Agroforestry Systems **13**: 203–224, 1991.

Design and development of agroforestry systems for Illinois, USA: silvicultural and economic considerations

G.E. CAMPBELL, G.J. LOTTES and J.O. DAWSON
Department of Forestry, 110 Mumford Hall, University of Illinois at Urbana-Champaign, 1301 W. Gregory Drive, Urbana, IL 61801, USA

Key words: Multicropping, joint production, marginal land, timber and agriculture, net present value, income taxation

Abstract. Recommended managerial inputs and associated outputs expected from practicing agroforestry on marginal farm lands in the central USA are discussed. Modeled management combinations are based on five timber species, three site indices, three timber growth rates, five agricultural crops, all common crop rotations, and three tillage systems. Black walnut (*Juglans nigra L.*), combined with row crop production, is used to illustrate a specific multicropping alternative. Based on net present value, modeled agroforestry systems incorporating black walnut performed better on the better sites and at the medium to high timber growth rates whereas management systems using red oak (*Quercus rubra L.*) with row crops performed better on the poorer sites and at the lower growth rates. For agroforestry to be competitive with traditional agriculture, medium to high timber growth rates were necessary. Also, lower interest rates and the existing U.S. income tax structure favored agroforestry versus traditional agriculture. Substantial increases in net income may be possible through incorporating other income producing activities such as nut production within the agroforestry system.

Introduction

Agroforestry in the central United States usually means multicropping (i.e., alternating rows of trees with strips of field crops). Benefits from a multicropping system may include land conservation, improved overall economic returns [16], and the opportunity to increase timber supply. Costs of plantation establishment can usually be offset by the early financial returns from the agricultural crop. Agricultural tillage, fertilizer, and weeding also benefit the tree crop [16], in return, the young trees in a multicrop system often serve as windbreaks or shield agricultural crops that benefit from partial shade [17]. Additional agroforestry benefits include easier stand access, reduced fire risk, and the potential of producing timber closer to processing facilities and markets [16].

The silvicultural and economic relationships of integrated forestry-farming with black walnut in Missouri have been reported by Kincaid [18] and Thurman [28]. The general conclusions from these studies were that black walnut multicropping management systems are an economically viable land use alternative, and that financial return is directly related to degree of management intensity. The incorporation of black walnut nut production contributed substantially to overall profitability.

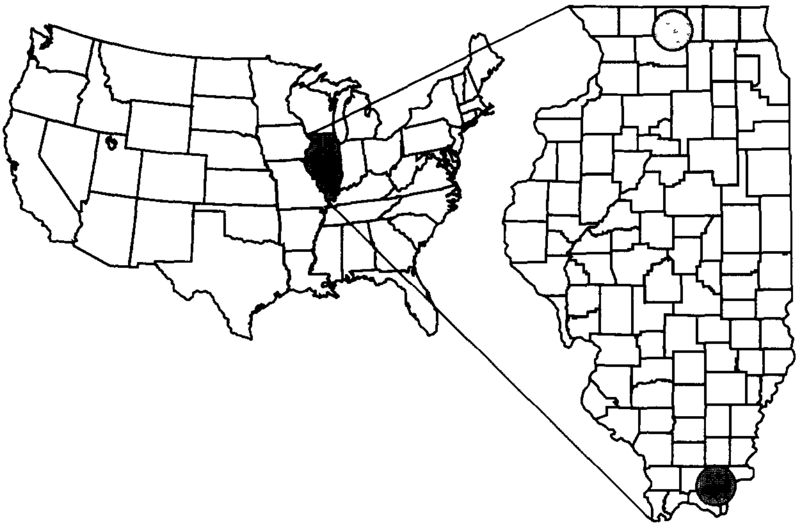
The purposes of this paper are (1) to describe the integrated agroforestry, multicropping management systems designed and developed by Lottes [21] for Illinois and (2) to evaluate the economic attractiveness of these types of management systems relative to traditional agriculture. Modeled multicropping combinations are based on five timber species, three site indices, three timber growth rates, five agricultural crops, all common crop rotations, and three tillage systems. Important model assumptions and estimates are discussed as well as the benefits of agroforestry attributed to reduced soil erosion.

Development and evaluation of the agroforestry regimes followed the typical land use planning process as described by Betters [3]: (1) set management objectives; (2) design system and define responses; and (3) perform system analysis, decision, and feedback. Development of the agroforestry models also was consistent with the micro-scale diagnosis and design methods and applications described by Raintree [24].

General management context

The hypothesis on which the integrated multicropping systems were based is that agroforestry will improve overall economic returns while reducing soil erosion on marginal agricultural lands in Illinois and the central states. The primary management objective was the maximization of net revenue from the simultaneous production of high-quality hardwood and agricultural crops subject to meeting the State of Illinois' voluntary soil loss tolerance level. This soil loss tolerance or "T" level varies by soil type and is set by the State in cooperation with the United States Department of Agriculture (USDA) Soil Conservation Service.

The majority of marginal agricultural lands in Illinois are concentrated in the nonglaciated northwestern and southern sections of the State. To establish a base for agronomic yields, three sites of varying quality were selected from each section (Map 1) as representative of marginal farm land (Table 1). For each site, rows of trees modeled at a 3.0 × 12.2 m spacing (267 trees per ha) were assumed to be planted on the contour with space available for a 9.1 m strip of field crops between each row. It was assumed that the 3.0 m buffer strips containing the tree rows including a suitable ground cover are sufficient to break up the slope length into shorter intervals between the



Map 1. Location of modeled agroforestry sites in northern and southern Illinois, USA.

Table 1. Site quality indices for timber and agriculture in northern and southern Illinois

SI[a]	PI[b]	Representative soil series[c]
Northern Illinois		
19.8	90	Edmund silt loam 5–9% slope
22.9	105	Kidder loam 5–9% slope
25.9	120	Miami loam 10–15% slope
Southern Illinois		
19.8	85	Zanesville silt loam 12–18% slope
22.9	105	Grantsburg silt loam 12–18% slope
25.9	115	Hosmer silt loam 8–12% slope

[a] Site index (SI) for white oak, base age 50 (e.g., a SI of 22.9 means that dominant and co-dominant trees are expected to reach 22.9 m in total height by age 50 (yrs)

[b] Productivity index (PI) is a relative measure of productive capacity based on estimated yields of major grain crops grown in Illinois as a single percentage of the average yields obtained under basic management, adjusted to high management; basic management includes the minimum inputs considered necessary for crop production to be feasible; high management includes inputs that are near those required for maximum profit with current technology

[c] Soils are considered marginally suited for traditional agriculture and are classified 3e, 4, or higher under the USDA Soil Conservation Service's Land Capability Classification System

runoff barriers. This is a critical input parameter into the Universal Soil Loss Equation (USLE) for determining the level of soil erosion losses.

For comparison purposes, recommended spacings for planting traditional hardwood forest plantations in Illinois range from 3.7 × 3.7 m (749 trees per ha) for pure black walnut sawtimber production to 2.4 × 2.7 m (over 1,483 trees per ha) for mixed plantings of ash, black walnut, red and white oak, and yellow poplar. General management activities for these timber plantation alternatives consist of site preparation and planting, early weed control, pre-commercial and commercial thinnings, and a final harvest in one or two stages.

Specific management context

To develop the specific multicropping management systems, it became necessary to make additional assumptions regarding species selection, growth and yield, the type and timing of management activities, production costs, and product prices. Given the primary management objective of maximizing net revenue, agroforestry systems were modeled to simulate feasible and potentially attractive land-use alternatives for Illinois landowners. The development and basis for these assumptions are described below.

Species

Five timber species were chosen for evaluation: eastern black walnut (*Juglans nigra L.*), red (*Quercus rubra L.*) and white oak (*Quercus alba L.*), yellow poplar (*Liriodendron tulipifera L.*), and white pine (*Pinus strobus L.*). Based on Carmean and Hahn [9], comparable site indices for each species were determined. Because of poor stumpage markets within Illinois for yellow poplar and white pine and a failure to exhibit superior simulated growth and volume, these two species were dropped form further analysis. The remaining higher valued species selected (eastern black walnut, red or white oak) were individually modeled as the timber component of the multicropping systems. Of these three species, black walnut possesses an additional advantage due to its relatively short growing period and because the light shade produced by its sparse foliage provides adequate sunlight for most interplanted crops. A potential disadvantage of black walnut is that the probability of reaching its growth potential may be lower than for red and white oak on marginal agricultural soils. The agricultural component consisted of crop rotations common to the northern and southern sections of Illinois. Corn (maize), soybeans, wheat, oats, and alfalfa or red clover were the major field crops planted.

Stand establishment

Initial site preparation followed standard mechanized agricultural practices. These costs were charged to the agriculture component of the agroforestry system. Seedlings (45.7 to 61.0 cm tall) were assumed to be machine planted on the contour and down the center of a 3.0 m buffer strip at a spacing of 3.0 × 12.2 m (267 trees per ha). A ground cover was planted within the buffer strip to control soil erosion. A recommended ground cover for plantations is hairy vetch, which has the ability to fix nitrogen and potential to increase tree growth since nitrogen is often the primary and only limiting nutrient for forest trees in Illinois. Hairy vetch has the added advantage of being a cool-season annual that is dormant during the warm season competing less for water and nutrients during the tree crops' critical summer growth period. The buffer strip also was expected to reduce physical interference between the forestry and agricultural operations.

Satisfactory weed control is also important for promoting significant increases in growth and survival in hardwood plantations [2,12]. Good weed control starts before planting by applying a non-selective herbicide (e.g., glyphosphate) to kill existing vegetation. After planting, pre-emergent herbicides (e.g., simazine and oxyzalen) are recommended to be sprayed in a narrow band along the base of the trees to control herbaceous vegetation immediately around the seedlings during the critical years of establishment [5].

A 9.1 m strip between the tree rows was available for agricultural production activities. Under this scheme, 25 percent of the area was covered by buffer strips and trees, the remaining 75 percent was devoted to producing row crops or hay. Variations in these percentages may occur in practice because of differences in farm machinery dimensions. Spacings used in this study will accommodate the machinery and machinery compliments most commonly found on farms of average size in northern and southern Illinois.

Agricultural tillage was modeled as either upslope (vertically) or on the contour. Tillage operations were defined with respect to percentage of residue cover left on the ground after all tillage operations were completed, and consisted of: conventional tillage (less than 10 percent residue cover remaining), minimum tillage (35 to 45 percent), and no-till or conservation tillage (greater than 90 percent).

Intermediate management activities

Chemical weed control in the immediate area surrounding the trees was continued for five years beyond establishment. In addition, weed control was carried out in the area between the buffer strips during the period of agricultural production as part of the regular management program. Maintenance levels for the expected crop yields, assuming high intensity management, were used

Table 2. Time of first and second clear length (bole) prunings by species and site for an agroforestry system[a]

First clear length pruning[b]			
Species	Site quality		
	Low	Medium ----(yr)----	High
Black walnut (*Juglans nigra L.*)	10	8	6
Northern red oak (*Quercus rubra L.*)	10	8	6
White oak (*Quercus alba L.*)	15	12	10
White pine (*Pinus strobus L.*)	10	8	6
Yellow-poplar (*Liriodenron tulipfera L.*)	10	8	6
Second clear length pruning[c]			
Species	Site quality		
	Low	Medium ----(yr)----	High
Black walnut (*Juglans nigra L.*)	30	18	15
Northern red oak (*Quercus rubra L.*)	23	18	15
White oak (*Quercus alba L.*)	30	24	20
White pine (*Pinus strobus L.*)	20	16	12
Yellow-poplar (*Liriodenron tulipfera L.*)	20	16	12

[a] Based on Kincaid [18] and Schlesinger [25]
[b] Pruning up to 2.7 m on bole, total tree height equals 6.9 m
[c] Pruning from 2.7 to 5.2 m on bole, total tree height equals 13.0 m

to set fertilizer requirements and other inputs for the agricultural component near those required for maximum profit with current technology.

The wide tree spacing eliminated the need for pre-commercial thinnings. However, this wide spacing created a need for corrective and lateral prunings to ensure optimal tree growth and form characteristics. Corrective prunings, scheduled in the second and fourth years, were designed to help train seedlings in the early stages of development to produce a single straight leader [4,26]. Lateral (bole or clear-length) pruning was necessary to develop merchantable logs free of side branches and defects (Table 2). Bole pruning was recommended to be performed in two stages and early in the timber rotation to allow pruning wounds to heal cleanly and reduce the chance of decay and insect infestation [25]. It was assumed that this pruning schedule would produce at least one 4.9 m, defect-free butt log. Epicormic branching, a possible problem, especially with the oaks, must be monitored in practice to ensure effective pruning.

Growth and yield

Three constant, annual dbh (diameter at breast height or 1.4 m above the ground) growth rates were estimated for each timber species and site quality combination. Lower bound estimates were derived from the central states version of TWIGS (The Woodman's Ideal Growth Projection System); a growth and yield model for natural stands developed by the U.S. Forest Service [19,22]. To reflect intensive plantation management, upper bound estimates were set at the most optimistic rates thought feasible for each species and site. These assumptions resulted in dbh growth rates of 3.6 to 6.9 mm per year (low site), 4.1 to 8.6 mm per year (medium site), and 4.3 to 12.4 mm per year (high site). The third or medium growth rate assumption represented the midpoint of the above ranges.

Commercial thinnings were based on stand density as measured by the crown competition factor (CCF) developed by Krajicek, Brinkman, and Gringrich [20]. CCF is based on the crown growth of open grown trees and, thus, is representative of the growing conditions modeled in the agroforestry systems. A CCF of 100 means that the crowns of adjacent trees are just touching. As thinning guidelines, upper and lower CCF limits were set at 110 and 70, respectively, to promote the production of high quality logs. CCF was allowed to exceed 110 in practice only if the interval between the planned thinning and final harvest was less than 10 years.

Two adjustments to estimated diameter growth of black walnut were

Table 3. Thinning and final harvest yields[a] for black walnut, site index 22.9, medium growth rate, by rotation age

Rotation age = 50 yrs

Year	DBH[b]	CCF[c]	Trees ha^{-1}	Harvest yield	
				Pulpwood	Sawtimber
				----(m^{3}ha^{-1})----	
10	6.1	18.1	267	0.0	0.0
20	12.2	41.0	267	0.0	0.0
30	17.3	69.8	267	0.0	0.0
40	22.6	100.0	267	0.0	0.0
50	26.9	131.8	267	69.2	0.0

Rotation age = 60 yrs

Year	DBH	CCF	Trees ha^{-1}	Harvest yield	
				Pulpwood	Sawtimber
				----(m^{3}ha^{-1})----	
10	6.1	18.1	267	0.0	0.0
20	12.2	41.0	267	0.0	0.0
30	17.3	69.8	267	0.0	0.0
40	22.6	100.0	267	0.0	0.0
44	24.1	110.2	267	0.0	0.0
44	28.7	70.2	128	18.0	0.0
50	31.5	82.1	128	0.0	0.0
60	36.3	104.0	128	26.7	78.6

Rotation age = 70 yrs

Year	DBH	CCF	Trees ha^{-1}	Harvest yield	
				Pulpwood	Sawtimber
				----(m^{3}ha^{-1})----	
10	6.1	18.1	267	0.0	0.0
20	12.2	41.0	267	0.0	0.0
30	17.3	69.8	267	0.0	0.0
40	22.6	100.0	267	0.0	0.0
44	24.1	110.2	267	0.0	0.0
44	28.7	70.2	128	18.0	0.0
50	31.5	82.1	128	0.0	0.0
60	36.3	104.0	128	0.0	0.0
70	40.6	126.9	128	31.8	98.8

[a] Based on DBH and site index, the TWIGS growth and yield simulator was used to estimate timber volumes

[b] Diameter (in cm) at breast height

[c] Crown competition factor

possible because of more extensive research information available for this species. The first adjustment increased dbh growth to reflect diameter gains through thinning. This resulted in a selection gain of 4.6 cm in dbh over the rotation. The second adjustment decreased diameter growth 8 percent for every 10 CCF points above a CCF level of 82.

Thinning and final timber harvest yields (Table 3) were estimated by TWIGS based on the primary inputs of species, dbh, and site index. Trees with a dbh between 12.7 to 27.9 cm were considered commercially valuable as either firewood or pulpwood, depending on species and demand. Trees greater than 27.9 cm in dbh were assumed merchantable as sawtimber. Sawtimber was allocated by grade based on Dale and Brisbin [10], Myers et al. [23], and Trimble [29]. Assuming satisfactory growth rates, a tree spacing of 12.2 × 12.2 m or 67 trees per ha was the stocking goal at final harvest. Black walnut deviated slightly from this goal because of the growth adjustments discussed earlier and its large crown characteristics.

County soil surveys and current research statistics were used to establish

Table 4. Agricultural yields (adjusted for slope) by soil type and productivity index[a]

Northern Illinois						
Soil type	PI[b]	Crop yields				
		Corn	Soybeans	Wheat	Oats	Hay
		----($kg\,ha^{-1}$)----				($t\,ha^{-1}$)
Miami	120	6835	2419	3091	2190	9.68
Kidder	105	5957	2217	2822	2262	8.63
Edmund	90	4891	1948	2688	1795	7.55
Southern Illinois						
Soil type	PI	Crop yields				
		Corn	Soybeans	Wheat	Oats	Hay
		----($kg\,ha^{-1}$)----				($t\,ha^{-1}$)
Hosmer	115	6020	2083	3024	0	9.19
Grants-burg	105	4954	1814	2553	0	7.62
Zaines-ville	85	3637	1344	1680	0	5.18

[a] High management is assumed and includes inputs that are near those required for maximum profit with current technology

[b] Productivity index (PI) is a relative measure of productive capacity and is based on estimated yields of major grain crops grown in Illinois as a single percentage of the average yields obtained under basic management, adjusted for high management

initial agronomic yields and soil profile for each soil type. Crop yields were adjusted for slope and current state of erosion assuming high intensity management. Benefits from reducing sheet and rill soil erosion through the use of buffer strips were modeled through SOILEC--a computerized, long-run simulation model developed (by the Dept. of Agricultural Economics, Univ. Illinois at Urbana-Champaign, USA) to estimate the effects of soil conservation on crop yields and economic return given specified climatic, site, crop rotation, and tillage system combinations. Inputs to SOILEC include soil type and depth, base yields (Table 4), selected production costs from the USDA Soil Conservation Service's crop budget generator, and USLE parameters.

Management costs and product prices

Estimates of timber management costs (Table 5) were obtained from the

Table 5. Timber management costs

Management activity	Cost of practice ----(US$/ha)----	State + Federal cost share
Site preparation	0.00[a]	25.40
Establishment of ground cover	30.89[b]	0.00
Timber planting stock	133.44[c]	99.71
Tree planting	66.72[d]	62.05
Weed control during establishment	8.65[e]	8.06
Weed control after establishment	13.64[e]	12.70[f]
Corrective pruning	29.65	0.00
First clear length pruning	96.07[g]	48.75
Second clear length pruning	151.97[h]	56.02
Annual operation & maintenance	3.71	0.00
Annual property taxes	2.47[i]	0.00

Final harvest expenses consist of consulting fees for professional forestry assistance (10% of gross harvest revenues) and a 4% harvest fee based on gross sawlog harvest value

[a] Site preparation costs are included within the agricultural component of the agroforestry system; for the second, and succeeding timber rotations, site preparation costs are increased by US$37.07/ha, representing a 50% increase over regular moldboard plowing, this incremental cost is charged to the timber component
[b] Ground cover is planted on 25% of the available area within the 3.0 m buffer strip
[c] Seedlings cost US$0.50 per tree [21]
[d] Seedings machine planted at US$0.25 per tree [21]
[e] Based on Lottes [21]
[f] Cost share is for first year only
[g] The per tree cost is US$0.36 [21]
[h] The per tree cost is US$0.82 [21]
[i] Property taxes reflect the 1/6 assessment allowed qualified forest land in Illinois

published literature and conversations with knowledgeable foresters in the central states. These costs may be significantly reduced through cost-sharing incentives provided by the State of Illinois and the federal government. Under the Illinois Forestry Development Act (FDA), the State will pay for 80 percent of approved forest management expenses with up to 65 percent of the remaining costs available for cost-sharing through the U.S. federal forestry incentives program (FIP). Current not-to-exceed limits apply to both state and federal cost-sharing as well as restrictions related to the frequency at which a particular activity can be repeated on the same area and still qualify for cost-sharing. The State's cost-share program is funded by a 4 percent harvest fee.

The present analysis incorporated existing cost-share incentives with one modification: all not-to-exceed limits were reduced to 1/3 the established FDA and FIP values to reflect the lower stocking levels of the modeled agroforestry systems (Table 5). Also, the land devoted to agroforestry was assumed to be eligible for classification as forest land for property tax purposes and, thus, qualified for reduced property tax assessment.

Agricultural production costs were determined by modifying existing USDA Soil Conservation Service crop budgets to correspond to the selected site, crop rotation, and tillage system combinations developed for the agroforestry and traditional agriculture alternatives. These revised crop budgets provided two types of information that were used as inputs for SOILEC: (1) variable costs dependent upon expected yields and (2) fixed costs inherent to the assumed crop rotation and tillage systems.

Illinois agriculture commodity prices (Table 6) were averaged over a 4-year period to dampen the effects of short-term market fluctuations and to provide a better long-term estimate for annual commodity prices. Statewide average stumpage prices for timber were obtained from the "Illinois Timber Prices Survey". Stumpage prices were adjusted to reflect

Table 6. Average agriculture commodity prices

Commodity	Code	Price[a] (US$)
Alfalfa	ALF	76.09 per t
Clover	M	60.44 per t
Corn (maize)	C	0.11 per kg
Oats	O	0.13 per kg
Soybeans	S	0.24 per kg
Wheat	W	0.12 per kg

[a] Commodity prices were averaged over a four year period from January 1981 to December 1984

"marked timber sales", as reported by the "Survey", and apportioned to five different log-grade classes based on the current grade distribution prevalent in the neighboring state of Indiana. This procedure generated the following set of "composite" prices, measured in US dollars per cubic meter (US$/m^3), by dbh size class for black walnut (BW), red oak (RO), and white oak (WO).

Composite stumpage prices

dbh (cm)	BW	RO -(US$/m^3)-	WO
30.5	26	6	7
35.6	50	12	13
40.6	82	27	28
45.7	104	32	35
50.8	125	38	42
55.9	147	44	49
61.0	164	48	55
66.0	185	53	62

Both sets of agriculture and timber prices were designed to correspond to periods of relatively good demand.

The SOILEC model was used to derive net cash flow estimates for the agricultural component of the agroforestry system and for traditional agriculture, the current land-use practice. A net income stream was estimated for six soil types under a variety of common crop rotations and tillage systems. These cash flows were adjusted within SOILEC for expected yield losses due to soil erosion. In the case of agroforestry, these net income streams (Table 7) were also reduced to reflect the effects on yields and production period assumed from tree competition. Soil loss expected under each alternative, estimated by SOILEC, was compared to the State's soil loss tolerance 'T' level.

A land-use alternative combining black walnut and row crop production is used to illustrate a complete net income stream for an example agroforestry management regime (Table 8). Selected costs have been decreased through cost-sharing and reduced property tax assessment. Revenues from agricultural crop production also were reduced to reflect the decrease in land availability resulting from use of the 3.0 m buffer strips. Timber revenues were based on estimated composite stumpage prices and yields, plus an assumed relative stumpage price increase of 0.5 percent per year. Based on past trends for high quality hardwoods, this price assumption is well within historic rates of change [8].

State and federal income taxes also play an important role with respect to an investment's expected profitability or position relative to competing alternatives [27]. For these reasons, expected cash flows were adjusted for

Table 7. Agricultural component net cash flows[a] and associated soil loss (SLoss) by site and crop rotation/tillage system

Northern Illinois

Yr[b]	Miami loam ALF[c]	Miami loam CC/NT/CN[d]	Kidder loam ALF	Kidder loam CCS/MT/CN[e]	Edmund silt loam ALF	Edmund silt loam CCS/MT/CN
			(US$ $ha^{-1} yr^{-1}$)			
1	297.44	264 80	227 21	215.70	186.10	165 81
2	273.62	240 53	227 04	214.44	179.60	159 21
3	273.25	239 69	226 97	213 20	179 57	159 04
4	272 88	238 90	226 84	211 94	179.55	158 91
5	272.53	238 09	226.77	210.73	179.52	158.77
6	272 14	237.25	226.65	209.50	179.50	158 62
7	146.11	127.09	127 28	119 92	179 47	158.49
8	40 30	29 80	75.29	74.40	179.45	158 35
9				27 38	74.43	69 46
10					45.79	51 10
			($t\,ha^{-1} yr^{-1}$)			
SLoss[d]	8.1	9.6	3.6	9 4	2.9	2.9
"T"[f]	11 2	11.2	9 0	9 0	6.7	6 7

Southern Illinois

Yr	Hosmer silt loam CC/NT/CN	Grantsburg silt loam CSWM/MT/CN[g]	Zainesville silt loam
		(US$ $ha^{-1} yr^{-1}$)	
1	198.72	112.90	–[h]
2	189.28	103.54	
3	188.76	103 49	
4	188.24	103.39	
5	187.75	103.34	
6	187.23	103.27	
7		57.20	
8		18 06	
		($t\,ha^{-1} yr^{-1}$)	
SLoss	2 9	6 7	> 6.7
"T"	9 0	9 0	6.7

[a] Simulated by SOILEC, Univ. Illinois, Urbana, USA
[b] Years in agroforestry timber rotation where net returns from the agricultural component are positive
[c] Alfalfa (ALF) is planted on a 5 yr rotation
[d] CC = corn-corn rotation, NT = no-till, CN = on contour
[e] CCS = corn-corn-soybean rotation, MT = minimum tillage
[f] "T" = State of Illinois tolerable soil loss level
[g] CSWM = corn-soybeans-wheat-clover-rotation
[h] All economic agriculture strategies failed to meet "T"

the effects of income taxation. With the exception of years in which significant timber income was generated, the taxpayer's marginal federal and state income tax rates were assumed to be 15 and 2.5 percent, respectively. these rates currently correspond to those applicable to average taxable income from Illinois farms. The highest federal marginal income tax rate used in the analysis was 33 percent.

Table 8. An example net income stream for a combined black walnut/row crop agroforestry management regime[a]

Periodic mgmt. activities	Yr	Net cash flow[b] (US$/ha)
Site preparation	0	0.00
Establishment of ground cover	0	−30.89
Timber planting stock	0	−33.73
Tree planting	0	−4.67
Chemical weed control	0	−0.59
Corrective pruning	2 & 4	−29.65
First clear length pruning	8	−47.32
Second clear length pruning	18	−95.95
First commercial thinning	44	26.23[c]
Second commercial thinning	–	0.00
Third commercial thinning	–	0.00
Timber sale expenses	70	−1613.41
Final harvest	70	11539.45[d]
Annual mgmt. activities	**Yr**	**Net cash flow (US$/ha)**
Chemical weed control	1–5	−13.64[e]
Agricultural crop production	1–9	161.78|20.54[f]
Operation and mgmt. expenses	1–70	−3.71
Property taxes	1–70	−2.47

[a] Example assumes a medium site in northern Illinois, medium timber growth rate, and CCS/MT/CN crop rotation

[b] First timber rotation only; net state and federal cost-share

[c] Firewood/pulpwood is sold at US$1.71 per m^3

[d] All stumpage prices are assumed to appreciate in relative value at a rate of 0.5%/yr

[e] First year weed control is cost-shared at US$12.70/ha

[f] See Table 7 for full set of agricultural cash flows; above net income stream reflects a 25% reduction due to the area covered by the buffer strips

Current federal income tax laws also allow timber establishment costs to be amortized over the first seven calendar years in addition to an investment tax credit (ITC) of 10 percent. All management costs, interest charges, and property taxes were assumed to be expensable (deductible) from ordinary income in the year in which they were incurred. To validate this assumption, it was assumed that the agroforestry investment was incidental to a farm business and that the owner materially participated in its operation. The present analysis incorporated the above tax adjustments and incentives.

Measurement criteria

The decision criterion on which the agroforestry and traditional agriculture land-use alternatives were evaluated and compared was net present value (NPV). This criterion measures the sum of discounted profits at a specified rate of interest. This interest rate, used to discount future after-tax cash flows, must also be 'after-tax' for the analysis to be correct [1,11,27]. In addition, each alternative was assumed to be repeated in perpetuity to insure a common basis for investment life. This assumption sets the salvage value of each investment equal to the capitalized value of its future net income stream. General inflation was set equal to 4 percent.

Discussion

Black walnut, combined with agricultural crop production, is used to illustrate a specific multicropping alternative (Table 8). A medium-quality site in northern Illinois, medium timber growth rate, and 70-year rotation were assumed. Initial periodic management activities included site preparation, ground cover establishment, tree planting, and weed control. Corrective pruning was scheduled for years 2 and 4, and bole pruning was planned for years 8 and 18. Because of the expected timber growth rate, only one commercial thinning was scheduled at year 44. The final harvest was planned for year 70. Annual expenses included weed control during the first five years as well as management costs throughout the entire rotation. Agricultural crop production was assumed to be economically feasible during the first nine years.

The assumptions that underlie development of the above agroforestry regimes critically affect expectations and, thus, overall performance. Furthermore, the probability of achieving an expected outcome depends, in part, on how reasonable the assumption models reality. The three most basic, and perhaps most important, assumptions used here relate to (1) the basic structure of the multicropping system, (2) the rates of annual dbh growth, and (3) the period of agricultural production including yield reductions due to tree competition.

The wide spacings assumed for the tree plantings pose problems with respect to stem straightness and quality. It was assumed that corrective and lateral prunings would compensate for the natural training and pruning which could be derived from higher stocking levels. Recently, this assumption has been questioned for black walnut growing on less than ideal sites.

Thus, closer spacings may be advisable to ensure high quality crop trees. One way to accomplish this would be to plant nitrogen-fixing nurse trees or shrubs in the buffer strip to train and naturally prune crop trees as well as to provide additional nitrogen for increased growth [7]. Another alternative is to plant pine between the walnut for later removal as Christmas trees or pulpwood, or to simply plant more walnut trees per unit area.

Because growth and yield information is quite limited for hardwood plantations, especially for wider spacings, annual dbh growth was projected as an average, constant rate. As a result, yield estimates may have been understated early in the rotation, but overstated at the end of the rotation. It may be better to estimate dbh growth based on a linear projection of dbh squared [7]. This method gives a more realistic dbh growth curve, increasing over time at a decreasing rate. Also, in the present study, TWIGS was used to determine harvest volumes based on site index, species, and estimated dbh. Another option would be to use an alternative volume equation, say from Ferell and Lundgren [13], to estimate tree volume.

The influence of trees within the agroforestry system on agricultural production depends on site quality, tree spacing, expected timber growth, branching habit, climatic conditions, shade tolerance of the agriculture crop, and other possible ecological interactions. Assumptions used in this study were obtained from experience gained in Missouri and critically affect total performance, since returns from the agricultural component occur early in the rotation and are expected to be significant. Therefore, these estimates should be given close attention.

Nut crops from black walnut trees, while not included here, also have been shown to contribute substantially to the total return expected from agroforestry systems [15,28]. In addition, it may be possible to double-crop the area between the tree rows to increase total productivity early in the rotation, and then to moderately graze the area later in the rotation once row crop production becomes uneconomical and the trees are in less danger of being damaged by livestock. Mixed plantings with other timber crops might also be considered to lower biological and financial risk through diversification.

The economic and financial attractiveness of the planned agroforestry and agriculture alternatives were based on NPV. An implicit assumption was that unmodeled benefits and costs (including risk) were equivalent among alternatives. This seems a fair assumption for comparisons among modeled agroforestry systems, but may be questionable when the comparison is between agroforestry and traditional agriculture. The validity of the latter comparison can be justified on two grounds: (1) for most private farm operators, the generation of net income is an extremely important concern and (2) an individual landowner can simply attach his or her own value to an important unmodeled benefit (e.g., enhancement of aesthetics or wildlife habitat) or cost (e.g., off-site water pollution) when the comparison among alternatives is made.

Because private, nonindustrial 'marginal' farm land was the focus of the developed agroforestry alternatives, study results are presented on an after-tax basis. However, with noted exceptions, the general results discussed below are applicable to the before-tax situation as well. Keep in mind that the relative comparisons are more accurate, and often more important, than the absolute estimates for NPV.

Northern Illinois

NPVs are presented for the best agroforestry and traditional agriculture alternatives modeled for northern Illinois (Table 9). For example, given the objectives and assumptions underlying model development, the best agroforestry management system for a medium site, assuming a medium timber growth rate and nominal after-tax discount rate of 8.5 percent, is a combined black walnut and alfalfa alternative under a 70-year timber rotation. This best timber rotation length generally decreases as either the discount rate or site quality increases.

Due to its relatively high stumpage value and assumed grade quality, black walnut was found to be better than red or white oak for maximizing NPV. This was especially true for the better sites and at the higher timber growth rate assumptions. However, on the poorer sites assuming low growth rates, red oak contributed more to NPV at all specified rates of discount. The main reason is red oak's relatively faster rate of growth on these poorer sites. This is consistent with the known site requirements and growing characteristics of the two species.

In northern Illinois, based on estimated NPVs and assuming high timber growth and low discount rates, agroforestry was competitive with traditional agriculture only on the better sites. One reason for this increased competitiveness is that final timber harvest values increased at a much faster relative rate than did returns from agriculture as site quality increased. Low discount rates were needed in order to preserve the present value of these higher timber value gains. Another reason for the increased competitiveness of agroforestry is that the better site (modeled here) possessed steeper slopes requiring costlier soil conservation measures for the agriculture alternative.

It is interesting to note that the after-tax competitive edge for agroforestry

Table 9. Best agroforestry and traditional agriculture alteratives for northern Illinois by site and discount rate[a]

r[b] (%)	Low Site Mgmt.[c]	AT[d]	RCT[d]	Medium Site Mgmt.	AT	RCT	High Site Mgmt.	AT	RCT
		----After-tax net present values (US$/ha)----							
4	RO50L	724	598	RO7OL	734	687	BW70L	1129~	974~
(6.8)	BW70M	1230~	1122~	BW70M	2061	2016	BW70M	3996	3842
	BW70H	1964	1856	BW70H	4287	4240	BW60H	8350	8187
	ALF	5295		ALF	6570		ALF	7453	
	CSWM		3509	CCOM		5199	CCOM		4870
6	RO50L	583	487	RO70L	583	544	BW70L	781#	652#
(8.5)	BW70M	709#	618#	BW70M	946	904	BW5OM	1774	1633
	BW70H	909~	818~	BW70H	1609	1569	BW60H	3338	3207
	ALF	3269		ALF	4097		ALF	4752	
	CSWM		2165	CCOM		3289	CCOM		3158
8	RO50L	521	437	RO70L	534	497	BW70L	677*	561*
(10.2)	BW70M	558#	477#	BW70M	647#	610#	BW5OM	1102	981
	BW70H	620#	539#	BW70H	885	848	BW50H	1846	1725
	ALF	2365		ALF	2985		ALF	3506	
	CSWM		1562	CCOM		2426	CCOM		2352
10	RO50L	482	405	RO60L	506	470	BW70L	632*	524*
(11.9)	BW70M	494*	418*	BW60M	544*	509*	BW50M	825	714
	BW6OH	516*	440*	BW60H	645	610	BW50H	1221	1110
	ALF	1851		ALF	2348		ALF	2785	
	CSWM		1223	CCOM		1925	CCOM		1878

[a] Additional assumptions include 4% inflation; 15% federal and 2.5% state income tax rates; expensing of ordinary costs; a 10% ITC plus 7-year amortization of timber establishment costs; and an infinite investment life

[b] r = real, before-tax discount rate; the parentheses identify the equivalent, nominal after-tax rates used to discount the after-tax cash flows

[c] For each agroforestry alternative, the first two characters identify the timber species, the second two specify the rotation age, and the last character refers to the timber growth rate; alfalfa and a common crop rotation represent the "best" traditional agriculture alternatives

[d] AT refers to the simultaneous production of alfalfa and timber; RCT refers to row crops and timber

Note: agroforestry alternatives using red oak often possessed estimated NPVs close to black walnut: ~ signifies NPVs within 9%, # within 5%, and * within 1%

on the better 'marginal' sites in northern Illinois was diminished on a before-tax basis. This is because income taxation in the United States is not 'neutral' and favors longer-term capital investments where the benefit of deferred tax liability exists [6,14]. This is true whether long-term capital gains are or are not taxed at differential rates.

Overall, one reason for agriculture's strong showing is that the northern Illinois soil types selected as 'marginal' exceeded expectations with respect to productivity. In fact, depending on the slope, the two better sites could be classified as 'good' prime farm land. It is anticipated that agroforestry will improve its overall attractiveness relative to traditional agriculture as soil productivity decreases.

Southern Illinois

In southern Illinois, agroforestry was more competitive because of the poorer soils and higher erosion hazard for traditional agriculture (Table 10). For the low and medium sites, no traditional agricultural system was able to meet the State's soil loss tolerance 'T' level. In addition, for the high site, agroforestry was the superior land-use alternative at the low discount rate, assuming a high timber growth rate. Again, among agroforestry alternatives, black walnut performed better on the better sites and at the higher timber growth rates while red oak was more attractive on the poorer sites and at the low timber growth rate.

The benefit of ameliorating soil erosion, attributed to the agroforestry systems, is clearly seen for the medium site (Table 10). To achieve the goal of meeting 'T', the State's voluntary soil loss tolerance level, agricultural production was possible on this site only within an agroforestry system. This is a significant benefit given the growing concerns of non-point source water pollution and the desire to develop low input, sustainable land-use management altenatives.

Soil erosion estimates for all agroforestry alternatives ranged from 3.1 to 8.1 $t\,ha^{-1}yr^{-1}$, well within the State's soil loss tolerance levels. For comparison purposes, soil loss from ungrazed forest land in Illinois was estimated by the USDA Soil Conservation Service (SCS) to average 3.6 $t\,ha^{-1}yr^{-1}$ in 1982. Similar estimates for total cropland ranged from 7.4 to 76.9 $t\,ha^{-1}yr^{-1}$ with an overall average of 15.7. Losses from less productive cropland in SCS Land Capability Classes III and IV (and more similar to the sites modeled for the agroforestry alternatives) were estimated to range from 21.5 to 42.4 $t\,ha^{-1}yr^{-1}$.

Summary

Agroforestry is a feasible, relatively low-input, sustainable land-use alternative offering benefits of land conservation and improved overall economic

Table 10. Best agroforestry and traditional agriculture alternatives for southern Illinois by site and discount rate[a]

r[b] (%)	Low Site Mgmt.[c]	–[d]	Medium Site Mgmt.	RCT[e]	High Site Mgmt.	RCT
		----After-tax net present values (US$/ha)----				
4	RO70L	−410	RO70L	163	BW70L	662
(6.8)	BW70M	212	BW70M	1490	BW70M	3529
	BW70H	944	BW70H	3716	BW60H	7855
	CS[f]	−415	CSWM[f]	3030	CC	4843
6	RO70L	−306	RO70L	109	BW70L	393~
(8.5)	BW70M	−131	BW70M	470	BW50M	1357
	BW70H	69	BW70H	1134	BW60H	2940
	CS	−242	CSWM	1932	CC	3086
8	RO70L	−257	RO70L	101	BW70L	329#
(10.2)	BW70M	−195~	BW70M	217	BW50M	739
	BW70H	−133	BW70H	452	BW50H	1483
	CS	−166	CSWM	1426	CC	2291
10	RO70L	−225	RO70L	104	BW70L	306*
(11.9)	BW70H	−203#	BW70M	143~	BW50M	494
	BW70H	−180~	BW60H	242	BW60H	890
	CS	−121	CSWM	1164	CC	1834

[a] Additional assumptions include 4% inflation; 15% federal and 2.5% state income tax rates; expensing of ordinary costs; a 10% ITC plus 7-year amortization of timber establishment costs; and an infinite investment life

[b] r = real, before-tax discount rate; the parentheses identify the equivalent, nominal after-tax rates used to discount the after-tax cash flows

[c] For each agroforestry alternative, the first two characters identify the timber species, the second two specify the rotation age, and the last character refers to the timber growth rate; a common crop rotation is used as the "best" traditional agriculture alternative

[d] Agroforestry alternatives possessing only timber component

[e] RCT refers to the combined production of row crops/timber

[f] For the low and medium sites, no traditional agriculture system was able to meet the State's soil loss "T" level

Note: Agroforestry alternatives using red oak often possessed estimated NPVs close to black walnut; ~ signifies NPVs within 6%, # within 2%, and * within 1%

return. In Illinois and the central states, agroforestry seems most attractive on marginal agricultural land where soil erosion is a concern and soil conservation measures are needed for sustained agricultural production.

Modeled agroforestry systems incorporating black walnut performed better on the better sites and at the medium to high growth rates whereas management systems with red oak performed better on the poorer sites and at the lower timber growth rates. For agroforestry to be competitive with traditional agriculture, medium to high timber growth rates were necessary. This means that sound silvicultural practices must be followed, particularly, good weed control.

The complex external economic and institutional environments faced by rural landowners also are important. For example, high interest rates favored traditional agriculture while low rates favored longer-term investments such as agroforestry. Agroforestry is also favored by the existing income tax structure due to timber's deferred tax liability. From a management perspective, substantial increases in net income also may be possible through incorporating other income producing activities such as nut production within the agroforestry system. In addition, other (nonmarket) benefits, such as enhanced wildlife habitat, may accrue to individual landowners.

As shown, the decision to invest in agroforestry rests on many factors such as management goals, land suitability, activity mix and management level, alternative opportunities, and the external economic environment. For agroforestry to be successful in Illinois and elsewhere, careful consideration should be given these factors.

References

1. Adams RD (1977) The effect of income tax progressivity on valuations of income streams by individuals. Amer J Agric Econ 59(3): 538–542
2. Athen FW (1971) Effects of weed control on the survival and growth of planted black walnut, white ash, and sugar maple. For Chron 47(4): 1–4
3. Betters DR (1988) Planning optimal economic strategies for agroforestry systems. Agroforestry Systems 7: 17–31
4. Bey CF (1973) Genetic variation and selection. In: Black Walnut as a Crop, USDA For Serv Gen Tech Rep NC-4, North Central For Exp Sta, St Paul, MN. pp 62–65
5. Bey CF and Williams RD (1976) Weed control in black walnut plantations. USDA For Serv Res Note NC-203, North Central For Exp Sta, St Paul, MN. 4 pp
6. Brinner R (1973) Inflation, deferral and the neutral taxation of capital gains. National Tax J 26(4): 565–573
7. Campbell GE and Dawson JO (1989) Growth, yield, and value projections for black walnut interplantings with black alder and autumn olive. North J Appl For 6(3): 129–132
8. Campbell GE and White DC (1989) Interpretations of Illinois stumpage price trends. North J Appl For 6(3): 115–120
9. Carmean WH and Hahn JT (1983) Site comparisons for upland oaks and yellow-poplar in the Central States. J For 81(11): 736–739
10. Dale ME and Brisbin RL (1985) Butt log quality of trees in Pennsylvania oak stands. USDA For Serv Res Pap NE-568, Northeastern For Exp Sta, Radnor, Pa. 8 pp
11. DeGarmo EP, Sullivan WG and Canada JR (1984) Engineering economy (7th ed). New York: Macmillan Publishing Co
12. Erdmann GG (1967) Chemical weed control increases survival growth in hardwood plantings. USDA For Serv Res Note NC-34, North Central For Exp Sta, St Paul, MN. 4 pp

13. Ferell RS and Lundgren AL (1976) Mathematical functions for predicting growth and yield of black walnut plantations in the central states. USDA For Serv Gen Tech Rep NC-24, North Central For Exp Sta, St Paul, MN. 5 pp
14. Gaffney M (1970) Tax-induced slow turnover of capital, II. Amer J Econ and Sociol 29(2): 179–197
15. Garrett HE and Kurtz WB (1981) Nut production – a valuable asset in black walnut management. In: Black Walnut for the Future, USDA For Serv Gen Tech Rep NC-74, North Central For Exp Sta, St Paul, MN. pp 53–56
16. Gold MA and Hanover JW (1987) Agroforestry systems for the temperate zone. Agroforestry Systems 5. 109–121
17. Jackson JP (1987) Soybeans and sawlogs, the promise of agroforestry. American Forests (Jul/Aug): 26, 28, 30–31
18. Kincaid WH (1982) Silvicultural economic assessment of black walnut management alternatives. MS Thesis. Univ Missouri, Columbia, MO. 99 pp
19. Kowalski DG and Gertner GZ (1989) A validation of TWIGS for Illinois forests. North J Appl For 6: 154–156
20. Krajicek JE, Brinkman KA and Gingrich SF (1961) Crown competition a measure of density. Forest Sci 7: 35–42
21. Lottes GJ (1985) Economics of integrated forestry systems in Illinois. MS Thesis. Univ Illinois, Urbana, IL. 185 pp
22. Miner CL, Walters WR and Belli ML (1988) A guide to the TWIGS program for the north central United States. Gen Tech Rep NC-125, North Central For Exp Sta, St Paul, MN. 105 pp
23. Myers JR, Miller GW, Wiant HV, Jr and Barnard JE (1986) Butt-log grade distributions for five Appalachian hardwood species. USDA For Serv NE-RP-590, Northeastern For Exp Sta, Radnor, PA. 4 pp
24. Raintree JB (1987) The state of the art of agroforestry diagnosis and design. Agroforestry Systems 5: 219–250
25. Schlesinger RC (1982) Pruning for quality In: Black Walnut for the Future, USDA For Serv Gen Tech Rep NC-74, North Central For Exp Sta, St Paul, MN. pp 87–91
26. Schlesinger RC and Funk DT (1977) Manager's handbook for black walnut. USDA For Serv Gen Tech Rep NC-38, North Central For Exp Sta, St Paul, MN. 22 pp
27. Smith GW (1987) Engineering economy, analysis of capital expenditures (4th ed). Ames: Iowa St Univ Press
28. Thurman SL (1989) The economics of agroforestry on Missouri soils. MS Thesis. Univ Missouri, Columbia, MO. 378 pp
29. Trimble GR, Jr (1965) Improvement in butt-log grade with increase in tree size, for six hardwood species. USDA For Serv Res Pap NE-31, Northeastern For Exp Sta, Radnor, PA. 15 pp