Agroforest Syst (2009) 76:437–453
DOI 10.1007/s10457-008-9173-y

Transitioning from wild collection to forest cultivation of indigenous medicinal forest plants in eastern North America is constrained by lack of profitability

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Received: 5 October 2007 / Accepted: 8 September 2008 / Published online: 25 September 2008

Abstract The forest flora of eastern North America includes many herbaceous plant species traded in domestic and international medicinal markets. Conservation concerns surrounding wild-collection exist and transitioning to cultivation in agroforestry systems has potential economic and ecological benefits. Costs and revenues associated with adopting forest cultivation were modeled for eight North American medicinal forest plants. Sensitivity analysis examined profit potential in relation to (1) discount rates; (2) propagation methods; (3) prices; (4) growing period; (5) production costs; and (6) yields. Results indicate that intensive husbandry of six of eight species would be unprofitable at recent (1990–2005) price levels. Exceptions are American ginseng (*Panax quinquefolius* L.), and under certain circumstances (e.g., maximum historic prices, low production costs) goldenseal (*Hydrastis canadensis* L.). Direct marketing to consumers and retailers might improve grower profits, but is undermined by the availability of cheaper, wild-collected product. We suggest that the North American medicinal plant industry could play a key role in facilitating any transition from wild to cultivated product, perhaps through development of a certification and labeling program that brands "forest cultivated" products. This could generate price premiums, to be passed along to growers, but must be accompanied by aggressive consumer education. A "forest cultivated" certification and labeling program has potential to benefit industry and consumers if assurances regarding product identity and quality are a central feature. Plant species that are not viable candidates for commercial cultivation due to limited consumer demand (i.e., species with "shallow," erratic markets) are best addressed through proactive government and industry initiatives involving targeted harvester education programs.

Keywords Financial analysis · Forest farming · Medicinal plant conservation · Non-timber forest products · Plant husbandry · Specialty forest products

Introduction

As many as 50 plant species indigenous to eastern North American forestlands annually find their way into domestic and international medicinal trade networks (American Botanicals 2008; Robbins 1999; Strategic Sourcing 2008). Commerce in a particular species fluctuates in response to consumer and industry demand, and frequently changes within and between years (AHPA 1999, 2003, 2006, 2007).

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Sudden increases in consumer demand for a particular medicinal plant, due to "fads" or positive media, initiates wholesale price increases which, in turn, drives interest in collecting and/or growing. Such price increases, however, are often short-lived and price decreases follow as inventory is replenished or consumer demand abates. This pattern of alternating "boom and bust" market cycles is a key feature of the North American medicinal plant trade (Craker et al. 2003).

Most botanical trade items originate through wild collection (AHPA 1999, 2003, 2006, 2007). Some of the most prominent North American trade species are gathered from forestlands (Bailey 1999; Emery et al. 2003; McLain and Jones 2005) and represent important non-timber forest products (NTFPs). Among these, collection pressure is widely acknowledged for American ginseng (*Panax quinquefolius* L.) and goldenseal (*Hydrastis canadensis* L.); however, there is also significant commerce in other species including black cohosh (*Actaea racemosa* L.), blue cohosh (*Caulophyllum thalictroides* L.), bloodroot (*Sanguinaria canadensis* L.), false unicorn root (*Chamaelirium luteum* L.) and wild yam (*Dioscorea villosa* L.) (AHPA 1999, 2003, 2006, 2007).

Collection from wild populations is a concern since many species are slow-growing perennials with low fecundity and/or juvenile recruitment rates (Bierzychudek 1982; Charron and Gagnon 1991; Meagher and Antonovics 1982; Sinclair et al. 2005). Harvest of these species removes all or a significant portion of the root or rhizome, resulting in high mortality. Harvesting that does not allow for plant reproduction and/or sufficient propagules (i.e., seeds, root pieces) to remain in an area may result in local extinctions (Albrecht and McCarthy 2006; Farrington 2006; Sanders and McGraw 2005; Van Der Voort et al. 2003). Presently, two North American medicinal forest plants—American ginseng and goldenseal—are included in Appendix 2 of the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) due to concerns over sustainability of wild harvests and additional species have been suggested as suitable candidates for listing.

Rather than collect from wild populations, cultivation of indigenous North American medicinal forest plants is an alternative (Bannerman 1997; Gladstar and Hirsch 2000; Robbins 1998a, 1999; United Plant Savers (UPS) 2008). In situ cultivation using agroforestry practices such as forest cultivation are especially attractive (Hill and Buck 2000; Rao et al. 2004), as there are potential advantages or benefits compared with field-based cultivation. One advantage is production cost savings, since many forest plants are shade obligate. Significant investment in artificial shade is necessary when plants are grown in open field settings; materials and associated labor costs in American ginseng field-based production, for example, average $30–50,000 (US$) per hectare (Schooley 2003).

Another advantage of forest cultivation is final product characteristics or qualities. American ginseng, for example, has a unique international market in which "wild" characteristics are preferred (Persons and Davis 2005; Roy et al. 2003). For this species, differences in final product appearance can translate into substantial price disparities, with $20–60 (US$/dry/kg) paid for root that appears "cultivated" versus $500–1,300 (US$/dry/kg) for roots with "wild" attributes. "Wild" characteristics are difficult to produce using conventional, field-based cultivation techniques but are much more easily achieved through judicious selection and utilization of forested habitats. American ginseng is the only species currently valued on the basis of "wild" appearance. However, product quality for other species could benefit from possible reductions in crop disease and pestilence if grown in appropriate forest habitats. Causative links have been made between choice of growing site and disease incidence and severity in black cohosh (Thomas et al. 2006), American ginseng, and goldenseal (Ontario Ministry of Agriculture Food and Rural Affairs (OMAFRA) 2005). Cultivating forest plants in their native habitats may eliminate or reduce disease problems and, in turn, the need for pesticide use, and facilitate access to "organic" and other niche markets. There may also be differences in chemical constituent levels associated with where and how plants are cultured (Bennett et al. 1990; Lim et al. 2005; Salmore and Hunter 2001).

Finally, forest cultivation offers multiple economic and ecological benefits to landowner and society, since the practice has the potential to increase income while maintaining forest integrity (Dix et al. 1997; Hill and Buck 2000). Income derived from forest cultivation is received at shorter intervals than timber, giving private forest landowners more revenue options, enabling them to pay annual taxes and other carrying costs. Facilitating private landowner interest in adopting forest cultivation can therefore drive interest in forest stewardship, raise awareness about indigenous forest plants, and positively influence silvicultural decisions.

Transitioning from wild-collection to forest cultivation of indigenous North American medicinal forest plants is an economic opportunity with concomitant conservation and ecological merits. However, there has been limited financial evaluation of agroforestry crop candidates in relation to recent market price trends. While cash flow budgets are available for American ginseng (e.g., Beyfuss 1999b; Persons and Davis 2005; Schooley 2003) and to a lesser extent goldenseal, black cohosh and bloodroot (e.g., Davis 1999; Persons and Davis 2005), none incorporate sensitivity analysis for key variables such as length of cropping period, material and labor costs, and final yield variation nor do they account for the impact of inflation and discounting on prices, costs, and revenues. Since nearly all indigenous crop candidates require multiple years to yield a product, it is necessary to consider these factors in developing realistic budgets and technical guidance for growers.

This paper presents financial analyses (i.e., cost and revenue models) for agroforestry cultivation of eight North American medicinal forest plants, using sensitivity analysis to examine profit potential relative to costs, revenues, discount rates, production length, propagation methods, and yields. Market price data were compiled for the period 1990–2005 and were adjusted for inflation. Results identify market and production factors requiring careful consideration by those interested in agroforestry cultivation of indigenous North American medicinal forest plants, and highlight constraints to transitioning from wild collection to forest cultivation.

Materials and methods

All analyses were conducted utilizing a spreadsheet template (=basic model) which was modified (=adjusted model) for sensitivity analyses (e.g., discount rate, time to harvest, no stock costs, no annual costs). The term "basic model" as used in this paper refers to the original template whereas "adjusted model" indicates modified templates where key variables were altered.

Species selection

Eight herbaceous plant species were selected for analysis (Table 1). All are indigenous to eastern North American forestlands and have commercially harvested roots or rhizomes. Additionally, these species were used because they met one or more of the following criteria: (1) significant volume is traded, as indicated by recent industry data (AHPA 1999, 2003, 2006, 2007) and government harvest/collection statistics (USFWS 2008); (2) strong consumer demand in recent years with potential for additional market growth (e.g., black cohosh); and/or (3) continued collection from the wild is of particular conservation concern.

One exception, poke (*Phytolacca americana* L.), was included in the analysis for comparative purposes. This species grows rapidly (harvest can occur after 1 or 2 years) and is considered "weedy" from biological and ecological perspectives. The other species, by contrast, require multiple (three or more) years of growth before harvest is possible and have much more demanding cultural and husbandry requirements.

Approaches to forest cultivation

The agroforestry practice of forest cultivation, or *forest farming* as it is frequently known and promoted in the United States (Dix et al. 1997; Hill and Buck 2000), involves two general approaches. The first is more intensive, often using raised beds, and is referred to as *woods-cultivated*. The second is less intensive, attempting to replicate "wild" growing conditions, and is referred to as *wild-simulated* (Beyfuss 1999a, 2000; Persons 1986; Persons and Davis 2005).

The woods-cultivated method involves greater investment of time, labor, and equipment since it generally incorporates forest understory manipulation (e.g., thinning), soil tillage and amendments (e.g., fertilizer, crushed limestone), preparing and maintaining beds, and pest management. These site modifications are intended to hasten and improve yields as well as facilitate convenient management. The wild-simulated approach, conversely, follows a less-intensive strategy that may involve nothing more than the planting of seed or root in existing forest habitat.

Table 1 Plants included in this analysis, their medicinal uses, and known trade volumes

Scientific name	Abbreviation in this paper	Trade name[a]	Medical applications and uses[b]	Reported trade volume range (kg/yr/dry)
Actaea racemosa L.	ACRA	Black cohosh	Treatment of menopause and post-menopausal symptoms	~259,600–1,675,100[c]
Caulophyllum thalictroides Michx.	CATH	Blue cohosh	Promotion of menstruation; uterine stimulant	~10,000–18,000[c]
Chamaelirium luteum (L.) A. Gray	CHLU	False unicorn	Diuretic; uterine tonic	~9,800–14,300[c]
Dioscorea villosa L.	DIVI	Wild yam	Source of steroidal hormones; contraceptive; anti-inflammatory	~69,600–149,200[c]
Hydrastis canadensis L.	HYCA	Goldenseal	Antibiotic; haemostatic; stomachic, laxative; mucus membrane tonic	~94,300–583,600[c]
Panax quinquefolius L.	PAQU	American ginseng	Adaptogenic; tonic	~132,500–350,200[d]
Phytolacca americana L.	PHAM	Poke	Anti-inflammatory; hypotensive; diuretic; emetic; anti-rheumatic	~2,200–26,400[e]
Sanguinaria canadensis L.	SACA	Bloodroot	Antibiotic; anti-plaque (in toothpastes); animal feed additive	~58,300–107,100[c]

[a] Accepted trade names are from McGuffin et al. (2000)

[b] Includes both traditional/folk and modern/clinical uses. Sources: Lewis and Elvin-Lewis (2003), Van Wyk and Wink (2004), Foster and Duke (2000)

[c] Includes both wild collected and cultivated materials, though the cultivated fraction is insignificant for all species except goldenseal. Trade period: 1997–2005 (except CATH, CHLU, SACA: 2000–2005). Sources: AHPA (1999, 2003, 2006, 2007). Fresh product is also traded, but is not included in these figures

[d] Includes only the recorded wild harvest. However, this figure likely includes at least some "wild simulated" and "woods cultivated" product sold and marketed as "wild." Trade period: 1989–2006. Source: USFWS (2008)

[e] No published trade data available. Edward Fletcher of Strategic Sourcing, Inc. (Banner Elk, NC) provided this estimate based on his long-term buyer experience

Basic model parameters use the woods-cultivated approach to forest cultivation premised upon the idea that more intensive methods would tend to increase yields by increasing survival, growth, and root weight. However, adjusted models in which annual costs are removed are included and could be considered similar to the less intensive wild-simulated cultivation approach.

Price information

Price data for developing this analysis came from contacts with "local buyers/country dealers" and "regional consolidators" and covers the period 1990–2005. In any given year, there were at least two sources of price information available although as many as four price sources were available for half of the years. Price sources included price lists, buyer circulars, and consultations with buyers made between 2002 and 2006. Companies and buyers providing price information were American Botanicals Inc. (MO), Strategic Sourcing Inc. (NC), Millin's Hides, Furs, Roots, and Seeds (PA), Hawk Mountain Trading Company (WV), Gruver's Trading Post (PA), Ohio River Ginseng and Fur (OH), Wilcox Natural Products (NC, MO, KY), Potter Fur and Hide Inc. (OH), Duncan's Fur, Hide and Root Co. (IN), Owens Roots and Herbs (IL), and Tuckasegee Valley Ginseng (NC).

Before conducting any analyses, all prices were adjusted for inflation using consumer price index (CPI) data available from the United States Bureau of Labor Statistics (United States Department of Labor, Bureau of Labor Statistics (BLS) 2007). This standardized prices for the 15-year sample period. The price data therefore represents 'real' rather than 'nominal' prices, adjusted to 2005 (US$) equivalents.

Planting stocking requirements and costs

The basic model includes two propagation methods: seed and juvenile rootstock transplants sourced from a commercial nursery (see Table 2 for stocking requirements and estimated costs).

Seed stock

The number of seeds per gram was compiled using collected seed counts, published data, and personal contact with researchers working with particular species. Direct, first-hand counts, were made with mature seed collected from wild and cultivated plants during 2004–2006. For increased reliability, seed count values were compared with, and found to be consistent with published (Cech 2002, 2008; Persons and Davis 2005; Richters 2008) and unpublished counts (M. Albrecht, personal comm., 27 March 2006).

Seed for some species included in this analysis must remain partially moist to retain viability or for best germination success (Baskin and Baskin 2001; Cech 2002; Cullina 2000; Persons and Davis 2005). Therefore, about half of the values are moist weight (i.e., ACRA, CATH, HYCA, PAQU, SACA) while the remaining are dry weight (i.e., CHLU, DIVI, PHAM) (see Table 1 for species abbreviations).

Table 2 Planting stock needs and associated costs for establishing commercial North American medicinal forest plantings (1/10 Ha)

	Propagation from seed				Propagation using transplants		
	Seeds per gram	Quantity needed (grams)	Cost per gram (US$)	Total cost (US$)	Quantity needed	Cost per root (US$)	Total cost (US$)
ACRA	300	17	10.00	170	5,000	0.50	2,500
CATH	5	1,000	1.00	1,000	5,000	0.50	2,500
CHLU	1,800	11	50.00	550	20,000	0.50	10,000
DIVI	80	63	10.00	630	5,000	0.50	2,500
HYCA	50	400	5.00	2,000	20,000	0.50	10,000
PAQU	15	667	0.25	167	10,000	0.50	5,000
PHAM	150	33	4.00	132	5,000	0.50	2,500
SACA	80	250	5.00	1,250	20,000	0.50	10,000

ACRA, *Actaea racemosa*; CATH, *Caulophyllum thalictroides*; CHLU, *Chamaelirium luteum*; DIVI, *Dioscorea villosa*; HYCA, *Hydrastis canadensis*; PAQU, *Panax quinquefolius*; PHAM, *Phytolacca americana*; SACA, *Sanguinaria canadensis*

Root stock

All species included in the analysis may be propagated by transplanting young plant roots or by parental rootstock divisions (Cech 2002; Cullina 2000; Persons and Davis 2005; McCoy et al. 2007; Van Der Voort et al. 2003). The number of propagules possible from parental stock varies by species, age, and individual root size; a conservative model assumed one transplant or parent rootstock was needed for each crop plant established. Thus, root transplants (i.e., small juvenile roots) and nursery stock (i.e., larger roots) are treated the same. This probably inflates actual planting stock needs (and thus costs) for those species that are readily propagated by vegetative division of rootstock (e.g., goldenseal, wild yam).

Planting stock price sources and cost estimates

Planting stock cost estimates for nursery sourced seed and rootstock were compiled by surveying existing commercial vendors. Vendors consulted were Horizon Herbs (Williams, OR), Sleepy Hollow Farm (Dalton, GA), Richters (Ontario, Canada), Sylvan Botanicals (Cooperstown, NY), and Tuckasegee Valley Ginseng (Tuckasegee, NC). The most important price variable for nursery sourced seed and rootstock was quantity purchased, and this lead to the need for several assumptions.

Seed is commercially available for all species included, and costs per gram were either quoted directly or averaged when two or more prices were noted. In some cases, seed costs were probably overestimated slightly because economy of scale price data was not available and cost was then calculated using price per gram. In other cases, prices were slightly underestimated because costs were calculated on a per gram basis from prices based on a larger quantity (e.g., pound, kilogram).

Costs varied more for transplant stock than for seed. For lesser quantities (100 or less plants), a range of \$0.75–5.00 per transplant were observed; conversely, stock purchased in greater quantities (e.g., 1,000 or more plants) ranged from \$0.25 to 1.75 per transplant. To simplify observed price variability, and to account for likely additional economy of scale price discounts for 5,000 or more transplants, a standard price of \$0.50 per transplant for all species was selected for the basic model.

The adjusted "no stock costs" model excludes all stock costs in order to examine the influence of this cost on profitability. In practice, this model represents growers collecting their own seed or transplants or established growers generating their own planting stock.

Crop production parameters and yield estimates

All crop production parameters (i.e., stocking needs, labor and material costs) and yield calculations were modeled for 10 raised beds consisting of 100 m^2 planting area per bed, or 1,000 m^2 (1/10 Ha) total planted area (Table 3). The use of a relatively small area in modeling was for purposes of examining the economics of small-scale adoption. Additionally, growers consulted for estimating crop production requirements were able to more accurately gauge model parameters (such as time spent in an activity) when presented with a smaller scale (e.g., per bed) scenario.

Plant spacing and numbers

Plant stocking levels were informed by several growers and root buyers, and existing literature (Cech 2002; Persons and Davis 2005). This parameter remained consistent across models (i.e., there was no adjusted model).

Years to harvest

Two values for cropping period were incorporated into this analysis (Table 3). The average number of years required before harvest can occur (=basic model), and the minimum number of years (=adjusted model). This latter "early harvest" model was included in order to examine the sensitivity of the basic results to production time, discount rates, and associated costs (supply and labor).

Yield estimates

Root weight data were obtained over a 3-year period (2003–2006) by sampling forest grown (both wild and cultivated) roots. Each sample consisted of 50 roots per species. For increased reliability, the mean root sample weight values were compared with, and found to be consistent with, root weight data from

Table 3 Cropping requirements and yield estimates for commercial forest production of North American medicinal plants (1/10 Ha)

	Plant spacing and numbers			Years to harvest[a]		Yield weights (dry)		Final yields (dry/kg)	
	Plants/m^2	Plants/ 100 m^2 bed	Plants/ 1,000 m^2	From seed	From division or transplant	Per root (g)	Roots/ kg	Per 100 m^2 bed	Per 1,000 m^2
ACRA	5	500	5,000	6 (4)	4 (3)	20	50	10	100
CATH	5	500	5,000	8 (6)	6 (4)	10	100	5	50
CHLU	10	1,000	10,000	8 (6)	6 (4)	5	200	5	50
DIVI[b]	5	500	5,000	6 (4)	4 (3)	10	100	5	50
HYCA	20	2,000	20,000	6 (4)	4 (3)	5	200	10	100
PAQU	10	1,000	10,000	8 (6)	6 (4)	5	200	5	50
PHAM	5	500	5,000	2 (1)	1 (1)	20	50	10	100
SACA	20	2,000	20,000	6 (4)	4 (3)	5	200	10	100

ACRA, *Actaea racemosa*; CATH, *Caulophyllum thalictroides*; CHLU, *Chamaelirium luteum*; DIVI, *Dioscorea villosa*; HYCA, *Hydrastis canadensis*; PAQU, *Panax quinquefolius*; PHAM, *Phytolacca americana*; SACA, *Sanguinaria canadensis*

[a] The first value is the average number of years until harvest. The parenthetical value is the minimum number of years until harvest

[b] This plant species has a markedly rhizomatous growth habit. Yield assumptions were based on 15-cm (long) × 1-cm (wide) section of dried rhizome

sources including growing trial results (Brush 2006; McCoy et al. 2007; Renaud 2004), grower experience, and published samples and projections (Cech 2002; Persons and Davis 2005).

One seed or transplant was assumed to yield each root. This is likely to be an overestimate of establishment success in many cases since some seeds will not germinate and some plants will be lost to various adversities (e.g., disease, pests). Rather than attempt to account for any differences in establishment between species due to seed germination and/or transplant success rates, we assumed a 1:1 ratio. While simplistic, this allows for model results to reflect best possible scenarios for each species. Model results can be adjusted to reflect less ideal circumstances, for example, 50% establishment success, by halving yields or doubling NPV and break even prices.

Labor and material costs

In the basic model, labor costs were derived by first developing a list of the major labor activities associated with forest cultivation using raised beds, and then estimating the hours required for each (Table 4). This list of activities and estimated labor needs were assembled from grower consultation and using published labor estimates for American ginseng (Persons and Davis 2005; Schooley 2003). General commercial guidelines by Whitten (1999) were also consulted.

While the labor activities included in Table 4 may not be done with hired labor, an hourly wage was included as an opportunity cost to highlight the trade-off of adopting forest cultivation for income generation rather than alternative income opportunities. An hourly wage of $13.00 was selected for the model; an average of 2005 U.S. average hourly wages for “blue collar” professions (=$15.87) and “nursery workers” (=$10.26) (United States Department of Labor, Bureau of Labor Statistics (BLS) 2007).

Estimated material costs for the basic model are provided in Table 5. Only variable costs were included. Fixed costs such as machinery (e.g., roto-tiller, small tractor) were not included nor are land rental or purchase costs. It is assumed that production occurs without significant farming machinery (or with machinery already owned or borrowed), and on forestland that is under grower tenure or available without cost (e.g., family owned property).

An adjusted “no annual costs” model was also developed without annual labor and material costs to examine their effect on profitability. Labor and material costs from the first year (planting) and from the final year (harvest) were the only costs included in this adjusted model, since growers are still required to invest in establishing and harvesting their crop despite the possibility of reducing labor and material costs during the cropping period.

Table 4 Labor needs and estimated costs for establishing, maintaining, and harvesting commercial forest plantings (1/10 Ha)

Activity	Time spent (hours)		
	Planting	Years 1–8	Harvest
Planting site preparation			
Forest understory preparation (pruning, clearing)	25		
Bed preparation (5 h/100 m^2 bed)	50		
Planting (5 h/100 m^2 bed)	50		
Mulching (1 h/100 m^2 bed)	10		
Annual maintenance			
Fallen limb removal, debris clean-up		5	
Bed shaping, edging		5	
Re-mulching		10	
Miscellaneous		5	
Pest scouting, management and control			
Weeding (3 h/100 m^2 bed)		30	
Disease: e.g., fungi (1.5 h/100 m^2 bed)		15	
Insects: e.g., slugs (1 h/100 m^2 bed)		10	
Animals: e.g., deer, vole (1 h/100 m^2 bed)		10	
Harvest and post harvest			
Digging (10 h/100 m^2 bed)			100
Washing and drying			50
Hour totals	135	90	150
Labor costs (US$ @ $13/h)	$1,755.00	$1,170.00[a]	$1,950.00

[a] This is an annual cost and is multiplied by the number of cropping years for each crop to derive a total cost

Table 5 Production supply needs and associated costs for establishing, maintaining and post-harvest handling of commercial North American medicinal forest plantings (1/10 Ha)

Item	Cost (US$)		
	Planting	Years 1–8	Harvest
Soil/bed related			
Straw mulch (50 bales @ $2 each)	$100.00	$100.00	
Compost or fertilizer (for 1,000 m^2)	$100.00	$100.00	
Limestone (for 1,000 m^2)	$50.00		
Pest management and control			
Fungicides		$100.00	
Pesticides (including slug poison)		$100.00	
Rodenticide or rodent repellent (for voles)		$100.00	
Miscellaneous			
Tools, drying supplies, packing	$250.00	$50.00	$500.00
Totals (US$)	$500.00	$550.00[a]	$500.00

[a] This is an annual cost and is multiplied by the number of cropping years for each crop to derive a total cost

Choice of discount rate

Discounting is a financial procedure that takes an expected future return in a given time period and discounts it (using a given interest rate) back to the present (today's) value to find Net Present Value (NPV). The following formula was used for discounting in our models:

$$\text{NPV} = \sum_{y=0}^{n} \frac{R_y}{(1+r)^y} - \sum_{y=0}^{n} \frac{C_y}{(1+r)^y}$$

where R, revenues; C, costs; r, real discount rate; y, number of years

The basic model incorporated a 4% discount rate. Two slightly higher rates, 6 and 8%, were used in adjusted models to examine net present value (NPV) sensitivity. Because both basic and adjusted models utilized real prices, future revenues were treated the same by removing inflation from discount rates (Klemperer 1996).

Calculation of break even prices and yields

Break even prices were calculated by dividing production costs by the projected yields. Break even yields were calculated by dividing production costs by minimum, maximum, and mean prices. In both calculations, only variable costs were used, in keeping with the variable versus fixed cost assumptions presented under "labor and material costs."

Results

Discount rate

NPV results for both basic and adjusted models are given in Table 6. Only the most favorable production method (most profitable/least unprofitable) results are given for each selected discount rate. As expected, as discount rate increased, profitability decreased for all species. However, there were no changes from profitable to unprofitable with any species in response to increasing discount rates.

In general, the NPV results for all models suggest adoption of forest cultivation for all species except American ginseng would be unprofitable at even the lowest discount rate. This is true regardless of propagation method, although for most species propagation from seed is apparently less costly despite the generally longer cropping period. The results did not differ with price level.

Price received

To examine whether recent industry pricing will support forest cultivation, break even prices (i.e., the cost of production divided by the yield) were calculated for each species and compared with 1990–2005 prices (Table 7). With only one exception, American ginseng, both basic and adjusted model break-even price results were much higher than historic prices. This suggests that, barring significant future price increases, forest cultivation would not be profitable for seven of eight species included in this analysis. The exception, American ginseng, had break-even prices well below historic price levels in all model scenarios.

These findings did not change even when parsimonious adjusted models were created (i.e., early harvest + no stock costs + no annual costs), and did not differ with propagation method. Only goldenseal showed profit earning potential in adjusted models, if cropping period (early harvest) and production costs were reduced (no stock + no annual costs) and mean or maximum prices were obtained.

Table 6 Net present value (NPV, US$, 1/10 Ha) of North American medicinal forest crop candidates at three discount rates and three price levels (mean, minimum, maximum prices, 1990–2005)

	NPV (4% discount rate, US$)			NPV (6% discount rate, US$)			NPV (8% discount rate, US$)		
	Mean price	Min price	Max price	Mean price	Min price	Max price	Mean price	Min price	Max price
ACRA	−12,731^{T}	−12,888^{T}	−12,485^{T}	−12,312^{S}	−12,441^{S}	−12,092^{T}	−11,654^{S}	−11,770^{S}	−11,472^{S}
CATH	−15,609^{T}	−15,662^{T}	−15,495^{T}	−14,851^{T}	−14,899^{T}	−14,750^{T}	−14,171^{T}	−14,214^{T}	−14,081^{T}
CHLU	−14,137^{S}	−15,454^{S}	−12,720^{S}	−13,272^{S}	−14,403^{S}	−12,056^{S}	−12,505^{S}	−13,479^{S}	−11,458^{S}
DIVI	−12,971^{T}	−13,044^{T}	−12,810^{T}	−12,543^{T}	−12,610^{T}	−12,394^{T}	−12,148^{T}	−12,210^{T}	−12,010^{T}
HYCA	−10,518^{S}	−12,084^{S}	−8,423^{S}	−10,257^{S}	−12,084^{S}	−8,388^{S}	−10,011^{S}	−11,259^{S}	−8,340^{S}
PAQU	15,261^{T}	4,610^{S}	32,030^{T}	12,414^{T}	2,879^{S}	27,372^{T}	9,937^{T}	1,455^{S}	23,307^{T}
PHAM	−7,782^{S}	−7,816^{S}	−7,707^{S}	−7,611^{S}	−7,643^{S}	−7,538^{S}	−7,448^{S}	−7,480^{S}	−7,379^{S}
SACA	−13,441^{S}	−14,234^{S}	−12,632^{S}	−12,783^{S}	−13,490^{S}	−12,061^{S}	−12,190^{S}	−12,822^{S}	−11,545^{S}

NPV given is for the most profitable propagation method (Method of propagation: S, seed; T, transplant)

ACRA, *Actaea racemosa*; CATH, *Caulophyllum thalictroides*; CHLU, *Chamaelirium luteum*; DIVI, *Dioscorea villosa*; HYCA, *Hydrastis canadensis*; PAQU, *Panax quinquefolius*; PHAM, *Phytolacca americana*; SACA, *Sanguinaria canadensis*

Table 7 Comparison of three actual price levels (US$, mean, minimum, maximum prices, 1990–2005, adjusted for inflation) with model break even prices (4% discount rate) for commercial forest production of North American medicinal crop candidates

	ACRA		CATH		CHLU		DIVI		HYCA		PAQU		PHAM		SACA	
1990–2005 prices (US$/kg/dry)																
Mean price	4.23		2.51		55.81		2.84		59.34		846.98		1.24		12.86	
Minimum price	2.39		1.15		19.76		1.15		39.53		558.43		0.87		2.83	
Maximum price	7.11		5.38		94.59		6.61		85.85		1271.33		2.05		23.10	
Break-even prices (US$/kg/dry) according to method of propagation[a]																
Basic model	S	T	S	T	S	T	S	T	S	T	S	T	S	T	S	T
	169.27	153.17	455.06	397.51	442.75	587.30	350.18	306.33	192.43	240.91	432.26	460.77	85.41	91.15	182.94	240.91
Adjusted models																
Early harvest (EH)	125.91	131.68	359.55	306.33	348.16	481.81	262.58	263.36	147.32	216.04	338.46	364.82	66.52	N/A	138.54	216.04
No stock costs (NSC)	167.12	123.92	427.69	334.24	427.69	334.24	334.24	247.84	167.12	123.92	427.69	334.24	83.98	65.15	167.12	123.92
No annual costs (NAC)	60.68	85.63	149.09	180.33	136.78	370.13	133.01	171.25	83.84	173.37	126.29	243.60	55.82	79.45	74.35	173.37
EH & NSC	123.92	103.56	334.24	247.84	334.24	247.84	247.84	207.11	123.92	103.56	334.24	247.84	65.15	N/A	123.92	103.56
EH & NAC	58.37	83.49	142.37	171.25	130.98	346.73	127.50	166.97	79.78	167.85	121.29	229.75	54.82	N/A	71.00	167.85
NSC & NAC	58.53	56.38	121.72	117.07	121.72	117.07	117.07	112.76	58.53	56.38	121.72	117.07	54.39	53.45	58.53	56.38
EH, NSC, & NAC	56.38	55.37	117.07	112.76	117.07	112.76	112.76	110.73	56.38	55.37	117.07	112.76	53.45	N/A	56.38	55.37

ACRA, *Actaea racemosa*; CATH, *Caulophyllum thalictroides*; CHLU, *Chamaelirium luteum*; DIVI, *Dioscorea villosa*; HYCA, *Hydrastis canadensis*; PAQU, *Panax quinquefolius*; PHAM, *Phytolacca americana*; SACA, *Sanguinaria canadensis*

[a] Method of propagation: S, seed; T, transplant

Propagation method

When break-even prices were examined by propagation method (Table 7), the calculated break-even price from seed was lower than transplants for more than half of the plant species (i.e., CHLU, HYCA, PAQU, PHAM, SACA), despite the fact that a shorter cropping period is generally required using transplants (in turn reducing labor and material costs). This resulted from the fact that seed is usually less expensive than rootstock in the nursery trade. Scenarios in which cultivation using transplants had a lower break-even price (i.e., ACRA, CATH, DIVI) resulted from relatively higher seed costs, coupled with added labor and material costs necessitated by the longer cropping period when grown from seed.

Even when all stock costs were removed from models (no stock costs), calculated break-even prices for all species except American ginseng remained well above recent historic prices. Moreover, removing stock costs from models affected break-even prices to a lesser extent than shortening the cropping period (early harvest) or eliminating annual production costs (no annual costs). These results suggest that while planting stock costs are an important determinant of profit potential, they are less important than other production costs such as cropping period, annual labor, and materials.

Time to harvest

The influence of crop period on profitability was examined using an adjusted model to consider the shortest possible rotation (early harvest). The break-even prices calculated from these results (Table 7) indicate that hastening harvests can improve the economics of forest cultivation, but this alone is not enough to change the general findings that recent historic prices are well below break-even. Shortening the cropping period did have more influence on determining break-even prices than did eliminating planting stock costs.

Production costs

Adjusted models in which annual production costs such as labor and materials were excluded (no annual costs) had the most significant impact on break-even prices (Table 7). In all cases, the exclusion of annual costs produced break-even prices that were at most half those calculated in basic models.

Yields

Yields are an important model parameter affecting profitability, but will vary depending on many production factors. Rather than creating a series of adjusted models to examine the impact of yield variation, break-even yield values (i.e., total costs of production divided by the average price received per kg) were calculated for all species, for both crops grown from seed and transplant. Basic model production costs were used for these calculations (i.e., no adjusted model assumptions were incorporated).

Calculated break-even yield values are presented in Table 8. In general, results indicate that yields for all species except American ginseng would need to greatly increase to recover investment costs. Half of the species (ACRA, CATH, DIVI, PHAM) would require unrealistic yield increases for cost recovery and profit potential. Of the remaining, three (CHLU, HYCA, SACA) would require modest yield increases and favorable market prices (e.g., mean, maximum prices). Only American ginseng would require no yield increases to recover production costs and provide profit; according to model results, yields for this species could be reduced and cost recovery and profit potential would likely remain.

Discussion

Implications for adoption of forest cultivation

Individuals may choose to adopt forest cultivation for other than purely financial reasons such as personal interest, household consumption, and/or conservation intentions; however, any broad transition from wild collection to forest cultivation of the plants considered in this study is likely to require financial justification or rewards for adopters. This is especially true since many species require multiple years before harvesting, and the investment tied-up in each forest crop can be significant during intervening years. Net present value (NPV) results revealed that, with one exception (e.g., American ginseng), adopting forest cultivation for the plants considered in

Table 8 Modeled break even yields for commercial production of North American medicinal forest plants, as determined by price received (mean, minimum, maximum prices, 1990–2005)

	Break even (kg/1,000 m^2)		Break even (g/per root)		Yield increase needed (multipliers)[a]	
	S	T	S	T	S	T
ACRA						
Mean price	4,002	3,621	800	724	40×	36×
Maximum price	2,381	2,154	476	431	24×	22×
Minimum price	7,082	2,930	1,416	1,282	71×	64×
CATH						
Mean price	9,065	7,918	1,813	1,584	181×	158×
Maximum price	4,229	3,694	846	739	85×	74×
Minimum price	19,785	17,283	3,957	3,457	396×	346×
CHLU						
Mean price	397	526	40	53	8×	11×
Maximum Price	234	310	23	31	5×	6×
Minimum price	1,120	1,486	112	149	22×	30×
DIVI						
Mean price	6,165	5,393	1,233	1,079	123×	108×
Maximum Price	2,649	2,317	530	463	53×	46×
Minimum Price	15,225	13,319	3,045	2,664	305×	266×
HYCA						
Mean price	324	406	16	20	3×	4×
Maximum price	224	281	11	14	2×	3×
Minimum price	487	609	24	31	5×	6×
PAQU						
Mean price	26	27	3	3	None	None
Maximum price	17	18	2	2	None	None
Minimum price	39	41	4	4	None	None
PHAM						
Mean price	6,888	7,351	1,378	1,470	69×	74×
Maximum price	4,166	4,446	833	889	42×	45×
Minimum price	9,817	10,477	1,963	2,095	98×	105×
SACA						
Mean price	1,423	1,873	71	94	14×	19×
Maximum price	792	1,043	40	52	8×	10×
Minimum price	6,464	8,513	323	426	65×	85×

ACRA, *Actaea racemosa*; CATH, *Caulophyllum thalictroides*; CHLU, *Chamaelirium luteum*; DIVI, *Dioscorea villosa*; HYCA, *Hydrastis canadensis*; PAQU, *Panax quinquefolius*; PHAM, *Phytolacca americana*; SACA, *Sanguinaria canadensis*

[a] Relative to model assumptions (refer to Table 3 for values)

these models would be unprofitable, assuming wholesale product prices continue at recent historic levels.

Adjusted models (i.e., sensitivity analyses) were used to examine the relative influence of key variables in determining break-even prices and yields. Of the variables examined, annual production costs (i.e., labor and supply costs) most affected break-even prices, because the majority of the species considered require multiple years until harvest, and annual production costs accrue during this period. From a practical standpoint, this suggests that husbandry approaches using minimal husbandry practices, i.e., "wild-simulated" approach, may best reduce production costs and thereby improve revenue potential.

However, there are likely trade-offs to adopting a minimal husbandry approach, including reduced plant survival and yields. It must be emphasized that even when annual production costs (i.e., all costs except planting and harvesting costs) were removed from adjusted models, calculated break-even prices were still much greater than recent prices. Thus, reducing production costs is likely to be only part of any solution to improving the economics of forest cultivation.

Shortening the time between planting and harvest (i.e., cropping period) was the second most influential factor in determining break-even prices. Accordingly, propagation methods and production practices that reduce the cropping period are likely to benefit producers. Such practices might include using transplants rather than seed as planting stock. While transplant costs are generally greater than seed costs, annual production costs represented the greatest single investment expense in these models; thus, careful deliberation must be given to potential cost savings accrued by using transplants. The time to harvest is perhaps best shortened by selecting cropping sites most favorable to optimal growth for each species. Manipulation of soil conditions, via tillage or amendments, may encourage rapid growth and higher yields, but these will also increase production costs.

The economics associated with forest cultivation might also be improved by responsible gathering of local planting stock, since stock from nursery suppliers is presently very expensive for most species. One potentially less expensive alternative to buying nursery stock (although there will still be time and labor costs) is to use local germplasm through seed, seedling, or rootstock collection and replanting, which can concomitantly help to retain genetic diversity in the species. The erosion or loss of local and regional genetic characteristics has become a concern in recent years with the planting of American ginseng on forestlands using "commercial" propagules (USFWS 2008). Similar concerns could arise with other plant species should broad adoption of forest cultivation occur. In cases where a crop candidate (and sufficient propagules) are already present on grower forestlands, propagation using existing local stock could be practiced with potentially little adverse consequence. In scenarios where candidate crop species are not already present, the transfer of plant materials across ownership or tenure boundaries could occur, but must be carefully advocated and/or practiced to prevent legal and ethical problems.

Manipulating production practices through fertilization, irrigation, and/or increasing sunlight levels to improve yields may favorably alter forest cultivation economics. However, modeled break-even yield estimates indicate that significant yield increases would need to occur for nearly all species to recover costs, much less earn profits. Of the plants considered here, the economics associated with forest cultivation are most likely to improve for CHLU, HYCA, SACA through increased yields. It is likely that yield increases necessary to support cultivation of ACRA, CATH, DIVI, PHAM are unattainable, regardless of adjustments to production practices. Several species in this analysis show dramatically higher yields when grown under artificial shade, as compared with yields from plants grown in beds within forested habitats (McCoy et al. 2007; Renaud 2004). Thus, the future of cultivation for many species may be beyond agroforestry cropping systems (e.g., under artificial shade), particularly if there is no "premium" paid for forest grown product, such as presently occurs with "wild" American ginseng. Even where field cultivation appears to hold promise, artificial shade is a significant production cost to include in economic projections.

The profitability of American ginseng as a forest crop is driven exclusively by Asian consumer preferences for whole, intact "wild," wild-appearing, and forest-raised product. In recent years, roughly 80–90% of the annual United States "wild" ginseng harvest was exported with 98% of exports destined for Asian markets and consumers (Robbins 1998b). In "western" cultural traditions, conversely, little or no attention is afforded to product origins and appearance, and most of the ginseng consumed by Euro-American consumers is field-cultivated, under artificial shade, ending up as processed powders, extracts, and teas. Thus, Asian markets currently provide a critical price support that makes forest production of this species profitable. If this unique relationship changes in coming years, with Asian demand and consumption decreasing due to trade issues or shifts in consumer preferences, the economic feasibility of forest cultivation for American ginseng is likely to decline as well.

One solution for increasing grower profits, and thus forest cultivation, might be the development of industry certification and labeling programs for forest cultivated product. Such programs could be used to generate economic "premiums" and raise wholesale market prices to levels that support cultivation. Without price "premiums" generated through certification and labeling programs, transitioning from wild to forest cultivated sources for many plants is not likely to be profitable unless there are significant, demand driven increases in wholesale prices (in which case collection pressure would also increase) or unless alternative market opportunities develop. Growers are not likely to find widespread direct marketing opportunities if retailers are able to obtain cheaper plant materials from wild collected wholesale sources and consumers have little or no regard for product origins. Educational efforts and promotional campaigns must therefore be a component of any efforts to develop product certification and labeling programs, and encourage consumer attention to product origins. Such efforts must articulate the benefits to consumer and society from purchasing certified forest cultivated materials, and should include assurances regarding identity, source, sanitation, and quality (i.e., appearance, chemical or otherwise).

Implications for wild collection

The willingness of some individuals to collect indigenous forest plants despite low prices facilitates low prices in the wholesale market. Collectors may engage in collection regardless of pricing because wild plant products serve as a secondary or tertiary income source, or a "safety net" during difficult financial times (Bailey 1999; Cozzo 1999; Emery et al. 2003). Accordingly, there may be little desire or ability to adopt intensive husbandry practices requiring significant investment and costs. Many collectors choose to collect wild plant products for enjoyment (Bailey 1999; Emery et al. 2003). Additionally, markets for many plants are easily satiated, and annual consumer demand unpredictable. Although the outlook at the time of establishment can be favorable, one cannot predict future market conditions, and "bust" cycles can erode any projected profits (Craker et al. 2003). Buyers frequently require contractual agreements before purchasing larger quantities (e.g., 100 lbs or more), and growers may consequently have a difficult time selling product even if market conditions are "good" at the time of planting. In this context, wild-collection is considered by many in the North American industry as perhaps the only practical means for obtaining plant materials when consumer demand for a particular botanical suddenly increases (American Botanicals 2008).

Because of these constraints, wild collection is likely to continue for many indigenous forest plants. Concern for trade species that do not garner a high enough price to support cultivation must be addressed through alternative programs including wild management and collector education programming, rather than through initiatives encouraging cultivation. In such efforts, the development of certification programs for non-timber forest products or harvesters may provide a mechanism for addressing stewardship concerns for wild-collected species (Shanley et al. 2005). While these could be state or federal government programs, programs would likely be more effective and self-sustaining if industry initiated, in consultation with botanists, horticulturalists, collectors and others who can provide guidance and grounded perspective. Basic guidelines and standards for North American species could be regionally tailored, using published international standards for wild collection (e.g., Medicinal Plant Specialist Group 2007; World Health Organization (WHO) 2003) as a foundation. Product certification and labeling accompanied by consumer education could provide assurances to consumers, and generate price "premiums" to support harvester outreach and other program components.

Conclusion

The model results obtained suggest that forest farming of many native medicinal plants in eastern North America would not be not profitable at recent historic prices. Wholesale market prices are far below production costs for many species, and pricing is not equitable among species with similar production requirements. Significant price differences exist between species with approximately the same production requirements and yield potentials (e.g., American ginseng versus blue cohosh). While this difference can be attributed to market factors (e.g., differences in consumer demand, scarcity of supplies), there is nevertheless little incentive for adoption of intensive husbandry given such realities. Even the most parsimonious crop production models (e.g., early harvest + no stock costs + no annual costs) failed to generate break-even prices commensurate with recent historic wholesale prices; rather, with all species except American ginseng and goldenseal, calculated break-even prices far exceeded recent industry prices. Yield increases alone are not likely to resolve financial shortcomings since many species would need dramatic, and largely unrealistic, yield gains to even recover production costs, much less earn a profit.

Although this analysis only included eight plant species, these conclusions are equally applicable to other indigenous forest plants including bethroot (*Trillium erectum* L.), cranesbill (*Geranium maculatum* L.), mayapple (*Podophyllum peltatum* L.), stoneroot (*Collinsonia canadensis* L.), and Virginia snakeroot (*Aristolochia serpentaria* L.). For all of these species, the wholesale prices paid during 1990–2005 for raw materials was well below agroforestry production costs (data and model results not included in this paper). Wild collection is likely to continue for these species because investment in cultivation is simply not profitable, and because collection is amenable to the industry's need to respond to intermittent demand in an often highly volatile marketplace (i.e., "boom and bust" cycles). Accordingly, there is need for both technical support for agroforestry production of species with profit potential and significant demand (e.g., American ginseng and goldenseal) as well as for collector guidance for species that are likely to continue to be collected because prices do not support intensive husbandry and/or demand is sporadic. While there may be conservation benefits associated with forest cultivation of indigenous plant species, guidance provided to those interested in transitioning from lesser to more intensive forms of forest plant husbandry must include consideration of inflation, discount rates, and other time-related economic factors that will inevitably impact the profitability of crops requiring multiple years to attain harvestable maturity. Species that are not economically feasible for cultivation, particularly due to limited market demand, are best served through development of proactive government and industry initiatives involving targeted harvester education and possibly NTFP certification programs.

Acknowledgments This analysis and paper benefited greatly from the contributions of Marc McDill, Jim Finley, Rich Stedman, Lee Newsom, Stephen Turchak, Joel Messner, David Thompson, Larry Harding, Jim Kirsch, Wayne Weigle, Barry Wolfe, John Steiner, Edward Fletcher, Floyd Huggins, Dennis Millin, Allen Lockard and American Botanicals, Michael McGuffin, Matthew Albrecht, Amy Brush, Chip Carroll, Erica Renaud, Chris Firestone, and two anonymous reviewers. This research was supported in part by the Wild Resources Conservation Fund (WRCF), administered by the Pennsylvania Department of Conservation and Natural Resources (PA DCNR).

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