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THE ECONOMICS OF ECOSYSTEM SERVICES OF TREE-BASED INTERCROPPING SYSTEMS

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ABSTRACT

The paper aims to determine the potential environmental benefits of multifunctional tree-based intercropping (TBI) systems. Here we evaluate ten ecosystem services using a mix of mathematical models for quantification and economic valuation. The results reveal a total annual margin of 2 558 CAN\$ $ha^{-1}y^{-1}$. The economic value of combined non-market services is 1 634 CAN\$ $ha^{-1}y^{-1}$, which is higher than the value of marketable products (i.e. timber and agricultural products). The present value of the services for a rotation of 40 years is 54 782 CAN\$ ha^{-1}, about a third of which is contributed by agricultural products. Water quality regulation ranked highest among the non-market benefits followed by air quality maintenance, soil quality regulation, biological control, and pollination.

Keywords: tree-based intercropping systems, economic valuation, ecosystem services, benefit transfer.

INTRODUCTION

It is increasingly recognized that tree planting on agricultural land through agroforestry systems provides diverse ecological services and can mitigate the adverse impacts of extreme weather events (Limoges 2009; Eco Resources 2009). It helps fight against wind erosion, reduce the thermal amplitude, increase water infiltration and encourage pollinator and predator abundance (Griffin et al. 2008) compared to conventional farming systems. Various studies have shown that diversified agricultural and forestry systems provide more services, including higher productivity, than those with less diversity (Paquette and Messier 2011, Duffy 2009), especially in the most intensive human systems (Bennett and Balvanera 2007).

Although little known in Canada, tree-based intercropping systems (TBI) are well established in Europe, the United States and China, where various simulations have shown that they compare favorably, both in terms of productivity and economic profitability, to monoculture and conventional plantations (Graves et al. 2007). The intercropping systems indeed respond to many environmental issues. They increase microbial biomass and earthworm populations (Price et al. 1999), thereby improving soil fertility. The presence of roots can reduce surface runoff and soil erosion. The deep roots of trees can also recover certain nutrient leaching beyond cultures, as has been revealed in studies in Saint-Rémi, Québec (Lacombe 2009).

The intercropping systems may also play a major role in carbon sequestration and reducing atmospheric concentrations of other greenhouse gases, such as nitrous oxide (N_2O). The use of some fast-growing species such as the hybrid poplar can increase the potential of fixing atmospheric carbon (Peichl et al. 2006). Some studies in eastern North America have shown that the diversity and abundance of predator populations were higher in these systems than in agricultural monocultures, which may limit the use pesticides (Howell 2001). The same is true of avian diversity, as has been observed in Ontario (Thevathasan and Gordon 2004).

In this article we evaluate several important ecosystem services provided by tree-based intercropping systems. The overall goal is to calculate the monetary value of those services and evaluate economic performance of the system when non-market benefits are included in benefit-cost equation.

ANALYTICAL FRAMEWORK

The overall objectives of this paper include a marginal analysis of economic value of ecosystem services as well as an evaluation of the present value of future provision of the services for a period of 40 years. We made use of a 4-step analytical framework in this study. In the first step, we identified the full suits of ecosystem services, which are meaningful in the context of our study. In doing so we made an inventory of all possible Ecosystem Goods and Services (EGS) from agroforestry; then based on consultation with expert colleagues and literature reviews we short-listed 10 services for analysis. In the second step, we quantified the service providing units and their relationships with the provision of services. In the third step, we attempted economic valuation of each of the ecosystem services. The final step involved extrapolation of results and examining trade-offs.

We used a variety of mathematical models for quantification of various ecosystem services and their economic valuation. In some instances we used already existing models and equations (e.g. for soil quality maintenance), but in most instances we modified those to fit into our needs. There are several TBI experimental sites established in different parts of Canada. We heavily depended on the data published from the experiments in various TBI sites in Québec and Guelph. In some cases, however, we also transferred data from other study sites situated elsewhere. Details of experimental set up, species composition, management regime and results on TBI systems in Canada can be found in Rivest et al. (2010), Thevathasan and Gordon (2004), Peichl et al. (2006) and Oelbermann et al. (2006).

The final list of ten ecosystem services includes: soil quality regulation (ES_1), water quality regulation (ES_2), climate regulation (ES_3), air quality maintenance (ES_4), pollination (ES_5), nutrient mineralization (ES_6), windbreak (ES_7), biological control (ES_8) and provision of agriculture (ES_9) and timber products (ES_{10}). We use the following sets of general equations for economic analysis:

$$ES_{TEV} = \sum ES_{n} = \sum ES_{non\text{-}market} + \sum ES_{market} \quad (1)$$

Where, n=1, 2, 3… 10
TEV= Total economic value
$\sum ES_{non\text{-}market} = \sum ES_{1\text{-}8}$ and
$\sum ES_{market} = \sum ES_{9\text{-}10}$

A summary of various indicators can be found in Table 1. In the following we provide an overview of the method used for the quantification and valuation of the carbon sequestration service in a climate regulation context, along with economic data, assumptions and results. This is for the purpose of this conference proceedings; the methodology and results associated with the other services will be available in more detail in conference presentation and in future publications.

Table 1: Indicators of ecosystem services of tree-based intercropping systems

TBI Ecosystem services	Indicators	Indicator quantity
Soil quality	Earthworms	2.5 ton ha^{-1} y^{-1}
	Invertebrates	1 ton ha^{-1} y^{-1}
Water quality	N decontamination	11 kg $ha^{-1}y^{-1}$
	P decontamination	7.5 kg $ha^{-1}y^{-1}$
	Sediment dredging	-
Biological control	Pest infestation levels	-
Air quality	Pollutant removal	1.67 kg/tree
Wind break	Productivity change	1.47 ton ha^{-1}
Nutrient Mineralization	N input	7 kg $ha^{-1}y^{-1}$
	P input	11.42 kg $ha^{-1}y^{-1}$
	K input	21.22 kg $ha^{-1}y^{-1}$
	Change in yield (timber)	0.162 m^3 $ha^{-1}y^{-1}$
Climate regulation	Carbon sequestration	8.3 Mg CO_{2e} $ha^{-1}y^{-1}$
Pollination	Yield changes (crop)	1.47 ton ha^{-1} yr^{-1}
Timber provisioning	Annual yield	3.5 m^3 $ha^{-1}y^{-1}$
Agriculture provisioning	Annual yield	1.47 t $ha^{-1}y^{-1}$

The Economics of Carbon Sequestration

From an agroforestry perspective, carbon sequestration is made possible through the removal of atmospheric CO_2 and its transfer to both above and below ground biomass. While above ground components include various tree parts (stems, leaves) as well as the alley crops, below ground biomass includes roots, soil organisms and soil organic carbon.

The following is one of the equations employed for the estimation of the carbon sequestration potential of agroforestry trees (a 0.5 ratio of C per unit biomass is used here) (Hernandez et al. 2008):

CO_2 (kg/ha) = [(total biomass (m^3/ha) x bone dry density of wood (kg dry/m^3)) x Carbon/dry matter (kg/kg)] x CO_2/Carbon (kg/kg)] + C contained in the litter and dead wood (kg/ha) (2)

Another way of estimating C content *in situ* is to use remote sensing data. In this case species-specific allometric equations which were developed using biophysical properties of trees for a given environment are used for estimation of C stocks. Although this method is fairly common for large scale estimation in forests, it has had limited use in agroforestry (Nair 2011).

In agroforestry systems a considerable portion of C which is added to soil through litter falls goes back to the atmosphere through soil respiration. Further, an amount of C, along with other nutrients, is leached out through soil profiles (Peichl *et al*. 2006). Therefore, a simple representation of an estimation of net carbon sequestration from an agroforestry plot can be stated as:

Net carbon sequestration = Above ground C sequestration + Below ground C sequestration – Carbon liberation (3)

For operational purpose a more detailed breakdown of above equation can be written as:

$$NCS = (B_t + B_r + B_l + CR + SOC) - (C_r + C_l) + C_{N2O} \quad (4)$$

where, NCS, Net Carbon Sequestered; B_t, and B_r, Carbon stored in tree trunk biomass (including branches and leaves) and roots respectively; B_l, Carbon stored in litter fall; CR, Carbon stored in crop residues; SOC, Carbon pool in soil; C_r, Carbon returned back through soil respiration; C_l, Carbon lost through leaching into soil profiles; C_{N2O}, CO_2 equivalent avoided emission of N_2O.

Several valuation methods exist to estimate the economic value of carbon sequestration. Most relevant methods would be the social cost of carbon, carbon tax, emission trading, investments in alternative technologies, but only the social cost of C sequestration is presented here.

Elevated greenhouse gas concentrations in the atmosphere will cause societal damage in a number of ways including property damage due to elevated sea-levels, increased occurrence of extreme weather events, decrease in crop yields, damage in fisheries and increased health hazards. The Social Cost of Carbon (SCC) represents the marginal cost of emitting an additional unit of CO_2 into the atmosphere, i.e. the estimate of monetary value of damage resulting from CO_2 emissions. Thus SCC can also be referred to as Damage Cost Avoided. The societal value of carbon sequestration can be mathematically represented by the following function (Conte et al. 2011):

$$VAD_{xtT} = \sum_{z=t}^{T-1} \frac{\Delta C_{x,z,z+1}\, SCC_{z+1}}{(1+r)^{z-1}} \qquad (5)$$

Where, VAD_{xtT} is the present value of all damage avoided (or additional damage when negative), due to carbon sequestration on x land parcel from time t to T. In the right hand side $\Delta C_{x,z,z+1}$ is the carbon sequestered over the rotation period (between time z and z+1), SCC_{z+1} is the SCC in year z+1 and r is the discount rate. In our analysis the duration of the rotation of TBI is 40 years and SCC is assumed to increase with time as additional carbon will be emitted in the future and as societal willingness to pay should increase due to income increase (Pearce, 2003). If δ is the rate of increase then $SCC_t = SCC_0 (1+\delta)^t$; we use δ=0.04 assuming an increase of SCC at a rate of 4% (Yohe et al 2007; Johnson et al 2012). Thus the function can be re-written as:

$$VAD_s = \sum_{t=0}^{t=39} \{SCC_0\,(1+\delta)^t\} \frac{\Delta C_t}{(1+r)^t} \qquad (6)$$

Where: VAD_s is the value of damage avoided for scenario s, t is the rotation period, r is the discount rate, ΔC_t is the change in carbon sequestration during time t, SCC_0 is the initial SCC.

Choosing a SCC can be challenging since we cannot sensibly calculate an SCC without assuming that future emissions and stocks following a specified path. Different specified paths will present different SCC (Stern, 2007). As a result, Conte et al. (2011) suggested the use of an average or median value. There are several estimates of SCC in the literature. Yohe et al. (2007) estimates SCC to be ranging from as low as $10 to as high as $350 with a mean of $43 and a standard deviation of $83 per ton of carbon sequestered. This mean value of $43 was used in our analysis. Any observed differences between SCC and the price of carbon in markets would not be surprising. Conte et al. (2011) argued that there is no ‘functional relationship’ between these two values given that in a regulated market, the price of carbon reflects producers’ cost of sequestration and buyers’ willingness to pay, while SCC reflects the damage cost that is avoided through carbon sequestration. Similarly, SCC should differ from the price of other measures such as carbon taxes imposed in various jurisdictions since the tax rates are designed to meet local or regional needs.

RESULTS

The total annual margin of TBI ecosystem services has been estimated to be \$2 558 $ha^{-1}y^{-1}$. The economic value of combined non-market services is \$1 634 $ha^{-1}y^{-1}$, which is higher than the value of marketable products (i.e. timber and agricultural products). The economic return from agriculture in monoculture is \$1 110 $ha^{-1}y^{-1}$, whereas the return from agriculture in TBI is \$784 $ha^{-1}y^{-1}$. Table 3 presents breakdown of the marginal value of ecosystem services stemming from TBI.

An analysis of the present value of future benefits of ecosystem services for a rotation of 40 years was also carried out and the results suggest that provision of agricultural products ranked highest ($16 287 ha^{-1}) among the ecosystem services followed by water quality ($11 581 ha^{-1}), air quality ($9 510 ha^{-1}), soil quality ($3 631 ha^{-1}), biological control (1 556 ha^{-1}) and pollination ($500 ha^{-1}) (Table 3). Total economic value (TEV) of all the ecosystem services for the rotation period was $54 782 ha^{-1}, only a third of which is contributed by agricultural products. Total non-market benefits constitute two-thirds of the TEV i.e. twice as high as the provisioning services combined (i.e. timber and agriculture) (Table 4).

Table 3: Marginal and present values of TBI ecosystem services

Ecosystem services	Marginal values ($ ha^{-1}y^{-1})	NPVs ($ ha^{-1})
Soil quality maintenance	175	3 631
Air quality regulation	462	9 510
Water quality regulation	558	11 581
Carbon sequestration	356	7 346
Pollination services	24	500
Windbreak	39	813
Nutrient mineralization	31	652
Biological control	75	1 556
Ag provisioning	784	16 287
Timber provisioning	140	2 905

We do not have precise estimates on the number of available farms that can be converted into agroforestry in Québec. Oelbermann et al. (2006) stated that 40% of Canada's approximate 7M ha marginal lands are eligible to be converted into agroforestry, whereas spatial analysis done by Hernandez et al (2008) showed that a 34% increase in wooded area in the L'Ormière River watershed in Québec is possible through agroforestry practices. If we assume in a conservative manner that 20% of Québec's 1.93 M ha croplands can be converted to TBI, then the potential marginal benefits of TBI ecosystem services equivalents to about $5 billion per year. This land area excludes summer fallow land (4 288 ha), tame or seed pasture (147 387 ha), natural land for pasture (158 602 ha) and other land areas including Christmas tree area, woodlands and wetlands (>1.2 M ha) (Statistics Canada 2006).

Table 4: Ecosystem Services in Various Bundles

Bundles	Marginal values ($ $ha^{-1}y^{-1}$)	NPVs ($ ha^{-1})
Agriculture in Monoculture	1 110	23 046
Agriculture in TBI	784	16 287
TBI Provisioning	924	19 192
TBI Non-market	1 634	35 590
Total Economic Value (TEV)	2 558	54 782

DISCUSSION AND CONCLUSIONS

There are several limitations to the biophysical and economic estimates used in our study. We suffered from the lack of sufficient quantitative data in the existing literature. Certain relevant studies, such as in tropical agroforestry systems, have limited use in this study because of a completely different environmental setting. In contrast to the limitations associated with the transfer of economic data from other studies, one of the strengths of our approcah is that we depended heavily on the biophysical data from 'local' experimental sites in Canada during quantification process. Secondly, it takes for an ecosystem many years to develop interactions among its various components, and therefore it may take years to start realizing benefits after establishing a system. The same is true for an agroforestry system. In this study we assume a uniform distribution of the provision of the ecosystem services throughout the rotation period, which is certainly not the case in reality. However, addressing such complex issues is out of the scope of this study.

Despite the inherent caveats and uncertainties in quantification and valuation of goods and services this study provides a reasonable estimate of the economic contribution of tree-based intercropping systems to society's welfare. The benefits are substantial, however, are realized at the cost of farmers' private benefits due to reduced provisioning services and the expected cost of adoption and maintenance of this new technology for a longer time frame. While it is impractical to suggest that all agricultural lands should be converted to agroforestry, a land inventory can determine the areas suitable for TBI based on environmental and technical feasibility and the willingness of the farmers in doing so. Therefore, adoption and expansion of TBI in Québec as well as in other parts of Canada is certainly worthy of discussion in policy forums.

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REFERENCES

Bennett, E. M. and Balvanera, P. 2007. The future of production systems in a globalized world. Frontiers in Ecology and the Environment 5(4): 191-198.

Conte, M., Nelson, E., Carney, K., Fissore, C., Olwero, N., Plantnga, A.J., Stanley, B. and Ricketts, T. 2011. Terrestrial Carbon Sequestration and Storage. In: Kareiva, P., Tallis, H., Ricketts, T.H., Daily, G.C. and Polasky, S. (eds). Natural capital: theory and practice of mapping ecosystem services. Oxford University Press, New York, NY, pp. 111–128.

Éco-Ressources, CEPAF and Activa-Environnement 2009. Biens et services écologiques et agroforesterie : l'intérêt du producteur agricole et de la société. Rapport final. Agriculture et agroalimentaire Canada.

Graves, A. R., Burgess, P.J., Palma, J.H.N., Herzog, F., Moreno, G., Bertomeu, M., Dupraz, C., Liagre, F., Keesman, K., van der Werf, W., Koeffeman de Nooy, A. and van den Briel, J.P. 2007. Development and application of bio-economic modelling to compare silvoarable, arable, and forestry systems in three European countries. Ecological Engineering 29: 434-449.

Griffin, J. N., de la Haye, K. L., Hawkins, S. J., Thompson, R. C. and Jenkins, S.R. 2008. Predator diversity and ecosystem functioning: density modifies the effect of resource partitioning. Ecology 89(2): 298-305.

Howell, H.D. 2001. Comparison of arthropod abundance and diversity in intercropping agroforestry and corn monoculture systems in southern Ontario. M.Sc., University of Toronto.

Lacombe, S., Bradley, R.L., Hamel, C. and Beaulieu, C. 2009. Do tree-based intercropping systems increase the diversity and stability of soil microbial communities? Agriculture, Ecosystems and Environment 131: 25-31.

Limoges, B. 2009. Biodiversité, services écologiques et bien-être humain. Le naturaliste canadien 133.

Nair, P.K.R. 2011. Carbon sequestration studies in agroforestry systems: a reality-check. Agroforest. Syst. DOI 10.1007/s10457-011-9434-z.

Oelbermann, M., Voroney, R. P., Thevathasan, N. V., Gordon, A. M., Kass, D. C. L. and Schlönvoigt, A. M., 2006. Soil carbon dynamics and residue stabilization in a Costa Rican and southern Canadian alley cropping system. Agroforest. Syst. 68(1): 27–36.

Paquette, A. and Messier, C. 2011. Biodiversity effect on forest productivity increases from temperate to boreal forests. Global Ecology and Biogeography 20(1): 170–180.

Peichl, M., N.V. Thevathasan, A.M. Gordon. 2006. Carbon sequestration potentials in temperate tree-based intercropping systems , southern Ontario , Canada. *Agroforestry Systems* 66: 243–257.

Pearce, D. 2003. The social cost of carbon and its policy implications. Oxford Rev. Econ. Pol. 19(3): 362-384.

Price, G. W., & Gordon, A. M. (1999). Spatial and temporal distribution of earthworms in a temperate intercropping system in southern Ontario , Canada, 141–149.

Rivest, D., Cogliastro, A., Bradley, R. L. and Olivier, A. 2010. Intercropping hybrid poplar with soybean increases soil microbial biomass, mineral N supply and tree growth. Agroforest. Syst. 80(1): 33–40.

Sandhu, H. S., Wratten, S. D., Cullen, R., & Case, B. (2008). The future of farming: The value of ecosystem services in conventional and organic arable land. An experimental approach. *Ecological Economics*, *64*(4), 835–848. doi:10.1016/j.ecolecon.2007.05.007

Stern, N. 2007. The economics of climate change: The Stern review. Cambridge University Press, ISBN: 9780521700801

Thevathasan, N.V. and Gordon, A. 2004. Ecology of tree intercropping systems in the North temperate region: Experiences from southern Ontario, Canada. Agroforest. Syst. 61: 257–268.

Yohe, G.W., R.D. Lasco, Q.K. Ahmad, N.W. Arnell, S.J. Cohen, C. Hope, A.C. Janetos, R.T Perez. 2007. Perspectives on climate change and sustainability. In: Parry, M.L., Canziani, O.F., Palutikof, J.P., van der Linden, P.J., Hanson, C.E. (Eds.), Climate Change 2007: Impacts, Adaptation and Vulnerability: Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK, pp. 811–841.