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SITE INDEX AND BIOMASS PRODUCTIVITY ESTIMATES FOR HIMALAYAN ALDER-LARGE CARDAMOM PLANTATIONS: A MODEL AGROFORESTRY SYSTEM OF THE MIDDLE HILLS OF EASTERN NEPAL

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ABSTRACT The Himalayan alder (*Alnus nepalensis* D. Don)-large cardamom (*Amomum subulatum* Roxb.) intercrop grown in the Middle Hills of eastern Nepal was studied as a model highland agroforestry system. Sixty-six sites were sampled and 42 farmers were interviewed in four districts of the Kosi and Mechi Zones of the Eastern Development Region to develop site index curves and quantify biomass productivity. Edaphic and physiographic parameters were correlated with site indices. Annual tree biomass production was estimated at 14 t/ha/yr for a typical plantation cycle, with an average 11 t/ha/yr annual increase in standing biomass after thinning. Tree component standing biomass accumulation was estimated by site index classes, and used to derive a predictive equation for average total standing biomass (273 t/ha) at a plantation reference age of 25 years. Biomass and productivity estimates were correlated with results from farmer interviews and used to quantify annual cardamom production (364 kg/ha), labor requirements (237 man days/yr), and gross annual income (US $864/ha). Fuelwood requirements for cardamom processing (2.6 t/ha/yr), and removal of wood through thinning (3.2 t/ha/yr), were also quantified. Conservation and service functions provided by the agroforestry system are described.

RÉSUMÉ *Indices de site et estimations de la productivité biomassique pour les plantations himalayennes d'aulne et de cardamome géante: un système modèle d'agroforesterie dans les montagnes médianes de l'est du Népal.* La culture en lignes alternantes d'aulne himalayen (*Alnus nepalensis* D. Don) et de cardamome géante (*Amomum subulatum* Roxb.) dans les montagnes médianes de l'est du Népal a été étudiée en tant que système modèle d'agroforesterie montagnarde. Soixante six sites ont été examinés et quarante deux cultivateurs ont été interviewés dans quatre districts des zones Kosi et Mechi dans la région de développement orientale, dans le but de tracer des courbes d'indices de site et d'évaluer la productivité biomassique. Les paramètres édaphiques et physiographiques ont été mis en corrélation avec les indices de site. La production annuelle de biomasse d'arbres a été estimée à 14 t/ha pour un cycle de plantation typique, avec une augmentation annuelle moyenne de 11 t/ha en termes de biomasse sur pied après éclaircissage. L'accumulation de biomasse sur pied composée d'arbres a été estimée au moyen de classes d'indices de site et utilisée pour dériver une équation de prédiction de la biomasse totale sur pied moyenne (273 t/ha), pour un âge de référence de 25 ans pour les plantations. Les estimations de biomasse et de productivité ont été corrélées avec les résultats d'interviews avec les cultivateurs et utilisées pour évaluer la production annuelle de cardamome (364 kg/ha), la main-d'oeuvre annuelle nécessaire (237 journées de travail) et le revenu annuel brut (864 US $/ha). La consommation annuelle de bois de chauffage pour le traitement de la cardamome (2,6 t/ha) et l'extraction annuelle de bois par éclaircissage (3,2 t/ha) ont également été évaluées. Les fonctions de conservation et de service assurées par le système d'agroforesterie sont décrites.

ZUSAMMENFASSUNG *Lagenindex und Ertragsschätzungen der Biomasse für Erlen- und Kardamompflanzungen im Himalaya: Ein Modell für Agroforstwirtschaft in den östlichen Middle Hills, Nepal.* In den Middle Hills des östlichen Nepal wurden Erlenbestände (*Alnus nepalensis* D.Don) und zwischengepflanzter Kardamom (*Amomum subulatum* Roxb.) als Beispiel für ein agroforstwirtschaftliches Modell der Hochlande untersucht. Um Kurven für den Lagenindex zu entwickeln, die den Biomassenertrag quantitativ darstellen, wurden 66 Lagen erfaßt und 42 Bauern aus vier Distrikts der Kosi und Mechi Zonen, die Teil der Eastern Development Region sind, befragt. Bodenbedingte und physiographische Parameter wurden mit den Lagenindices korreliert. Für einen typischen Wachstumszyklus wurde der jährliche Biomassenertrag aus Bäumen auf 14 t/ha/Jahr geschätzt, mit einer durchschnittlichen jährlichen Steigerung von 11 t/ha/Jahr in verbleibender Biomasse nach dem Lichten. Die Zunahme in Biomasse für den Baumbestand wurde mittels Klassen für den Lagenindex abgeschätzt, und eine Vorhersagegleichung wurde für den durchschnittlichen Gesamtbestand an Biomasse (273 t/ha) über den Bezugszeitraum von 25 Jahren abgeleitet. Abschätzungen der Biomasse und der Produktivität wurden mit Ergebnissen von Bauernumfragen korreliert und dazu benutzt, die jährliche Kardamomproduktion (364 kg/ha), den Arbeitsaufwand (237 Mann Tage/Jahr) und das jährliche Bruttoeinkommen (US $864/ha) quantitativ abzuschätzen. Das nötige Brennholz zur Kardamomverarbeitung (2,6 t/ha/Jahr), sowie Holzverlust durch Lichten (3,2 t/ha/Jahr) wurden ebenfalls berücksichtigt. Konservierungs- und Nutzungsfunktionen, die das agroforstwirtschaftliche Modell liefert, werden beschrieben.

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INTRODUCTION

Agroforestry systems have the potential for satisfying a diversity of small farmer needs in temperate and tropical highlands, while providing essential ecological and soil conservation benefits (Brewbaker *et al.*, 1982; Foley and Barnard, 1984; Nair, 1984). The intercropping of Himalayan alder (*Alnus nepalensis* D. Don) and large cardamom (*Amomum subulatum* Roxb.) in the Middle Hills of eastern Nepal is an example of a traditional agroforestry system with many desirable attributes required for successful highland agroforestry (Figure 1). Recent diffusion and adoption of this cash-crop technology indicates its success. The objectives of this study were to develop and use biomass productivity estimates based upon site index (SI) curves, correlated with results from farmer interviews, and to quantify agricultural production, economic yield, and farmer profitability. The system was evaluated using a set of idealized agroforestry design criteria.

AGROFORESTRY SYSTEMS

Tree production in subsistence agriculture is a primary activity of an increasing number of rural development projects, especially in Nepal (Gilmour and Fisher, 1991). Forest-dependent nutrient and organic matter transfers to crop systems in the Middle Hills have been described by Bajracharya (1983), Mahat *et al.* (1987 a, b), Ives and Messerli (1989), and Gilmour and Nurse (1991). Woody perennials are known to benefit agro-ecosystems through enhanced nutrient cycling, reduction of leaching and soil erosion, amelioration of soil physical properties, conservation of soil water, microclimate enhancement, and increased ecosystem stability (Felkner and Bandurski, 1979; Brewbaker *et al.*, 1982; Nair, 1984; Nair *et al.*, 1984; NRC, 1984). Many of these benefits are derived from multipurpose trees, with economic products including timber, fuelwood, fodder, livestock bedding, leaf litter, and thatching materials (Young, 1988). In highlands or mountainous regions constraints on competing land-use options may improve benefit/cost ratios in favor of multipurpose agroforestry systems. Young (1988, 1989) identified two types of land-use problems to which agroforestry may be applicable: problems of the farmer and problems of the land.

Problems of the Farmer

Low cash income and/or inadequate supplies of food, fodder, or fuelwood are amongst the most common challenges faced by farmers, especially in Nepal and other heavily populated highland regions. Other constraints include shortages of shelter, water, raw materials for domestic industry, and savings or equity. On-farm trees provide fuelwood and fodder, reduce the need for wood gathering which is labor-intensive, and have other economic benefits. Standing tree biomass is a form of savings or equity which can supply a regular income or occasional large payments.

Problems of the Land

Soil erosion, fertility decline, and pasture and adjacent natural forest degradation are negative effects resulting from land-use systems that inadequately meet basic criteria for sustainability. Tree cover serves to reduce soil erosion and to conserve sloping land, fragile soils, and degraded sites; it contributes to the long-term stability of land resources (Nair, 1984; Blaikie, 1985). Nitrogen-fixing trees are resources that contribute substantially to overall soil fertility on farmland. Also, many nitrogen-fixing trees are fast growing and produce high quality, high protein livestock fodder and green manure. The availability of fuelwood and fodder on-farm reduces the need for cutting adjacent natural woodlands and forests, and is an observed response by farmers to increasing resource scarcity (Gilmour and Fisher, 1991; Gilmour and Nurse, 1991).

ALDER-CARDAMOM PLANTATIONS

The intercropping of alder and cardamom is a highly successful agroforestry system that meets many of the criteria mentioned above (Figure 2). The intercrop is apparently an age-old practice, introduced from Sikkim into the Ilam District of eastern Nepal some 40–60 years ago (de Waard and Ranjit, 1976; Moestrup and Bhandary, 1986; Singh *et al.*, 1989). Both species are indigenous to the eastern Himalaya and it is probable that the plant association is naturally occurring. Many stands are semi-natural, with farmers clearing the understory of existing alder stands to plant cardamom. This intercropping is practiced from Bhutan to central Nepal, at elevations from 1,000 to 2,000 m. The adaptive range, cultural practices, and cardamom trade have been described by Moestrup and Bhandary (1986), Gautam (1987), de Waard and Ranjit (1976), Singh *et al.*, (1989), and DFAM (1989).

Large cardamom is a highly valued commercial spice crop, produced primarily for export (de Waard and Ranjit, 1976; Ilyas, 1978). It is distinct from the more highly valued small cardamom (*Elettaria cardamomum* Maton), although it is sometimes utilized as a low-cost substitute (Ilyas, 1978). Both species belong to the ginger family (Zingiberaceae). Cardamom requires shade, so it is normally intercropped under various types of trees, most commonly alder. It is a perennial shrub that produces an annual harvest of seed capsules which are dried and sold as a cash crop. Cardamom starts to



FIGURE 1. The Himalayan alder (*Alnus nepalensis* D. Don)-large cardamom (*Amomum subulatum* Roxb.) intercrop of the Middle Hills of eastern Nepal is an example of a traditional agroforestry system with many desirable attributes required for successful highland agroforestry.

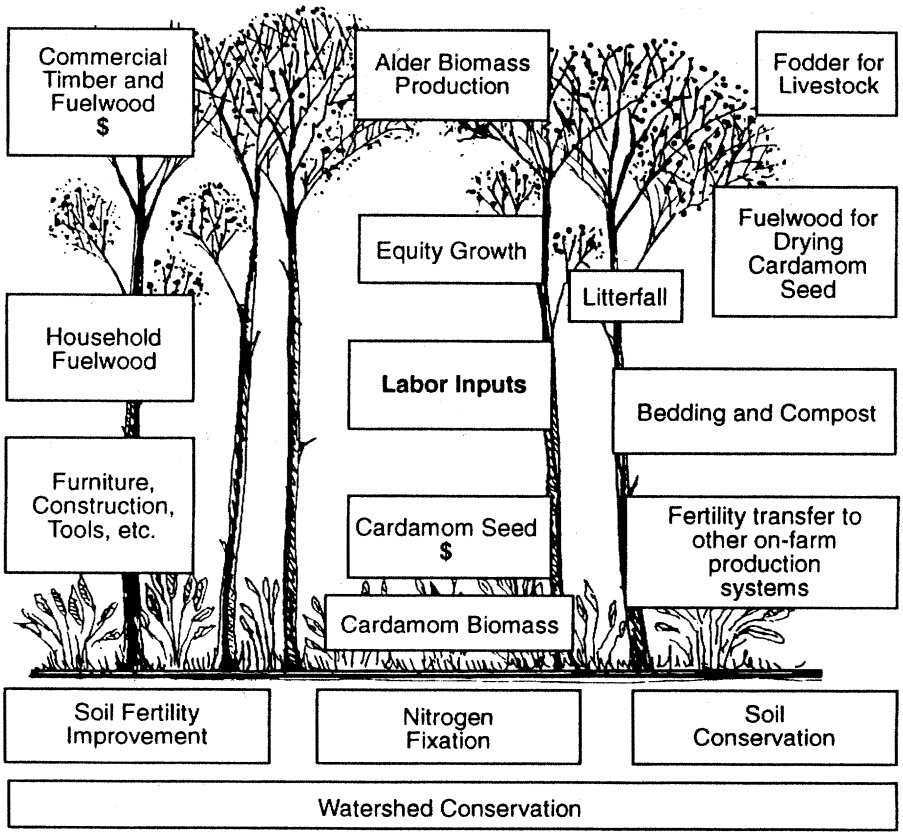

FIGURE 2. Interacting components of the Himalayan alder-large cardamom intercrop agroforestry system.

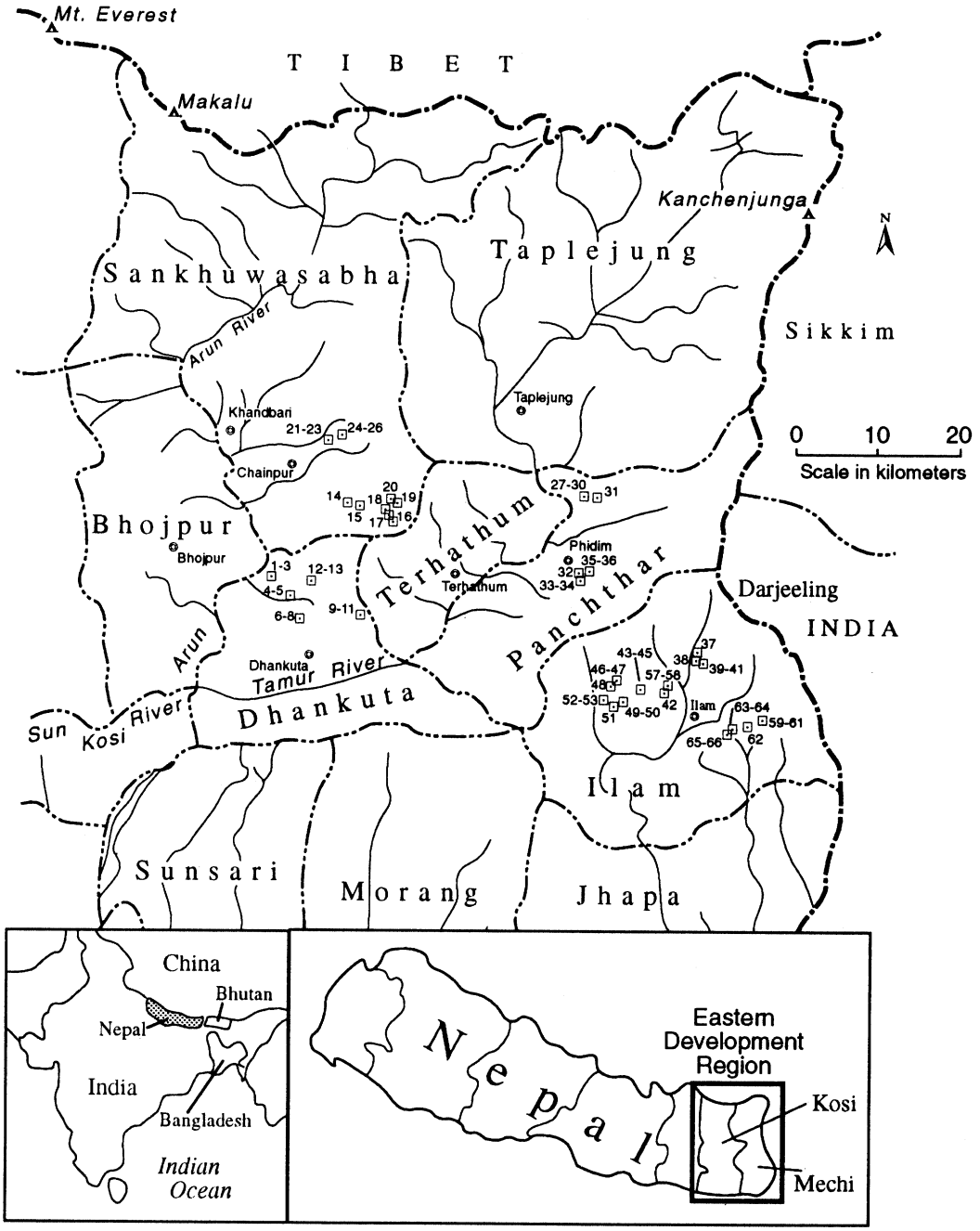

FIGURE 3. The study areas in eastern Nepal showing location of 66 sampled sites.

produce economic returns after 3 years, and continues to produce for up to 30 years or more, with peak cardamom production normally from 7 to 18 years.

The major cardamom producing districts in Nepal are Ilam and Panchtar (Figure 3), accounting for 86% of national production (Gautam, 1987). A majority of farm families (about 20,000) in Ilam District, where it was first introduced, grow some cardamom. Although the average area under cultivation is variously estimated at 0.05–0.17 ha per family (de Waard and Ranjit, 1976; Gautam, 1987), cardamom provides significant income at the district and individual farm levels (Gautam, 1987; DFAM, 1989). Recently, cardamom production has spread to several adjacent districts. Most of the production is in areas with no access to roads or motorized transport and inputs are limited to labor and small quantities of pesticides, with manures or fertilizers rarely, if ever, used.

Planted cardamom quickly achieves a closed canopy and eventually covers the soil under alder trees (Figure 4). Dense two-storied vegetative cover and extensive root systems help to protect marginal sites and fragile soils from intensive precipitation and runoff common in these



FIGURE 4. Soil protective cover of the cardamom understory averaged 82%, with a range from 50% in younger plantations to well over 100% for mature plantations. The cardamom understory reaches heights over three meters.

highly erosive lands with a monsoon climate. Throughout the Middle Hills of eastern Nepal small alder-cardamom plantations are commonly established on waste lands such as gullies and stream banks (Figure 5), or on mesic or shaded sites where other crops do poorly. Recently, due to their initial success on marginal sites, farmers have been converting both their upland maize and irrigated rice terraces to cardamom (Figure 6). Income from cardamom is higher and relatively more stable than that from maize and rice and this is a strong incentive to small farmers. More importantly, alder-cardamom intercropping is a high-value system that is effective on marginal sites with low productivity, eroded or otherwise. Farmers with small holdings are generally hesitant to convert from cereals to cash crops. Producing a cash crop on marginal sites allows them to generate cash without diminishing grain production. Farmers commonly employ this system to stabilize erosion hazard sites or reclaim areas where landslides have occurred. The resultant landscape is a mosaic of agricultural terraces interspersed with thickly vegetated, profit-producing riparian zones (Figure 7).

The incentives of cash income motivate farmers to invest resources into soil conservation practices. Whereas farmers with limited resources may recognize land stewardship problems and know what measures or practices can help, economic constraints may limit opportunities for upgrading marginal sites. For the farmer, obtaining an economic return from a soil-conserving agroforestry practice dramatically improves the benefit/cost ratio of improved land management. Additionally, upgrading on-farm production potential through cash-cropping may qualify small farmers for bank loans or other government credit-extension programs.

Diversification of the farm enterprise has allowed farmers, particularly in Ilam District, to experiment with other high value production technologies, such as fish farming, silk worm production, and dairy cooperatives. Due in part to cardamom and other cash-crop production (primarily tea), there has been a marked monetarization of the basic subsistence economy. Availability of cheap rice transported in from the adjacent Terai Plain on recently opened roads has facilitated this process. Roads function as collection points for cardamom carried by basket from outlying production zones. Loads of 40–60 kg, commonly carried for 4–6 days, over rough terrain and unimproved trails by men and women, are sold to traders in bazaar towns along the road; from there it is usually trucked and exported to India without further processing (Figures 8, 9, and 10). This is an example of a lowland-highland interaction (Allan, 1984) that increasingly has come to dominate the economy of this region (especially Ilam District) and to characterize regional agricultural production.

In addition to the cash income, substantial wood and leaf biomass are produced during the lifetime of the plantation. Plantations are intensively managed and trees are regularly thinned. Farmers commonly intersperse various high quality fodder trees, such as *Ficus nerifolia* var. *nemoralis, F. auriculata, Saurauia nepalensis,* and *Cordia dichtoma* within plantations, sometimes creating a middle stratum in the canopy structure. Other species such as *Litsea cubeba* and *Schima wallichii* provide spices or have medicinal uses. Land-poor farmers especially are apt to maximize production through intensive management of multiple-species tree components.

Cardamom plants are pruned regularly. Large quantities of cardamom leaves are removed annually and used for livestock bedding and subsequently composted with animal manures, along with cardamom fruit husks and other leaf litter gathered from the plantation floor. In the Middle Hills, this type of nutrient cycling from forest to field constitutes the principal fertility transfer that maintains agricultural productivity. From 1 to 4 ha of forest is required to sustain one hectare of arable land in the Middle Hills (Wyatt-Smith, 1982; Hrabovszky and Miyan, 1987; Mahat *et al.*, 1987a; Ives and Messerli, 1989). Tree fodder constitutes the largest proportion of the biomass being removed from natural forests (Mahat *et al.*, 1987b).

Post-harvest processing of cardamom seed requires substantial quantities of fuelwood for drying (Figure 8). Generally, fuelwood comes from the plantation. However,



FIGURE 5. Small alder-cardamom plantations are commonly established on wastelands such as gullies and streambanks. Dense two-storied vegetative cover and extensive root systems help to protect marginal sites and fragile soils from intensive precipitation and runoff.



FIGURE 6. Conversion of both irrigated and non-irrigated terraces to the alder-cardamom intercrop by many small landholders has created this contiguous extensive planting in the Kalo Pokhari area of Sankhuwasabha district.



FIGURE 7. Farmers employ the alder-cardamom intercrop both to stabilize and restore erosion-prone marginal sites. The resultant landscape is a mosaic of agricultural terraces interspersed with thickly vegetated, profit-producing riparian zones of this agroforestry system.

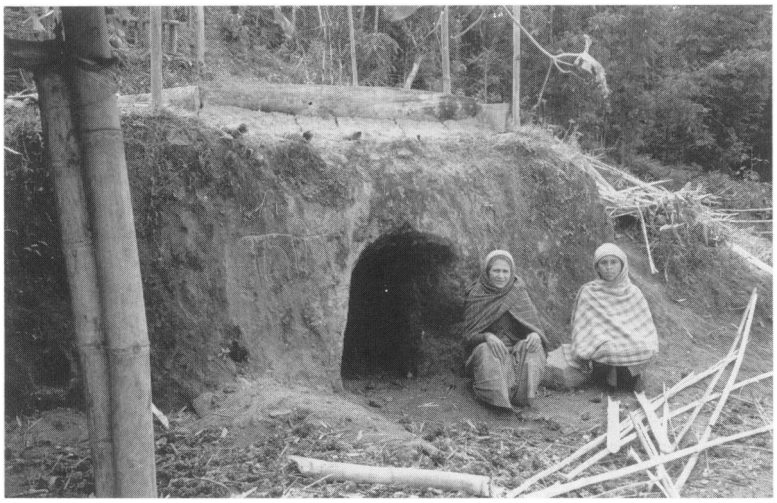

FIGURE 8. Post-harvest processing of cardamom seed requires substantial quantities of fuelwood for drying. Local dryers tend to be primitive, inefficient, and produce a poor quality end product. Farmers using improved dryers reap substantial premiums for higher quality cardamom seed.



FIGURE 9. Men and women commonly carry 40–60 kg loads of dried cardamom fruit over rough terrain and unimproved trails, up to 4–6 days, to be sold to traders in bazaar towns along the road. Many traders contract with farmers before harvest, paying a substantially reduced farm-gate price.



FIGURE 10. Roads function as collection points for cardamom, from where it is usually trucked and exported to India without further processing. Export regulations are a disincentive to further processing within Nepal.

farmers may use fuelwood from adjacent common forests when available, saving their own trees for other uses. Standing tree biomass provides long-term equity and financial security. In the Middle Hills, where the average farm size is 0.5 ha and average plantations are 0.1 ha (de Waard and Ranjit, 1976; Gautam, 1987), the alder-cardamom system contributes significantly to household budgets and wealth, and is a major source of income at the farm and national levels (Gautam, 1987; DFAM, 1989; Shrestha, 1989).

ALNUS SPECIES

Much agroforestry research has focused upon lowland tropical legume species (Brewbaker *et al.*, 1982; Nair *et al.*, 1984; Dawson, 1986). However, highlands throughout the tropics and subtropics are intensively developed and support large human populations where indigenous tree legumes are generally less prevalent. Actinorhizal nitrogen-fixing trees, such as alder, offer expanded opportunities in agroforestry systems (Coombe, 1979; Dawson, 1986; Russo, 1990). Alder is one of about 15 non-leguminous genera of trees that have been shown to fix nitrogen. Members of the birch family (Betulaceae), alders are found in many parts of the world, from the highland tropics to the temperate region. Of the 35 species of *Alnus,* 33 are known to possess nodules.

Various alder species have been reported to fix between 40 and 200 kg N/ha/yr, with a maximum of 320 kg N/ha/yr (Silvester, 1977). Alder can improve soil fertility to a level adequate for conifer establishment (Tarrant and Trappe, 1971). When planted in mixed stands with *A. rubra,* growth of Populus, Pinus, and Pseudotsuga was improved (Silvester, 1977). A mixed red alder and black cottonwood 2-year coppice produced more annual dry matter and 18% more nitrogen in cottonwood twigs than did monocultures of either species (DeBell and Radwan, 1979). In the highlands of Costa Rica, *A. acuminata* is planted on over 15,000 ha of grasslands in a highly productive sylvopastoral agroforestry combination (Coombe, 1979; Russo, 1990).

ALNUS NEPALENSIS

Himalayan alder (*Alnus nepalensis* D. Don) has attracted increasing interest in recent years (Sharma and Ambasht, 1984, 1986, 1987, 1988; Moestrup and Bhandary, 1986; Jackson, 1987; Lamichhaney, 1987). This fast-growing species has an extensive range throughout the eastern Himalaya and is found in the subtropical to temperate bioclimatic altitudinal zones (Shrestha, 1989) at elevations between 500 and 2,700 m (Jackson, 1987). This range is sympatric with the agroclimatic range of cardamom cultivation (Shrestha, 1989). Sharma (1988) found that the best growth of *A. nepalensis* usually occurs between 1,500 and 2,000 m, and most of the managed plantations are in this zone. Himalayan alder is a very fast growing pioneer species that typically is the first to colonize disturbed sites (Kayastha, 1985), and it is often planted in Nepal for erosion control on landslides or landslide-prone sites (Stewart, 1986). It is easily established, has high germination rates if seed is fresh, and exhibits good seedling survival. Many farmers establishing new alder-cardamom plantations reported that trees had not been planted, but instead had been allowed to "invade" naturally from adjacent stands.

Mature Himalayan alder trees are of very regular form, gentle taper, strongly monopodial, lightly branched, and can reach heights of 30–40 m (Stewart, 1986). Under suitable conditions alder can achieve sustained high growth rates for many years, well beyond the maturity and senescence of the cardamom understory. Of twenty multipurpose tree species examined, *A. nepalensis* had the highest rate of growth extension, photosynthesis, and high water-use efficiency (Nautiyal and Purohit, 1987). An ability to coppice well was observed to be among its most valuable characteristics, making it suitable for watershed management (Moestrup and Bhandary, 1986).

Total soil nitrogen, available phosphorus, exchangeable potassium, exchangeable calcium, and organic carbon have been shown to increase with age under stands of *A. nepalensis* (Sharma *et al.*, 1985). Soil analyses of samples from alder-cardamom plantations in Sankhuwasabha District (Figure 2) showed low to very low phosphorus levels, high to very high potassium levels, high organic matter content in top soil, and low pH (Serchan, pers. comm.). Added phosphate and micronutrients have been shown to have beneficial effects on growth of *A. nepalensis* seedlings on P deficient soil in Darjeeling (Lahiri, 1984).

Sharma and Ambasht (1987) showed approximately 50 kg N/ha were released in a 24-month period from litterfall in pure stands of *A. nepalensis.* Nitrogen accretion through fixation (Sharma and Ambasht, 1988) decreased as trees matured and needed less nitrogen, from 117 kg N/ha/yr for 7-year-old plantations to 29 kg N/ha/yr for 56-year-old plantations. Water samples taken in Ilam District show elevated nitrate levels for runoff from alder-cardamom plantations when compared to nearby irrigated terraces (Shrestha and Shrestha, pers. comm.).

Litter dynamics was quantified for pure stand plantations of *A. nepalensis* in Darjeeling (Sharma and Ambasht, 1987). Litterfall ranged from 3.2 t/ha/yr in a 7-year stand to 5.8 t/ha/yr in a 46-year stand. Forest floor litter was found to decompose rapidly, due to initial low C/N ratios. *A. nepalensis* leaf biomass is of moderate value and palatability as livestock fodder. Nitrogen content of fresh alder leaves is generally about 2–3% (Silvester, 1977). Mature leaves are eaten by sheep and goats, but not cattle (Panday, 1982), and they are used as fertilizer, bedding, and compost, and as a source of gums and resins (Nautiyal and Purohit, 1987).

A. nepalensis is used widely for fuelwood, probably due

to its abundance (Stewart, 1986). Alder wood has a relatively low calorific yield of 18,230 kj/kg, and it has a relatively low specific gravity of 0.32–0.37 (Shakya, 1987). In the eastern Middle Hills it is the fuelwood species most preferred by the local communities (Thapa *et al.*, 1989). In addition, *A. nepalensis* wood is moderately good for construction, furniture, tools, and agricultural implements, and is widely used for these purposes.

Although some information on silvicultural characteristics and nursery management techniques for *A. nepalensis* is available (Jackson, 1987), data on biomass production are limited (Ambasht, 1988; Thapa *et al.*, 1989). Stewart (1986) describes the lack of reliable data on growth, biomass, and yield of major tree species in Nepal in general, and for *A. nepalensis* in particular. Stewart (1986) attempted an assessment of past growth from tree-ring counts using stem analysis with varying results. Thapa *et al.* (1989) suggested this assessment should be made according to site quality class and developed a biomass table for individual trees and also derived biomass regression equations based upon diameter at breast height (dbh). In our study, representative site classes derived from computed SI curves were used to predict biomass accumulation. Conversion of tree dbh (cm) to biomass (kg) was based upon the biomass regression equations and coefficients developed by Thapa *et al.* (1989). Tree height is not included as a predictor variable, based upon suggestions by Hawkins (1987) that height estimation in the field was time consuming, subject to large error, and added only a small increase to the precision of the regression model. Also, including height as a parameter limits accessibility of SI classification to more highly trained personnel, i.e. those with the sophistication and equipment to estimate height, and greatly increases the cost of using the SI curves (Thapa *et al.*, 1989).

THE STUDY AREA

The study area included four districts in the Kosi and Mechi zones of the Eastern Development Region of Nepal (Figure 3). Sites in Dhankuta and Sankhuwasabha Districts of Kosi Zone lie within the watershed of the Arun River basin, and those of the Ilam and Panchtar districts of Mechi Zone are within the Tamur River drainage. This mountainous area has high topographic, microclimatic, vegetation, and cultural diversity. Generally referred to as the Middle Hills, these foothills of the High Himalaya range in altitude from 300 m at the bottom of the deep river valleys, to well above the 3,000 m limit imposed upon agriculture by the monsoon cloud-ceiling. Annual rainfall totals of 1,000–3,800 mm, heavily concentrated in the warm summer months from June to October, characterize the unimodal monsoon climate (Dunsmore, 1988; Shrestha, 1989). Rainfall distribution is variable and spatially discontinuous, with pockets of heavy rainfall and drier leeward slopes due to local rain-shadow effects. Temperature regimes are largely influenced by altitude. Within the zone of cardamom cultivation winter frosts are rare, although hail storms occur occasionally in early spring.

Altitudinal zonation controls both vegetation and agricultural cropping patterns. The zone of cardamom cultivation overlaps generally with the subtropical bioclimatic altitudinal zone (Shrestha, 1989), which is densely populated and intensively cultivated. Major crops include rice on irrigated terraces and maize and finger-millet relay-cropped on unirrigated upland terraces; other crops include spring wheat and potatoes double-cropped during the winter on summer rice terraces, tobacco, citrus, and mustard seed for oil production. Livestock production, primarily water buffalo, cattle, goats, pigs, and chickens, plays an important role in the mixed farming systems of this area (Shrestha, 1989).

Population densities range from 200–500/km^2 of arable land (Dunsmore, 1988), with Dhankuta District reporting areas with above 500 /km^2. Average landholding is 0.5 ha per household, with a ratio of cultivated land to shrub and forest of 1:2 (Shrestha, 1989). It is estimated that virtually all land capable of being terraced in this area of the Middle Hills (500–3,000 m) is in production, and has been for at least 30 years (Blaikie and Brookfield, 1987). With an annual population growth rate of 2.7% which is expected to accelerate to 3% by the year 2005 (Ives and Messerli, 1989), arable land per capita is in decline. An average 2.3% annual growth in national agricultural output after 1960 (World Bank, 1979) was largely the result of expansion of farms onto formerly forested land in the Terai lowland jungle, and some clearing of marginal sites in the Middle Hills.

Although there has been some increase in agricultural inputs, production per hectare has been steadily declining (Belbase and Graboski, 1985). Soil fertility is directly dependent on nutrient transfer from forest to field (Bajracharya, 1983; Mahat *et al.*, 1987 a,b; Ives and Messerli, 1989). This transfer is usually in the form of leaf litter applied as a direct soil amendment, or tree fodder and livestock bedding materials, which are collected in the forest and cycled through livestock to produce manures and composts. These forest products are the primary organic matter and nutrient inputs that are returned to the soil by the farmer. This dependence puts pressure on nearby forests and affects the local rural economy in several ways. Direct impacts include decreasing access to valuable and essential forest products; for example, the Middle Hills are dependent upon wood for more than 90% of total household energy consumption (Eckholm *et al.*, 1984; Ives and Messerli, 1989). Farmers have responded by increasing tree cover on their farms through agroforestry techniques (Gilmour and Fisher, 1991), including the alder-cardamom system.

MATERIALS AND METHODS

Traditional predictors of growth and yield of forest stands are: stand age or age distribution; site quality; extent of utilization of site quality potential; and effects of cultural treatments, such as thinning, fertilization, or vegetation control (Clutter *et al.*, 1983). Site quality is determined by biotic, edaphic, and climatic conditions. In the case of multi-purpose tree species, site quality is defined as the total production potential of a site for a particular species or group of species (Rose, 1988). Stand volume, or biomass, and stand height are the primary direct methods for estimating site quality (Clutter *et al.*, 1983); other factors may include stand density, species composition, genetic variation, and cultural practices.

Dimensions of larger dominant or co-dominant trees in even-aged stands are less affected by stand density and intermediate cutting, and these trees serve as site index (SI) trees. SI curves describe the incremental growth in height or dbh of SI trees over time (age). The height or dbh achieved at a reference age is associated with each curve as its SI number. Typically, the average rotation age for the species is used for the reference age.

Beck and Trousdell (1973) showed that rotations are shorter on better sites, and therefore the distribution of SI is different for different ages. Consequently, when relying upon temporary-plot data for construction of SI curves there is a risk of bias. Hägglund (1981) describes factors that affect the accuracy of estimated SI, including: sampling errors associated with generalization of plot data to populations; random and systematic errors in choice of dominant trees within plots; systematic errors caused by use of unsuitable analytical expressions; random errors caused by variations in site conditions; and the significant effect of small differences in age upon the SI value.

In this study, representative growth curves (Rose, 1988) for alder SI trees intercropped with cardamom and growing under farmer conditions were developed and used to predict average standing biomass at 25 years by site quality class. Site productivity and aboveground biomass production of the tree component were determined using regression estimation (Newbould, 1967; Art and Marks, 1971; Hägglund, 1981; Rose, 1988).

Sampling

Existing alder-cardamom plantations in the study area were sampled to determine their site productivity and resource status. Fieldwork was carried out in the fall of 1990. Sixty-six sites were selected along two north-south transects 30–50 km apart (Figure 2). These sites were selected to reflect a balanced sampling of diverse terrains and age classes, encompassing the range of altitudes and habitats of the alder-cardamom system within Nepal. In order to minimize production variability due to underutilization of site potential, only plantations showing no visible signs of insect or disease damage to alders were selected. Cultural practices were assumed to be a parameter of site quality, since this could not be held constant across sites.

Plots 100 m^2 in size were chosen within stands at a minimum distance of 10 m from the edge of the stand in order to minimize border effects. Plots were subjectively chosen as representative of the normal tree distribution for that stand. Two to four SI trees per site were chosen within plots. Only dominant trees showing no signs of whorling or suppression were selected. Crown heights of SI trees were determined by clinometer. Core samples were taken at breast height with an increment borer to determine age of all SI trees (Stokes and Smiley, 1968; Cook and Kairiukstis, 1989). Core age data were correlated with information from farmers to determine plantation age.

Total numbers of trees per plot and their diameter at breast height (dbh) were tallied. Canopy cover of the alder overstory was estimated by eye. Cardamom understory cover was estimated by the line-intercept method (Bauer, 1943) using two transects of 10 m each within the plot. Height of the cardamom understory was estimated using the same two transects with ten evenly-spaced sampling points (Lindsey, 1955).

Physiographic and edaphic site parameters were measured within all plots (Ball, 1986). Elevation was determined by altimeter readings as the average between the upper and lower limits of the plot. Slope was measured by clinometer and aspect was determined by compass. Soil texture and pH were calculated from a composite of four random samples taken in the surface (0–20 cm) and subsurface soil (20–40 cm). Soil pH was measured in the field using a Hellige-Truogg soil reaction pH test kit (Forestry Suppliers, Inc., Jackson, Michigan). Soil texture was determined using visual and tactile field estimation methods (Soil Survey Staff, 1981). Soil texture designations were converted to percent clay using the standard USDA soil textural triangle (Soil Survey Staff, 1975). Average soil depth was estimated by augering at four random locations per plot.

Additional data concerning the alder-cardamom plantations were collected in the form of a farmer survey (Shaner *et al.*, 1982) on agricultural practices, input levels, labor requirements, local prices, and farmer evaluation of the alder-cardamom system. Forty-two farmers were formally interviewed from a questionnaire consisting of 30 questions.

Analysis

1) Dbh tallies from sampled plots were related to standing biomass using allometric regression equations for *A. nepalensis* developed by Thapa *et al.* (1989). The total tree biomass regression equation,

$$[\text{Ln (Biomass)} = -3.408 + 2.744 \text{ Ln (dbh)}],$$

was used to convert all (822) tree dbh's tallied to their respective dry weight biomass (kg). Plot totals were

summed and multiplied by 100 to convert to a land area basis (ha). Average annual biomass accumulation was determined by dividing total tree component standing biomass of plots by the age of that stand, based upon what was found to be a linear relationship between total plot biomass and age. All values are presented in t/ha/yr dry weight.

2) A non-linear regression of the 138 SI trees using a least squares loss function was used to find the best fit line corresponding to the model

$$[Y = A * (1-e^{(-cx)})]$$

(Mitscherlich, 1919; Richards, 1959; Chapman, 1961; Hägglund, 1981), where x represents age, and A is the asymptote of the curve. Height and dbh were each used as the dependent variable (y) and compared. Site indices were then calculated for all trees. SI curves were developed based upon a reference age of 25 years. All SI trees on a plot were averaged to provide an SI value for each study site, using a reference age of 25 years.

3) Multiple regression analysis was used to investigate relations between site physiographic and edaphic parameters and site quality. In this process SI values were the dependent variable in a series of simple linear regressions with all other variables. After identification through stepwise regression, significant variables were entered into a multiple regression.

4) Average standing biomass at 25 years was predicted based upon a simple linear regression of annual standing biomass accumulation in t/ha/yr vs. SI. Average annual biomass production was determined by site quality classes and multiplied by 25 to predict standing biomass at the reference age, based upon the linear relationship between total plot biomass and age.

5) Average SI tree values were computed for all site quality classes at various stand ages, and a table was constructed to allow for the rapid on-site classification of sites and estimation of predicted tree-component standing biomass yield at 25 years.

6) Results from farmer interviews were used to estimate various parameters. Annual tree biomass removal was estimated by multiplying the number of trees harvested for biomass by the average tree biomass. Fuelwood use was estimated by multiplying farmer estimates of basket loads consumed by 40 kg dry weight per load. This overestimates consumption since many loads may not be fully dried. The price per kg of cardamom received by the farmer was used to estimate gross income in Nepalese Currency Rupees (NC Rps.) The current rate of exchange at the time of the study was NC Rps. 32.0 = US $1.00.

RESULTS AND DISCUSSION

SITE PARAMETERS

Average age of sampled alder-cardamom plantations was 12 years, ranging from 3 to 45 years (Table 1). Establishment dates for Ilam District were earlier than for other districts (Figure 3). A pattern of diffusion, first to adjacent districts within Mechi Zone and more recently to districts within the Kosi Zone, was observed.

TABLE 1

Mean, range (min, max), and standard deviation of 66 alder site and alder-cardamom plantation structural parameters

Site parameters	Mean	Min	Max	Std. dev.
Elevation (m)	1,570	1,037	1,890	201
Slope (°)	26	10	40	8
pH (0-20 cm)	6.4	5.0	7.5	0.5
pH (> 20 cm)	6.2	5.5	7.0	0.4
Plantation age (trees)	12	3	45	7
Cardamom				
Understory: % cover	82	50	100	14
Understory: height (m)	1.8	0.9	2.7	0.6
Alnus nepalensis				
Canopy: % cover	69	40	80	10
Canopy: height (m)	20	4	38	6
Density: (trees/ha)	1,300	200	4,800	800
Site index (cm) (dbh)	36	22	54	8
Site index (cm) ht)	26	9	37	5
Total standing biomass (t/ha)	135	21	528	99
Annual biomass accumulation (t/ha/yr)	11	3	29	5
Predicted biomass (at 25 yrs)	273	169	401	56



FIGURE 11. Soil depth did not significantly affect Himalayan alder growth rates, even though many sites were rocky and had soil depths less than 50 cm. Here, cardamom is seen growing in a shallow, rocky Entisol.

All plantations sampled occurred between 1,000 and 1,900 m, with a mean of 1,570 m. All sites were on sloped land and/or rough terrain. The majority of sites exhibited some degree of terracing. Most plantations were situated mid-slope on the hillside although some were near ridge crests. The average slope of all sites sampled was 26°, with a range from 10° to 40°. Soil pH tended towards acidic, as would be considered normal for the sandy loams and sandy-clay loams typically found in this climate (Serchan, pers. comm.). Soil characteristics were highly variable and showed little correlation with areas where the farmers chose to plant. Goldsmith (1981) found that soils could not be consistently classified in four districts of the eastern Middle Hills due to high microsite variability and that site quality and fertility were not the primary determinants of land use. Climate, slope, and soil depth were the major factors that were subsequently used for classification and land evaluation (Dunsmore, 1988).

Soil depth did not affect alder growth rates ($p<0.79$), even though 38% of sites sampled had soils less than 1 m in depth (Figure 11). More than 10% of the sites had less than 50 cm of soil. Increasing percentage of clay in the soil profile below 20 cm negatively influenced tree growth ($p<0.04$). This is probably related to a need for proper drainage (Jackson, 1987) and reduction of growth due to waterlogging and lack of aeration. Many sites were wet or waterlogged at time of sampling. Serchan (pers. comm.) observed that where irrigation is available soils are kept at field capacity throughout the growing season.

Average cover (Table 1) of the cardamom understory was 82%, with a range from 50% in younger plantations to well over 100% for mature plantations. Cover provided by the alder overstory averaged about 70%. Moderate light levels under alder provide ideal habitat for cardamom, especially when compared with the light levels under many of the thick-leaved fodder species otherwise preferred by farmers (Panday, 1982).

Alder densities (Table 1) were high in newly established plantations and decreased steadily over time and with repeated harvests (Figure 12 a,b,c,). Density of alder trees ranged from 4,800 trees/ha for newly established plantations to 200 trees/ha, with a mean of 1,300 trees/ha. Increased tree density showed a negative influence on SI (based on height, $p<0.05$), however this relationship is confounded by differential management and thinning regimes. All sites showed signs of intensive management and regular thinning. No farmers reported that they used any manures or synthetic fertilizers on their plantations.

SITE INDEX AND PRODUCTIVITY ESTIMATES

Non-linear regression of dbh (cm) on age of 138 SI trees gave a best fit line described by the following equation:

$$dbh = 41.087 * (1-e^{(-0.077 * Age)}).$$

The growth rate of the average tree in a plantation is estimated to level off to a maximum girth of 41 cm (Figure 13). This equation, based upon a model commonly used to describe tree growth (Richards, 1959; Chapman, 1961; Hägglund, 1981), was then used to construct a series of SI curves (Figure 14). When calculated for the plantation reference age of 25 years, the mean SI based upon dbh for all plots was estimated at 36 cm (Table 1), with a minimum of 22 cm and a maximum of 54 cm. Table 2 presents average dbh of SI trees in average stands for SI classes 20–55 for plantation ages from 5 up to 50 years.

A similar non-linear regression of height (m) on age of 138 SI trees gave the following equation:

$$Height = 27.169 * (1-e^{(-0.139 * Age)}).$$

This equation estimates a maximum height for the average tree of about 27 m (Figure 15). The mean SI based on height for all plots was estimated at 26 m at 25 years (Table 1), with a range from 9 m to 37 m (Figure 16).







FIGURE 12 a,b,c. Plantations are heavily managed, and trees are regularly thinned. Maintenance of a progressive optimal density of trees as the plantation matures allows competitive release and continued high biomass accumulation rates throughout the productive lifetime of the plantation, and provides optimal shade for the cardamom understory. Density of alder trees ranged from 4,800 trees/ha for newly established plantations to less than 200 trees/ha on the oldest sites, with a mean of 1,300 trees/ha for all plots (average age 12 years).

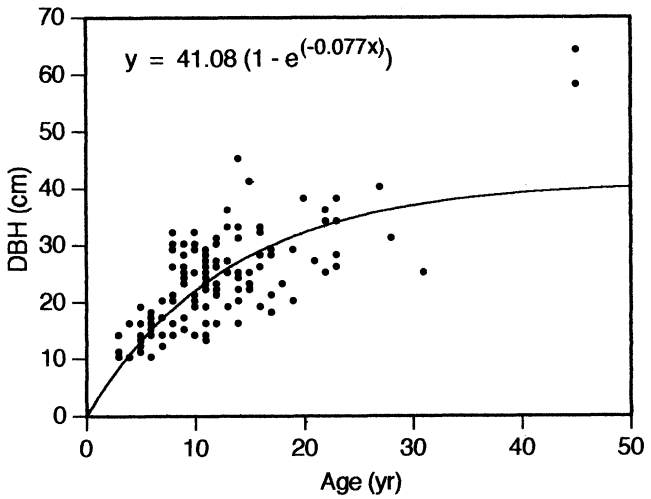

FIGURE 13. Non-linear regression model of tree diameter (dbh in cm) related to tree age (yr) based on 138 observations ($r^2 = 0.50$).

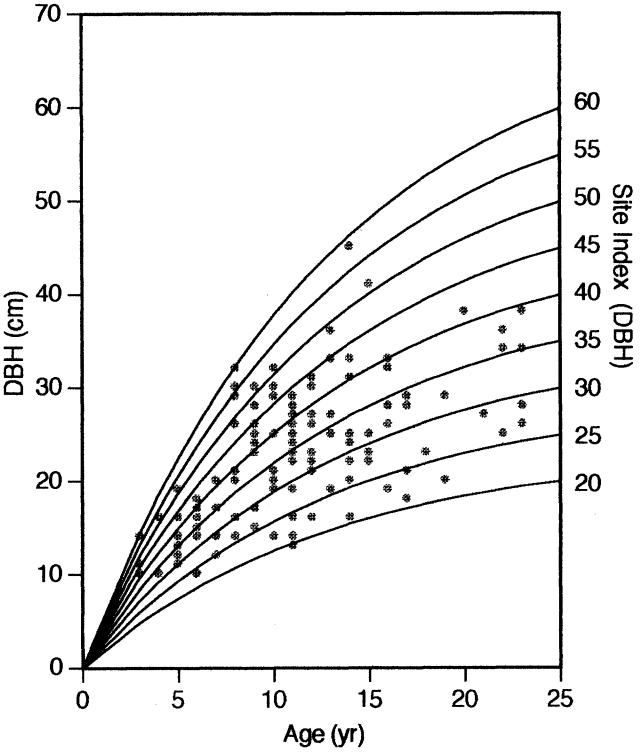

FIGURE 14. Representative growth and site index curves for the tree component in alder-cardamom plantations based upon dbh (cm).

Multiple and stepwise regression indicated that measured site parameters accounted for very little of the variability (proportions of R^2) of SI (zone, 0.00; elevation, 0.01; slope, 0.03; aspect, 0.02, % clay topsoil, 0.01; % clay subsoil, 0.07; soil depth, 0.00; pH topsoil, 0.03; pH subsoil, 0.01; understory % cover, 0.01; understory ht, 0.00, tree density, 0.01). High microclimate variability in mountainous terrain, absolute and seasonal availability of water, and a diversity of management levels are parameters not accounted for in the regression that likely have a large influence on site biomass production.

Annual alder biomass production was highly dependent ($p<0.001$) on SI but this relationship explained little ($R^2 = .22$) of the variation of growth among stands of similar SI (Figure 17). This variation is due to errors in age determination (Hägglund, 1981) and differential management and thinning regimes. Thus, the usefulness of the SI to predict actual biomass production on any particular site is limited. Plantation standing tree biomass yield (Figure 18) had a linear relationship to age ($p<0.001$, $R^2 = .73$), indicating no limitation on growth and this must be due to the management practice of removal of substantial and increasing amounts of biomass throughout the life of the plantation. Carefully managed progressive thinning increases the efficiency of biomass production. Close spacing in young plantations ensures quick canopy closure, early shade for young cardamom plants, and full stocking at all ages. Subsequent thinning releases remaining trees allowing them to maintain high growth rates.

TABLE 2

Average dbh (cm) of site index trees in average alder-cardamom stands by site index class and age

	Site index class							
Age	20	25	30	35	40	45	50	55
5	7	9	11	13	15	17	19	21
10	13	16	19	22	25	28	31	35
15	16	20	24	28	32	36	40	44
20	18	23	28	32	37	41	46	51
25	20	25	30	35	40	45	50	55
30	21	26	32	37	42	47	53	58
35	22	27	33	38	44	49	55	60
40	22	28	34	39	45	50	56	61
45	23	28	34	40	45	51	57	62
50	23	29	34	40	46	52	57	63

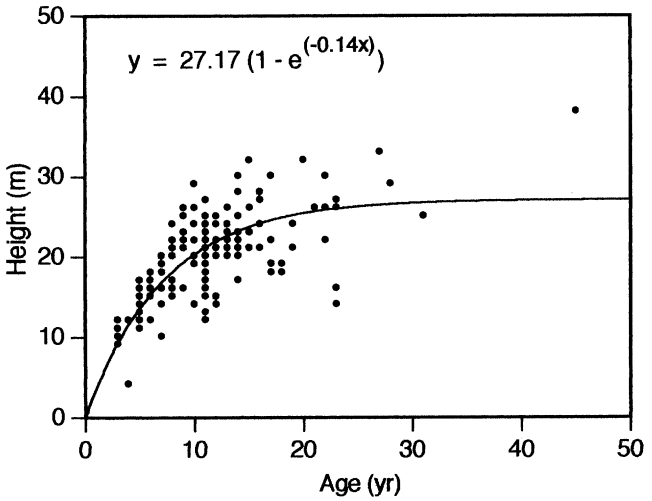

FIGURE 15. Non-linear regression model of tree height (m) related to tree age (yr) based on 138 observations (r^2 = 0.49).

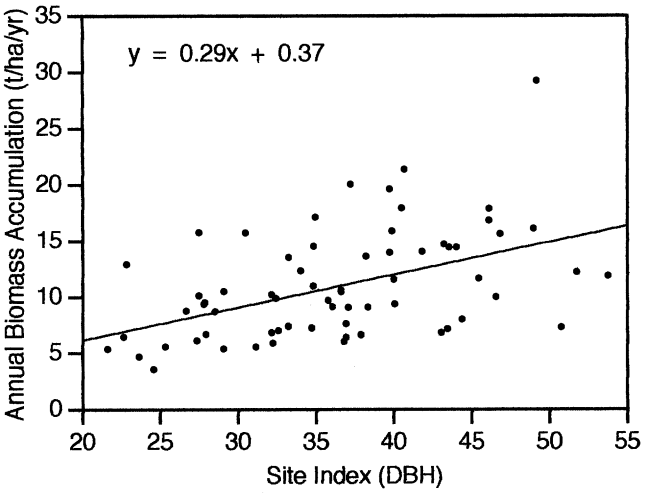

FIGURE 17. Linear regression model of the annual standing biomass accumulation increment (t/ha/yr) for the tree component in alder-cardamom plantations related to site index based upon diameter (dbh in cm) (r^2 = 0.22, $p<0.001$).

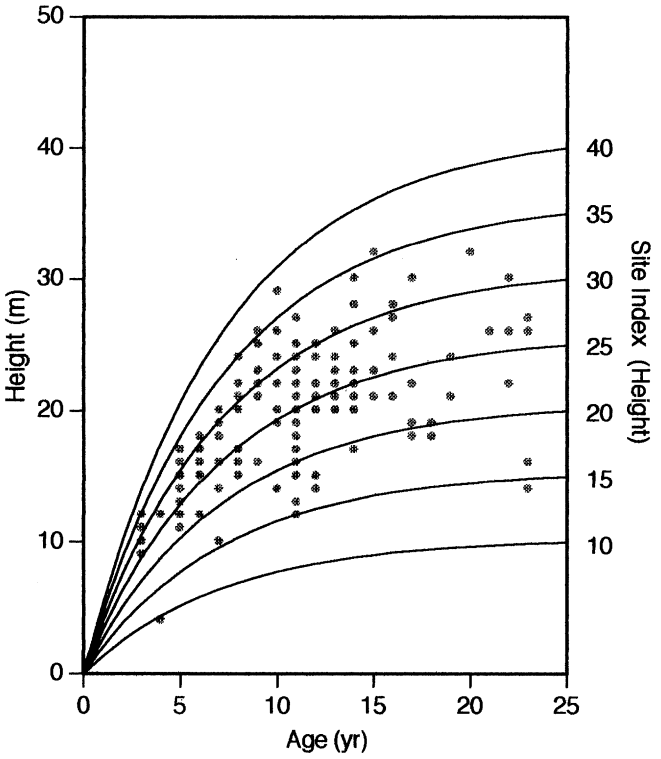

FIGURE 16. Representative growth and site index curves for the tree component in alder-cardamom plantations based upon height (m).

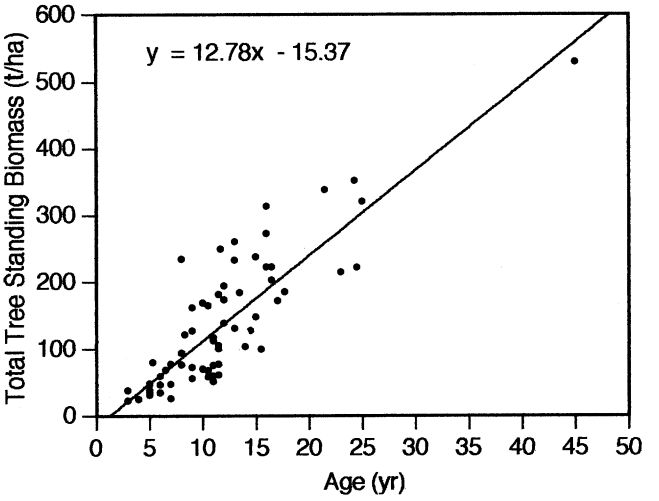

FIGURE 18. Linear regression model of the accumulated standing biomass (t/ha) for the tree component in alder-cardamom plantations related to plantation age (r^2 = 0.73, $p<0.001$).

Annual increases in standing tree biomass ranged from 3 to 29 t/ha/yr, with a mean of 11 t/ha/yr (Table 1). Growth rates for natural stands of 4–6 year-old red alder in northwest U.S.A. average 7 t/ha/yr (DeBell *et al.*, 1978) with yields of managed coppice rotations estimated to be 14 t/ha/yr. In British Columbia, mean annual yields for *A. rubra* grown as a biomass energy crop were 9 t/ha/yr with maximum production of 28 t/ha/yr (Smith, 1978). Natural stands of *A. rubra* studied in the U.S.A. (Zavitovski, 1970) were estimated to have a growth rate of 26 t/ha/yr. At our study sites, both seasonal rainfall and temperatures are higher than in these temperate zone alder forests and consequently biomass production estimates are also expected to be higher. Net annual productivity of *A. nepalensis* plantations in nearby Darjeeling District, India, ranged from 13 t/ha/yr in a 56 year-old stand to 25 t/ha/yr in a 7 year-old stand (Ambasht, 1988) In one of the few studies from Nepal, 6 year-old *A. nepalensis* plantations in the Phewa Tal watershed near Pokhara in central Nepal were estimated to produce a mean annual above ground biomass yield of 4.3 t/ha/yr (Moestrup and Bhandary, 1986).

The average aboveground tree biomass for the 66 plantations (average age 12 yrs) was estimated at 134 t/ha (Table 1). By comparison, 22 year-old plantations of *A. incana* in the U.K. had an estimated 125 t/ha (Ovington, 1956). Standing tree biomass of *A. rubra* was estimated at 250 t/ha in 50 year-old natural stands in northwest U.S.A. (Zavitovski, 1970).

Average standing biomass of *A. nepalensis* at a reference age of 25 years was estimated at 273 t/ha (Table 1), with 169 t/ha for the poorest sites to over 400 t/ha for the best sites (Figure 19). Although higher than the estimates given for temperate zone *A. rubra* (Zavitovski, 1970), this average falls well within biomass productivity estimates for similar biomes. Biomass of highly productive subtropical humid mountain broadleaf forests was estimated at 410 t/ha (Rodin *et al.*, 1975). Table 3 presents standing biomass estimates for site classes 20–55 at ages from 5 years up to the reference age of 25 years.

The maximum estimated standing biomass of the alder trees reached 528 t/ha in the oldest site at 45 years (Table 1). Trees at this site averaged 64 cm dbh. As illustrated

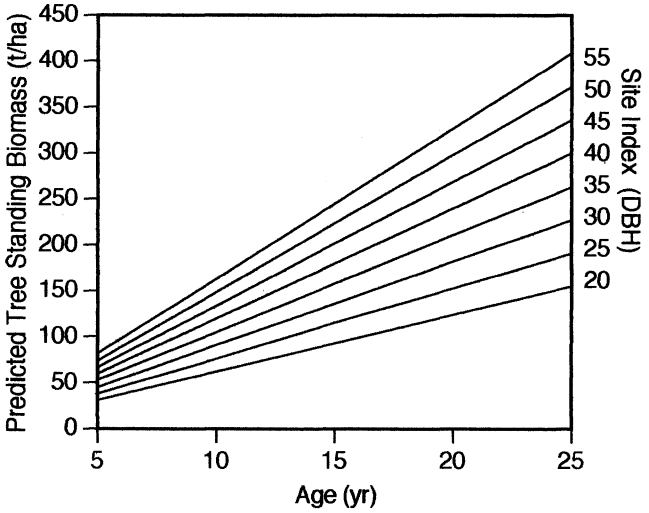

FIGURE 19. Predicted total tree standing biomass (t/ha) in alder-cardamom plantations related to age and site index class based upon model in Figure 17.

TABLE 3

Predicted total standing biomass (t/ha) of the tree component in average alder-cardamom stands by site index class (dbh) and age

	Site index class							
Age	20	25	30	35	40	45	50	55
5	7	9	11	13	15	17	19	21
10	13	16	19	22	25	28	31	35
15	16	20	24	28	32	36	40	44
20	18	23	28	32	37	41	46	51
25	20	25	30	35	40	45	50	55

TABLE 4

Mean, range (min, max), and standard deviation of cardamom post-harvest fuelwood requirements, and annual biomass removal from alder-cardamom plantation through thinning, as quantified by farmer survey

Fuelwood requirements for drying*	Mean	Min	Max	Std. dev.
Wood (kg)/cardamom (kg)	7.5	1.6	13.9	2.9
Wood (d.w. t/ha)	2.6	0.5	8.3	1.7
Value of fuelwood (NC Rp. 20/40 kg)	1,284	245	4,160	852
(U.S. $)**	40	8	130	27
Fuelwood is sold in village (% farmers)	38			
Fuelwood is not sold in village (% farmers)	62			
Tree cutting				
Number of trees/ha/hr	31	4	200	35
Annual biomass removal (d.w. t/ha/yr)	3.2	0.4	21.0	3.7

*Only producing plantations more than 4 years old were used in this calculation. This includes 34 of the 42 farmers surveys completed.

**Calculated at the rate of U.S. $1.00 = Nepalese currency rupees (NC Rps.) 32.00.

TABLE 5

Mean, range (min, max), and standard deviation of plantation area, cardamom yield, farm-gate price, labor, and pesticide use, as quantified by farmer survey

Plantation area and cardamom yield	Mean	Min	Max	Std. dev.
Area of plantation (ha)	1.02	0.10	5.00	1.02
Year of cardamom* (kg/ha)	364	80	900	199
Farmgate price of cardamom*				
Price (NC Rps./kg)	77	55	115	14
(U.S. $)**	2.41	1.72	3.59	0.45
Gross income/farmer (NC Rps.)	28,704	2,300	176,800	37,022
(U.S. $)**	897	72	5,525	1,157
Gross income/ha (NC Rps.)	27,662	5,200	58,500	14,348
(U.S. $)**	864	163	1,828	448
Labor requirements*				
Man-days/ha/hr	237	35	720	142
× NC Rps. 50/day	11,842	1,750	36,000	7,110
(U.S. $)**	370	55	1,125	222
Man-days/kg of cardamom	0.82	0.04	2.22	0.55
× NC Rps. 50/day	41.00	2.00	111.00	27.50
(U.S. $)**	1.28	0.06	3.47	0.86
Use of laborers (% of farmers)	88			
No use of laborers (% of farmers)	12			
Pesticide use				
None (% of farmers)	74			
Have used (% farmers)	26			

*Only producing plantations more than 4 years old were used in this calculation. This includes 34 of the 42 farmers surveys completed.

**Calculated at the rate of U.S. $1.00 = Nepalese currency rupees (NC Rps.) 32.00.

by the exponential regression equation used to convert tree dbh to biomass, an annual increase in diameter in a larger tree adds much more biomass than that same increase for a smaller tree. Blackman (1919) refers to this geometric series as the "compound interest law" of plant growth, where the rate of increase in biomass is clearly proportional to the quantity of standing biomass. By this same reasoning, it is assumed that biomass estimates for individual trees also have increasing error at larger diameters, and that this is compounded when translated to land area estimates. The extent of this error in the estimates for maximum biomass (Table 1) is unknown. However, only a few of the 822 sampled trees in this study exceeded the maximum dbh (41 cm) used by Thapa *et al.* (1989), and therefore errors due to extrapolation of his curve are minimal.

It was noted from tree-ring counts and dbh measurements that trees continued to show relatively high growth rates for all ages sampled. More than 2 cm of increase in diameter per year is not uncommon for this species (NAS, 1980) Some tree-core samples showed a distinct pattern of release after many years (>20) of moderate growth, e.g., 10 mm compared to 1-2 mm. This indicates that trees may be accumulating substantial quantities of biomass, at still relatively steep points along their growth curve, well beyond the normal senescence age of a plantation. In the Kohalia Forest Reserve in Hawaii, trees in planted stands of *A. nepalensis* have reached 63 cm dbh with stems 18 m in height at 23 years (NAS, 1980). *A. nepalensis* is described as often reaching over 2 m in diameter (NAS, 1980), with specimens of 80 cm in diameter and 33 m in height regularly recorded in Kashmir. In the eastern Himalaya alder trees of this size are rarely encountered, and diameters of 30-50 cm are more typical. However, many older alder-cardamom plantations are replanted with new cardamom seedlings beneath widely spaced mature trees. Studies conducted in Phewa Tal watershed (Moestrop and Bhandary, 1986) showed that biomass production of *A. nepalensis* declined after an estimated optimal productive age of 5-6 years. This low estimate can be attributed to suppression of growth in unthinned stands. Subsequent thinning trials did show "extraordinarily" positive effects on growth (Moestrop and Bhandary, 1986). Short rotation forestry practices may not take full advantage of the extended high growth rates exhibited by *A. nepalensis*, especially when there is intensive management as on small farms.

Farmer responses indicated that 1-12 t/ha/yr were removed by thinning, with an estimated mean of about 3.2 t/ha/yr (Table 4). This amounts to an additional 64

t/ha of tree biomass being removed over the 25-year reference age of the plantation, if a 5-year delay to the first harvest is assumed. Based upon farmer estimates, average annual consumption of fuelwood used in the post-harvest cardamom drying process was estimated at 2.6 t/ha/yr, allowing an estimated surplus for farm family household consumption of 0.6 t/ha/yr. Although 62% of farmers reported fuelwood was not commonly sold in their village, this represents a substantial additional economic benefit. With increasing scarcity and high demand, the value of this benefit will increase and annual removal rates are expected to increase. Research on thinning regimes and optimum stocking density is needed to help farmers manage plantations efficiently.

PESTS AND DISEASE

Approximately 26% of responding farmers (Table 5) said they had used pesticides at least once. Pesticide use was more prevalent in Ilam District where plantations were older and insect damage more problematic. Numerous instances of serious damage to cardamom plants caused by stem borers or leaf mining insects were observed during fieldwork. In some cases substantial reductions in yield were reported by farmers. Fungal diseases affecting the panicle and fruits, and root rot, were also reported more often by farmers in Ilam District.

As larger areas are planted with alder-cardamom, the disadvantages of pest control common to continuous monocultural cropping systems become more evident. As with monoculture, alder-cardamom plantations have continuity of growth, spatial homogeneity, and a potential reliance upon pesticides and fungicides because other control methods such as crop rotations or periodic fallow are not possible. High habitat diversity and low disturbance levels, however, create conditions for potentially effective biological control. Use of toxic inputs, such as pesticides, are undesirable due to high rural population densities, scattered-village type settlement patterns, common farm and household water supply, low literacy levels, and a lack of available training and extension. Identification of beneficial organisms for use in biological control methods specifically adapted to cardamom cultivation should be a priority for pest control research efforts.

PROFITS FOR THE FARMERS

The average annual cardamom yield was estimated at 364 kg/ha (Table 5) with an average farm-gate price of NC Rps. 77 (US $2.40) per kg. This equals a gross income from cardamom of more than NC Rps. 27,600 (US $860) per ha. These high value returns make cardamom a very lucrative crop enterprise when compared to alternative cropping systems. Double-cropping of rice/wheat may occasionally achieve these gross returns (Timsina, 1986), but at substantially higher input and labor costs.

Although it was estimated that an average of 237 man-days/ha/yr of labor were required, much of this is provided by the farm family, especially in the smaller farms. However, 88% of the respondents reported the use of some outside labor. Much of this is in the form of non-monetary exchange arrangements between community members. Larger farms do hire laborers and since the peak labor demand in cardamom occurs at a time of moderate general labor demand, before the onset of the rice harvest, it is well accommodated by other farm enterprises.

When equity growth of the standing biomass is considered in addition to cash returns, the advantages to the farmer of this agroforestry system become evident. No good estimates of monetary value of *A. nepalensis* as timber are available, but if the entire 273 t/ha predicted as the average mean standing biomass for a 25-year plantation were sold as fuelwood, returns would exceed NC Rps. 135,000 (US $4,250) per ha. This represents substantial equity and potential funds for improvements in the standard of living for thousands of farm families.

CONCLUSIONS

Agroforestry systems need to be evaluated in the context of an effective strategy for farmers and communities who are attempting to meet diverse needs through agricultural enterprise with limited resources. These needs include both problems of the farmer and problems of the land (Young, 1988). When faced with competing land-use options, farmers make rational economic choices, first satisfying immediate short-term goals and then, whenever possible, applying longer term solutions. Economic, demographic, social, political, and resource availability factors combine to determine which technologies are eventually adopted by the farmer (Gilmour and Fisher, 1991). Gilmour and Nurse (1991) refer to the dynamic nature of the farmer's decision-making processes as the most important consideration in evaluating the suitability of agroforestry technologies.

The successful adoption and diffusion of the alder-cardamom intercrop system into east Nepal is based upon an ability to satisfy a diversity of small farmer needs simultaneously. The economic benefit of this compared with alternative cropping systems has been a strong incentive for the adoption of alder-cardamom intercropping by farmers. The high rate of return for the cardamom cash crop, the lack of need for external inputs, and a modest labor requirement of 237 man-days/ha/yr all indicate a positive annual benefit/cost ratio. High biomass production rates of *A. nepalensis* easily compensate for the 2.6 t/ha/yr post-harvest cardamom processing fuelwood requirements of the system. Farmers reported that they removed 3.2 t/ha/yr by thinning of trees to supply this fuelwood requirement, the surplus presumably being used for household purposes. Esti-

mated rates of biomass accumulation as high as 11 t/ha/yr (not including the quantities removed through thinning), with a predicted average standing tree biomass of 273 t/ha at the 25-year reference age, represent a substantial quantity of resource-building that is managed and controlled by the farmer. Adoption of this agroforestry system results in long-term equity growth and increased stability and resilience for farm households with mature plantations.

Potential ecological and environmental conservation benefits to the overall land-use system are substantial. Average soil protective cover was estimated at 82% for the cardamom understory and nearly 70% for the alder overstory. Furthermore, soil conservation and watershed protection are enhanced by this high proportion of permanent cover. Alder-cardamom intercropping is located primarily in erosion prone areas and riparian zones, and its use by farmers as a land restoration technique indicates its high environmental value. In addition, biomass removal in the form of leaf litter and cardamom prunings, containing significant quantities of biologically fixed nitrogen, contribute to the soil fertility of other components of the mixed farming system.

As shown by this study, actinorhizal nitrogen fixing species such as *A. nepalensis* can function effectively in highland agroforestry systems, and make significant contributions to the well-being of mountain peoples, notably in the eastern Himalaya. Continued high biomass accumulation rates of alder throughout the productive lifetime of the plantation result from intensive management by farmers. This is mainly accomplished through maintenance of a progressive optimal density as the plantation matures. Short rotation forestry practices (less than the 25-year reference age) aimed strictly at biomass production by the tree component may not take full advantage of this management option and the high total biomass accumulation potential of individual trees.

Perennial cropping systems, as illustrated by the example of the alder-cardamom intercrop, can be risk-reducing and add stability to farming systems. In Nepal, however, small farmers reduce ultimate risk and avoid catastrophe by not relying exclusively on cash-cropping as their sole source of subsistence. The alder-cardamom intercrop's ability to utilize marginal sites and reclaim wastelands for productive use has made it accessible to the smallest landholders and it can be adopted by a range of land-owning classes of farmers. The development potential of incorporating a perennial tree-based component into the agricultural enterprise in mountain and highland areas has been amply demonstrated by experience in eastern Nepal. Lakhpa Sherpa, a progressive farmer in Manglebare, Ilam District, with a new imported silk-worm production facility and an improved cardamom drier, summarized his community's evaluation of the alder-cardamom system: "Before we were all poor. Maize does poorly on this ridge, due to the climate, and the soil is not good. Cardamom has been the uplift of our community."

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