journal of the Science of Food and Agriculture* 87 (9): 1613–19.

New York State Department of Environmental Conservation. 2009. Stumpage price report. http://www.dec.ny.gov/docs/lands_forests_pdf/spr2009summer.pdf (accessed January 25, 2011).

Ontario Ministry of Agriculture, Food and Rural Affair (OMAFRA). 2008. Publication 60 2008 field crop budgets. http://www.omafra.gov.on.ca/english/busdev/facts/pub60.htm (accessed December 16, 2010).

Ontario Ministry of Agriculture, Food and Rural Affair (OMAFRA). 2010. Field crop statistics. http://www.omafra.gov.on.ca/english/stats/crops/ (accessed December 15, 2010).

Ontario Ministry of Agriculture, Food and Rural Affair (OMAFRA). 2011. Biomass combustion. http://www.omafra.gov.on.ca/english/engineer/ge_bib/biomass.htm (accessed July 19, 2011).

Palma, J. H. N., A. R. Graves, P. J. Burgess, K. J. Keesman, H. van Keulen, M. Mayus, Y. Reisner and F. Herzog. 2007. Methodological approach for the assessment of environmental effects of agroforestry at the landscape scale. *Ecological Engineering* 29: 450–62.

Pattanayak, S. K., D. E. Mercer, E. Sills and J. Yang. 2003. Taking stock of agroforestry adoption studies. *Agroforestry Systems* 57: 173–86.

Peichl, M., N. V. Thevathasan, A. M. Gordon, J. Huss and R. A. Abohassan. 2006. Carbon sequestration potentials in temperate tree-based intercropping systems in southern Ontario, Canada. *Agroforestry Systems* 66: 243–57.

Puri, S. and K. S. Bangarwa. 1992. Effects of trees on the yield of irrigated wheat crop in semi-arid regions. *Agroforestry Systems* 20: 229–41.

Reynolds, P. E., J. A. Simpson, N. V. Thevathasan and A. M. Gordon. 2007. Effects of tree competition on corn and soybean photosynthesis, growth, and yield in a temperate tree-based agroforestry intercropping system in southern Ontario, Canada. *Ecological Engineering* 29: 362–71.

Rivest, D., A. Cogliastro, R. L. Bradley and A. Olivier. 2010. Intercropping hybrid poplar with soybean increases soil microbial biomass, mineral N supply and tree growth. *Agroforestry Systems* 80: 33–40.

Scherr, S. J. 1995. Economic factors in farmer adoption of agroforestry: Patterns observed in Western Kenya. *World Development* 23 (5): 787–804.

Singh, H. P., R. K. Kohli and D. R. Batish. 1998. Effect of poplar (*Populus deltoids*) shelterbelt on the growth and yield of wheat in Punjab, India. *Agroforestry Systems* 40: 207–13.

Torres, A. B., R. Marchant, J. C. Lovett, J. C. R. Smart and R. Tipper. 2010. Analysis of the carbon sequestration costs of afforestation and reforestation agroforestry practices and the use of cost curves to evaluate their potential for implementation of climate change mitigation. *Ecological Economics* 69: 469–77.

Toyne, P., C. O'Brien and R. Nelson. 2002. The timber footprint of the G8 and China: Making the case for green procurement by government. Report prepared for the World Wildlife Fund International, Gland, Switzerland, June. http://www.wwf.org.uk (accessed March 19, 2011).

Van Kooten, G. C., C. S. Binkley and G. Delcourt. 1995. Effect of carbon taxes and subsidies on optimal forest rotation age and supply of carbon services. *American Journal of Agricultural Economics* 77: 365–74.

Van Kooten, G. C. and H. Folmer. 2004. *Land and Forest Economics*. Cheltenham, UK: Edward Elgar.

van Oosten, C. 2006. Hybrid poplar crop manual for the Prairie provinces. Report prepared for the Saskatchewan Forest Centre, Nanaimo, BC.

Young, A. 1997. *Agroforestry for Soil Management*, 2nd ed. Wallingford, UK: CAB International.

Zsuffa, L., H. W. Anderson and P. Jaciw. 1977. Trends and prospects in Ontario's poplar plantation management. *The Forestry Chronicle* 53 (4): 195–200.