Agriculture and Agri-Food Canada
Agriculture et Agroalimentaire Canada

HARDWOOD INTERCROPPING SYSTEMS

Combining wood and agricultural production while delivering environmental services

Canada

Introduction

The evolution of agriculture in eastern Canada over the past half-century has been characterized by a spectacular gain in productivity with, in many cases, a concurrent but gradual exclusion of trees from croplands, particularly because of large farm mechanization. Combined with the intensification of agriculture, this decrease in forest area has resulted in a variety of environmental problems, including decreases in soil fertility, soil erosion, an increase in diffuse pollution and a reduction in biodiversity, all of which has resulted in an overall loss in terms of the quality of the rural landscape. In this context, the re-establishment of the tree as a fundamental element of the agricultural agro-ecosystem seems like one judicious solution to mitigating the impacts of intensive agriculture. Experiments conducted in eastern Canada and other temperate regions of the world have shown that intercropping systems (ICS) constitute a promising avenue for strategically reintroducing the ecological functions of the tree into an agricultural environment (Photo 1). Planting hardwood trees in such systems can also meet the need to increase the production of quality wood that is indispensable to the wood-processing and furniture-manufacturing industries, while at the same time delivering a variety of positive environmental services.

Photo 1: Intercropping systems consist of planting rows of widely spaced trees and cultivating agricultural crops in the 'alleys', between the tree rows.

This factsheet provides an overview of various types of temperate ICS observed in Canada and around the world and an account of current knowledge with respect to their productivity and associated environmental benefits. The technical itinerary necessary for the development of a successful intercropping system is then discussed: choice of tree species, their spacing, maintenance, and choice of crops and their management.

Modernization of traditional types of association between trees and crops

In temperate regions of the world, various traditional types of tree-crop associations have remained very much alive. In some countries, such as Italy, France and Greece, intercropping extends over several tens of thousands of hectares. Generally, 'intercropped' crops are cereal crops (e.g. corn, wheat, barley) and oilseed crops (e.g. soybean, sunflower); these crops are grown in the 'alleys' between the tree rows while the trees (e.g. walnut) are cultivated in linear hardwood plantations. Crops and plantations can share the same physical space until shade production from the tree inhibits crop growth (up to 15 to 20 years (Photo 2)), although in some systems (e.g. winter wheat - *Paulownia* in China (Wu and Zhu, 1997); cotton - pecan in southern United States (Zamora *et al.*, 2008)), this is not a major problem.

Recently, various initiatives aimed at increasing hardwood production while maintaining farming activity on rural lands have enabled new systems to be developed. In Europe, and especially in France, trees such as walnut and hybrid poplar have been grown in association with crops such as wheat, colza and various forage species (Photo 3). In Canada, the first experimental trials were established almost 25 years

Photo 2: Soybean-walnut intercropping at Dauphine, France. In this region, the practice of intercropping systems dates back to antiquity.

ago at Guelph, Ontario. A variety of hardwood trees (red oak, silver maple, sugar maple, American ash, black walnut, hybrid poplar) continue to be grown with a variety of crops (e.g. corn, beans, wheat) (Photo 4). In Quebec, the first experimental field plots were established six years ago. Soybeans, canola, buckwheat and a variety of cereal plants such as barley, oats, rye and wheat have been intercropped in mixed plantations of valuable hardwoods and hybrid poplars (Photo 5).

Photo 3: Intercropping hybrid walnut and colza at the experimental station at Restinclières, Hérault, France.

Photo 4: Intercropping American white ash trees with wheat at the agroforestry research station at Guelph, Ontario.

Photo 5: Intercropping hybrid poplar with oats at St-Paulin, Quebec.

Trees and intercrops: do they work well together?

The effect of intercropping on tree growth

For foresters, associating crop production with tree production is not a common custom. Can trees take advantage of their proximity to intercrops and benefit indirectly from the care (e.g. weeding, fertilization) that these crops receive? Although focused only on young trees, recent experiments conducted in Quebec seem to indicate that this is the case. It was observed that after three to four years of growth, above-ground biomass of various hybrid poplar clones associated with various annual intercrops was, on average, 40% greater than that observed when repeated harrowing was undertaken between tree rows, a practice commonly used in intensive poplar monoculture (Rivest *et al*., 2009) (Photo 6). According to this study, improved tree growth comes notably: i) from stimulating the soil microbial biomass and mineralizing nitrogen through intercropping; and ii) from recovery by the tree roots of a significant proportion of fertilizer residues used in intercropping, which improves their mineral nutrition. Similar results have been found in France (Chifflot *et al*., 2006).

Photo 6: On this experimental site at St-Remi, Quebec, hybrid poplars grown with a soybean intercrop for 3 years (left) have higher biomass than hybrid poplars grown in a non-intercropped condition (right). Note that the system also included other hardwood trees (centre).

The type of crop associated with the trees is very significant, however. For example, research conducted in Ontario showed that young trees were taller in the presence of corn or soybeans than in that of barley, a crop that creates competition for water early in the growing season (Williams and Gordon, 1992). Nevertheless, when associated plants are well chosen, all indications are that trees planted in ICS generally have somewhat shorter rotations than those in forest stands. As they are planted in large competition-free zones, trees planted in an ICS develop more extended canopies, which accelerates their stem radial growth. If they are not pruned regularly, butt logs at final harvest could therefore be shorter, but of greater volume than those harvested in natural forests (Cabanettes *et al*. 1999).

The effect of trees on intercrop yield

Farmers are often more familiar than foresters with tree-crop associations (e.g. shelterbelts and windbreaks). However, to date, the development of ICS whereby rows of trees are 'inserted' into crop production areas remains a rare practice in the agriculture sector. It is a well-known fact that young hardwoods generally cause only a negligible loss of productivity in associated crops; this effect could even be beneficial in some cases. However, as time passes, intercrops could suffer from competition with trees for light, water and nutrients in the soil. In Quebec and Ontario, studies have shown that the yield losses of crops such as soybeans and corn are generally a result of tree shade (Reynolds *et al*. 2007; Rivest *et al*. 2009). Several options can help to control competition for light. These include: i) giving preference, from the planting stage onward, to wide spacing between trees and within and between rows; ii) opting for tree species and clones that minimize shade (high porosity and low canopy width); iii) giving preference to thinning and continued pruning; and iv) positioning the tree rows along a north-south axis.

The effect of shade is not always a decrease in the yield of the associated crop. Some forage plants (e.g. tall fescue) can, under partial shade (i.e. 50%), produce a total biomass and protein content greater than those observed in full light (Lin *et al*. 1999). In Ontario, Clinch *et al*. (2009) also observed improved performance of a willow crop under moderate shade compared with the same crop grown in monoculture (Photo 7).

Photo 7: On this experimental site in Guelph, Ontario, it was observed that the biomass of a short rotation willow intercrop associated with 20-year-old trees was 45% higher than that of willow observed in open fields.

In the United States, some research has shown that tree competition for water can become critical to the point of significantly decreasing the productivity of the associated crops (Jose *et al*., 2004). However, it is possible to neutralize this competition by undertaking tree root-pruning; i.e. by mechanically controlling tree roots to prevent them from extending into the crop area (Photo 8). The few trials that have studied competition for nutrients in the soil have proven this competition to be generally negligible in that the nutritional requirements of intercrops are normally met through standard fertilization practices (Miller and Pallardy, 2001).

Photo 8: Research has shown that root-pruning (e.g. with the aid of a chisel plow) can limit underground competition between trees and crops.

Are intercropping systems profitable?

Because they are new, limited data are available about the actual profitability of ICS. Various economic studies, including those of a modelling nature, have shown that ICS compare favourably with monocultures and conventional plantations (Graves *et al*., 2007). The choice of tree species and the associated crop have a great influence on the profitability of ICS, however. Generally, profitability is favoured by: i) low interest rates (such as those that exist today); ii) choice of sites with a high fertility; iii) use of silviculture management and spacings that maximize crop yield and tree growth; iv) production of quality rotary-cut veneer wood, sold when market prices are at their highest; v) choice of tree species that also yield an annual product (e.g. berry, nut, maple syrup) of some value; and vi) contribution of financial incentives recognizing the positive externalities of trees from an environmental perspective (e.g. sequestration of carbon, lowered soil erosion) (Dyack *et al*., 1999; Benjamin *et al*., 2000; Graves *et al*., 2007).

Trees serving the environment

ICS are agro-ecosystems that address numerous environmental issues. Their particular structure, halfway between that of intensive monoculture agricultural systems and complex natural ecosystems, enables better exploitation of resources because of the complementarity of trees and crops in using water, nutrients and light as well as their beneficial impacts on the physical, chemical and biological properties of the soil.

Trees improve soil fertility

ICS, in comparison with agricultural systems, can contribute substantially to increasing the return of organic matter to the soil as a result of residues (litterfall) from aboveground tree biomass and *in situ* decomposition of tree roots, especially those of the fine root fraction. Humus from hardwood litters is often of excellent quality and can therefore be managed like a true fertilizer, which could translate into a decreased reliance on commercial inorganic fertilizer. Organic matter from trees generally results in an increase in soil microbial biomass and earthworm populations (Price *et al*., 1999), contributing to the improvement of soil fertility.

Trees stop soil erosion and diffuse pollution

In ICS, the presence of tree roots limits surface runoff and soil erosion. Deep tree roots can also recover soil nutrients, especially nitrates that escape the crop through leaching, which mitigates groundwater pollution. This is the aptly-named 'safety net hypothesis' (Allen *et al*., 2004). This was illustrated in a Quebec study in a hybrid poplar ICS: from May to mid-October there was a decrease of close to 80% of the quantity of nitrates leached in the groundwater, as a result of the buffering capacity of the tree roots (Lacombe, 2007). A study in Ontario suggested that ICS can also mitigate migration of some bacteria that are hazardous to human health, such as *Escherichia coli* (Dougherty *et al*., 2009).

Trees fix atmospheric carbon

As trees fix CO_2 and generally tend to increase the quantity of organic matter in the soil, ICS can also play a major role in the sequestering of carbon and the offsetting of other greenhouse gas emissions such as N_2O. Use of fast-growing tree species such as hybrid poplar can increase the potential for atmospheric carbon fixation in ICS. In Ontario, Peichl *et al*. (2006) estimated that in the 13th year of tree growth, the net annual carbon flux in an ICS (hybrid poplar - barley) was 13 tons C per hectare, compared with 1 ton C per hectare in an alternative ICS (Norway spruce - barley) and –3 tons per hectare in a barley monoculture system.

Trees improve landscape quality and biodiversity

Studies conducted in eastern North America have shown that the diversity and abundance of predators of agricultural pests was higher in ICS than in agricultural monocultures, which could ultimately reduce dependence on pesticides (Stamps and Linit, 1998; Howell, 2001). In Quebec, a greater diversity of microbial populations, especially those of arbuscular mycorrhizae, has been observed in the soil of an

ICS (hybrid poplar - soybeans), in comparison with soybean and hybrid poplar monocultures (Chifflot *et al*. 2009; Lacombe *et al*. 2009). Since they form a more complex and diversified mosaic of habitats than conventional agricultural systems, ICS also attract a greater quantity and variety of birds, as observed in Ontario (Thevathasan and Gordon, 2004). They can also foster the ease with which wildlife can migrate to connecting forest patches. ICS therefore constitute an obvious alternative to the normal spatial separation of agriculture and forestry practices. They can create original, attractive landscapes that are favourable to recreational activities. For that reason, their adoption appears especially advisable in areas where the landscape quality has been strongly influenced by historical agricultural practices (Photo 9).

Photo 9: Intercropping systems beautify landscapes, as depicted on this field plot where black walnut is intercropped with buckwheat at Poitou-Charentes, France.

Implementation and maintenance of intercropping systems

What to choose for tree species?

In planning ICS, the tree species is generally chosen in accordance with: i) its growth rate; ii) its commercial or environmental value; iii) its adaptation to the site's ecological conditions (soil and climate); iv) its resistance to disturbance; and v) its interaction with the intercrop. Agroforestry plantations may fail because the choice of tree species is inappropriate for the planting site. Table 1 illustrates the ideal soil conditions for planting valuable hardwoods adapted to the St. Lawrence Plain in Quebec and for which there is high demand from the forest industry (especially sawtimber and rotary cutting). In the table, the various texture, drainage and soil pH conditions were ranked according to their potential for accommodating these tree species. Several local experts are of the opinion that on good sites, these tree species can produce quality wood for rotary cutting in 50 or 60 years, whereas projections for natural forests are more often in the range of 80 to 100 years.

Table 1: Grid for choice of hardwood species in six soil conditions in Quebec (Cogliastro *et al*. 1998, with permission)

	CLASSIFICATION OF SOIL CONDITIONS					
	SOIL TEXTURE					
	LOAM		LOAMY SAND – SANDY LOAM			
	DRAINAGE		DRAINAGE			
Species	*good*	*moderate*	*fast*	*good*	*moderate*	*imperfect*
Bur oak	3	3	2	2	3	1
Red oak	4	4	1	2	4	3
Silver maple	2	2	2	2	2	1
Sugar maple	1	1	2	1	2	NR
American white ash	1	2	2	2	2	2
Green ash	2	2	4	4	3	1
Black walnut	1	2	NR	2	NR	NR

pH 5.9-6.4 pH 7.4-7.6

1) Best performance of species under these conditions
4) Worst performance of species under these conditions
NR) soil conditions not recommended for species

It can also be beneficial to combine valuable hardwoods with fast-growing hybrid poplars, as studied in some trials in Quebec and Ontario (Photo 10). Such an association, inspired by the natural succession of some forest ecosystems where poplar dominates the more shade-tolerant and long-lived hardwoods that succeed it, specifically offers the following advantages: i) creation of a microclimate favourable to hardwood growth; ii) availability of short-term income from harvesting hybrid poplar (removal age must be 15 to 20 years for the production of high-quality veneer wood); iii) rapid improvement of the agro-environment and landscape quality; and iv) restitution of some open areas when and where the hybrid poplar is harvested, which is favourable to a variety of crops.

Although intercropping conifers with crops is possible, this type of ICS is not widely employed in temperate regions. Generally, the quality of hardwood litter is better than that of conifers, which can result in higher nitrogen mineralization rates, and faster incorporation of nitrogen into the soil profile.

Photo 10: Intercropping hybrid poplar (left and right), and other hardwoods (black walnut and American white ash, centre) with soybean at St-Rémi, Quebec.

How far apart should trees be planted?

Contrary to hardwood forest plantations on farmlands, which are planted at densities of 800 to 1,500 trees per hectare, trees planted in ICS take up only a small proportion of the utilized space (40 to 160 trees per hectare), which corresponds roughly to a distance of 12 to 50 meters between rows, with trees spaced at 5 meters within rows. Generally, the density of the trees is adjusted in accordance with the balance sought between trees and crops. With a low tree density, sustained intercrop production is assured. With higher densities, priority is given to wood production. Between trees in the same row, spacing is generally from 3 to 6 meters to enable thinning, whereas between rows, where crop mechanization, and especially spray booms, must be accommodated, it is often wider (Photo 11). Experience in France shows that the best compromise between wood and crop production is often obtained with an alley of 25 to 35 meters for hardwoods that reach 15 to 20 meters in height after the final harvest.

Photo 11: On this field plot in France, the alley between the rows of trees is 14 m, which enables the farmer to operate easily with a 12-m spray boom.

Must a strip of untilled land be maintained?

In associations with annual intercrops, a strip of untilled land 1 to 3 meters in width is normally maintained under the tree rows (Photo 12). If the strip of untilled land is too narrow, the risk of mechanical damage to the trees is increased, as are the effects of competition for light, water and mineral elements between trees and crops. On the other hand, the wider the strip of untilled land, the greater the loss of area for crops. Several methods for controlling weeds in the tree rows may be used, including the application of herbicides or the use of plastic mulch. In the research plots at Guelph, Ontario, weeds were only controlled for the first decade; studies indicated that weed populations in the untilled land did not contribute to weed problems in the crop alleys, and that they could be used by small mammals for habitat (Kotey, 1996).

Photo 12: On this field plot at St-Paulin, Quebec, where organic crop production is practiced, the strip of untilled land is covered with plastic mulch and flanked by two straight vegetated areas that are mown mechanically.

How to care for trees in order to obtain quality wood: pruning and thinning

Trees planted with wide spacing tend to develop large, dense canopies, with branches low on their trunks, and this may compromise the quality of the wood production. Consequently, pruning remains essential to favouring formation of a straight, knot-free stem, enabling passage of machinery through the alleys, and reducing shading to intercrops. As for row thinning, it stimulates future tree growth for quality wood production and increases luminosity for the intercrop (Photo 13). Generally, thinning once or twice in the 25 to 30 years following planting will bring the stand to a final density of 20 to 80 trees per hectare. The thinning time and intensity can be adjusted in accordance with the intercrop's need for light. Early thinning is recommended for demanding crops such as corn, whereas later thinning will suffice for more shade-tolerant crops.

Intercrop choice and behaviour

The choice of crops depends first and foremost on the producer's needs and know-how. In general, any type of intercrop (tall crops, forage crops, vegetable crops, other small fruits, ornamental plants, etc.) is possible (Photo 14). In general, annual crops pose more constraints than perennial crops: a greater frequency of more expensive mechanical operations, a greater risk of harming trees, incompatibility of some herbicide treatments with the trees, the obligation to remove or chip debris from tree pruning, and irregularity (usually delayed) in crop development in the proximity of the tree. Nevertheless, annual crops, especially those with a slower growth cycle than that of trees (e.g. winter cereal crops) may prove to be less competitive than perennial crops.

In low-density planting systems (30 to 50 trees per hectare), it is possible to continue intercropping until the tree harvest. At higher densities, agricultural plant yields will probably diminish to the point that they are no longer profitable as trees approach maturity, and it will therefore be necessary to choose crops that are adapted to shade. In such a case, two options are possible: gradually introduce shade-tolerant crops (e.g. forage crops and pastures) as trees age or reduce the planted area between tree rows so that the associated crop will still benefit from the necessary resources to obtain an acceptable yield.

Photo 13: On this field plot at St-Rémi, Quebec, six-year-old hybrid poplars were thinned and pruned to a height of 4 m. By increasing the availability of light for a short time, these treatments resulted in greater consistency in soybean yield in the crop alleys.

Photo 14: It is entirely possible to associate trees with specialized crops, as shown in this example from France, where asparagus was planted between rows of hybrid poplars.

Land Equivalent Ratio (LER)

The land equivalent ratio (LER) (SEA, or Surface équivalente de l'association, in French) compares the biological efficacy of ICS to that of agricultural and forest monocultures. It is used for determining whether or not it is more beneficial to associate trees with crops than to produce them separately. The LER corresponds to the required land for obtaining production equivalent to one hectare using an ICS if trees and crops are produced separately. An LER greater than 1 therefore indicates that the ICS is more productive. With the help of modelling, Graves *et al*. (2007) estimated that the LER of several dozens of ICS scenarios integrating valuable hardwoods or hybrid poplar was, with a select few exceptions, greater than 1 and could even reach 1.4. In such cases, this means that 1 hectare using an ICS produces as much as 1.4 hectare where trees and crops would be produced separately.

Conclusion

Over the past several decades, research conducted in North America and Europe has demonstrated the performance of ICS from a productivity perspective and for their environmental benefits. Several tree-crop associations are possible as long as species are adapted to the conditions of the site and products (from both crops and trees) can be readily marketed or offer a potential for niche market development. It must also be considered that trees and crops have an influence on each other. Interventions must therefore be judiciously positioned to optimize positive interactions while minimizing those that are negative. For example, as trees age, owner-operators may need to opt for crop production that develops well in a semi-shaded environment, or resort to a regular regimen of pruning.

In the Canadian agricultural context, adopting ICSs nevertheless requires a significant adaptation effort from producers, the industry and governments. A recent survey of Quebec landowners showed that very few of them are familiar with these systems; the same is true of producers (Marchand and Masse, 2008). According to the survey, the lack of technical and financial incentives and a regulatory framework specific to ICS constitute a major roadblock to their development. In France for example, over 2,000 hectares of new ICS field plots have been established by producers in the past few years, in large part due to the improvement of agricultural, agri-environmental and forestry regulations. Intercropping systems therefore represent sustainable agricultural production models that require both practices and programs to be adapted. Because they contribute to the revitalization of marginal cropland and to the improvement of the agri-environmental performance of more fertile land, they are a prime solution for maintaining agricultural land capability for future generations.

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UNIVERSITÉ LAVAL

UNIVERSITY of GUELPH

Authors:

David Rivest, Ing. F., Ph.D., Université Laval, david.rivest.1@ulaval.ca
Alain Olivier, Ph.D., Université Laval, alain.olivier@fsaa.ulaval.ca
Andrew M. Gordon, B.Sc.F., Ph.D., R.P.F., University of Guelph, agordon@uoguelph.ca

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For more informations:

Agriculture and Agri-Food Canada
Agri-Environment Services Branch
Regional Agri-Environmental Adaptation
and Practice Change Division, Quebec region
Champlain Harbour Station
901, du Cap-Diamant Street, Room 350-4
Quebec, Quebec G1K 4K1

Telephone: 418-648-3652
Facsimile: 418-648-7342

Email: stephane.gariepy@agr.gc.ca
Website: www.agr.gc.ca

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