Medicinal and aromatic plants in agroforestry systems

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Medicinal and aromatic plants in agroforestry systems

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Abstract

A large number of people in developing countries have traditionally depended on products derived from plants, especially from forests, for curing human and livestock ailments. Additionally, several aromatic plants are popular for domestic and commercial uses. Collectively they are called medicinal and aromatic plants (MAPs). About 12.5% of the 422 000 plant species documented worldwide are reported to have medicinal values; but only a few hundred are known to be in cultivation. With dwindling supplies from natural sources and increasing global demand, the MAPs will need to be cultivated to ensure their regular supply as well as conservation. Since many of the MAPs are grown under forest cover and are shade tolerant, agroforestry offers a convenient strategy for promoting their cultivation and conservation. Several approaches are feasible: integrating shade tolerant MAPs as lower strata species in multistrata systems; cultivating short cycle MAPs as intercrops in existing stands of plantation tree-crops and new forest plantations; growing medicinal trees as shade providers, boundary markers, and on soil conservation structures; interplanting MAPs with food crops; involving them in social forestry programs; and so on. The growing demand for MAPs makes them remunerative alternative crops to the traditional ones for smallholders in the tropics. Being underexploited species with promising potential, the MAPs require research attention on a wide array of topics ranging from propagation methods to harvesting and processing techniques, and germplasm collection and genetic improvement to quality control and market trends. Joint forest management with farmers and contract farming with drug companies with buyback arrangement will promote cultivation of medicinal plants.

Introduction

Medicinal and aromatic plants (MAPs) play an important role in the healthcare of people around the world, especially in developing countries. Until the advent of modern medicine, man depended on plants for treating human and livestock diseases. Human societies throughout the world have accumulated a vast body of indigenous knowledge over centuries on medicinal uses of plants, and for related uses including as poison for fish and hunting, purifying water, and for controlling pests and diseases of crops and livestock. About 80% of the population of most developing countries still use traditional medicines derived from plants for treating human diseases (de Silva 1997). China, Cuba, India, Sri Lanka, Thailand, and a few other countries have endorsed the official use of traditional systems of medicine in their healthcare programs. For example, the Indian systems of medicine 'Ayurveda,' 'Sidha' and 'Unani' entirely, and homeopathy to some extent, depend on plant materials or their derivatives for treating human ailments (Prajapati et al. 2003). People in villages and remote areas primarily depend on traditional medicines as the modern system is out of reach and expensive. Many among the educated in Asian and African countries use traditional medicines for reasons of firm belief that they are more effective than modern medicines for certain chronic diseases, they do not have side effects of some of the modern medicines, and/or for economic reasons. Thus, in many societies, traditional and modern systems of medicines are used independently.

About 12.5% of the 422 000 plant species documented worldwide are reported to have medicinal value; the proportion of medicinal plants to the total documented species in different countries varies from 4.4% to 20% (Schippmann et al. 2002). About 25% of drugs in modern pharmacopoeia are derived from plants (phytomedicines) and many others are synthetic analogues built on prototype compounds isolated from plants. Up to 60% of the drugs prescribed in Eastern Europe consist of unmodified or slightly altered higher plant products (Lancet 1994). These drugs carry important therapeutic properties including contraceptives, steroids and muscle relaxants for anesthesia and abdominal surgery (all made from the wild yam, *Dioscorea villosa*); quinine and artemisinin against malaria; digitalis derivatives for heart failure; and the anti-cancer drugs vinblastin, etoposide and taxol. These compounds cannot be synthesized cost-effectively, which means that their production requires reliable supplies of plant material (van Seters 1997).

The global importance of MAP materials is evident from a huge volume of trade at national and international levels. During the 1990s, the reported annual international importation of MAPs for pharmaceutical use amounted on average to 350 000 Mg valued at over USD 1 billion (Table 1). A few countries dominate the international trade with over 80% of the global import and export allotted to 12 countries each. Whereas Japan and Korea are the main consumers of medicinal plants, China and India are the world's leading producing nations. Hong Kong, United States and Germany stand out as important trade centers. It is estimated that the total number of MAPs in international trade is around 2500 species worldwide (Schippmann et al. 2002).

Forests: the primary source of MAPs

Forests are the primary source of medicinal plants, and MAPs are one of the many valuable categories of nontimber forest products (NTFPs) that include food and beverages, fodder, perfumes, cosmetics, fibre, gums, resins, and ornamentals and materials for dyeing and tanning, plant protection, utensils and handicrafts (FAO 2003). The knowledge on NTFPs – their collection, processing, use and exchange – forms part of the social and natural capital of many rural communities (Vantomme et al. 2002). Forests provide a wealth of highly prized MAPs, whether in the alpine and sub-alpine Northwest Himalayas (Gupta 1986; Joshi and Rawat 1997), Afro-montane areas (ICRAF 1992; Cunningham 1997), humid tropics (On et al. 2001; Parelta et al. 2003) or temperate regions (Foster 1993; Hill and Buck 2000). The native woodlands and long-term fallows also are an important source of MAPs. In India, medicinal plants are harvested regularly in appreciable quantities and exported with government approval (Gupta 1988) or usufruct rights are extended to the so-called tribals and other indigenous communities at the forest margins. Collection and selling of secondary resources such as edible herbs and medicinal plants from natural sources is an economic activity that fetches greater returns than wage rates in many places, as in the savanna region in South Africa (Shackleton and Shackleton 2000).

In Nepal, over 15 000 Mg of medicinal herbs representing some 100 species are harvested every year from the wild for commercial and industrial purposes (Bhattarai 1997). In Sri Lanka, the number of species used in traditional medicine is estimated to be between 550 and 700 (de Alwis 1997). Of the 1000 commonly used medicinal plants in China, 80% in terms of number of species and 60% in terms of total quantity come from wild sources (He and Sheng 1997). In India, 1100 species are recognized as providing raw materials for Ayurvedic and Unani formulations (Gupta 1986). In the Near East region, the use of MAPs goes back to thousands of years and forms an important part of various cultures (Heyhood 1999). In sub-Saharan Africa, rural families are increasingly turning to medicinal plants and other NTFPs to cope with HIV/AIDS (Barany et al. 2001). In Amazonia, at least 1300 plant species are being used as medicines, poison or narcotics (Schultes 1979). Amazonian Shaman, the traditional healer, is also a skilled botanist and has a great talent on locating the requisite plant from the green vastness that makes up their natural pharmacy. In Latin America and Africa, this knowledge has largely remained undocumented and is handed down orally from parents to children.

The increasing demands for medicinal plants by people in developing countries have been met by indiscriminate harvesting of spontaneous flora including those in forests (de Silva 1997). Consequently, many

Table 1. Leading countries of import and export of medicinal and aromatic plant materials based on annual average during 1991–1998.

Country of import	Volume (Mg)	Value (1000 USD)	Country of export	Volume (Mg)	Value (1000 USD)
Hong Kong	73 650	314 000	China	139 750	298 650
Japan	56 750	146 650	USA	11 950	114 450
USA	56 000	133 350	Germany	15 050	72 400
Germany	45 850	113 900	Singapore	11 250	59 850
Singapore	6 550	55 500	India	36 750	57 400
Rep. Korea	31 400	52 550	Chile	11 850	29 100
France	20 800	50 400	Egypt	11 350	13 700
China	12 450	41 750	Mexico	10 600	10 050
Italy	11 450	42 250	Bulgaria	10 150	14 850
Pakistan	11 350	11 850	Albania	7 350	14 050
Spain	8 600	27 450	Morocco	7 250	13 200
UK	7 600	25 500	Pakistan	8 100	5 300
Total	342 550	1 015 200	Total	281 550	643 200

Source: Lange (2002).

species have become extinct and some are endangered. It is therefore, imperative that systematic cultivation of medicinal plants be developed and steps introduced to conserve biodiversity and protect threatened species. This article takes a critical look at the current sources of supply of MAPs, reviews literature on the prospects for their cultivation, conservation and sustainable use in agroforestry systems and identifies future research needs.

The need for conservation and cultivation of MAPs

Forest degradation throughout the tropical world has diminished the availability of widely used medicinal plant species. Five of the top 12 medicinal trees in the eastern Amazon region of Brazil have begun to be harvested for timber decreasing the availability of their barks and oils for medicinal purposes (Shanley and Luz 2003). Many valuable species are becoming endangered due to over-exploitation from wild. Some examples include '*yohimbe*' (*Pausinystalia johimbe*, bark is used to treat male impotence) in Central Africa (Sunderland et al. 1999), goldenseal (*Hydrastis canadensis*) collected from hardwood forests in eastern North America (Hill and Buck 2000) and African cherry (*Prunus africana*, bark used to treat prostatitis) in Cameroon and Madagascar (Cunningham et al. 2002). A survey in the Shinyanga region in northwestern Tanzania indicated that the top 10 priority medicinal species that people traditionally have been harvesting from natural woodlands have become scarce and are near extinction (Dery et al. 1999). Over-exploitation of these species is leading to unsustainable depletion of natural resources and narrowing of their genetic base. In India, 16 medicinal plants including the highly valued *Atropa acuminata*, *Dioscorea deltoidea* and *Rauvolfia serpentina* are listed as endangered species in the northwestern Himalayas (Gupta 1986). These are just a few examples and many such cases abound throughout the world.

To meet the requirements of expanding regional and international markets and healthcare needs of growing populations, increasing volumes of medicinal plants are harvested from forests and other natural sources. Loss of forestland for agriculture and plantations, overgrazing, irregular exploitation of herbs in forest and other natural woodlands by private individuals and commercial enterprises are further contributing to the depletion of the supply of MAPs from forests. During the past 15 years, there has been a substantial loss of habitats, notably tropical forests (which are disappearing at a rate of about 1% per year; FAO 2003), wetlands and other types of biome as a result of human action. The main threats to the resource base of MAPs are those that affect any kind of biodiversity that is used by humans such as habitat loss, habitat fragmentation, unsustainable use, largely unmonitored trade, over-harvesting or destructive harvesting techniques, alien and invasive species and global change. Over-exploitation and consequent depletion of medicinal plants not only affects their supply and loss of genetic diversity within these species but seriously affect the livelihoods of indigenous people living on forest margins. The most vulnerable species are popular, slow reproducing species with specific habitat requirements and a limited distribution.

Conservation of plant genetic resources has received worldwide attention in the past several years (McNeely 2004). In the case of medicinal plants, conservation policies and practices should meet future supply needs and have provisions for species conservation. On an international and/or national level, protective measures range from species conservation programs, shifting of processing from consumer to source countries and resource management to trade restrictions or even trade bans. Specific steps include basic studies to identify medicinal plants and traditional knowledge of their uses; sustainable utilization through cultivation, controlled wild harvest and reduction of waste; conservation both *in situ* – in natural habitats, *ex situ* – in botanic gardens and seed banks and through alternative technologies such as micropropagation and cryopreservation for those species that cannot be conserved *in situ* and that cannot be stored in seed banks; and increased public support for conservation of medicinal plants, built through communication and cooperation. Establishing high altitude nurseries and drug farms in the plants' natural habitat and education of herb collectors will be of further help (Joshi and Rawat 1997). Limiting harvest to a sustainable level is important but it is complicated by the conflict of interests between use and protection. It requires effective management systems and sound scientific information. In the past few years, field-based methods have been developed for sustainable harvest assessment and monitoring of NTFPs, resulting in the publication of research guidelines and predictive models (FAO 1995). Although in theory sustainable use of bark, roots, or whole plants as herbal medicines is possible, the inputs required in terms of money and manpower for intensive management of slow growing species in multiple species systems is unlikely to be found in many countries (Cunningham 1997). This emphasizes the need for cultivation to provide alternative supply sources for popular and high conservation priority species outside of core conservation areas.

Although many species are employed in traditional medicine, the number of MAP species currently in formal cultivation for commercial production does not exceed a few hundreds worldwide. For example, the species cultivated are only 100 to 250 in China (He and Sheng 1997), 38 in India (Prajapati et al. 2003) and about 40 in Hungary (Bernáth 1999). A survey carried out among companies involved in trade and production of herbal remedies and other botanical products revealed that although companies reported 60% to 90% of material was from cultivation, the number of species cultivated relative to the volume is small (Laird and Pierce 2002). Of the 1543 species traded in Germany, only 50 to 100 species are exclusively obtained from cultivation (Schippmann et al. 2002). Given the demand for a continuous supply of medicinal plants and accelerated depletion of forest resources, increasing the cultivation of MAP species appears to be an important strategy for meeting the growing demand and relieving harvest pressure on wild populations (Lambert et al. 1997). The high price paid for some of the species make them potential new crops (e.g., *Warburgia salutaris*, *Garcinia kola*, *G. afzelii* and *G. apunctata* in Africa) that can be grown in sole as well as agroforestry systems (Cunningham 1997).

From the marketing perspective, domestication and cultivation of MAPs offer a number of advantages over wild harvest for production of plant-based medicines. These include: 1) availability of authentic and botanically reliable products; 2) guaranteed steady source of raw material; 3) possibility for good rapport between growers and wholesalers (or agents of pharmaceutical companies) on volumes and prices over time; 4) controlled post-harvest handling and therefore rigorous quality control; 5) possibilities for adjustments of product standards to regulations and consumer preferences; and 6) possibilities for implementing product certification (Laird and Pierce 2002). Although the production of traditionally used medicinal plants has been suggested for over a decade, there has been little response in many countries. The lack of understanding with respect to cultivation, economics of cultivation and market opportunities are considered the main limiting factors in commercialization.

MAPs in agroforestry systems

Medicinal trees in traditional agroforestry systems

Many plants in traditional agricultural systems in the tropics have medicinal value. These can be found

Table 2. Examples of tree species reported to have medicinal values grown in traditional agroforestry systems in the tropics.

Tree species (Common name)	Agroforestry system	Medicinal use	Reference
Acacia nilotica (*babul*)	Field bunds, scattered trees in croplands, woodlots and grazing lands in East Africa and Indian sub-continent	Gum used for treating diarrhea, dysentery, diabetes, sore throat, bark used to arrest external bleeding	Pushpangadan and Nayar (1994)
Azadirachta indica (neem)	Woodlots, scattered trees, shelterbelts in Africa and India	Digestive disorders, malaria, fever, hemorrhoids, hepatitis, measles, syphilis, boils, burns, snakebite, rheumatism	Singh et al. (1996)
Erythrina spp.	Shade tree in coffee, live fence	Different *Erythrina* species have different uses.	Russo (1993)
Parkia biglobosa (*neré* or locust bean tree)	Parklands in West Africa	Piles, malaria, stomach disorders, jaundice	Teklehaimanot (2004)
Prosopis cineraria (*khejri*)	Scattered trees in croplands in arid to semiarid areas mostly in northwestern India	Flowers for blood purification and curing skin diseases. Bark against summer boils, leprosy, dysentery, bronchitis, asthma, leucoderma and piles	Pushpangadan and Nayar (1994)
Tamarindus indica (tamarind)	Field bunds and scattered trees in croplands in semiarid India and Africa	Fruit pulp is used in Indian medicine as refrigerant, carminative and laxative. It is also recommended in febrile diseases and bilious disorders	Singh et al. (1996)

(either planted or carefully tended natural regenerations) in homegardens, as scattered trees in croplands and grazing lands, and on field bunds (Table 2). Many *Acacia* species found in Africa such as *Acacia nilotica*, *A. seyal*, *A. senegal* and *A. polyacantha*, as well as several species in African croplands (e.g. *Faidherbia albida*, *Vitellaria paradoxa*, *Adansonia digitata*, *Markhamia lutea* and *Melia volkensii*) have medicinal value (ICRAF 1992). Similarly, '*arjun*' (*Terminalia arjuna*) in India, chinaberry (*Melia azederach*) in Asia and *Erythrina* species in Latin and Central America combine many uses including medicinal. Holy Basil or '*tulsi*' (*Ocimum sanctum*), drumstick (*Moringa oleifera*) and curry leaf (*Murraya koenigii*) are backyard plants in many Indian households and they are routinely used for common ailments or in food preparations. A number of plants used as live fences around home compounds such as henna (*Lawsonia inermis*) in India (Singh et a. 1996), *Ipomoea carnea* ssp. *fistulosa* in Bolivia and Asian countries (Frey 1995) and *Euphorbia tirucalli* around crop fields in Africa (ICRAF 1992) have medicinal values. Although the medicinal value of these plants is 'exploited' locally, they are seldom used for commercial purposes (except in the case of commercially exploited neem). In fact, many of these species are valued for poles, fuel wood, fodder, fruit, shade, and/or boundary demarcation and their medicinal value is secondary.

Forests and forest plantations

MAPs growing in forests require (or tolerate) partial shade, moist soils high in organic matter, high relative humidity, and mild temperatures. Cultivation of such MAPs can be taken up in thinned forests and cleared forest patches, and as intercrops in new forest plantations (Table 3). In China, cultivation of medicinal plants has been an age-old practice under the name of 'silvo-medicinal' systems. In northeast China, ginseng (*Panax ginseng*) and other medicinal plants are grown in pine (*Pinus* spp.) and spruce (*Picea* spp.) forests; in central China, many medicinal plants are planted with *Paulownia tomentosa* and in southern China medicinal herbs are often planted in bamboo (*Bambusa* spp.) and Chinese fir (*Cunninghamia lanceolata*) forests (Zou and Sanford 1990). In Yunnan province, China, traditional 'Dai and Jinuo' agroforestry systems involve the medicinal crop *Amomum villosum* in the forest areas cleared of undergrowth (Saint-Pierre 1991). The forest is thinned to give 30% to 40% shade and seedlings or cuttings are planted, which produce an average dried fruit yield of 375 kg ha^{-1} per annum (Zhou 1993). Gupta (1986) listed a number of indigenous understory herbs and shrubs that can be produced as part of forest farming or in new forest plantations to improve economic returns from forests in India (Table 3). Indigenous people living in the Himalayan forest margins in Uttaranchal, India, are known to have conserved and cultivated several medicinal species for centuries (Kumar et al. 2002).

A farmers' cooperative in the northern lowlands of Costa Rica has successfully demonstrated cultivation of the medicinal herb 'raicilla' (*Cephaelis ipecacuanha*) in natural forests for export to the Netherlands and Germany (Hager and Otterstedt 1996). American ginseng (*Panax quinquefolium*), a medicinal herb exported to China from the United States and Canada is grown as an understorey in red maple (*Acer rubrum*) forests (Nadeau et al. 1999) or deciduous hardwoods such as black walnut (*Juglans nigra*) and sugar maple (*Acer saccharum*), instead of growing under artificial shade with considerable expense (Hill and Buck 2000). Indeed, cultivation of ginseng and several other medicinal plants in the forests is a common and growing form of forest-farming practice of agroforestry in North America (Table 3). Light demanding understory species (e.g., *Echinacea* sp.) may be intercropped initially to provide early returns from plantations and after canopy closure, shade-tolerant species such as ginseng and goldenseal can be intercropped (Teel and Buck 2002). Studies in New Zealand have indicated that the American ginseng can be successfully grown under *Pinus radiata* with best growth under a tree stand of 130 stems ha^{-1} (Follett 1997). In addition to providing shade, the trees may also benefit the understory component from hydraulically lifted water. Fungal diseases are a major concern in forest farming but the application of fungicide can be detrimental to the forests' health, therefore proper spacing and mixed cropping is recommended (Cech 2002). Mechanical cultivation may not be feasible under forested conditions so labor availability needs to be considered as a constraining factor (Hill and Buck 2000).

As in the taungya system, newly established forest plantations can be intercropped with MAPs similar to food crops until the trees cover the ground. The participation of the local people with right to share benefits of the plantations, especially ownership to crops, has helped governments to establish and protect large-scale tree plantations without conflict with the local people in many Asian countries (Nair 1993). The same approach can be employed for the cultivation of MAPs in the new plantations. In the rehabilitation of degraded forestlands, participatory planning and implementation with local communities and economic benefits from an early stage onwards will ensure commitment of the people (Rao et al. 1999).

The intensity of shade experienced by the understory MAPs growing in forests and tree plantations affects their growth and chemical composition. Growth, and bark and quinine yields of *Cinchona ledgeriana* grown on the Darjeeling hills, India, increased when it was associated with shade of five species compared with that of a nonshaded stand (Nandi and Chatterjee 1991). The best yields were obtained when *C. ledgeriana* was planted under the shade of *Crotalaria anagyroides* or *Tephrosia candida* initially and *Alnus nepalensis* in the later stages. *Alnus* is planted at 3.6 × 3.6 m and is progressively thinned to 14.4 × 14.4 m as *C. ledgeriana* grows. The other factors that affect MAPs yields are their growth cycle and nutrient inputs. The optimum rotation for *C. ledgeriana* in the Himalayan region is 16 years (Nandi and Chatterjee 1991). *Dioscorea deltoidea* grown in deodar (*Cedrus deodara*), fir (*Abies* spp.) and spruce plantations attains exploitable tuber size in about 10 years (Gupta 1988).

Homegardens

Homegardens are complex agroforestry systems involving many plant species characterized by different morphology, stature, biological function and utility, practiced mostly in the humid and subhumid tropics (Kumar and Nair 2004). Food, fruit and timber species may dominate the homegardens and occupy the middle and upper strata, but medicinal plants, spices and vegetables occupy the lower stratum. Three categories of medicinal plants could be noted in homegardens: species used exclusively for medicine, horticultural or timber species with complementary medicinal value, and 'weedy' medicinal species. While the first two categories are deliberately planted the latter group is part of spontaneous growth. The species composition, plant density and level of management vary considerably depending on the soil, climate and market opportunity and cultural background of the people. Homegardens of individual holdings generally cover small parcels of land and are established around homesteads. Although these systems in the past were mostly seen to meet the home needs of small-scale farmers in the forest margins, increased urbanization, transport and market opportunities in recent times are helping to produce cash value crops. Multistrata systems involve fewer species (three to 10 species) than in homegardens in definite planting arrangement and can be designed for home consumption as well as commercial production.

Table 3. Examples of commercially valuable medicinal plants under cultivation or that can be produced as understory component(s) in forests and tree plantations.

Latin name	Common name	Plant type	Parts used	Medicinal use	Location
Aconitum heterophyllum	*Atis*	Tall herb	Rhizomes	Hysteria, throat diseases, astringent	Alpine and sub-alpine Himalayas
Amomum subulatum	Large cardamom	Perennial herb	Seeds	Stimulant, indigestion, vomiting, rectal diseases	Sub-Himalayan range, Nepal, Bhutan
Amomum villosum	*Saren*	Perennial herb	Seeds	Gastric and digestive disorders	China
Caulophyllum thalictroides	Blue cohosh	Perennial herb	Roots	Gynecological problems, bronchitis	North America
Cimicifuga racemosa	Black cohosh	Perennial herb	Roots	Menses related problems	North America
Chlorophytum borivilianum	*Safed musli*	Annual herb	Tubers	Male impotency, general weakness	India
Costus speciosus	Crepe ginger	Cane	Leaves, stem, rhizomes	Purgative, depurative and as a tonic	India
Dioscorea deltoidea	Himalayan yam	Vine	Tubers	Source of saponins and steroids	India, Pakistan
Echinacea purpurea	Coneflower	Perennial herb	Roots, rhizomes	Enhancing immune system	North America
Hydrastis canadensis	Goldenseal	Perennial herb	Rhizomes	Tonic	North America
Panax ginseng	Ginseng	Herb	Roots	Tonic	China, Korea, Japan
Panax quinquefolium	American ginseng	Perennial herb	Roots	Tonic	North America
Cephaelis ipecacuanha	Raicilla, Ipecac	Shrub	Roots	Whooping cough, bronchial asthma, amoebic dysentery	Brazil, India, Bangladesh, Indonesia
Rauvolfia serpentina	Rauvolfia	Shrub	Roots	Hypertension and certain forms of insanity	Sub-montane zone, India
Serenoa repens	Saw palmetto	Shrubby- palm	Fruits	Swelling of prostrate gland	Southeastern USA

Source: Gupta (1986); Saint-Pierre (1991); Rao et al. (1999); Garrett and McGraw (2000); Hill and Buck (2000); Teel and Buck (2002).

Medicinal plants are an invariable component of homegardens, whether they are in the Peruvian Amazon (Lamont et al. 1999), on the slopes of the Mt. Kilimanjaro in Tanzania (O'Kting'ati et al. 1984), or in the humid and semiarid Cuba (Wezel and Bender 2003). The species composition differs depending on cultural background, distance from markets and influence of tourism. Medicinal plants accounted for about 27% of total plant species in the homegardens in Amazon (Padoc and de Jong 1991), 56% in northern Catalonia (Iberian Peninsula) (Agelet et al. 2000) and 45% in the floodplains of the river Jamuna in Bangladesh (Yoshino and Ando 1999). In the Soqotra Island, Yemen, endemic medicinal plants such as *Aloe perryi*, *Jatropha unicostata* and *Commiphora ornifolia* are cultivated in homegardens (Ceccolini 2002). On St. Croix and St. Thomas, U.S. Virgin Islands, the medicinal trees neem, moringa, and noni (*Morinda citrifolia*) have become popular in homegardens (Palada and Williams 2000).

The slash-and-burn system, which is so widely practiced in the humid and sub-humid tropics, has reduced soil fertility, crop yields, biodiversity and mature forest vegetation. Agroforests that mimic local ecosystem processes can be developed to provide livelihoods for farmers while protecting and preserving forest reserves and biodiversity. Based on the analysis of plant species in different strata and analog hypothesis, an agroecological system can be designed that meets the farmers' needs of food, timber, medicinal plants and other NTFPs, efficiently uses the on-site resources and protects the natural resource base of the region (Clerck and Negreros-Castillo 2000). Integration of medicinal plants in agroforests and multistrata systems provides an answer to the plantation commodity conundrum. These complex agroforestry systems can be utilized to grow MAP species for home use and markets. MAPs produced in agroforests may be targeted to niche markets to secure higher premium on the premise of better quality similar to those harvested from wild. The forest-type environment of these systems facilitates the integration of species that generally grow in the forest (for example see Table 4) and thereby helps conserve the endangered species and produce them for markets. Homegardens and multistrata systems are recognized as the most productive, remunerative, environmentally sound and ecologically sustainable alternative land use systems to slash-and-burn systems and 'alang alang' (*Imperata cylindrica*)-infested degraded lands in humid tropics (Tomich et al. 1998). High value MAPs may be integrated in the newly establishing homegardens and multistrata systems.

Riparian buffer zones

An agroforestry system that has received considerable attention in North America is riparian buffers zones (Schultz et al. 2004). Riparian buffer zones can improve water quality and protect streams and rivers from degradation by nutrient loading and chemical pollutants from agriculture and urban areas, from erosion by attenuating peak flows and provide habitat for wildlife. NTFP production can help defray the cost of buffer zone installation and maintenance. Slippery elm (*Ulmus rubra*), harvested for its aromatic and medicinal inner bark, is commonly found in riparian areas in North America (Teel and Buck 2002). Riparian buffer zones are an ideal location for the production of this species, which suffers from commercial over-exploitation and the Dutch elm disease.

Intercropping of MAPs

Two types of intercropping systems can be distinguished involving MAPs: (1) medicinal plants as upperstory trees and (2) MAPs as intercrops in other tree crops.

Medicinal plants as overstory trees

Coffee (*Coffea arabica*), cacao (*Theobroma cacao*) and tea (*Camellia sinensis*) are traditionally grown under shade offered by multipurpose trees that produce timber, fruit, flowers, nuts, palms etc. Medicinal tree species that grow tall and develop open crown at the top can also be used for this purpose, for example *yongchak* (*Parkia roxburghii*) in India, the protein rich seeds of which are used to treat stomach disorders (Balasubramanian 1986) and *Ginkgo biloba* in China, the nuts of which are used in Chinese medicine and fetch high value (Shen 1998). In Ivory Coast, 19 of the 41 tree species planted as shade trees in coffee and cacao provide pharmaceutical products for traditional medicine (Herzog 1994). New plantations of coffee, tea, and cacao offer scope for cultivation of forest medicinal trees that are under demand. However, research needs to identify the medicinal trees that can be grown in association with these plantation crops and develop management practices for them. Tall and perennial medicinal trees that need to be planted at wider spacing such as *Prunus africana*, *Eucalyptus globulus* (for oil), sandalwood (*Santalum album), ashok (Saraca indica*), bael (*Aegle marmelos*), custard apple (*Anona squamosa*), *amla* (*Emblica officinalis*), drumstick or moringa (*Moringa oleifera*) and soapnut tree (*Sapindus mukorossi*) can be intercropped with annual crops in the early years until the tree canopy covers the ground. Some of the medicinal trees may allow intercropping for many years or on a permanent basis depending on the spacing and nature of the trees. The intercrops give some income to farmers during the period when the main trees have not started production.

Medicinal plants as intercrops

Many tropical MAPs are well adapted to partial shading, moist soil, high relative humidity and mild temperatures (Vyas and Nein 1999), allowing them to be intercropped with timber and fuel wood plantations, fruit trees and plantation crops. Some well known medicinal plants that have been successfully intercropped with fuel wood trees (e.g., *Acacia auriculiformis*, *Albizia lebbeck*, *Eucalyptus tereticornis*, *Gmelina arborea*, and *Leucaeana leucocephala*) in India, include *safed musli* (*Chlorophytum borivilianum*), rauvolfia (*Rauvolfia serpentina*), turmeric (*Curcuma longa*), wild turmeric (*C. aromatica*), *Curculigo orchioides*, and ginger (*Zingiber officinale*) (Chadhar and Sharma 1996; Mishra and Pandey 1998; Prajapati et al. 2003). Only 10 out of 64 herbaceous medicinal plants tried in intercropping with two-year old poplar (*Populus deltoides*) spaced 5 m apart gave poor performance (Kumar and Gupta 1991), indicating that many medicinal plants can be grown in agroforestry systems. The trees may benefit from the inputs and management given to the intercrops. Short stature and short cycle MAPs and culinary herbs are particularly suited for short-term intercropping during the juvenile phase of trees. Wherever markets are established, MAPs are remunerative alternative intercrops to the

Table 4. Important medicinal trees currently exploited from Peruvian Amazon forest that can be grown in multistrata or homegarden agroforestry systems.

Name	Plant type	Part used	Medicinal use
Cedrella odorata	Tree	Bark	Snake bite
Croton lechleri	Tree	Latex	Swellings
Euterpe precatoria	Palm	Roots	Kindness, diabetes
Ficus insidpida	Tree	Latex	Anemia
Maytenus macrocarpa	Tree	Bark	Arthritis, diarrhea, stomach disorders
Tabebuia serratifolia	Tree	Bark	Vaginal diseases, hepatitis, diabetes, arthritis
Uncaria tomentosa	Shrub	Bark	Infections, cancer

Adapted from: Clavo et al. (2003).

traditionally grown annual crops (Maheswari et al. 1985; Zou and Sanford 1990). The number of years MAPs can be intercropped with a given tree species depends on the size and intensity of its canopy shade, tree spacing and management, especially pruning of branches and nature of the MAPs. Shade-tolerant and rhizomatic MAPs can be grown on a longer-term basis in widely spaced plantations.

Intercropping of medicinal plants in coconut (*Cocos nucifera*) and arecanut (*Areca catechu*) stands is an age-old practice in India and other parts of south- and southeast Asia. These palms allow 30% to 50% of incident light to the underneath, which is ideal for some MAPs, including cardamom (*Elettaria cardamomum*). *Kacholam* or galang (*Kaempferia galanga*) – a medicinal herb – is traditionally intercropped in mature coconut gardens in Kerala, India. *Kacholam* intercropped in a 30 year-old coconut plantation produced 6.1 Mg ha^{-1} of rhizomes compared with 4.8 Mg ha^{-1} as a sole crop (Maheswarappa et al. 1998). Twelve-year old coconut trees did not adversely affect the growth and yields of a number of medicinal species grown as intercrops compared to the yields in the open (Nair et al. 1989). In Karnataka and Kerala states, India, arecanut palm is commonly intercropped with ginger, turmeric, black pepper (*Piper nigrum*) and cardamom (Korikanthimath and Hegde 1994). Some of these intercrops may cause small reduction in arecanut yields but the combined returns from both the components are greater than from arecanut alone. Another plantation crop intercropped with MAPs is rubber (*Hevea brasiliensis*), for example with *Dioscorea floribunda* in the state of Assam in India (Singh et al. 1998) and with *Amomum villosum* in Yunnan province of China (Zhou 1993). In Sikkim, India, large cardamom (*Amomum subulatum*) is grown under 30 different shade tree species (Patiram et al. 1996). In Fujian Province, China, *Cunninghamia lanceolata* – an important timber tree – is intercropped with a variety of cereals, cash and medicinal and oil-producing crops (Chandler 1994). Many of the medicinal herbs commonly grown in thinned forests can also be grown intercropped with trees (Zhou 1993).

In the Caribbean islands, there has been increased interest on alternative crops that have better economic potential than traditional crops. For example, in the U.S. Virgin Islands, a number of farmers are now opting for specialty crops such as the West Indian hot peppers (*Capsicum chinense*), thyme (*Thymus vulgaris*) and chives (*Allium schoenosprasum*) instead of vegetables (Crossman et al. 1999). The prospects of growing indigenous MAPs such as 'japana' (*Eupatorium triplinerve*), worrywine (*Stachytarpheta jamaicensis*), inflammation bush (*Verbersina alata*) and lemongrass (*Cymbopogon citratus*) in association with the medicinal trees noni (*Morinda citrifolia*) and moringa have been explored at the University of the Virgin Islands, St. Croix, (Palada and Williams 2000). These local herbs are commonly used as bush teas and very popular in the Caribbean. Medicinal plants and herbs in intercropping produced similar yields to those in sole cropping at the first harvest, but they tended to be lower than in sole cropping at subsequent harvests (Palada and Williams 2000).

Aromatic plants as intercrops

Studies have been conducted in India since mid-1980s on the feasibility and economic aspects of intercropping aromatic plants with timber trees. Experiments at different sites in India demonstrated that aromatic *Mentha* spp. (*M. arvensis*, *M. piperita*, *M. citrata* var. *citrata*, *M. spicata*, *M. cardiaca* and *M. gracilis*) and *Cymbopogon* spp. [lemon-

Table 5. Yields of aromatic plants in intercropping with trees relative to those in sole cropping at a few locations in India and Nepal.

Location	Tree species and spacing	Aromatic plant	Intercrop yield as % of sole crop		Comments
			Herbage	Oil	
Pantnagar, India	*Populus deltoides*	*Cymbopogon flexuosus*	82	82	Results averaged over five years
	5 × 4 m	*C. martinii*	96	86	
	Eucalyptus	*C. flexuosus*	96	90	
	hybrid 2.5 × 2.5 m	*C. martinii*	100	86	
Pantnagar, India	*Populus deltoides*	*Mentha arvensis*	90	90	Results averaged over three years
	5 × 4 m	*M. piperita*	85	88	
		M. citrata	90	90	
		M. spicata	87	87	
		C. flexuosus	99	97	
		C. martinii	99	98	
		C. winterianus	98	99	
Hyderabad, India	*Eucalyptus citriodora*	*C. flexuosus*	87	87	Results averaged over two years
	3 × 2 m	*C. martinii*	87	87	
		C. winterianus	112	91	
		Pelargonium sp.	91	90	
Nepal	*Dalbergia sissoo* 10 × 2 to 8 m	*C. winterianus*	–	100	Results average over two years

Source: 1. Singh et al. (1989); 2. Singh et al. (1990); 3. Singh et al. (1998); 4. Amatya (1996).

grass (*C. flexuosus*); Java citronella (*C. winterianus*); and palmarosa (*C. martinii*)] can be grown intercropped with *Populus deltoides* or *Eucalyptus* spp. for three to five years after planting the trees (Table 5). Some of the above aromatic species and *Pelargonium* sp. (geranium) can also be intercropped with another essential-oil-yielding tree *Eucalyptus citriodora* (lemon- or citron-scented gum) (Singh et al. 1998). Tree growth was generally little affected or improved probably due to the inputs given to the intercrops. Herb growth and oil yields of these aromatic plants were not affected during the first two years of intercropping, but they decreased slightly from the third year compared with sole crops (Singh et al. 1990). Essential oil profiles of citronella and palmarosa grown in open and partial shade were not significantly different, but the oil of menthol mint (*M. arvensis*) produced in the open was richer in menthone while that produced under shade was richer in menthol (Singh et al. 2002). This implies the need to consider the effect of intercropping on oil quality of some aromatic plants. These intercropping systems gave two to four times greater economic returns than sole cropping of the components. These studies indicate that aromatic plants can be profitably grown in association with linearly growing fuel- and timber trees such as *L. leucocephala*, *Casuarina* spp., and *Grevillea robusta.*

MAPs in other agroforestry systems

Aromatic grasses such as vetiver (*Vetiveria zizanioides*), lemongrass and citronella (*Cymbopogon nardus*) can be grown on field bunds and soil conservation bunds in croplands. Vetiver has extensively been tested and is being promoted for planting in contour strips or as a live hedge barrier and to stabilize terrace risers on sloping lands in a number of countries, for example, in India, Fiji, Haiti and Indonesia (NRC 1993). In the hill subsistence farming systems, maintaining woody perennials in contour strips across slopes and around fields is a common practice. The trees and shrubs produce fodder and firewood and reduce soil erosion hazards allowing crop production on steep slopes where it would otherwise be difficult. Many locally available medicinal plants can be incorporated into these systems (Fonzen and Oberholzer 1984). The harvest of grass strips on sloping lands for economic purpose should be planned carefully to avoid soil erosion. Indiscriminate digging of vetiver for distilling oil from its roots has often resulted in worst erosion problems in Haiti (M. Bannister pers. comm., October 2003).

Hardy medicinal and fruit trees can be grown in community lands in villages and degraded lands. In the state of Madhya Pradesh, India, *amla* – a rich source of vitamin C, and custard apple, for both fruit and medicine, have been taken up as part of social forestry (Chadhar 2001). *Amla* and bael withstand saline and alkali conditions and can be grown on salt-affected soils (Khanna 1994). Similarly, in West Bengal, India, *Costus speciosus*, a diosgenin-producing plant, is recommended as a major understorey crop in social forestry programs (Konar and Kushari 1989). Other medicinal trees that can be grown on wasted lands include soapnut tree and wood apple. A study of the medicinal species in the Shinyanga region of northwestern Tanzania indicated that the top 10 priority species can be integrated into land use systems such as *ngitili* (grazing lands planted with economically valuable trees and shrubs), scattered trees in croplands, on field bunds or in homesteads (Table 6). It is recognized in India that many medicinal trees can be integrated into croplands by planting them on field bunds or as scattered trees (Pushpangadan and Nayar 1994).

Future trends and research needs

The demand for MAPs will continue to increase in developing and industrialized countries because of population growth and awareness about the benefits of natural products to provide economical, safe and effective alternatives to expensive industrially synthesized drugs. The best recourse to meet the expanding trade in medicinal plants is cultivation of priority MAPs for conservation as well as continuous supply of raw material to the industry and to provide high returns to farmers. Successful cultivation of MAPs requires information on the species adaptation to outside their natural habitats, cultivation practices and management, but there is, however, limited information on these aspects of medicinal plants in many countries. As domestication and cultivation cannot be taken up for all potential MAPs, research as a first step should establish priority species based on participatory surveys and market analysis involving rural people, traditional healers, material collectors and drug industry. Research should focus on species for which there are ready markets and natural sources are fast depleting. Work should follow for priority species on ecology and natural distribution, reproductive biology, propagation techniques, germplasm collection, evaluation and genetic improvement aimed at improving both yield and quality of the product. Simultaneously, information should be produced on the soil and environmental conditions to which they are adapted, systems in which they can be grown, nutrient management, harvest techniques and processing. Attention should also be given to the potential danger of pests and diseases cropping up with intensive cultivation of medicinal plants. The on-going efforts on domestication and cultivation of *Prunus africana* in agroforestry involving smallholders in Cameroon and East Africa should serve as a case study to illustrate the methodology and economic potential of some species (Cunningham et al. 2002; Simons and Leakey 2004).

An important area that needs investigation is how production of MAPs in nontraditional systems affects content and quality of the principal compounds for which they are grown. Research tends to focus on increasing biomass yields rather than on quality of the compounds for which the plants are valued. The production of secondary compounds is not necessarily linear to increases in biomass of all species. Edaphic factors, timing of inputs and intensity and duration of shade effects are important determinants of plant productivity of secondary products. For example, the diosgenin concentration in *Costus speciosus* rhizomes was increased by treatment with mango leaf leachate, unaffected by the *Shorea robusta* and teak (*Tectona grandis*) leaf leachates and decreased by the *Eucalyptus globulus* leaf leachate (Konar and Kushari 1989). As quality determines the acceptability and price of product, especially for export market, research should examine the appropriate practices that achieve good quality.

Research should simultaneously focus on processing methods at the farm-level and exploring market opportunities. Area expansion without knowledge of market potential can lead to over production and disappointment to growers. The recent spurt in the cultivation of *Chlorophytum borivilianum* in India is an example where many farmers have taken up cultivation to sell tubers as seed material at a high premium, rather than laboriously processing them. Consequently, not only the prices of seed (fresh tubers) and dried materials have dropped considerably in the past three years but also growers have begun to perceive marketing this high-input-requiring crop at a remunerative price as a major concern (Oudhia 2003).

Table 6. The top 10 priority medicinal trees currently harvested from wild in Shiyanga region of Tanzania that can be grown as scattered trees in grazing lands ('*Ngitili*'), croplands or in homesteads.

Latin name	Local name (English name)	Parts used	Medicinal use
Albizia anthelmintica	*Mgada/mkutani* (Worm-cure albizia)	Bark, roots, leaves	Abdominal problems, convulsions and infertility
Cassia abbreviata	*Mlundalunda* (Long-pod cassia)	Bark, roots	Abdominal problems, pain relief and urinary problems
Combretum zeyheri	*Msana* (Large-fruited combretum)	Bark, roots, leaves	Pneumonia, peptic ulcer, coughs and soar throat
Entada abyssinica	*Ngeng'wambula/Mfutwambula* (Tree entada)[a]	Bark, roots, leaves	Abdominal problems, cough, asthma and hernia
Entandrophragma bussei	*Mondo* (Wooden banana)	Bark, roots, leaves	Abdominal problems, diarrhea and anemia
Securidad longipedunculata	*Nengonego* (African violet tree)	Bark, roots, leaves	Convulsions, abdominal problems, gonorrhea, syphilis, and asthma
Terminalia sericea	*Mzima* (Silver terminalia)	Bark, roots, leaves	Fever, anemia and abdominal problems
Turraea fisceri	*Ningiwe* (honeysuckle tree)	Bark, roots, leaves	Abdominal problems, hypertension, and dysentery
Zanha africana	*Ng'watya/mkalya* (Velvet-fruited zanha)	Bark, roots, leaves	Convulsions, abdominal problems and psychosis
Zanthoxylum chalybeum	*Mlungulungu/Nungubalagiti* (Knobwood)	Bark, roots, leaves	Jaundice, abdominal problems and pain relief

[a]This can also be grown in row intercropping with annual crops.
Source: Dery et al. (1999).

As part of promoting cultivation of MAPs, government departments such as forestry may enter into partnership with local farmers to cultivate MAPs in association with forest plantations on profit-sharing basis. This is similar to the taungya system except that instead of food crops farmers are encouraged to plant selected MAPs under the guidance of the forest department. This type of joint forest management with 25% to 50% share of profit to farmers was found successful in the Gujarat state of India (Singh 1997). Partnerships between drug industry and farmers in the form of contract farming with buyback arrangement of the product will go a long way in promoting cultivation of MAPs. The drug companies embarked on exploiting medicinal plants should be made development partners in the production areas. For instance, the drug company Merck Sharpe & Dome has paid USD 1 million for research in Costa Rica and has agreed to contribute 25% of profits made from Costa Rican plants to rainforest conservation in Costa Rica (Sittenfeld and Gamez 1993). Shaman Pharmaceutical Inc., a pioneer in natural product research since 1989, considers indigenous people as partners and only collects plant samples on the indication of a shaman. This approach appears to be more effective than random collection methods and has already resulted in the discovery of three novel drugs (van Seters 1997). The national governments should ensure that the local people do derive benefits for their contributions to the new innovations. Many developing countries, however, may not be having appropriate national bodies to safeguard the intellectual property rights (IPR) over indigenous knowledge of local people, protect from potential biopiracy of genetic material, or to undertake research, promotion and marketing of MAPs.

The pharmaceutical industry rediscovered tropical rainforests as an unmatched source of chemicals with potential for modern drug development (Pistorius and van Wijk 1993). Thousands of plant extracts taken from all continents are being screened for activity against HIV and cancer in the laboratories of the U.S. National Cancer Institute. For example, an alkaloid casuarine from the bark of *Casuarina equisetifolia* was found to have potential against HIV and cancer (Nash et al. 1994). While efforts to find new chemicals continue, investigations should also be encouraged on the traditionally used plant medicines to dispel myths and strengthen the case for valid ones. It is likely that not all the indigenous healthcare practices currently in use have scientific bases. A study conducted among tribals in Kaimur Bhabhua district in Bihar state, India, indicated that their use of *Acacia nilotica* against bleeding gum and soar throat, neem as antibiotic and *Terminalia arjuna* for curing heart diseases had scientific merit, but not the use of *Madhuca longifolia* and *Terminalia belirica* (Pandey and Varma 2002).

Policies that deprive ownership to medicinal trees as in the case of some parkland trees in West Africa or imposing license fees even with good intentions of protecting the trees would be counterproductive to planting and management of medicinal trees. For example, farmers in the southern highlands of Tanzania have stopped planting the traditionally grown, native multipurpose tree *Hagenia abyssinica* (hardwood, fuelwood, fodder, green manure, flowers used for deworming humans and livestock, seed as a condiment or spice), since the introduction of a royalty fee as license for its management in the mid-1980s; instead, exotic species are planted (East and Thurow 1999). Farmers need to be encouraged by making available planting material and appropriate technical know-how.

Conclusion

Traditional systems of medicine in most developing countries depend primarily on the use of plant products either directly or indirectly. Besides serving the healthcare needs of a large number of people, medicinal plants are the exclusive source of some drugs even for modern medical treatment. The use of plant products as nutrition supplements and in the cosmetic and perfume industry has increased the value of medicinal and aromatic plants in recent years. The over dependence on forests, natural woodlands and long-term fallows for extraction of MAPs is threatening the survival of many valuable plant species. It is imperative therefore that such endangered species are cultivated outside their natural habitats to ensure their regular supply for human needs as well as to preserve the genetic diversity. Cultivation is an important strategy for conservation and sustainable maintenance of natural stocks, but, few MAPs are actually cultivated. Lack of basic knowledge on biology, ecology, propagation methods and cultural practices for the concerned species is an important constraint.

Agroforestry offers a convenient way of producing many MAPs without displacing the traditional crops. Research is needed in each country, however, on germplasm improvement for priority species, appropriate systems in which they can be grown, input management, and value-adding processes. Existing government policies may not be conducive to promotion of MAPs in many places. The potential of MAPs can be realized when policy constraints are removed and efforts are made simultaneously to commercialize the products and explore markets for less known species. Although research has indicated that agroforestry can be a viable approach to production of MAPs, few commercially important species are actually produced outside homegardens and forest plantations.

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