SITE-SPECIFICITY, GROWTH AND PRODUCTIVITY OF 'RUI' BAMBOO (*Arundinaria maling* Gamble) IN JANG AREA OF ARUNACHAL PRADESH

(ABSTRACT)

BY

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ABSTRACT

Arundinaria maling Gamble (locally called 'Rui' bamboo) a temperate bamboo with narrow culm is a rare and endemic bamboo species. *A. maling* grows profusely covering *ca.* 3.17 x 10^3 hectare in Jang area of Tawang district of Arunachal Pradesh.

Present study analyses the site - specificity, growth and productivity of 'Rui' bamboo and nutrient dynamics of 'Rui' bamboo forest in Jang area of Tawang district of Arunachal Pradesh. The study was carried out at three sites along an altitudinal gradient. The low elevation site ranges between 2400 to 2800 m asl., the medium elevation site between 2800-3200 m asl. and high elevation site ranges between 3200-3600 m asl. Studies on biology of *A. maling* including its phenology and growth (culm height, DBH, basal area), clump density, clump area, and production of new individuals were made from April 2001 to April 2003 at all the three elevation sites. Systematic position, description and distribution pattern of the genus *Arundinaria* as well as species have also been provided in this thesis. Studies were made on age-dependent variation in dry matter accumulation in *A. maling*, and biomass allocation to culm, branch and leaf to the total aboveground bamboo biomass. The biomass of herbs and shrubs was also determined during different seasons to understand their contribution to the total aboveground biomass of the Jang bamboo forest. Annual dry matter production of *A. maling* at the three elevation sites including periodic and annual leaf litter production and bamboo biomass extraction from *A. maling* forest were also determined. In addition to the above, the temporal variation in distribution of N, P and K in culms, branches and leaves of *A. maling* at all the three elevation sites and

age-dependent variation in leaf chlorophyll content were also studied. The influence of climatic variables and soil physico-chemical parameters on growth and biomass of 'Rui' bamboo, and N, P and K distribution in its aboveground parts at different elevation sites has also been studied. Salient findings of the investigation are as follows:

The pure *Arundinaria maling* brake occurring in Jang locality of Tawang district of Arunachal Pradesh (27^0 30′-27^0 35′ N latitude and 91^0 55′-92^0 E longitude) is a secondary successional forest, developed after the removal/overexploitation and destruction of *Taxus baccata* mixed forest. In Jang area, *A. maling* is restricted between 2400 to 3600 m asl., its maximum growth and biomass was recorded at the medium elevation site *i.e.*, between 2800 to 3200 m asl. Topography, climate and soil played a key role in the distribution of *A. maling* in Jang area. Anthropogenic pressures like unscientific mode of bamboo exploitation and human habitation at the periphery of the forest coupled with grazing and trampling of new shoots by wild and domestic animals also contributed to the restricted distribution of *A. maling*.

Annual rainfall was highest at the medium elevation site, whereas snowfall was maximum at the high elevation site. Mean maximum and mean minimum air temperature were highest at the low elevation site and the temperature decreased with the increase in elevation. Soil temperature decreased with the increase in soil depth except during December and January at the high and medium elevation sites, where surface soil temperature was lower than the subsurface layers due to snow cover. Soil was sandy at the low and high elevation sites, whereas at the medium elevation site, it was loamy sand. The medium elevation site had higher water holding capacity compared to the other two elevation sites. Soil moisture content decreased with the increase in soil depth and the maximum soil moisture content was observed at the medium elevation site. Bulk density increased significantly with the increase in soil depth, and it was lowest at the medium elevation site. Soil at the medium elevation site was less acidic compared to that of the low and high elevation sites, and the acidity decreased with the increase in soil depth. Concentrations of soil organic carbon, total nitrogen and available phosphorus decreased with the increase in soil depth, whereas soil potassium content was highest at 10-20 cm depth. Mean soil organic carbon content was maximum at the medium elevation site. Soil nitrogen content was highest at the low elevation site whereas soil available phosphorus was highest at the medium elevation site. Soil potassium content did not differ significantly among elevation sites.

A total of 29 species of herb and 28 species of shrub were recorded from the Jang *A. maling* forest, where highest number of species was observed at the medium elevation site, followed by the high and low elevation sites. *Eleocharis atropurpurea* of Cyperaceae, *Eragrostis ciliaris* of Poaceae and *Gnaphalium apiculatum* of Asteraceae family were the dominant species at the low, medium and high elevation sites, respectively. Species composition between the medium and high elevation sites had greater similarity in comparison to the similarity between medium and low, and between low and high elevation sites. Density of herbaceous species was highest at the high elevation site, whereas density of shrub species was highest at the medium elevation site. The values of species richness and Shannon-Wiener index were highest at the medium elevation site.

A. maling growing in Jang area flowered gregariously during 1940s and it regenerated through seeds in natural condition. Sporadic flowering which occurred at the high elevation site during the study period (2001-2003) caused production of viable seeds, but the latter did not develop into seedlings. Emergence of new shoots took place during June-July with the onset of rainy season. Branches in the new individuals were induced at the age of nine months, whereas induction of new leaves took place at the age of twelve months.

A. maling growing at the medium elevation site had significantly taller culms with larger diameter compared to the other two sites. The culm height and diameter were lowest at the high elevation site. Regression equations to predict culm height and DBH of *A. maling* at different ages, irrespective of elevation sites were established as Log (Y) = 5.4754 + 0.7573 Ln (X) and Log (Y) = 2.1208 + 0.1625 Ln (X), respectively. Culm height prediction equation considering DBH was established as Log(Y) = 0.8066 + 2.2743 Ln (X). Clump density decreased with the increase in elevation. Clump area and new shoot production were maximum at the medium elevation site. Climatic variables and soil physico-chemical parameters had positive influence on growth and biomass of *A. maling* at Jang area, whereas soil bulk density and wind velocity had strong negative influence.

Aboveground dry matter accumulation in two year old *A. maling* was 1.95, 2.42 and 0.90 kg/ individual, respectively at the low, medium and high elevation sites. The contribution of culm, branch and leaf to the total dry matter accumulation was in the ratio of 90%, 6% and 4%, respectively at the low elevation site, whereas it was 91%, 5% and 4% at the medium elevation site, and 91%, 6% and 3% at the high elevation site. The rate of dry matter production in *A. maling* during the first month after shoot emergence at the low, medium and high elevation sites was 10.10, 17.00 and 6.93 g day^{-1} $individual^{-1}$, respectively. Biomass prediction equations of *A. maling* through culm height, DBH and basal area per culm have been established as Log (Y) = -3.143 + 2.2765 Ln (X), Log (Y) = -0.796 + 2.0703 Ln (X) and Log (Y) = -0.9809 + 1.1678 Ln (X), respectively. The standing crop of *A. maling* was 79.73, 107.47 and 9.11 tonnes ha^{-1}, respectively at the low, medium and high elevation sites. The contribution of culm, branch and leaf to the total biomass was 92%, 5% and 3% at the medium and high elevation sites, and 91%, 5% and 4% at the low elevation site. The contribution of aboveground bamboo biomass towards the total aboveground biomass in the Jang forest area was 98% at the low and medium elevation sites and 79% at the high elevation site. The contribution of herbs and shrubs to the total aboveground biomass was only 2% at the low and medium elevation sites and 21% at the high elevation site.

The rate of dry matter accumulation in *A. maling* was 12.52, 31.39 and 1.37 tonnes ha^{-1} yr^{-1}, respectively at the low, medium and high elevation sites, whereas biomass accumulation by herbs and shrubs was 1.6, 2.25 and 3.30 tonnes ha^{-1} yr^{-1}, respectively at the low, medium and high elevation sites. The annual litterfall was 6.59, 6.16 and 6.97 tonnes ha^{-1} at the low, medium and high elevation sites, respectively and the bamboo biomass extraction was at the rate of 18.47, 15.28 and 3.40 tonnes ha^{-1}, respectively at the low, medium and high elevation sites. The net aboveground primary production was highest at the medium elevation site with 55.08 tonnes ha^{-1} yr^{-1} followed by the low and high elevation sites with 39.18 and 15.04 tonnes ha^{-1} yr^{-1}, respectively.

Number of bamboo individuals recorded per hectare at the end of the study period at the low, medium and high elevation sites was 61982, 73200 and 9984, respectively while the number of individuals produced during 2001-2003 was 36822, 46000 and 5928 individuals ha^{-1} respectively, at the low, medium and high elevation sites. The percent annual harvest was 13.3, 7.3 and 18.2 at the low, medium and high elevation sites, respectively.

N, P and K content in the culms, branches and leaves of *A. maling* decreased with the age, and the highest concentration was recorded during the initial stage. The concentration of nitrogen and potassium in the aboveground parts of *A. maling* was in the order of leaf > branch > culm, whereas in case of phosphorus, it was branch > leaf > culm. Leaf chlorophyll content decreased with the increase in leaf age, and leaves at the medium elevation site had maximum chlorophyll content. The N, P and K content in leaf litter were highest at the medium elevation site (0.98%, 0.043% and 0.894%, respectively) followed by the low (0.88%, 0.022% and 0.806%, respectively) and high (0.85%, 0.020% and 0.739% respectively) elevation sites. The N, P and K accumulation increased with the increase in stand age. The contribution of bamboo parts to N and K accumulation was in the order of culm > leaf > branch, and in case of P it was culm > branch > leaf. The aboveground N accumulation in *A. maling* was 191.96, 296.46 and 20.07 kg ha^{-1}, respectively at the low, medium and high elevation sites, whereas P accumulation was 71.82, 142.30 and 6.41 kg ha^{-1}, respectively and K was accumulated in the rate of 301.88, 477.55 and 40.82 kg ha^{-1}, respectively at the low, medium and high elevation sites. The N, P and K lost through culm removal was 25.07, 12.60 and 47.01 kg ha^{-1}, respectively at the low elevation site, 23.42, 15.59 and 41.46 kg ha^{-1}, respectively at the medium elevation site and 3.65, 1.80 and 10.99 kg ha^{-1}, respectively at high elevation site. The annual N, P and K return through *A. maling* leaf litter was 57.63, 1.42 and 53.38 kg ha^{-1}, respectively at the high elevation site, 60.41, 2.63 and 55.24 kg ha^{-1}, respectively at the medium elevation site and 61.24, 1.47 and 53.68 kg ha^{-1}, respectively at the low elevation site.

The present study on site - specificity, growth and productivity of 'Rui' bamboo (*Arundinaria maling*) in Jang area of Tawang district of Arunachal Pradesh, revealed that localized distribution of *A. maling* is highly influenced by abiotic and biotic factors, where topography, climatic variables and soil physico-chemical parameters as well as anthropogenic pressures play key roles. Growth and biomass production was also highly influenced by both biotic and abiotic factors, where optimal performance was observed at 2800-3200 m asl *i.e.*, at the medium elevation site. Hence, it may be assumed that, the range of climatic and soil conditions prevailing at the medium elevation site is most suitable habitat for *Arundinaria maling* in Jang area of Arunachal Pradesh. Based on the scientific data collected during the present investigation, the potential areas to be brought under *A. maling* plantation can be located. Further, detailed studies on flowering and regeneration status, growth, biomass and nutrient distribution in belowground compartments of *A. maling* and soil, along with nutrient content in herbs and shrubs may provide a clear picture on the total biomass and productivity as well as nutrient dynamics in the *A. maling* forest in the Jang area. This may also provide strong indication regarding the site-specificity of *Arundinaria maling,* which may be helpful in the plantation and management of this bamboo resource.

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JUNE, 2005

DECLARATION

I, Ksh. Lal Bihari Singha, hereby declare that the subject matter of this thesis entitled ***"Site-specificity, growth and productivity of 'Rui' bamboo (Arundinaria maling Gamble) in Jang area of Arunachal Pradesh"*** is the record of work done by me, that the contents of this thesis did not form basis of the award of any previous degree to me or to the best of my knowledge to anybody else, and that the thesis has not been submitted by me for any research degree in any other University / Institute.

This is being submitted to the North-Eastern Hill University, Shillong for the award of the degree of Doctor of Philosophy in Botany.

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CHAPTER I

GENERAL INTRODUCTION

1.1 AN OVERVIEW

'Bamboo', the perennial woody grass from the sub-family Bambusoideae of Poaceae family, is one of the most important renewable multipurpose plants of high economic and environmental value. A.J. Retzius, a Swedish taxonomist first coined the term 'Bambos' to represent bamboo as a whole. During 317-420 A.D., in the Jin Dynasty of China, Dai Kaizhi recorded in his "Zhupu" (bamboo manual), the first monograph of bamboos in the world, 61 types of Chinese bamboos. There is further description of bamboo varieties, and their distribution, shapes, characteristics, habits and cultivation techniques in Jia Sixie's "Qiminyaoshu" (530 A.D.), Zan Ning's "Zhupu" (the late 10th century), Li Kan's "Zhupuxianglu" (1312 A.D.), Wang Xiangjin's "Qunfangpu" (1621 A.D.), Xu Guangqi's "Nongzhengquanshu" (1639 A.D.) and Wang Ying's "Guangqunfangpu.

Bamboos are evergreen, monocotyledonous plants which produce primary shoots without any later secondary growth. Each shoot has a distal aerial part called the culm, a proximal, ground level part called the culm neck, and a subterranean part called the rhizome. Culms consist of nodes and internodes-the former with meristematic tissue from where culm sheaths and branches arise. Bamboos vary in height from 15 cm to over 30 m. According to their mode of growth, they are either 'sympodial' type *i.e.* the clump forming, such as *Bambusa, Dendrocalamus* or they are 'monopodial' type with the single culms laterally distributed, such as *Phyllostachys* and *Chimonobambusa* (Ma Naixum 2000).

Bamboos occur mostly in Asia and South America and to a limited extent in Africa. They have a wide range of ecological amplitude and are distributed throughout the tropical, sub tropical and cold temperate regions except in Europe, from sea level to 4000 m asl,(Soderstrom and Calderon 1979). Diversity and natural distribution of bamboo are governed mainly by geographical location and physiographical features like altitudinal variations. Edaphic, climatic and biotic factors play equally important role in the distribution of bamboo. Rainfall plays a very important role in the distribution of different species of bamboo as well as their growth. The genera found in South America are quite distinct from those of Asia except the pantropical genus *Arundinaria* that is found in both continents.

More than 1250 species belonging to 75 genera of bamboo are reported worldwide (FAO 1978). However, a recent report indicates that approximately 87 genera and over 1500 species of bamboo exist with roughly 100 species comprising those of economic importance (Dive 2002). The distribution pattern of bamboo in the globe is shown in Figure 1.1. In Asia the largest number of bamboo species occurs in China (300 species) and India (130 spp.). They are also found in Nepal (30 spp.), Bangladesh (50 spp.), Sri Lanka (14 spp.), Myanmar (90 spp.), Pakistan, Cambodia, Thailand (50 spp.), Malaysia (44 spp.), Laos, Vietnam (92 spp.), New Guinea (26 spp.), Philippines (54 spp.), Indonesia (31 spp.), Korea (13 spp.), Japan (237 taxa) and Singapore (23 spp.) (Vivekanandan 1980, Sharma 1987, Das 1990, Tewari 1992). India has contributed around 130 species belonging to 23 genera (Sharma 1980, Varmah and Bahadur 1980, Soderstrom and Ellis

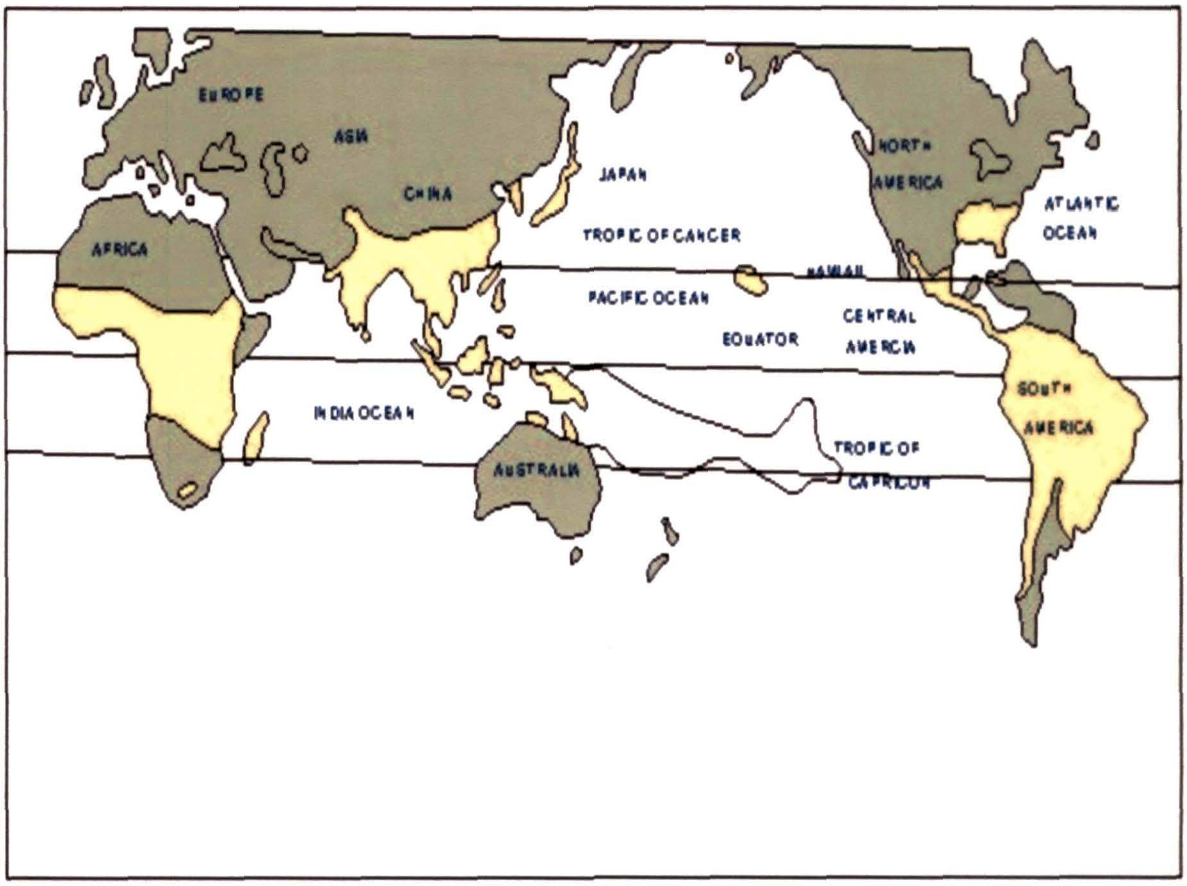

Figure 1.1. A broad outline (yellow) of the native bamboo regions in different continents of the world (Source: Marden 1980).

1987, Biswas 1994). More than 50% of the Indian bamboo resource is confined to north-east India. As many as 78 bamboo species (both indigenous and exotic) belonging to 19 genera have been reported from this region (Hore 1998). According to Haridashan *et al.* (2000), more than 89 bamboo species grow in this region and there are possibilities of finding out some new species, if detailed studies are carried out. Arunachal Pradesh with more than 12 genera and 30 bamboo species is rich in bamboo resource which forms a major forest produce of the state (Haridashan and Deori 1987). Most of the bamboo species available in the state are used for various purposes like construction, agriculture, vegetables, household articles and transport, etc.

Bamboo generally forms an understorey or it grows mixed with other tree species in the tropical, subtropical and temperate forests. Few species of *Phyllostachys* and *Arundinaria* form pure bamboo forests in temperate and sub alpine regions. These species are very rare in tropical forests. Few species of the genus *Melocanna* and *Dendrocalamus* in north-east India form pure bamboo patches in tropical and sub tropical zones as a result of clear felling of natural mixed forests or in areas abandoned after shifting cultivation (Rao 1986). In India, bamboos form an important component of the dry and moist deciduous, wet evergreen or tropical evergreen rainforests as an understorey, or they occur as pure bamboo brakes (Qureshi and Deshmukh 1962). It spreads from tropical to temperate and alpine regions (Varmah and Bahadur 1980).

The distribution of bamboo species in nature is highly influenced by altitude, topography, agro-climatic and edaphic factors and anthropogenic pressures. Different species require different temperature, rainfall, humidity, soil structure, drainage, soil moisture, soil nutrients, altitude and physiographic features for their growth and development. There is reduction in bamboo culm size with the increase in latitude and altitude.

In India bamboos occur in all states except Jammu & Kashmir and form rich belts of vegetation in well-drained parts of tropical and subtropical habitats to altitudes up to 3700 m in the Himalayas. The principal genera of bamboos occurring in India are *Arundinaria, Bambusa, Cephalostachyum, Chimonobambusa, Dendrocalamus, Dinochloa, Gigantochola, Indocalamus, Melocanna, Ochlandra, Oxytenanthera, Phyllostachys, Pseudostachyum, Schizostachyum, Sinarundinaria, Sinobambusa, Teinostachyum,* and *Thamnocalamus. Pseudosasa* and *Thyrostachys* are the two exotic genera that have been introduced in India from other countries. The genus '*Arundinaria*' occurs at higher elevation in the Himalayan tracts between 600 m to 3700 m asl.

Worldwide, more than 14 million ha land area is covered by bamboo (Dransfield and Widjaja 1995, Fu and Banik 1995). As per the recent assessment, India has a forest cover of 67.55 million ha constituting 20.55% of the geographical area (Anonymous 2001). The area under bamboo in India (including plantations) has been estimated at between 3 to 10 million ha (Bahadur and Jain 1981, Biswas 1988, Pathak 1989, Tewari 1992, Fu and Banik 1995, Rai and Chauhan 1998). The bamboo cover of north-east India has been estimated to be 3.82 million ha. Bamboos occupy an area of 0.78 million ha in Arunachal Pradesh with 0.20 million tonnes of annual bamboo production (Trivedi and Tripathi 1984, Tewari 1992, Hore 1998).

India is one of the leading countries of the world after China in bamboo production with 3.23 million tonnes per year (Pathak 1989), which represents one-fifth of the country's total wood production. More than half of the bamboo wood production is consumed by paper and rayon industries. The four existing paper mills in north-eastern region consume more than 2,000 tonnes of bamboo per day (Singh 1986). Bamboo, therefore, constitutes one of the most important renewable natural resources of India and hence, its judicious extraction is necessary for the growth and development of clumps. Bamboo and its plethora of essential uses and its accessibility to all, is called by several names like 'poor man's timber, green gold, friend of the people, cradle to coffin', etc.

Bamboo has three principal uses: (a) domestic use as vegetable stakes, trellis poles, shade laths etc.; (b) use in building construction, food (edible bamboo shoots), and for making fishing poles and fishing rods, furniture, crafts, musical instruments etc.; and (c) ornamental, landscape and conservation uses (e.g. as specimen plants, living screens, hedges, riparian buffer zone etc). Bamboo evokes the essential color of green, and yet there exists a myriad of cultivars with yellow, gold, burgundy, blue and even black stems, and leaves displaying intense variegation of gold and white. Over thousands of economic applications of this plant have been compiled around the world (Mc Clure 1966, Ueda 1981). Rao *et al.* (2004) reported that woody biomass production of bamboo is 15 tonnes ha^{-1} which can be used for producing electricity. Their calculation revealed that 1,200 ha of marginal land, with protective irrigation, could yield adequate biomass to run one MW power generation plant efficiently. The range of use of bamboo for human is remarkable, with an estimated annual use of 12 kg of bamboo products per capita in Asia (Recht and Wetterwald 1988, Sastry 1998). It is an important raw material of commercial pulp. Many utility items including fresh and fermented edible shoots, leaves (for medicine and fodder), culms as construction material, tools, agricultural implements, handicrafts, fuel, and even clothing are being obtained from bamboo. '*Banslochan*' also known as '*tabashir*' in Persian, a silicaceous deposit inside the hollow culms of many bamboo species, has high medicinal value (Shukla and Das 1981). It is valued as a stimulant, febrifuge, cooling tonic and aphrodisiac. It is also used for the treatment of asthma, cough, paralytic complaints and other debilitating diseases. The use of bamboo as key material in the livelihoods of over 100,000 kite makers in Gujarat is one among the mega applications of bamboo (Morrison 2004). In India about 43.2 million workdays are generated annually by bamboo sector. The new areas of application of bamboo include stabilizer of soils helping in soil conservation and flood control (White and Childers 1945, Ueda 1960), wind breaks (Hsiung 1987), earthquake proof building materials (Chaturvedi 1986), stand board, medium density fiberboard, laminated lumber, particleboard, corrugated sheets, parquet, charcoal, pyrolysis, gasification etc. In combination with selected trees that can penetrate root to a greater depth, bamboos provide a low cost means of slope stabilization in Bhutan (Stapleton 1994). Effective use of bamboo charcoal as odor remover, water purifier, food preservative and dehumidifier has also been reported. Bamboo and its charcoal make a good fuel of high calorific value (4600 to 5400 cal kg^{-1}), which makes it as an energy crop with an effective use in ceramic industry (FAO 1978, Sharma 1982). Researches at the University of Agriculture, Malaysia (UPM) also indicated that a number of bamboo species have been found to possess tension strength equivalent to that of iron or steel (Sabaruddin 1987, Bhattia 2004). In the tropics, bamboo is a very important plant, providing livelihood for over 500 million people and providing housing and shelter for over 1 billion people. In Europe, it is an ornamental plant mainly for garden use, but it is also allowed to develop its potential as an agricultural plant (Gielis and Oprins 2000) with possible applications in wood industry (Van Acker *et al.* 2000).

For centuries, young succulent edible bamboo shoots remained one of the highly palatable dishes for its delicacy. China and Taiwan are among the leading countries to earn foreign currency through bamboo shoots. In metropolitan Tokyo alone, more than 8,000 tonnes of young shoots are consumed per annum (Ueda *et al.* 1989). It is reported that more than 6,000 tonnes of fresh bamboo shoots and 680 tonnes of processed bamboo shoots are being consumed per year in the north-eastern region of India (Bhatt *et al.* 2004, 2005). Among the major applications of bamboo, the most innovative and interesting are its use as filament in the first electric lamp invented by Thomas Alva Edison and use of bamboo made needle in gramophone invented by Graham Bel. Invention of an aircraft made of bamboo ply (Plyboo) in China and 'Bambucicletas' a bicycle by Smithy and Flavio Deslandes are among the new additional inventions in this bamboo era.

Bamboo has the peculiarity of flowering and seeding at the end of very long vegetative growth phase, the length of which is considered to be species-specific (John and Mascarenhas 1994). Differences in flowering habit between tropical and temperate bamboos reported so far revealed that temperate bamboos are monocarpy with evident synchronously flowering behaviour in considerably longer intermast periods, not less than hundred years. On the other hand, bamboos in tropical regions flower is less synchronized with rather shorter intervals (Makita 2004). Flowering and fruiting of bamboo is a physiological course of transforming the vegetative growth into the reproductive growth. The duration of this course remarkably varies from species to species and the effect of environment on the delay or promotion of bamboo flowering is significant (Zhang and Ma 1991). The gregarious flowering of bamboos is considered as one of the great mysteries in botany. Flowering is considered a catastrophic event, destroying large areas and whole populations, depriving pandas from food, and people from income. Rational view of flowering in bamboos would also imply demystification, since many of the 'tales' are very often based on non-proved facts and assumptions. Because of the peculiar flowering habits in bamboo it has been almost impossible to breed for superior traits in woody bamboos. The first report on induced flowering of bamboo through tissue culture generated great excitement (Nadgauda *et al.* 1990, Rao and Rao 1990). It opened up the possibility of controlled flowering that can be used for breeding of bamboo.

Major growth and developmental phases of bamboo generally take place within 3-4 months after the emergence of new shoots. In tropical regions, higher rate of culm elongation takes place during night (Osmaston 1918), while in temperate regions, it takes place during day time (Ueda 1960). The rate of culm extension growth is species-specific, which may vary from few centimeters to more than a meter (Osmaston 1918, Ueda 1960, Banik 1993).

Biomass is the total quantity of organic matter per unit area present in an ecosystem at a given time and may relate to a particular species or a group of species of a community as a whole. 'Bamboo' the only woody perennial grass having the shortest gestation period, plays a key role in carbon sequestration by fixing atmospheric CO_2, which is one of the most important green house gases (Pande 2004). Depending on the species and the forest type, bamboo biomass production ranges from few to several hundreds of tonnes per ha (Banik 2000, Singh *et al.* 2004). Although biomass production of bamboo is species-specific, it also depends on the stock density and age. The expansion of bamboo clump area is rapid up to few years (species-specific), and thereafter becomes slow (Banik 1988). Long-necked tropical bamboo species like *Melocanna baccifera* and temperate species like *Arundinaria maling* provide larger space and longer period for the continuous induction of new shoots than those of short-necked clump forming bamboos.

Among the plant nutrients, nitrogen, phosphorus and potassium (N, P and K) are the most essential macro elements that limit the growth and productivity of plant communities. They play an important role in functioning of the ecosystem (Uchimura 1980, Kinhal 1985, Huang 1987). In addition to the knowledge on the status of N, P and K in soil, studies on their distribution in the vegetation subsystem and its inputs and outputs in various components and compartments are essential for complete understanding of N, P, and K cycling within the ecosystem. Litter constitutes an important component in forest ecosystems and is the major pathway for supplying energy and nutrients to the soil decomposer subsystem. The recycled nutrients from decomposing forest litter are one of the main nutrient sources for maintaining the growth of forest trees (Staaf and Berg 1981).

Several studies have been reported from various regions of the world on ecological and edaphic aspects of different bamboo species (Lyall 1928, Kadambi 1949, Sen Gupta 1952, Yadav *et al.* 1963, Iyppu 1964, Kaul 1964, Yadav 1964, 1969, Qureshi *et al.* 1969, Gupta 1979, Soderstrom and Calderon 1979, Kopper 1980, Uchimura 1981, Toky and Ramakrishnan 1982, 1983, Hassan and Nurul Islam 1984, Hassan *et al.* 1988, Othman 1989, Lakshmana 1990, Maoyi *et al.* 1990, Rao *et al.* 1991, Alam 1992, Lakshmana and Hittalmani 1992, Tewari 1992, Banik 2000, Shanmughavel and Francis 2001, Singha *et al.* 2003) as well as on their nutrient requirements (Wang *et al.* 1977, Hussain 1980, Madhusoodhana Rao *et al.* 1980, Uchimura 1980, Huang 1987, Qui and Maoyi 1987, Shi *et al.* 1987, He and Ye 1987, Raina *et al.* 1988, Thomas 1990, Totey *et al.* 1989, Joshi *et al.* 1991, Banik 2000, Quing *et al.* 2004).

1.2 IMPORTANCE OF THE STUDY

During the last few decades, bamboo has been treated as the most wanted non-timber and renewable forest resource. And hence, to meet the current need of the country, an assessment of density/stocking, total availability and productivity of bamboo has become very important. As many bamboo species form an understorey in the natural forests, it is difficult to obtain a clear picture by aerial survey. The density has to be determined only by ground survey and sample enumerations. In Bangladesh, United Nations Environmental Programme (UNEP) recently assisted in the determination of the extent of bamboo in the villages, and it was estimated to be 190 million mature and 558 million of new bamboos (Sharma 1980, Hammer Master 1981).

Realizing the importance of bamboos, due priority has been given for their sustainable management, utilization and conservation. Bamboos exhibit unique behavior in their growth and development differing from other flowering plants and in morphological characters, especially of their small and peculiar flower, so they have a higher position in evolution. North-east India is one such region where bamboo utilization is traditionally associated with human life, especially among the tribal people (Haridashan and Deori 1987).

Though the traditional use does not endanger bamboo populations, some of the rapid exploitations like that of paper industries coupled with deforestation and habitat destruction have pushed some of the species under the endangered status. Some new bamboo species have also been reported from this region, which are endemic and treated as endangered. Conservation efforts are essential for survival of such species. Further, information on some of the bamboo species of the region is totally inadequate.

Bamboo flowering is the most important devastating natural phenomenon, which heralds natural disaster when they flower gregariously. Understanding the phenology and flowering behaviour of endemic and rare bamboo species is of prime importance, which will enable us to take precautionary measures to protect the species from extinction.

Arunachal Pradesh is having a predominantly indigenous tribal population comprising of over 25 tribes and nearly 100 sub-tribes. These people practice the age-old shifting cultivation whereby sizeable chunks of forests are cleared and used for agriculture purposes in a cyclic manner. This has an adverse ecological impact on the wild habitats. Further, there has been a spurt in the human population which had led to an increased demand of forest resources. Road construction and other urbanization activities in the state have caused destruction and fragmentation of natural habitats of many endemic and endangered plant species including some bamboo species growing in the subtropical and temperate zones of the state.

Studies on bamboo throughout the world and India are especially concerned mostly with the tropical and subtropical species. It may be due to their larger size and high commercial value. Worldwide, ecological studies on temperate and alpine bamboo species are meager or negligible in comparison to those of tropical and subtropical ones. The ecology and habitat characterization of different species of bamboos with their requirements for a wide range of physiography, climatic and soil quality is a subject, which requires some intensive study. For proper understanding and management of the forest ecosystem, the total biological approach necessitates the knowledge of nutrient status of the forest ecosystems. Substantial information is available on nutrient status and dynamics in tropical, subtropical and temperate ecosystems of the world, but comparatively no data is available on the nutrient dynamics during the growth of bamboo.

Arundinaria maling Gamble (locally called 'Rui'), a temperate bamboo species has been an integral part of the local Monpa tribe's lifestyle in Arunachal Pradesh (Plate 1- A and B). It is used for house construction, vegetable stakes and supports for climber and twined agricultural crops, handicrafts, fencing, and has many religio-spiritual and ethno-botanical importance (Plate2 and 3). Young shoot is known as 'Shongje' and is used to prepare 'Rhoo', which is one of the most delicious traditional dishes of the area. From the ecological point of view, *Arundinaria maling* Gamble is identified as a rare and endemic species localized in few very specific pockets of Arunachal Pradesh, Sikkim and hills of Bengal in India and in Nepal and Bhutan. In Arunachal Pradesh, only three habitats of this species have been identified, where 'Rui' forms pure bamboo brake. In Jang area, very few tree species grow which may be due to the peculiar topography and unsuitable agro-climatic and soil condition. Most of the logging takes place in *Cephalotaxus* sp. forests available in the adjoining areas (Plate 1C). In Jang, the 'Rui' bamboo forest is the major source of fuelwood for cooking as well as for keeping the dwellings warm during the chilly winter. Besides, this bamboo

Plate 1. (A) A two-year old individual of 'Rui' bamboo, (B) A clump of 'Rui' bamboo with old and current year individuals, and (C) *Cephalotaxus* forest with snow cover nearby the 'Rui' bamboo forest in Jang area.

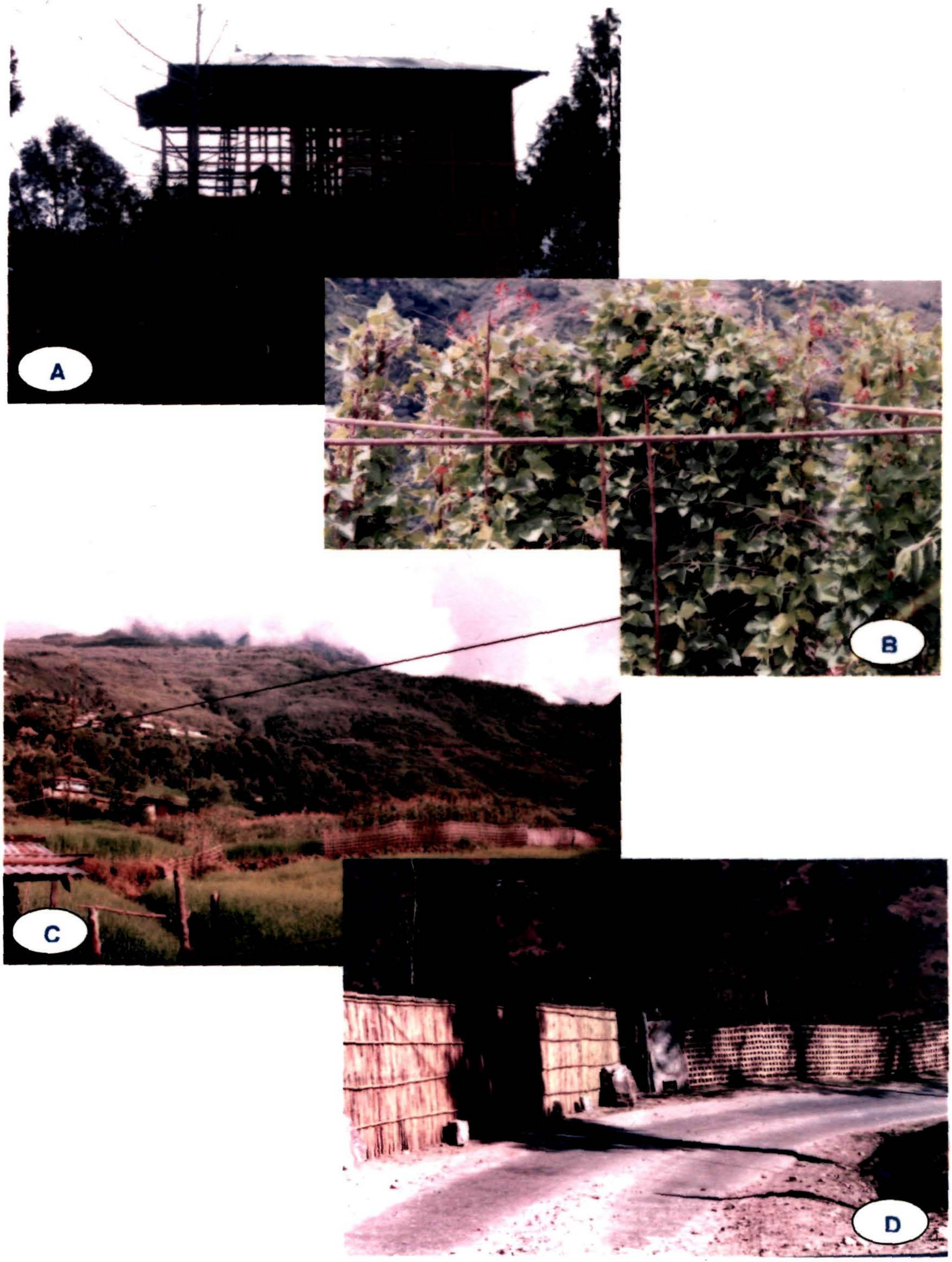

Plate 2. (A) A house with walls made of splits of 'Rui' bamboo in Jang village, (B) Application of 'Rui' bamboo as supports to climber and twined agricultural crops, (C) Use of 'Rui' bamboo splits for fencing in cultivable lands, and (D) Whole 'Rui' bamboo for fencing in residential areas.

Plate 3. (A) Different type of baskets made of 'Rui' bamboo, (B) Smoke treatment of bamboo baskets in the kitchen to increase their lifespan, (C) Use of the baskets in collection of NTFPs (collection of the leaves of a dye yielding plant is seen), (D) Making of bamboo fence using splits of 'Rui' bamboo, (E) Strips and sticks of 'Rui' bamboo used in rituals, and (F) Use of Rui bamboo in tent house during socio-cultural gatherings.

species provides natural habitat, food and breeding ground for several wild temperate animals. It may also be used as raw material for paper and pulp industries, and for making musical instruments, umbrella and incense sticks. Despite its commercial and socio-economic importance, fast growing nature and unique ecological niche, there is complete lack of studies on its distribution, growth, productivity and nutrient accumulation. In view of the limited information available on the ecology of this important bamboo species, the present investigation was undertaken to study *Arundinaria maling* at Jang area of Tawang District of Arunachal Pradesh with the following objectives:

- to evaluate the site-specificity of 'Rui' bamboo (*Arundinaria maling*) with special reference to topographic, biotic and abiotic factors,
- to study growth and productivity along the altitudinal gradient in the Jang bamboo forest,
- to study nutrient (N, P and K) distribution and accumulation in aboveground parts of 'Rui' bamboo.

1.3 ORGANIZATION OF THE THESIS

The thesis is organized in seven chapters dealing with varied but interrelated aspects. Chapter I (General Introduction) presents an overview on uses of bamboos, distribution (worldwide, India, north-east and Arunachal Pradesh), diversity, bamboo forest cover, flowering, growth, biomass and productivity and plant nutrients. The major objectives of the study are also included in this chapter. Chapter II (Review of Literature) reviews the chronological development and changing content of the studies on bamboos of different climatic zones. It highlights the works done on the abiotic and biotic factors influencing the distribution, growth and productivity of bamboos in different climatic zones. Chapter III describes the study site with special reference to location, geology, climate and vegetation. Soil physico-chemical parameters of the study site are also included in this chapter. Chapter IV highlights the biology and site specificity of *Arundinaria maling* ('Rui' bamboo). Data on growth performance and population studies of 'Rui' bamboo in the natural stand, and the Influence of different climatic variables and soil physico-chemical parameters on its growth is also incorporated in this chapter. Biomass and productivity of *Arundinaria maling* are presented in Chapter V, whereas the temporal variation in distribution of nutrients (N, P and K) and their accumulation in different aboveground parts of bamboo plants of different ages are highlighted in Chapter VI. The effect of age on leaf chlorophyll content in *A. maling* is also incorporated and discussed in this chapter. All the findings of the present study have been discussed in Chapter VII (General Discussion).

CHAPTER II

REVIEW OF LITERATURE

Bamboos are both homogeneous and divergent group. Each species has its own requirements and peculiarities (Brandis 1899). Numata (1987) and Uchimura (1987) stated that restricted distribution of bamboo species in nature is highly influenced by altitude, topography, agro-climatic and edaphic variation, and anthropogenic pressures. This is presumed to be the reason why each species occupies a characteristic habitat and rarely occurs mixed with other species of bamboo (Qureshi and Deshmukh 1962). Clump forming (pachymorph) bamboos are observed to predominate at low and medium elevations, while the non-clump forming (leptomorph) type occurs more abundantly at high elevation (Numata 1987, Uchimura 1987). Bamboos have not only site preferences, but also altitudinal zonation as is evident by their distribution pattern in the region of Bengal, North-Eastern Himalaya and Assam collectively where in general, *Dendrocalamus hamiltonii* occurs in the north, *Bambusa tulda* in the middle region, and *Melocanna baccifera* in the south gregariously. Further, *Bambusa tulda, B. balcooa* and *B. bambos* occur in the plain valleys of lower Bengal, while *D. hamiltonii* occurs on lower hills and Tarai belt. Ascending up to 1220 m asl. are *B. nutans, D. sikkimensis* and *Arundinaria intermedia* and between 1200 m and 1830 m are *Cephalostachyum capitatum, Schizostachyum polymorphum, Arundinaria hookeriana, Schizostachyum dullooa* and *D. petallaris.* Still higher up in Darjeeling, Sikkim and Arunachal Pradesh, *Arundinaria racemosa* occurs between 1880 m to 2745 m asl. Beyond this elevation, it gets reduced in size and is associated with *Arundinaria aristata* and *A. falconeri* (Bedell 1997).

Temperature, rainfall and humidity influence the growth and distribution of bamboo in a big way. The influence of topographical features (slope inclination and altitudes) on different growth attributes of *Dendrocalamus strictus* was studied by Joshi (1984) who reported negative correlations between bamboo growth and these topographic features. Majority of bamboos tolerate wide temperature variations *i.e.* from 8° C to 40° C (Huberman 2003, Banik 2000). Some species however grow at high altitudes, as is the case with some *Arundinaria* species which grow up to 3050 m asl. in India and up to 3650 m asl. at Latin America, or in regions where frost and snow are common, as *Chusquea* in Chile (Huberman 2003). High temperature in general accelerates the growth of bamboo whereas low temperature inhibits its growth. Bamboos prefer light for their healthy growth (Hasan 1966). Partial sunlight and absence of competition from weeds were found to be essential for the survival of bamboo seedlings during the natural regeneration process (Banik 1988). A heavy upper tree canopy inhibits bamboo regeneration and growth. It has been reported that bamboos growing in the open sites produce culms of much better quality and quantity than the clumps growing under heavy shade (Hasan 1966). Gamble (1896) reported that distribution of bamboo in India was related to the rainfall, where 1200 mm to 4000 mm per year is the most common range. As the water requirement of bamboo is high, the amount of rainfall is also a limiting factor for its distribution (Numata 1987). The upper limit is not known but bamboos are found in zones with over 6350 mm of rainfall (Huberman 2003). Around 28° C soil (50-200 cm depth) temperature, 26° C air temperature, above 60% mean relative humidity and monthly mean total rainfall within 100-800 mm seem to be minimum requirements for culm emergence in Bangladesh (Banik 2000). High wind velocity affects bamboo growth and there always exists a negative influence of wind velocity on biomass accumulation (Zhou *et al.* 1991, Ambasht and Ambasht 1999). Numata (1987) reported that, sites with more than 100 stormy days (with velocity 10 m per sec) could not produce good quality bamboos. Hasan (1966), Yang *et al.* (1991) and Elgi and Schmid (1999) have studied the influence of light intensity on growth and biomass accumulation in bamboo.

Bamboo grows luxuriantly on deep loamy soils, sandy loams and fertile clayey loams, though some species like *Oxytenanthera* sp. occupy hilltops and plateaus, with a rather depleted soil layer (Banik 2000, Tewari 1992). Species like *Dendrocalamus strictus* and *Bambusa arundinacea* flourish along riverbanks, brooks, streams and low-level depressions (Banik 2000). The ecology and habitat of different bamboo species and their requirements for moisture and soil are the aspects which require more intensive studies. *Dendrocalamus longispathus* occurs along ravines, while *Cephalostachyum pergracile* prefers sites between dry and moist and *Teinostachyum helferi* prefers moist humid valleys in evergreen forests (De 1940, Bahadur and Naithani 1976). The study on the relation between soil conditions and fountain bamboo (*Sinarundinaria fangiana*) growth showed that it grew well on the acid, low base saturation, deep and low gravel content soils but died on the alkaline, shallow, calcareous soils with high gravel content (Zhang *et al.* 1990).

The type of soil and good drainage also appear to be equally important (Alam 1992). The physico-chemical properties of soil on which bamboos grow assume greater significance on account of the shallow root system of the bamboos (Qureshi *et al.* 1969). Widmer (1998) opined that individual bamboo species owing to their distinct requirements of soil conditions could serve as fairly reliable indicators of soil site quality. Yadav (1963) provided detailed data about physical and chemical properties of eleven widely distributed soil profiles, which supported *Bambusa arundinacea* and *Dendrocalamus strictus.* The soils of both the species were low in total as well as available phosphorus, and any factor which influences soil moisture appeared to be important in causing dominance of one bamboo to the exclusion of the other. Kedarnath and Chatterjee (1966) reported occurrence of *Phyllostachys bambusoides,* a temperate bamboo species at an elevation of 2438 m in Himachal Pradesh where the soil was clayey-loam shale with an annual precipitation of 1500 mm and 1200-1500 mm snowfall. Suri and Chauhan (1984) opined that besides the rainfall, temperature and soil, distribution of bamboo is also governed by altitude. Biswas (1988) in a study reported the best growth of *D. strictus* in soils with high N, P and K content. In a comparative study, Pant *et al.* (1993) observed that the presence of bamboo in the forest significantly affected the physical and chemical properties of soils.

Soil characteristics and topographical features play a significant role in determining bamboo growth. The majority of bamboos occur on sandy loam soil. All bamboos generally avoid saline and alkaline soils. Most bamboos also avoid shallow stiff heavy clays and steep precipitous slopes (Yadav 1969). Loose soil with loamy-sand texture characterized by higher silt but low clay content favoured the growth and bamboo biomass accumulation (Yadav 1969 and Chung and Ramm 1990). Qing *et al.* (2004) reported that greater soil moisture availability, loose soil with low bulk density and high porosity has a positive influence on biomass accumulation in *Pleioblastus maculata* in China.

Most of the bamboo species are reported to prefer soil pH within 5 to 6.5 (Uchimura 1978, Hassan *et al.* 1988, Rao 1993).

It is a well-known fact that nitrogen plays a key role in plant growth and biomass production. The growth and biomass accumulation in subtropical to temperate bamboo stands of *Phyllostachys pubescens* was reported by Shi *et al.* (1987) to be better at soil with nitrogen concentration of 0.046% to 0.228% at 0-30 cm depth. Yadav (1963) has reported soil total nitrogen of tropical bamboo stands of *Bambusa bambos* and *Dendrocalamus strictus* to be 0.077% and 0.134%. On the other hand, many workers have also reported insignificant role of soil nitrogen on growth and biomass accumulation of many bamboo species (Adamson *et al.* 1978, Patil *et al.* 1980, Qui and Maoyi 1987, Raina *et al.* 1988, Thomas 1990). Quing *et al.* (2004) reported that at low moisture availability and in the presence of sufficient soil nitrogen, there was an increase in belowground rhizome length and development of new clumps in close proximity. The higher soil nitrogen level causes lodging and decrease in cell wall thickness owing to the poor development of mechanical tissues of culm/rhizome (Kanwar 1976). Deol and Khosla (1983) have also reported an adverse effect of excess nitrogen on the growth characteristics in *Poplus* species.

While working with *Dendrocalamus strictus*, the importance and role of soil available phosphorus and organic carbon as limiting factor in bamboo biomass accumulation was reported by Totey and co-workers (1989). Appasamy and Ganapathi (1992) reported the association of vesicular-arbuscular mycorrhizal (VAM) fungi with many bamboo species like *Bambusa bambos, Dendrocalamus strictus, Ochlandra scriptoria* and *O. travancorica* with significant influence of soil phosphorus on bamboo growth and biomass accumulation. There is also a report of seven-fold increase in biomass accumulation in *Dendrocalamus strictus,* when it was inoculated with VAM fungi (Singh *et al.* 1999). Effect of phosphorus and other elements on vegetative reproduction is reported in *Ixia flexuosa* (Hocking 1984) and in *Solidago* sp. (Abrahamson and Caswell 1982).

Potassium is a versatile nutrient involved in plants in many metabolic processes such as enzyme activation, osmotic control of the water economy, carbohydrate production and partitioning and the anion/cation balance. K has a motor function in cycling nutrients for growth, i.e., nitrogen from the roots to the shoot and carbon from the source (shoot) to the sink (roots, storage organs like grains, tubers). K travels as counter-ion together with NO_3 in the xylem to the shoot (Marschner *et al.* 1996). Early wilting in plants during drought is typical of K deficiency. Inadequate stomata regulation restricts the photosynthesis and ultimately yields. The NK ratio plays a particular role in the host/pathogen relationship. Perrenoud (1990) reviewed almost 2450 literature references on this subject and concluded that the use of potash decreased the incidence of fungal diseases in 70% of the cases. The corresponding decreases for other pests were: bacteria 69%, insects and mites 63% and viruses 41%. Besides, K increased the yield of plants infested with fungal diseases in 42% of the cases, with bacteria in 57%, with insects and mites in 36% and with viruses in 78%.

Soil organic matter acts as one of the most important factors limiting plant growth (He and Ye 1987). Sun and Ye (1988) also reported a similar trend on the role of organic matter in biomass accumulation by increasing soil porosity and water holding capacity, and proper nourishment to the microbes, which mineralize and release those nutrients that are locked in the plant residues. Yen and Hsu (1950) found 2.2% of organic matter content in both the surface and subsurface bamboo soils and concluded that the rooting habit of the bamboo prevents leaching. A canonical correlation analysis for bamboo growth showed that surface soil depth, total nitrogen and soil organic matter content had high positive correlation, and clay content was negatively correlated with the bamboo growth (Chung and Ramm 1990). Sun and Ye (1988) observed that proportion of vigorous rhizomes was related to soil organic matter and N content.

Gregarious and mass flowering of few dominant commercial bamboo species are the natural threats causing drastic change in their population structure, productivity and young shoot production. All plants from the same stock bloom at the same time regardless of geographic locations or climatic conditions, indicating that there must be an "alarm clock" (also known as "biological clock") in each cell of every portion of the plant with fixed schedule. When this alarm clock rings at that scheduled period, which is species-specific, all energy goes towards the flower production and vegetative growth is ceased. It was reported that in many cases, the bamboo clumps do not die after sporadic flowering, however there are reports on the death of clumps of few bamboo species after sporadic flowering (Banik 1986, Singha *et al.* 2003). It is a known fact that, gregarious flowering is usually followed by the death of clumps (Chen 1973, Das 1976, Banik 1989, Alam 1997, Ramanayake and Yakandawala 1998). All bamboo species do not produce viable seeds as well as seedlings after flowering, and if they do so, the period of phenophages are quite different (John and Mascarenhas 1994).

Flowering oriented deposition of huge bamboo resources will rot and wasted if not utilized in time, and may result in many environmental problems including epidemic, fire and ecological imbalance besides famine due to sudden increase in rodent population (Chauhan and Saxena 1985). Such incidences of gregarious flowering of bamboo was recorded in

Arunachal Pradesh, Mizoram, Tripura and Barak valley of Assam during 1959, which was followed by a severe famine in those areas (Pathak and Kumar 2000). The reports on sporadic and gregarious flowering have been reported in many bamboo species such as *Dendrocalamus hamiltonii* (Tanimoto and Kobayashi 1998); *Dendrocalamus hookeri, Oxytenanthera* sp. *and Dendrocalamus* sp. (Gupta 1968, 1987); *Phyllostachys bambusoides* (Majumdar *et al.* 1985); *Bambusa tulda, Dendrocalamus longispathus, D. sikkimensis, Melocalamus compactiflorus, Schizostachyum polymorphum* (Mohan Ram and Hari Gopal 1981); *Schizostachyum dullooa* (Nath 1962) and *Melocanna baccifera* (Sharma 1992). It is reported that mass flowering of *Sasa kurilensis* var. *jotanii* at Mt. Oyama, Mikura-jima, Izu Islands during March to April 1997 in Japan, was caused by endogenous or genetic factor/s rather than environmental factors, where last flowering occurred 60 years back. Ahmad (1937) has reported flowering incidence in two-year old seedling of *Dendrocalamus strictus*. The rate of recovery after flowering in nezasa bamboo (*Pleioblastus variegatus* Makino) was reported to be ten or more years (Koyama and Ogawa 1997), whereas regeneration of *Dendrocalamus strictus* in Balaghat forests of Madhya Pradesh took six years to form small clumps, and after twelve years the normal commercial sized culms were developed (Pande and Lohani 1963). Gielis and co-workers (1999) reported that plants of *Fargesia murieliae* subjected to different conditions of light intensity and temperature showed different modes of flowering. Lowrie (1900) reported the effect of drought on flowering incidence of *Dendrocalamus strictus.* The period between two gregarious flowerings of a species over the same area seems to be constant and cyclic. Clement (1956) has reported that *Dendrocalamus strictus* was introduced in Cuba, probably in 1912 from seeds from Garhwal (India} and it flowered in Cuba in 1956 after 44 years. Wang and Chen (1971) reported that a plantation of *D. strictus* raised in 1912 in Taiwan from the material sent from Bihar province, (India) flowered in 1969 - a cycle of 47 years.

That bamboo is "one of the fastest growing plants" is attributed to the rate of culm growth. This fast growth phase results from expansion of individual internodes, and depending on species, culms can grow from 3-30 m long within 3-4 months (Liese and Weiner 1995, Chua *et al.* 1996). Extension growth occurs through more elongation of the zero order branches, whilst radical growth is through cell enlargement and thickening of preformed tissue (Halle *et al.* 1978). The daily extension growth is generally about 10-30 cm, but it reaches up to 58 cm in *Dendrocalamus giganteus*, (Osmaston 1918) and up to 121 cm in *Phyllostachys reticulata* (Ueda 1960). Banik (1993) reported that maximum elongation rate of culm per day was 77 cm in *Bambusa balcooa*, 66 cm in *B. vulgaris* and 40 cm in *Melocanna baccifera* during their total elongation period in Bangladesh. Such rapid elongation rate was observed during the second half of the complete culm elongation period, and the total elongation periods for *B. balcooa* and *B. vulgaris* were within 75-85 days and 55-60 days in *M. baccifera* (Banik 1993). Hence, elongation rate of an emerging bamboo culm, in general, can be grouped among the fastest growing stems of the plant kingdom (Ueda 1960, Mc Clure 1966).

It is generally agreed that height and diameter of the annual flush of culms increase up to a certain age (Londoño 1992). Banik (1993) studied the culm emergence periodicity of major bamboo species in Bangladesh and observed that the culm emergence mostly takes place at the beginning of rainy season, either from May or June, and may continue up to 6-7 months ending either in October or November. Maximum shoot emergence was *recorded between June to August. According to Ueda (1960), shoot* emergence and vigor are dependent on the activation of culm buds on the rhizomes and the amount of stored food in them. Particular environmental conditions, such as higher temperature (Sun and Yang 1988, Lan 1990), greater water availability (Koyama and Uchimura 1995) and higher air humidity (Farrelli 1984) promote culm emergence and culm growth (Banik 1993). Culms which emerge early in the season can fully develop during the warm summer in temperate climates and during the wet season in tropical climates, whereas "late" culms rarely survive during the second growing season due to cool conditions in temperate climates or to dry soil conditions in tropical climates (Pearson *et al.* 1994).

Bamboo forests grow faster than most forests of other species: they reach maximum height and diameter in 3 to 7 years. They have high leaf area index (LAI) that could absorb 95% of the incident solar radiation (Qiu *et al.* 1992). The LAI of *Phyllostachys pubescens* and *P. bambusoides*, the two most important and efficient bamboo species in China, Japan and Thailand was reported to be 8.02 and 11.6, respectively (Isagi *et al.* 1993). Understandably, the LAI of a complete bamboo canopy increases with leaf biomass across bamboo species and ranges from 5 to 12 (Qiu *et al.* 1992, Huang *et al.* 1993, Isagi *et al.* 1993, Fang *et al.* 1998, Li *et al.* 1998a).

The conducting tissues of bamboo consist of xylem in the form of metaxylem vessels and phloem in the form of sieve tubes (Liese 1995). According to Fu and Banik (1995), bamboo culms attain their maximum fibre content at one year of age. Ageing of culms is associated with significant chemical and structural changes in parenchyma and fiber tissues, decrease in moisture content (Espiloy 1994, Satter *et al.* 1994), cell wall thickening (Liese 1995) and increase or decrease in certain nutrient ions (Chen *et al.* 1987). Liese (1991) reported that the deposition and accumulation of metabolic residues in metaxylem and sieve tubes of bamboo culms progressively decrease the conductivity of xylem for water and nutrients and that of phloem for assimilates. Finally, it leads to the breakdown of the transport system and death of culms (Liese 1995, Liese and Weiner 1995).

A wide range of extension growth patterns has been recognized in different plants. There are species with a single flush of shoot growth wholly performed in the previous year's over wintering bud (determinate growth), as exemplified by many north temperate tree species. Typically, shoot elongation in such species is completed rapidly (less than eight weeks) during favourable growing conditions, which include the long photoperiod. On the other hand, there are species where more leaves are produced along the leader in a growing season than there are embryonic leaves and primordia in the winter bud. This has been referred to as 'indeterminate growth'. These two patterns of growth have been widely recognized in temperate regions.

Shanmughavel and Francis (2001) reported that *Bambusa bambos* a tropical bamboo species can accumulate larger quantity of dry matter with 52-72 kg individual^{-1} during the first year. On the other hand, subtropical bamboo species like *Phyllostachys glauca*, *P. nigrahexonis* and *P. viridis* could accumulate 1.82, 1.67, and 2.16 kg individual^{-1} (Othman and Shamsudin 2002) and *P. heteroclada* could accumulate 1.03 kg individual^{-1} (Sun *et al.* 1987). Aboveground biomass as well as dry matter accumulation increases concomitant with DBH and culm height, which contribute a major share to the total biomass (Shanmughavel *et al.* 1997). There are also reports on influence of age on the improvement of aboveground biomass, which was maximum at the age of six for *Bambusa bambos* (Banik 2000, Shanmughavel and Francis 2001). An age-dependent reduction in moisture content in the bamboo culms of *Bambusa tulda, Dendrocalamus longispathus, Melocanna* *baccifera, Ochlandra nigrociliata* and *Schizostachyum dullooa* has been reported by Banik (2000), and Shanmughavel and Francis (2001). There appear to be only small differences in partitioning of aboveground biomass: allocation to culms, branches and leaves was 82%, 12% and 6% in monopodial bamboos and 77%, 13% and 10% in sympodial bamboos (Kleinhenz and Midmore 2001). Dry matter allocation in culm, branch and leaf of the standing crop of *Phyllostachys bambusoides* was reported to be 93, 10 and 9 tonnes ha^{-1}, respectively (Isagi *et al.* 1993), whereas in *P. pubescens* it was reported to be 49, 10 and 3 tonnes ha^{-1} at disturbed stands (Li *et al.* 1998a). Singh and Singh (1999) estimated a total biomass of 46.9 tonnes ha^{-1} in the 3-year old and 74.7 tonnes ha^{-1} in 5-year old bamboo plantation, where foliage contributed 14% of total biomass and 36% of net primary production.

Shanmughavel and Francis (1996) reported standing crop of *Bambusa bambos* as 122-287 tonnes ha^{-1}, whereas in case of *Dendrocalamus strictus*, another tropical to sub-tropical medium size bamboo, it was reported to be 4-22 tonnes ha^{-1} (Tripathi and Singh 1994). In an improved plantation stands of *Dendrocalamus strictus*, standing crop was reported 144.34 tonnes ha^{-1} by Singh *et al.* (2004). Gerrit and Antoine (1994) have reported 26.25 tonnes ha^{-1} standing crop of *Chusquea tessellata* a temperate to alpine bamboo species in Colombia. In case of *Gigantochloa scortechnii* from Malaysia, 71.9 tonnes ha^{-1} standing crop was reported from natural stand and 36.36 tonnes ha^{-1} from a three year old plantation (Othman 1992). Standing crop of *Phyllostachys bambusoides* and *P. pubescens*, two most important multipurpose bamboo species of China and Japan was reported to be 112 and 139 tonnes ha^{-1} (Isagi *et al.* 1993, 1997). Rao (1986) has reported the aboveground biomass of bamboo species available in jhum lands as 0.08-6.2 tonnes ha^{-1}. Standing crop of a few fast growing tree species is reported as 8.6 tonnes ha^{-1} in 4 year old *Eucalyptus globules* (Cromer and Williams 1982), 47 tonnes ha^{-1} in 5 year old *Leucaena leucocephala* (Pandey *et al.* 1989) and 87 tonnes ha^{-1} in six year old *Pinus caribaea* (Madgwick *et al.* 1977). The total aboveground biomass of *Phyllostachys bambusoides* in a well-managed stand was 137.91 tonnes ha^{-1}, having 18.1 tonnes ha^{-1} net annual aboveground production (Isagi *et al.* 1997). Kigomo and Kamiri (1987) also found that the relative contribution of various components to the standing biomass was in the order: bamboo culms > bamboo branches > bamboo leaves > forest floor herbs. However, they observed an increase in N mineralization resulting in 10 Kg ha^{-1} additional mineral N in the 1st year and 5 Kg ha^{-1} in the 2nd year following the bamboo harvest.

According to Embaye (2003), the average annual production of clump forming and non clump forming bamboos in Ethiopia was 8 tonnes ha^{-1}. The overall range in total biomass between clump forming and non-clump forming bamboo species was essentially similar. The total biomass in both types averaged 145 tonnes ha^{-1} (Kleinhenz and Midmore 2001). The total aboveground biomass of Masha bamboo forest of Ethiopia was 110 tonnes ha^{-1} (Embaye 2003). The mean total aboveground biomass of 26 bamboo forests in South East Asia was reported to be 130 tonnes ha^{-1} (Kleinhenz and Midmore 2001). The world's annual production of bamboo has been estimated as more than 20 million tonnes (Sharma 1980). The annual production and productivity of bamboo in China, India and Japan was reported as 5.0, 3.2 and 0.3 million tonnes yr^{-1}. Japan produces 0.3 million tonnes and 2.41 $tonnes^{-1}$ ha^{-1}, whereas, in India it was reported to be 3.2 million tonnes and 0.33 $tonnes^{-1}$ ha^{-1} (Pathak 1989). A comprehensive account on different aspects of biological productivity has been presented by

Ovington *et al.* (1963) and Kira and Shidei (1967). Net primary productivity of tropical forests averaged 25.3 tonnes ha^{-1} $year^{-1}$, the gross primary production being 80 tonnes ha^{-1} $year^{-1}$. Working on the forests of Thailand, Ogawa *et al.* (1961) concluded that biomass of an ecosystem or an individual species tend to change with time and space. Whittaker (1966) reported that biomass production in cove forests was larger than any other reported from either temperate or tropical forests. He also added that at any elevation, biomass was observed to decrease from mesic to xeric sites. In view of the possibilities of obtaining higher yields, studies on energy plantations are now being conducted with specific prospects of species and area rather than a general concept. Westlake (1963) has worked out the productivity levels of temperate deciduous and coniferous forests to be 12 and 28 tonnes ha^{-1} yr^{-1}, respectively. He also reported that the rate of biomass productivity of birch and alder as 8.9 and 16 tonnes ha^{-1} yr^{-1}, respectively. The bamboo management, culm growth and clump expansion behaviour of different bamboo species were reported from South East Asia e.g., *Bambusa arundinacea* (Kondas *et al.* 1973, Lakshmana 1990, Rao *et al.* 1991, Shanmughavel and Francis 1993), *Dendrocalamus strictus* (Lovegrove 1990), *D. longispathus* (Hassan 1975), *D. hamiltonii* (Rao and Ramakrishnan 1990), *Gigantochloa levis, G. ligulata, G. scortechnii* (Othman 1992). Jones *et al.* (1992) concluded that the primary production of bamboo forest in Thailand was comparable to that of other tropical grasslands. Ma *et al.* (1994) reported that bamboo biomass was identical with that of bush land.

In sub-tropical croplands of the north-eastern hill region of India, Boral (1993) reported maximum aboveground biomass of herbs and shrubs during rainy season, while minimum was reported during dry season. On the other hand, Singh (1981) has reported maximum value during December and minimum during April. The aboveground herbs and shrubs biomass at Himalayan high altitude grasslands was reported to be 0.22-0.30 kg m^{-2} (Joshi *et al.* 1991) and 0.296 kg m^{-2} in the subtropical croplands (Boral 1993).

Isagi *et al.* (1997) reported that the standing stock of *Phyllostachys pubescens*, a non-clump forming bamboo in China was 7,100 individuals ha^{-1} during 1991. According to Embaye (2003), the average stocking in a low land with clump forming bamboo species in Ethiopia was 8000 individuals ha^{-1}, whereas it was 6000 individuals ha^{-1} in a high land with non-clump forming bamboo species. In Chittagong hill tracts of Bangladesh, figures of 3000 to 9000 culms ha^{-1} and in another stand an average of 15000 culms ha^{-1} have been reported on a three-year rotation (Ahmad 1954).

In plantation bamboo, the peak concentration of nutrients like N, P and K was reported at the bud stage, which declined during organ expansion stage (Shanmughavel and Francis 2001). Higher concentrations of many nutrients were reported to occur in the actively growing regions (Rodin and Bazilvitch 1968). In general, there is a decrease in nutrient content with increasing age of bamboo, associated with the reduction of photosynthetic activity in leaves after full expansion (Huang 1986, Huang *et al.* 1989 and Qiu *et al.* 1992). Shanmughavel and Francis (2001) reported that nitrogen content in the just sprouted (two-days old) *Bambusa bambos* was 2.85%, which gradually declined to 2.60% on 32nd day and to 2.5% on 64th day. On 52nd day, branch buds appeared, where nitrogen content was 1.69%. On 105th day, he noticed leaf bud production, where the nitrogen concentration in leaf, branch and culm was 1.90%, 1.55% and 1.21% respectively. Further nitrogen content declined in all biomass components during 135th, 156th and 195th day, and thereafter it remained constant. Rao and Ramakrishnan (1989) observed higher concentrations of nitrogen, phosphorus and potassium in four bamboo species (*Bambusa khasiana, B. tulda, Dendrocalamus hamiltonii* and *Neohouzeoua dullooa*) than in shrubs and trees. Mengel and Kirkby (1987) reported that higher concentration of nutrients such as nitrogen promotes development and premature collapse of chloroplasts in leaves and is closely related with the growth and biomass performance in bamboo. Shanmughavel *et al.* (1997) also reported that the concentration of chlorophyll in one-year old leaves was 1.5 times greater than that in six-year old leaves of *Bambusa bambos*. Under natural stand, biochemical constituents of wild bamboo leaf were reported to be manifold higher than the plantation crops, which may be due to slow metabolism resulting in lower turn over of biomass (Chinte 1965, Othman 1992). Primary productivity in an ecosystem is influenced by several factors including the availability of nutrients and water in the soil as well as in plant parts (Uchimura 1980, Kinhal 1985, Huang 1987). Embaye (2003) reported that the trend of nutrient concentration in the bamboo parts was: leaf > rhizome > root > culm and higher concentration was reported during dry seasons than the rainy seasons. In *Dendrocalamus hamiltonii,* a tropical to subtropical bamboo species, the nutrient elements in leaf were in the order of N, K and P, while in branch, culm and rhizome these were in the order of K, N, and P (Toky and Ramakrishnan 1983). Raghubanshi (1994) in a separate study made similar conclusion. Joshi *et al.* (1991) studied the nutrient dynamics in a bamboo forest and concluded that removal of bamboo culms every four years for commercial purposes impoverished the soil nutrient status, where, nutrient concentrations were higher in leaves than any other plant components.

The significance of chlorophyll content in characterizing the productive potential of various crops has been repeatedly stressed (Suryanarayan 1978, Hegde and Bawachker 1983, Tyagi and Malik 1988 and

Malik *et al.* 1993). Bamboo leaf revealed Kranz anatomy which apparently provides that bamboo is a tropical grass and its total chlorophyll may be inversely proportional to age. Mengel and Kirkby (1987) reported that higher concentration of nutrients such as nitrogen, phosphorus and potassium promotes development of chloroplasts, and the premature collapse of chloroplasts in leaves is closely related with the growth and biomass accumulation in bamboo. Shi *et al.* (1987) showed specifically that leaf nitrogen increases chlorophyll a, chlorophyll b and total chlorophyll in *Phyllostachys pubescens.* Midmore and Kleinhenz (2000) reported a hyperbolic relationship between nitrogen application rate and leaf nitrogen concentration in *Phyllostachys pubescens* and *Bambusa oldhamii,* and showed that the relationships vary with species and stand age.

Shanmughavel (1993) reported nutrient return through litter in 5-year-old *Bambusa bambos* plantations, where highest concentration of N and P was in leaf litter, and maximum K concentration was recorded in twig litter. On an annual basis, the total return of nitrogen was 141 kg ha^{-1}, followed by 121 kg ha^{-1} potassium and 131 g ha^{-1} phosphorus. Singh and Singh (1999) reported that nutrient deposition through leaf litter in plantation bamboo was 45-79 Kg N and 6-11 Kg P per hectare. The role of bamboo on conservation of soil nutrients especially potassium was reported by many authors (Toky and Ramakrishnan 1982, Rao and Ramakrishnan 1989, Joshi *et al.* 1991, Mailly *et al.* 1997, Shanmughavel *et al.* 1997, Lin and Lin 1998, Marschner *et al.* 1996 and Qiou and Maoyi 1987). A large quantity of nutrient loss through culm removal has been reported in bamboo stands (Kleinhenz and Midmore 2001).

Studies on biomass as well as nutritional aspects on bamboos in the north-east region are very meager. Not a single study could be traced out on site-specific distribution, growth performance and soil nutrient status of bamboo stands in the region. Among the works done on bamboo in the region, Toky and Ramakrishnan (1983, 1992) and Rao and Ramakrishnan (1989) have studied the nutrient conservational aspect of bamboos. Population studies on *Dendrocalamus hamiltonii* and *Neohouzeaua dullooa* in a successional environment was worked out by Rao and Ramakrishnan (1987). Although the north-eastern region has the largest bamboo resource in India, no serious studies have been carried out on site characteristics and growth and productivity of bamboos, and nutrient dynamics in the bamboo stands. Most of the temperate bamboo species occurring in the region are rare and endemic (Biswas 1994, Hore 1998). Few of them are also highly threatened due to natural destruction of their habitats and due to anthropogenic stresses. Most of the studies on bamboo in India as well as in the north-east have focused on tropical species, and temperate species have not been studied. In view of this, it was proposed to undertake a detailed study on a temperate bamboo species (*Arundinaria maling)* to understand its site preference, growth, biomass and productivity and nutrient accumulation pattern.

CHAPTER III

STUDY SITE: LOCATION, CLIMATE, VEGETATION AND SOIL

3.1 LOCATION

The study was carried out in *Arundinaria maling* forest growing at three different elevation zones (2400- 2800 m, 2800-3200 m and 3200-3600 m asl.) in Jang area of Tawang district of Arunachal Pradesh. According to the classification made by Varmah and Bahadur (1980), this bamboo forest can be categorized as a pure and dense bamboo forest (Plate 4A). It is located at the extreme east of Tawang district (27^0 30′-27^0 35′N latitude and 91^0 55′-92^0E longitude) which lies in the western part of Arunachal Pradesh. The location map of the study site showing the *A. maling* forest in Jang area of Tawang district of Arunachal Pradesh (Figure 3.1a). The area is a hilly terrain with very steep slopes. The three elevation zones have been designated in the thesis as the low elevation (2400-2800 m), medium elevation (2800-3200 m) and high elevation (3200-3600 m asl.) zones (Plate 4B-D). Beyond the high elevation site, there were barren lands with few perennial deciduous shrubs (Plate 4E). At the low elevation, *Arundinaria maling* forest covers an area of *ca.* 1,491 ha, at the medium elevation *ca.* 1,078 ha and at the high elevation *ca.* 600 ha area. The slope of all the three study sites ranged between 25^0-60^0 facing towards north-west. The layout of the field experiment set up for this study in the *A. maling* forest is shown in Figure 3.1b.

Rocky mountains with very poor vegetation with snow cover surround from all directions. Jang is a historical place, where Indian battle

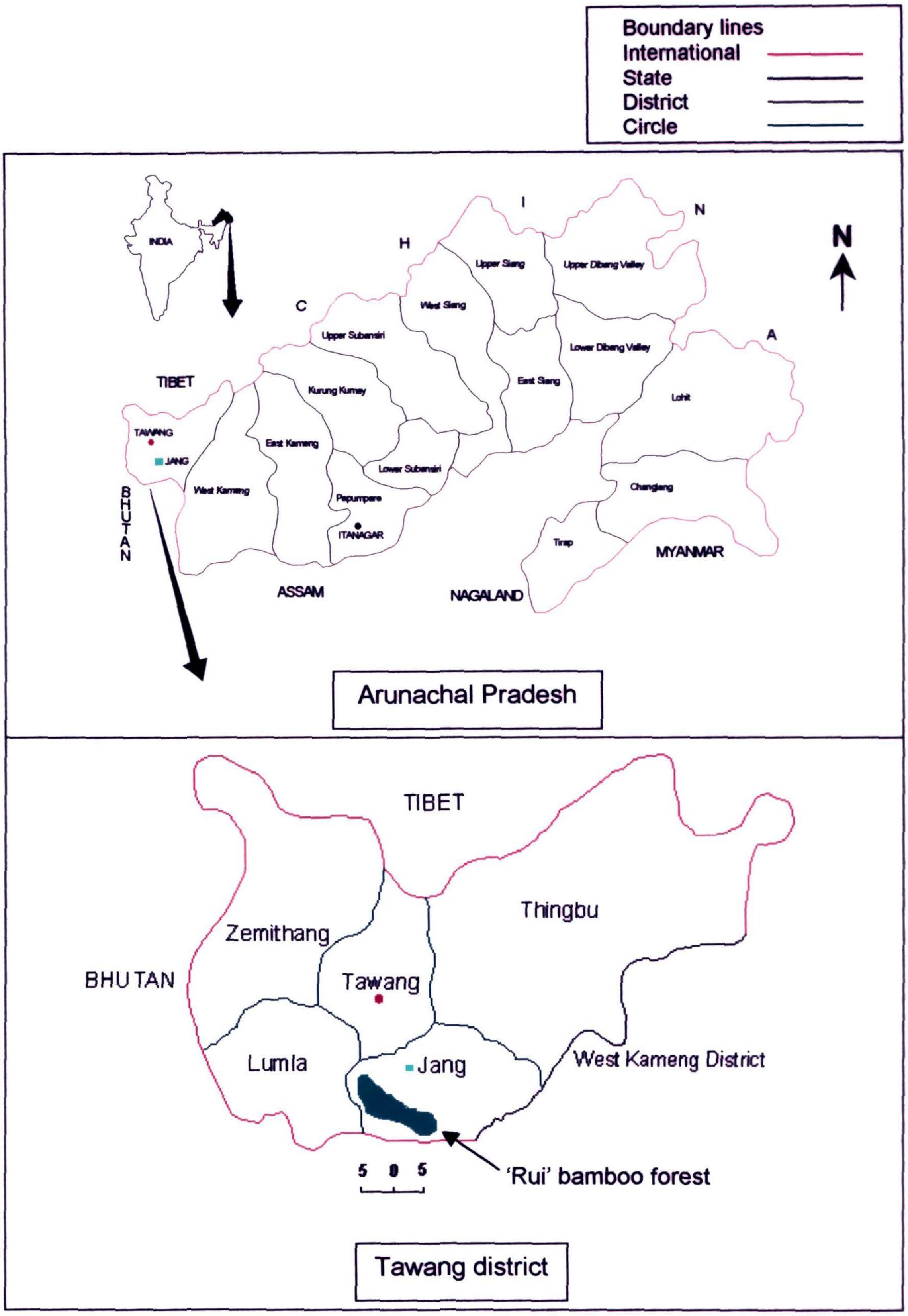

Figure 3.1a. Location map of the study site showing the 'Rui' bamboo (*Arundinaria maling*) forest at Jang area of Tawang district of Arunachal Pradesh.

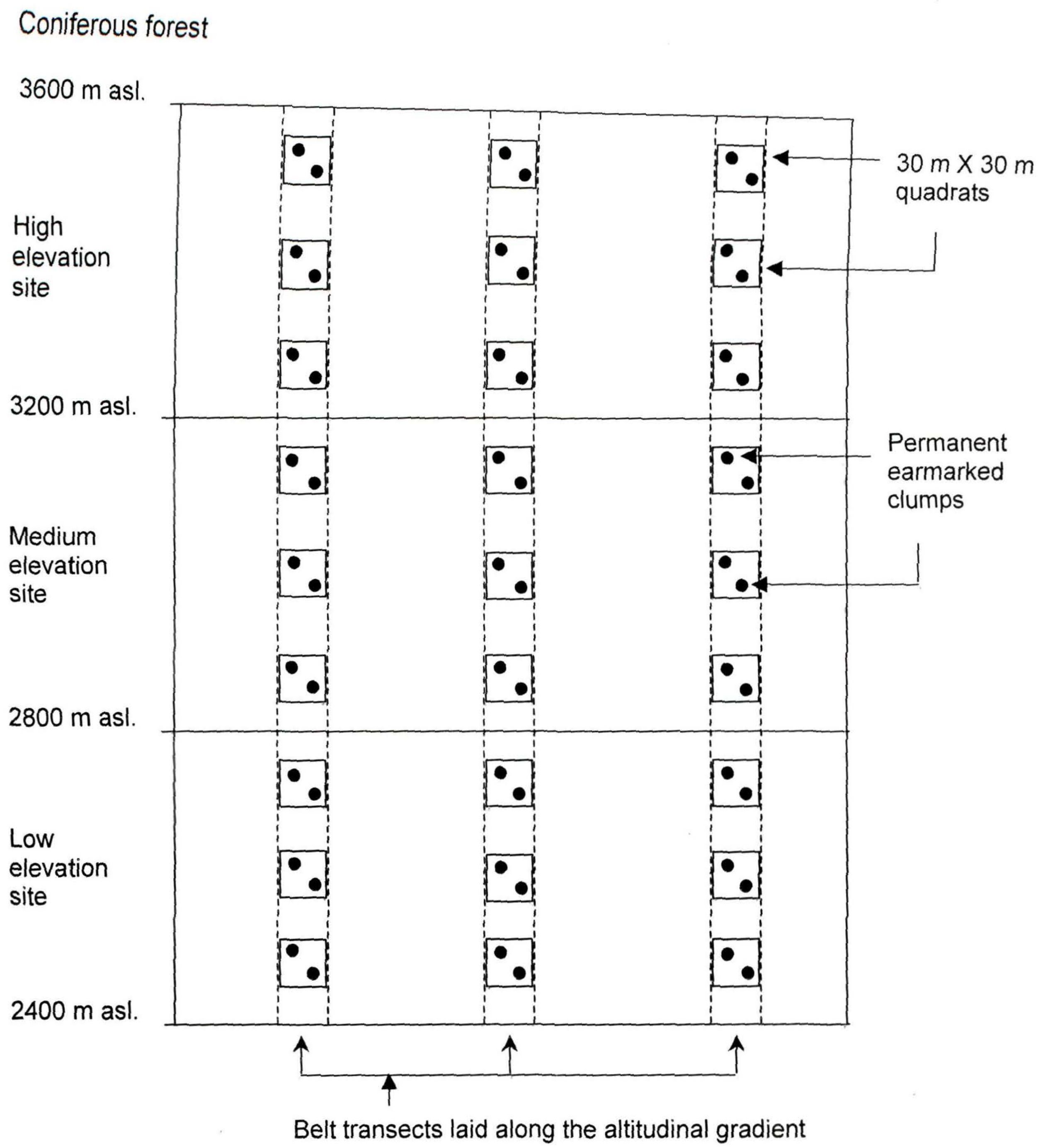

Figure 3.1b. Experimental layout showing the three elevation sites, belt transects, quadrats and earmarked clumps of *Arundinaria maling* in the Jang bamboo forest.

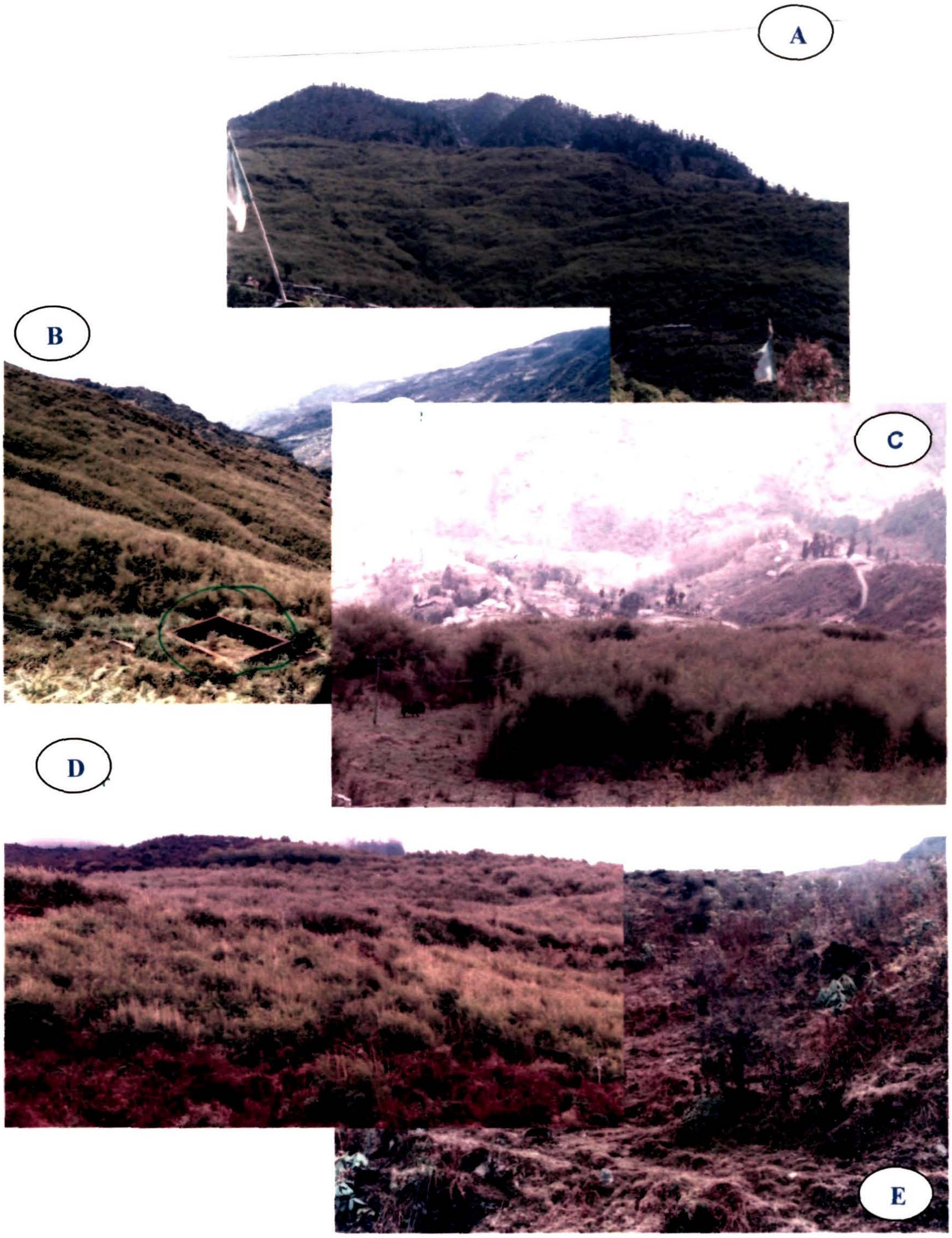

Plate 4. (A) A bird's eye view of the 'Rui' bamboo forest, (B) A very dense forest patch of 'Rui' bamboo with close canopy at the low elevation site (a water harvesting tank is also seen), (C) A forest patch of 'Rui' bamboo at the medium elevation site with moderate clump density and open areas inside, (D) An open 'Rui' bamboo forest with sparsely distributed clumps at the high elevation site in association with many woody shrubs, and (E) Barren lands with few perennial deciduous shrubs beyond the high elevation site.

posts were set up during 1962 Indo-China war, for which the area is named as 'Jang' means battlefield. Earlier the area was covered with dense forest of *Taxus baccata*, which forms pure and mixed forest patches in the temperate and alpine zones. Mass harvest of *Taxus baccata* for commercial purpose resulted in sudden denudation of its natural forest stands. Villagers of the Jang area harvest the bark of *Taxus baccata* for medicinal use and leaves as major fodder for the domestic animals like yak and cattle. It has also accelerated the mortality rate due to the non-systematic removal of bark and lopping of this precious species.

The *Arundinaria maling* forest of the Jang area is a secondary successional forest which has replaced the earlier existing *Taxus baccata* mixed forest. During the Indo-China war, large area of this mixed forest was destroyed due to temporary constructions of concrete bunkers inside the forest. Bamboos due to their fast growth and strong competitiveness for nutrients, generally do not allow other plant species to grow in association. Therefore, the original mixed *Taxus* forest was converted into a secondary bamboo brake of *Arundinaria maling* following human disturbances. A few remnants of *Taxas baccata* in the form of dry tree trunks and a negligible population of saplings traced during this study also support its earlier existence in the Jang bamboo forest (Plate 6- E and F).

3.2 TOPOGRAPHY

Arunachal Pradesh has generally a rugged terrain charecterised by hill ridges and valleys. The ridges are either parallel or in opposite direction, and between the hill ridges, wide or narrow, deep or shallow valleys exist. The hills gradually rise from south to north with an east-west orientation. Elevation ranges from 200 m in case of Siwalik formations from the plains of Assam in the northern part of Brahmaputra valley to the Himalayas up to 7750 m asl. along the Tibet-China border. Some of the known peaks are Gorichen (7300 m asl.), Kangto (7090 m), Namcha Barwa (7756 m), Kulangri (7544 m) and Chomo Lhari (7344 m).

3.3 GEOLOGY

The eastern Himalayas of Arunachal Pradesh are geographically divided into three zones from south to north viz. the Sub-Himalayas, the Lesser Himalayas and the Greater Himalayas. The Sub-Himalayan zone consists of Neogene molassic sediments (Siwalik) whereas the Lesser Himalayas comprises Upper Proterozoic to Lower Palaeogene self sediments (Bomdila Group, Buxa-Miri Formations) and the Greater Himalayas has been characterized by para and ortho metamorphites and acid to intermediate igneous intrusions from Precambrian to tertiary age (Sela Group, Siang Group, Lumla Formation, etc.). The study site belongs to the Sela group of Greater Himalayas. The eruptic rocks in Arunachal Himalaya are represented by an extensive occurrence of Abor Volcanics. Abor Volcanics occur interbedded both with Buxa Permian Gondwanas and Rajmahal traps (Pascoe 1950, Anonymous 1976).

3.4 SOIL

Owing to predominantly hilly terrain, soil in major parts of Tawang district is rocky with dark brown colour. Soils are acidic in reaction with rich humus, having thick layer of organic matter as a result of high litter accumulation. Soils are coarse with sandy to loamy sand texture. Soils of this region have developed from high-grade metamorphics containing schists, shales, granodiorites, sand stones, quartzites, conglomerates and mica etc.

3.5 CLIMATE

The climate of Arunachal Pradesh is monsoonic and exhibits a mosaic of climatic zones, varying from place to place due to their geographical position and varied topography. The average mean maximum and minimum temperature is 30^0 C and 17^0 C, respectively in subtropical humid region and 21^0 C and 2^0 C in cold humid region. The average annual rainfall in the humid subtropical region is *ca.* 2972 mm, while it is 2087 mm in cold humid regions. Broadly, based on monsoon the climate of Arunachal Pradesh is characterized by four distinct seasons. The period from December to February represents winter, whereas the period from March to May represents spring. The period from June to August with about 80% of the total annual rainfall represents rainy season (monsoon), and the period from September to November represents the autumn (post monsoon).

According to the climatic condition, the study site may also be characterized into four seasons. The period from December to February, when maximum snowfall takes place, represents winter. The period from March to June represents spring with little rain. The period from July to September with about 68% of the total annual rainfall represents rainy season (monsoon), and the period from October to November represents the autumn (post monsoon) with little shower.

3.6 MICROCLIMATE OF THE STUDY SITES

The microclimatic data pertaining to the respective study sites were recorded for two consecutive years (April 2001 to March 2003) with the kind cooperation of 99 APO battalion, 90 RCC GREF and CWC, Jang. Rainfall, snowfall, relative humidity (RH), air temperature, soil temperature, light intensity and wind velocity were measured throughout the study period. Rainfall and snowfall were measured using standard rain gauge and snow gauge; RH and air temperature were measured by using hygrometer and max-min thermometer, respectively. Wind velocity and wind direction were recorded through fan wheel anemometer with wind vanes. Light intensity was measured using a Lux meter (LUBRON LX-101) and soil temperature by using soil thermometer (ELITE) without disturbing the soil.

3.6.1 Rainfall

The annual rainfall did not differ significantly among the three elevation sites, although it varied significantly among the seasons ($F = 161.74$, $P < 0.001$). Mean annual rainfall during the study period was highest at the medium elevation site (1996 mm), followed by the low elevation site (1986 mm) and lowest at the high elevation site (1894 mm). At all the three elevations, low rainfall was received between October to March, while good rainfall was received during April to September, and the highest rainfall was recorded in the month of July (Fig. 3.2).

3.6.2 Snowfall

Snowfall increases with elevation, and the differences were significant among the three elevation sites ($F = 5.397$, $P < 0.01$) and seasons ($F = 12.791$, $P < 0.001$). The mean annual snowfall was much higher at the high elevation site with 1736 mm, while it was 581 mm and 516 mm at the medium and low elevation sites, respectively. At all the elevation sites, maximum snowfall takes place during January. At the high elevation site

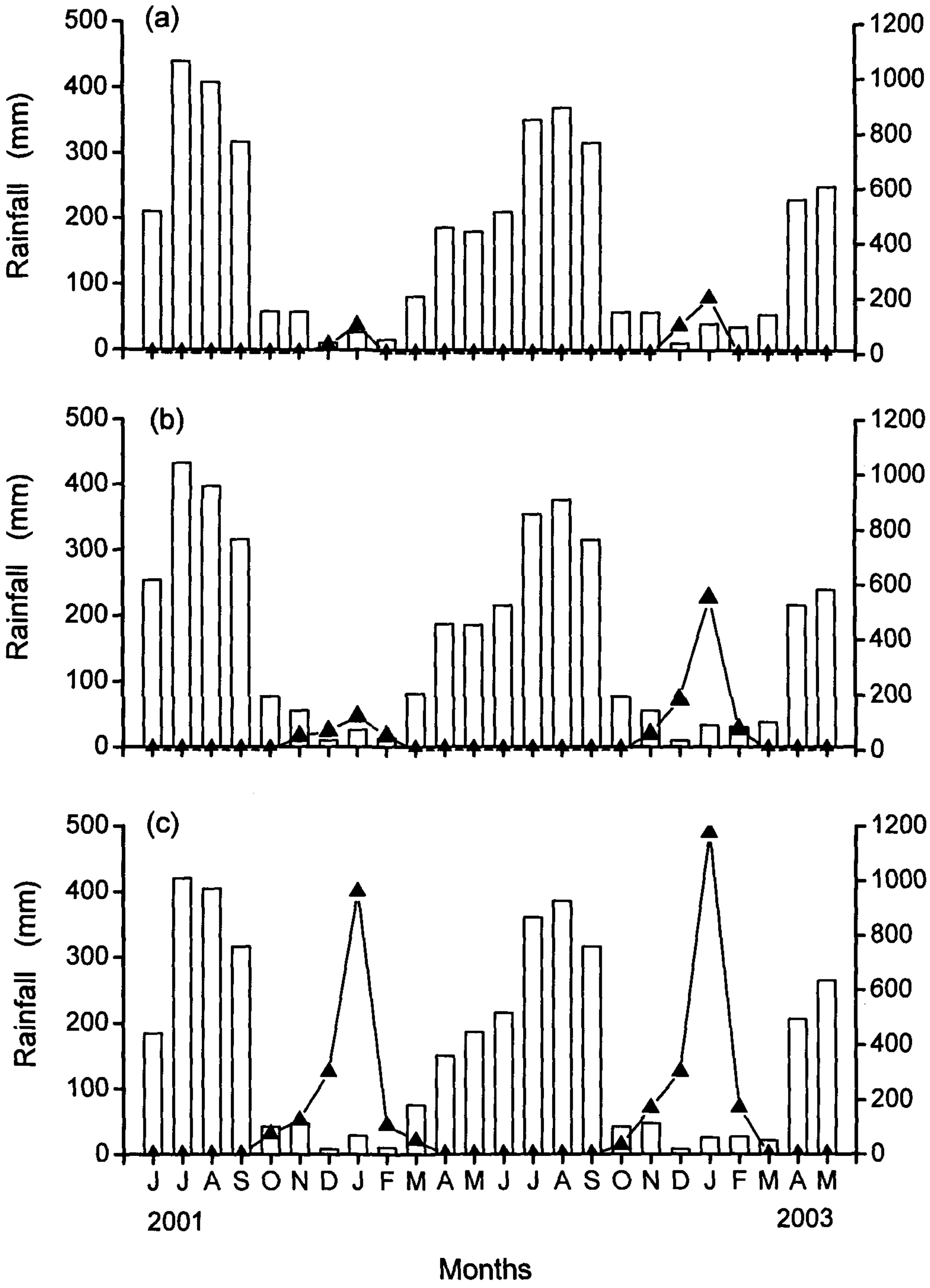

Figure 3.2. Monthly variation in rainfall (□) and snowfall (-▲-) at the low (a), medium (b) and high (c) elevation sites of *A. maling* forest.

snowfall occurs between October to March, whereas it occurs during November to February and December to February at the medium and low elevation sites, respectively (Fig. 3.2) (Plate 5-A and B).

3.6.3 Air temperature

Differences in mean monthly maximum and minimum temperatures of the three elevation sites during the study period were significant among the sites ($F = 15.617$ and 11.652 respectively, $P < 0.001$) and seasons ($F = 7.32$ and 40.259 respectively, $P < 0.001$). Air temperature was recorded higher at the low elevation site than the medium and high elevation sites. At all the three sites, the maximum air temperature was observed during July and minimum during January. Mean annual maximum temperatures observed at the low, medium and high elevation sites were 19.3^0 C, 15.8^0 C, and 12.8^0 C, respectively, whereas minimum temperatures were recorded as 2.3^0 C, 0.0^0 C and (-)1.6^0 C, respectively at the low, medium and high elevation sites (Fig. 3.3a).

3.6.4 Relative humidity

The relative humidity (RH) at all the three elevation sites was significantly different among the sites and season ($F = 113.62$ and 27.00 respectively, $P < 0.001$). Maximum mean monthly RH was observed during July at all the elevation sites due to the high rainfall and maximum air temperature during this month. The minimum RH was observed during January at all the elevation sites due to the lowest air temperature in this month. Mean annual RH at the low, medium and high elevation sites was recorded as 87%, 66% and 62%, respectively (Fig. 3.3b).

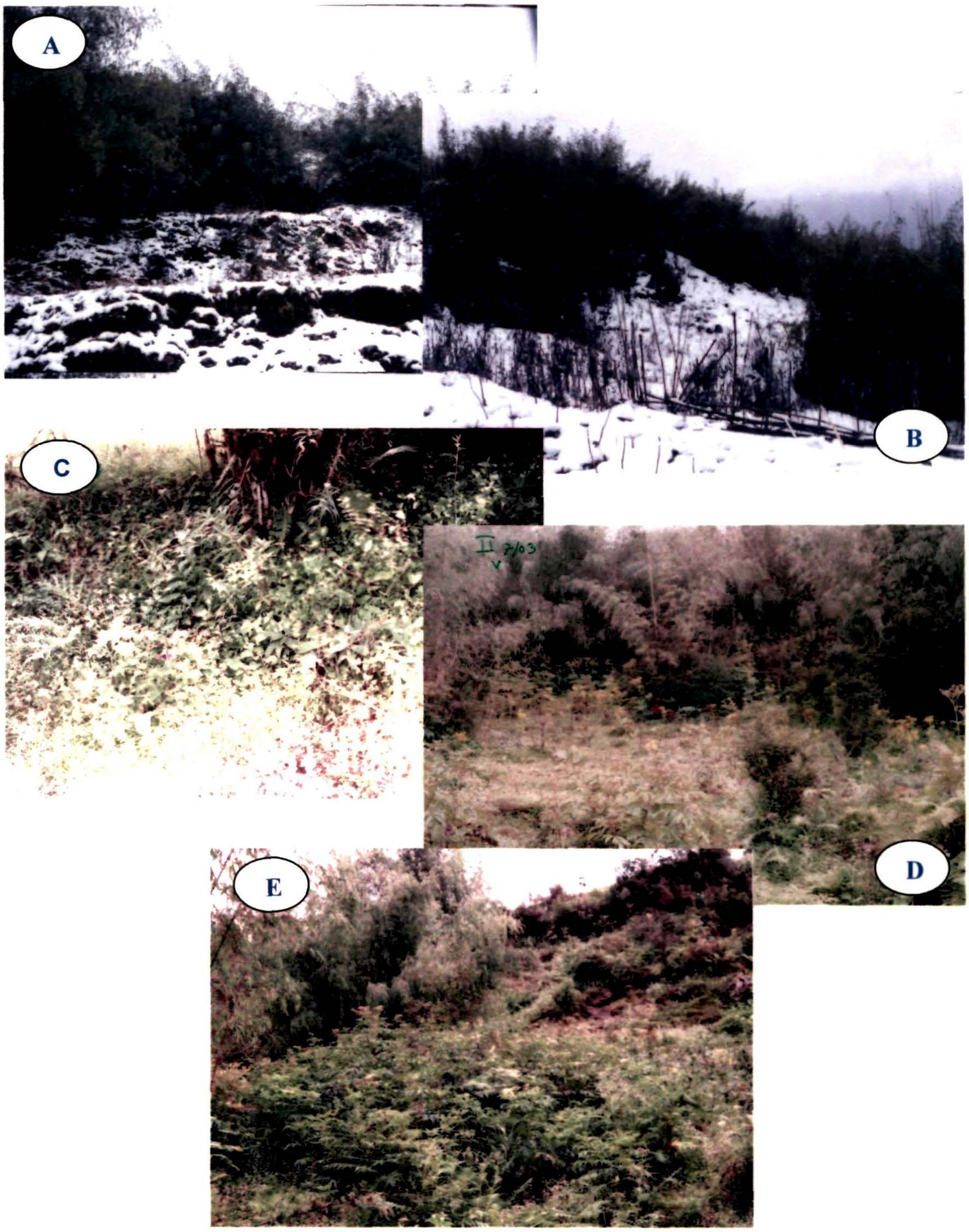

Plate 5. (A and B) A view of the 'Rui' bamboo forest with snow cover during January 2002 in the high and medium elevation sites, respectively, (C) Undergrowth vegetation with annual herbs at the low elevation site, and (D and E) Annual and perennial herbs and shrubs at the medium and high elevation sites, respectively.

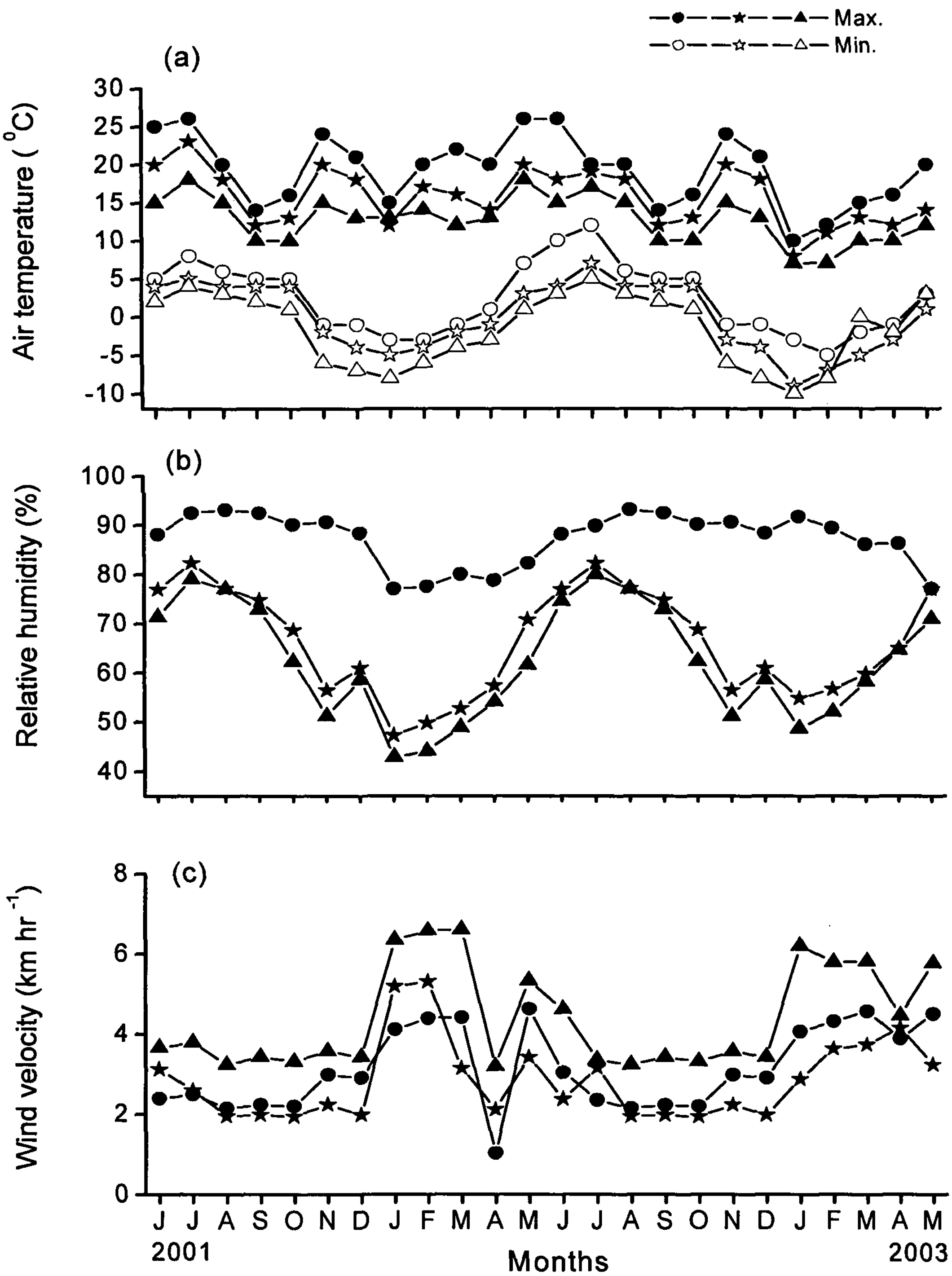

Figure 3.3. Monthly variation in air temperature (a), relative humidity (b) and wind velocity (c) at the low (-●-), medium (-★-) and high (-▲-) elevation sites.

3.6.5 Wind velocity

Wind velocity differed significantly among the three elevation sites and seasons (F = 17.187 and 12.794 respectively, P< 0.001), with higher velocity at the high elevation site followed by the low elevation site and minimum at the medium elevation site. The aspect of the *Arundinaria maling* forest was north-west facing slope. A high mountain peak lies in the front side, and hence, the direction of the wind was always from south-west to north-east direction or vice versa throughout the year. Maximum and minimum wind velocity at the low elevation site was observed during May (4.57 km hr^{-1}) and August (2.10 km hr^{-1}). At the medium elevation site, it was recorded as 4.47 km hr^{-1} during February and 1.94 km hr^{-1} during October. At the high elevation site, mean wind velocity was recorded maximum during January with 6.28 km hr^{-1} and minimum during August with 3.23 km hr^{-1} (Fig. 3.3c).

3.6.6 Light intensity

There were significant differences in light intensity among the sites and seasons (F = 164.48 and 36.76 respectively, P< 0.001). It was higher at the medium elevation site due to open canopy and low fog. Although the high elevation site had greater open canopy, due to the presence of very dense fog it received poor sunlight. The low elevation site was having very close canopy with higher clump density and hence, the light intensity was low at this site too. Maximum light intensity was recorded during October, while minimum was recorded during January at all the elevation sites. Mean annual light intensity was recorded as 20517, 88395 and 67703 lux respectively, at the low, medium and high elevation sites (Fig. 3.4).

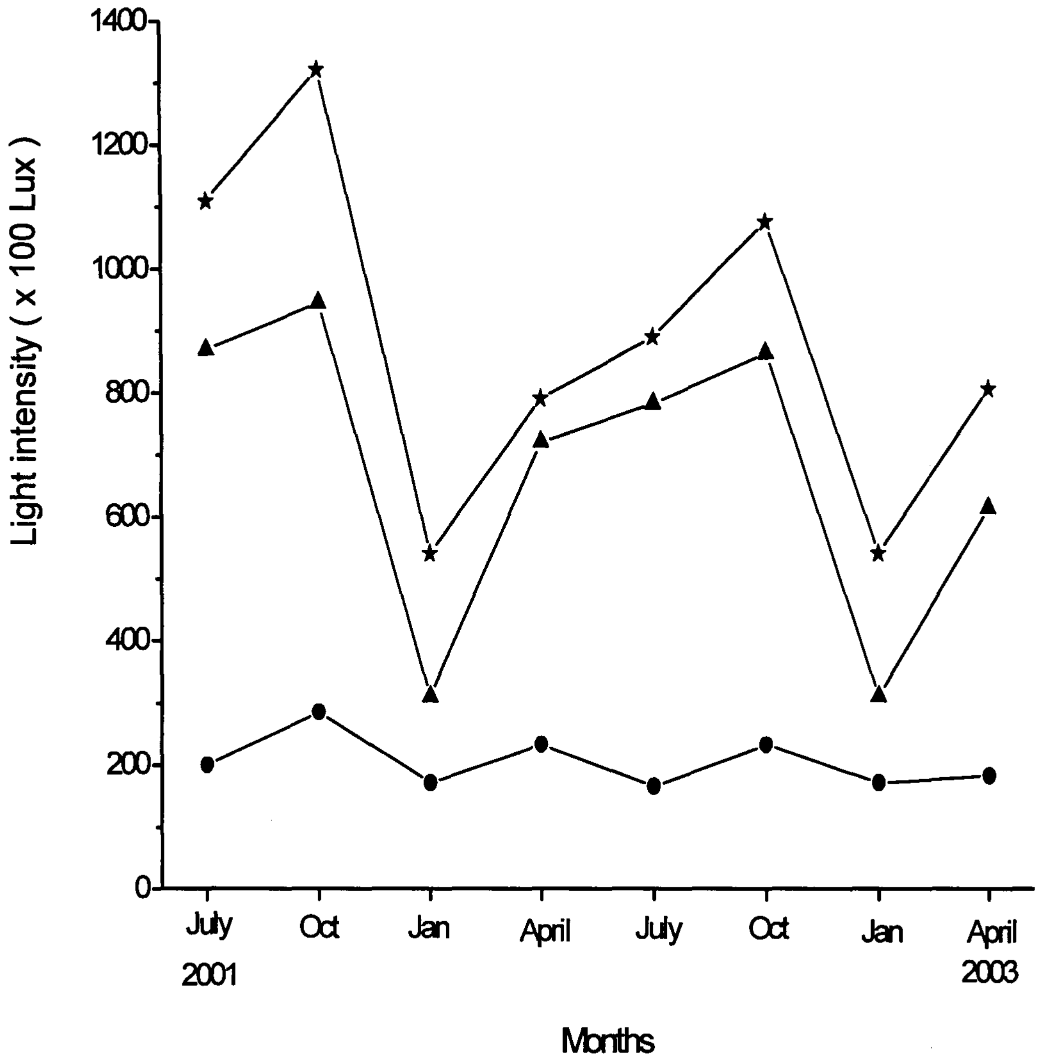

Figure 3.4. Temporal variation in light intensity at the low (●), medium (★) and high (▲) elevation sites in the *A. maling* forest at Jang.

3.6.7 Soil temperature

At all the elevation sites, maximum soil temperature was recorded during July, whereas minimum was encountered during January. Three-way ANOVA revealed significant differences in soil temperature among the elevation sites, seasons and soil depths (F = 39.147, 7.389 and 44.301 respectively, P< 0.005). Soil temperature at the high elevation site was observed to be lower than the other two sites throughout the year ranging from (-)3 to 6.9^0 C. The medium elevation site was having a moderate soil temperature ranging from (-)2 to 10^0 C, while higher soil temperature was recorded at the low elevation site (0 to 11.7^0 C). Soil temperature decreased with the increase in soil depth (0-10, 10-20 and 20-30 cm) at all the three elevation sites, except during January. During January, soil temperature of the surface layer (0-10 cm depth) at the high and medium elevation sites was lower than the other two depths (10-20 and 20-30 cm) due to snow cover. Mean annual soil temperature at 0-30 cm depth at the low, medium and high elevation sites was observed to be 6.3^0 C, 4.4^0 C and 1.8^0 C, respectively (Fig. 3.5).

3.7 VEGETATION AND VEGETATIONAL ANALYSIS

The vegetation of Arunachal Pradesh has been classified into five broad forest types viz., tropical forests, subtropical forests, pine forests, temperate forests and alpine forests. These are interlaced with sub-types and secondary forests depending upon local conditions. Forests below 900 m asl. are treated as the tropical type which again is subdivided into tropical semi evergreen, tropical wet evergreen and tropical moist deciduous types. The tropical forests have a remarkable floral diversity and rich species composition

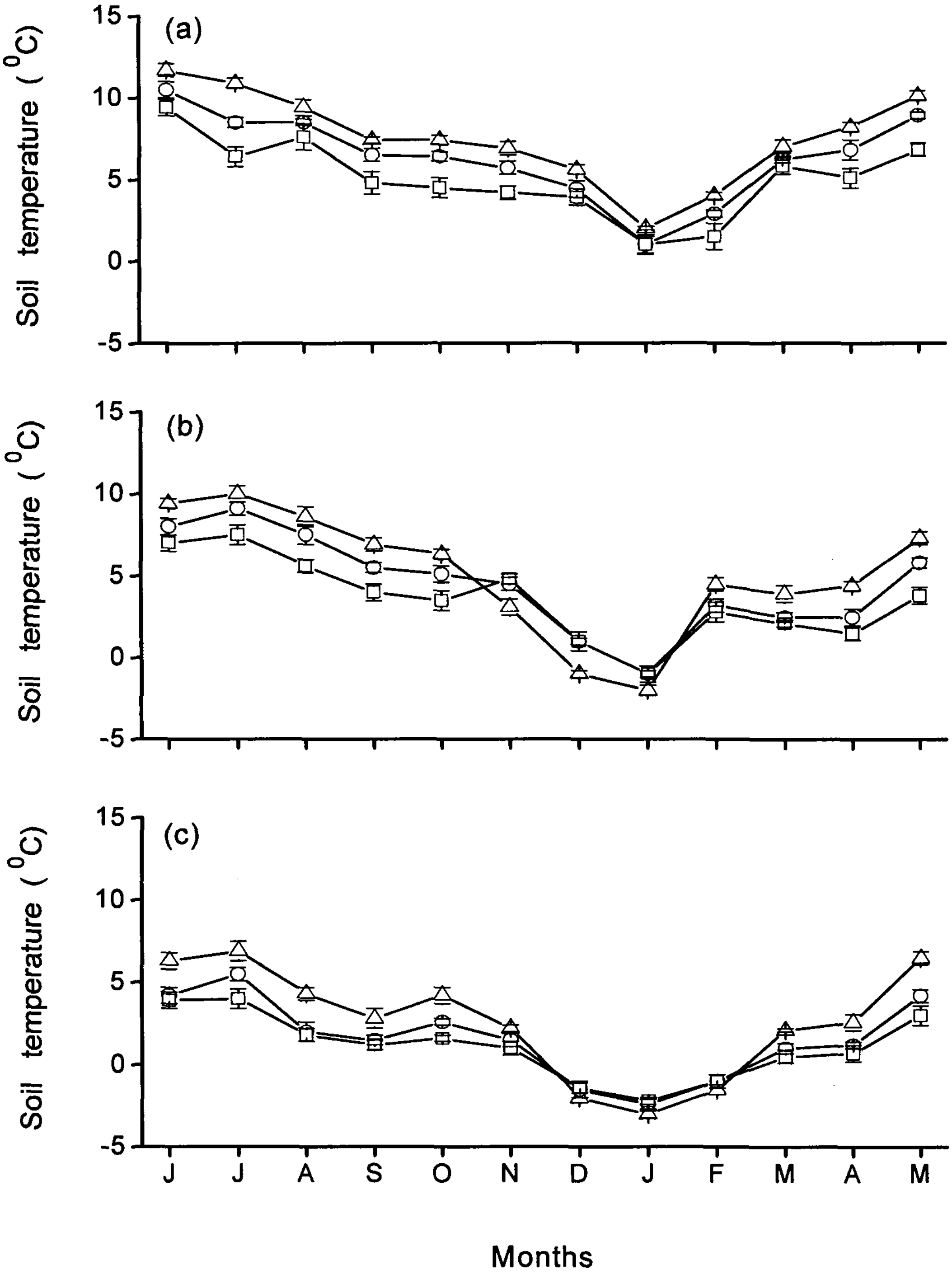

Figure 3.5. Monthly variation in mean soil temperature at three soil depths (-△-, 0 - 10 cm;-○-, 10 -20 cm;-□-, 20 -30 cm) at the low (a), medium (b) and high (c) elevation sites. Vertical line bar indicates ± SE.

(Kaul and Haridashan 1987). The tropical type is followed by subtropical forests above 900 m and up to 1800 m asl. Due to increase in moisture at this elevation and favourable climatic conditions, the biodiversity is equally rich in these forests, though the species composition is different (Kaul and Haridashan 1987). Above the altitude of 1800 m and up to 3500 m asl., in the hills of Arunachal Pradesh, luxuriantly grow the temperate forests (broad leaved or conifer type). Beyond 3500 m, the forests are reduced to the level of scrubs and grasslands. These meadows provide suitable habitat for a great variety of medicinal and aromatic plants.

In addition to the above broad categories of forests, there are a few secondary types resulting from various biotic factors. Shifting agriculture, various developmental activities, extraction of timber and other commodities have led to the destruction of original vegetation and secondary types have been formed. Some of these secondary types are grasslands, bamboo brakes or degraded forests.

The main forest types of Tawang district (study area) are temperate and alpine forests. Temperate forests can be subdivided into broad leaved (1800 m -2800 m asl) and temperate coniferous forests (2800 m - 3,500 m asl). The most dominant tree species occurring in these forests are *Quercus lamellosa, Q. patchyphyla, Q. fenestrata, Q. spicata, Q. lineata, Acer campbellii, A. hookeri, A. pectinata, Michelia excelsa, Michelia lanuginosa, Prunus nepalensis, Alnus nepalensis, Tsuga brunoniana, Taxas baccata, Cephalotaxus griffithi, Cuninghamia lanceolate, Abies delavayi, Betula cylindrostachys, Pinus wallichiana, P. roxburghii, Cupressus* sp., *Abies densa, Rhododendron nivale, R. thomsonii, R. fulgens, Saxifraga* sp., *Saussaurea* sp., *Arenaria* sp., *Sedum* sp. etc. (Kaul and Haridashan 1987, Haridashan 2000). Above this zone plant life virtually ceases.

As the study was carried out in a secondary pure bamboo forest of *Arundinaria maling*, it allowed few herbs and shrubs to grow as undergrowth (Plate 5C-E). Hence, the ground vegetation of this bamboo forest at three elevation sites along an altitudinal gradient was also studied for its floristic composition.

In all the three elevation sites of the *A. maling* forest, vegetation analysis was done during July 2003, as this month represents the period of peak vegetative growth. Herb and shrub specimens were collected and identified consulting the Flora of Arunachal Pradesh (Hajra *et al.* 1996), Flora of Assam (Kanjilal *et al.* 1934-1940) and Flora of British India (Hooker 1872-1897). Wherever necessary, the herbaria of State Forest Research Institute and Botanical Survey of India (BSI), Itanagar and Botanical Survey of India and Forest Research Institute, Dehra Dun were consulted for correct identification. For determining phytosociological attributes, belt transect method was employed (Misra 1968). Three belts of 30m width and 300 m length were laid along the altitudinal gradient (2400-3600 m asl.) at each of the elevation sites. Within each belt, 10 quadrats of 1m x 1m were laid randomly for herbs and 10 quadrats of 5 m x 5 m for shrubs at each of the three elevation sites (Fig. 3.1b).

Other community indices such as Shannon-Wiener diversity index, Whitford's index and Sorensen's similarity index were computed as follows:

Whitford's index (Whitford 1948) = Abundance / Frequency

A / F ratio < 0.025 (Regular distribution)

0.25-0.05 (Random distribution)

> 0.05 (Clump distribution)

Similarity index (Sorensen 1948) $= \dfrac{2c}{a + b}$

where, a = Number of species in stand a, b = Number of species in stand b, c = Number of species common to both stands a and b.

Species richness index (Magurran 1988) $= \dfrac{S-1}{\log_e N}$

where, S = Number of species, N = Number of individuals.

Shannon and Wiener index of diversity (Shannon and Wiener 1963) =

$$\bar{H} = - \Sigma (pi \ln pi)$$

where, pi = proportion of number of i^{th} species in the number of all the species.

3.7.1 Floristic composition, their distribution pattern and dominance

A total of 29 species of herb and 28 species of shrub were recorded from the *Arundinaria maling* forest of Jang area (Table 3.1). Most of the herbaceous species were annual and were mostly absent during winter months at all the three elevation sites. However at the low and medium elevation sites, few species of Cyperaceae and Poaceae family were observed to grow during the winter. Amongst the 29 species of herb, 14 had broad ecological amplitude and were distributed at all the three elevation sites. They included *Anthopogon lanceolatus, Carex condensata, Cyanotis vaga, Dicrocephala latifolia, Echinochloa crus-galli, Eleocharis atropurpurea, Galium asperifolium, Juncus lampocarpus, Polygonum berbatum, P. capitatum, P. filicaule, Potentilla atrosanguinea* and *Psilocarya scirpoides.*

Table 3.1. Herb and shrub diversity at the low, medium and high elevation sites (species are arranged in alphabetical order).

Name of the species	Family	Occurrence of species at elevation sites		
		Low	Medium	High
Herbaceous species				
Anaphalis cinnamomea C.B. Clarke	Asteraceae	-	+	+
Anthopogon lanceolatus (Roxb.) Hochst.	Poaceae	+	+	+
Brunella vulgaris L.	Lamiaceae	-	+	+
Calamogrostis sp.	Poaceae	-	-	+
Calanthe sp.	Orchidaceae	-	-	+
Carex condensata Nees.	Cyperaceae	+	+	+
Cyanotis vaga (Lour) Schult. f	Commelinaceae	+	+	+
Cynoglossum zeylanicum (Vahl) Thumb	Boraginaceae	-	+	+
Cyperus difformis	Cyperaceae	-	+	+
Dicrocephala latifolia DC.	Asteraceae	+	+	+
Echinochloa crus-galli Beauv.	Poaceae	+	+	+
Eleocharis atropurpurea Kunth.	Cyperaceae	+	+	+
Eragrostis ciliaris Trin.	Poaceae	-	+	+
Galium asperifolium Wall.	Rubiaceae	+	+	
Geranium aconitifolium L. Herit	Geraniaceae	-	+	+
Gnaphalium apiculatum	Asteraceae	-	+	+
Impatiens thomsoni Hook f.	Geraniaceae	-	+	+
Juncus elegans Samuls	Juncaceae	-	+	+
Juncus lampocarpus Ehrh.	Juncaceae	+	+	+
Launaea acaulis Roxb. Babe	Asteraceae	-	+	+
Osmunda claytoniona	Osmundaceae	-	-	+
Polygonum berbatum	Polygonaceae	+	+	+
Polygonum capitatum Ham.	Polygonaceae	+	+	+
Polygonum filicaule Wall.	Polygonaceae	+	+	+
Potentilla atrosanguinea Lodd.	Rosaceae	+	+	+
Psilocarya scirpoides Torrey	Cyperaceae	+	+	+
Swertia chirayita (Roxb. Ex Fleming) Karsten	Gentianae	-	+	+
Veronica sp.	Asteraceae	+	+	+
Viola sp.	Violaceae	-	+	+
Shrub species				
Acer palmatum Thumb	Aceraceae	+	+	-
Anemone sp.	Ranunculaceae	+	+	+
Aster salsuginosus Richardson	Asteraceae	+	+	+

Table 3.1. Continued.

Name of the species	Family	Occurrence of species at elevation sites		
		Low	Medium	High
Berberis wallichiana DC.	Berberidaceae	+	+	+
Cnicus sp.	Asteraceae	+	+	+
Daphne papyracae	Thymaleaceae	+	+	+
Dipsacus inermis Wall.	Dipsaceae	+	+	+
Elaegnus sp.	Elaegnaceae	+	+	+
Euphorbia wallichii	Euphorbiaceae	+	+	+
Gentiana sp.	Gentianae	-	+	+
Litsea citrata Bl.	Laurinae	+	+	-
Lyonia ovalifolia	Ericaceae	+	+	+
Lyonia sp.	Ericaceae	+	+	+
Mahonia leschenaultic Tak.	Berberideae	+	+	+
Meliosma dilleniaefolia Wall.	Sabiaceae	+	+	+
Prunus bukhariensis	Rosaceae	+	+	+
Rhododendron arboreum	Ericaceae	-	+	+
Rhododendron thomsonii	Ericaceae	-	+	+
Rhododendron fulgens	Ericaceae	-	+	+
Rhododendron tawangensis	Ericaceae	-	+	+
Rubus alpestris Blume	Rosaceae	+	+	-
Rubus paniculata Smith	Rosaceae	+	+	-
Rumex nepalensis Spreng	Polygonaceae	+	+	+
Sambucus ebulus Linn.	Caprifoliaceae	-	+	+
Sarcococca saligna Muell.Arg.	Buxaceae	+	+	-
Schefflera sp.	Araliaceae	+	+	-
Senecio chrysanthemoides DC.	Asteraceae	-	+	+
Viburnum stellulatum Wall.	Caprifoliaceae	+	+	-

+, - Indicates presence and absence of the species, respectively

Amongst the 28 species of shrub, 14 species were observed to occur at all the three elevation sites (Table 3.1). The distribution of the four *Rhododendron* species namely *Rhododendron arboreum, R. thomsonii, R. fulgens* and *R. tawangensis* were restricted to the high and medium elevation sites, whereas they were absent from the low elevation site. Except *R. fulgens*, the other three species were observed to be highly dominant at the medium elevation site (Plate 6A-D). Few most common plant species associated with 'Rui' bamboo in Jang bamboo forest are presented in Plate 7.

Whitford's index showed the horizontal distribution pattern of all the herb and shrub species at the three elevation sites, where most of the species were distributed in clumps. At all the three elevation sites, not a single species were found to show regular distribution. Twenty species of herb and shrub showed random distribution. Among the three elevation sites, medium and high elevation sites had greater number of species as compared to the low elevation site. Among the herbs and shrubs, *Eleocharis atropurpurea* of Cyperaceae was the most dominant species at the low elevation site, whereas *Eragrostis ciliaris* of Poaceae was dominant at the medium elevation site and *Gnaphalium apiculatum* of Asteraceae at the high elevation site (Table 3.2). Sorensen's similarity index revealed that the medium and high elevation sites had greater similarity (90.4%) followed by the similarity between the medium and the low elevation sites (78.6%), whereas least similarity was recorded between the high and the low elevation sites (65.9%).

3.7.2 Density, species richness and diversity

Density of the herbaceous species was highest at the high elevation site (53.21 m^{-2}), and it decreased with the decrease in elevation, which may

Plate 6. Perennial shrubs and tree species associated with 'Rui' bamboo - (A) *Rhododendron tawangensis,* (B) *R. arboreum*, (C) *R. thomsonii,* (D) *R. fulgens*, and (E and F) A dry tree trunk and a sapling of *Taxus baccata*, respectively.

Plate 7. A terrestrial orchid and four most common plant species associates with 'Rui' bamboo in Jang bamboo forest - (A) *Calanthe* sp. (orchid), (B) *Sambucus ebulus*, (C) *Imatiens thomsoni* (D) *Geranium nepalense*, and (E) *Senecio chrysanthemoides*.

Table 3.2. Frequency, density, IVI and Whitford's index of herbs & shrubs at the three elevation sites.

Name of the species	Frequency (%)			Density			IVI			Whitford's index		
	Low	Medium	High	Low	Medium	High	Low	Medium	High	Low	Medium	High
Herbaceous species												
Anaphalis cinnamomea C.B. Clarke	NA	13.33	53.33	NA	0.53	3.20	NA	1.419	6.907	NA	0.300	0.113
Anthopogon lanceolatus (Roxb.) Hochst.	46.67	53.33	33.33	7.00	5.33	2.67	17.314	9.998	5.181	0.321	0.188	0.240
Brunella vulgaris L.	NA	33.33	40.00	NA	2.67	3.60	NA	5.349	6.736	NA	0.240	0.225
Calamogrostis sp.	NA	NA	13.33	NA	NA	0.67	NA	NA	1.554	NA	NA	0.375
Calanthe sp.	NA	NA	60.00	NA	NA	2.40	NA	NA	6.215	NA	NA	0.067
Carex condensata Nees.	33.33	33.33	26.67	2.00	2.33	1.87	6.671	4.899	3.799	0.180	0.210	0.263
Cyanotis vaga (Lour) Schult. f	13.33	46.67	60.00	0.67	2.13	3.33	2.415	5.328	7.425	0.375	0.098	0.093
Cynoglossum zeylanicum (Vahl) Thumb	NA	26.67	40.00	NA	0.80	1.33	NA	2.479	3.798	NA	0.113	0.083
Cyperus difformis	NA	6.67	20.00	NA	0.13	0.33	NA	0.530	1.467	NA	0.300	0.083
Dicrocephala latifolia DC.	53.33	33.33	33.33	3.33	2.33	2.00	10.927	4.899	4.317	0.117	0.210	0.180
Echinochloa crus-galli Beauv.	6.67	33.33	66.67	0.20	0.33	0.73	0.954	2.198	4.399	0.450	**0.030**[#]	**0.017**[#]
Eleocharis atropurpurea Kunth.	73.33	53.33	46.67	11.00	4.53	3.47	**27.208**[†]	8.918	6.908	0.205	0.159	0.159
Eragrostis ciliaris Trin.	20.00	53.33	40.00	2.00	7.67	2.00	5.522	**13.148**[†]	4.662	0.500	0.270	0.125
Galium asperifolium Wall.	66.67	33.33	53.33	3.00	2.00	1.60	11.443	4.449	4.833	0.068	0.180	0.056

Low – low elevation site, Medium – medium elevation site, High- high elevation site.

Table 3.2. Continued.

Name of the species	Frequency (%)			Density			IVI			Whitford's index		
	Low	Medium	High	Low	Medium	High	Low	Medium	High	Low	Medium	High
Geranium aconitifolium L. Herit	NA	33.33	66.67	NA	1.67	2.67	NA	3.998	6.905	NA	0.150	0.060
Gnaphalium apiculatum	NA	20.00	66.67	NA	0.47	5.67	NA	1.679	**10.795**†	NA	0.117	0.128
Impatiens thomsoni Hook f.	NA	26.67	60.00	NA	2.40	3.00	NA	4.639	6.993	NA	0.338	0.083
Juncus elegans Samuls	NA	6.67	20.00	NA	0.07	0.47	NA	0.440	1.639	NA	0.150	0.117
Juncus lampocarpus Ehrh.	20.00	40.00	53.33	0.33	0.67	1.00	2.357	2.998	4.055	0.083	**0.042**#	**0.035**#
Launaea acaulis Roxb. Babe	NA	6.67	20.00	NA	0.07	0.27	NA	0.440	1.380	NA	0.150	0.067
Osmunda claytoniona	NA	0.00	26.67	NA	NA	0.33	NA	NA	1.811	NA	NA	**0.047**#
Polygonum berbatum	26.67	46.67	66.67	0.60	0.67	1.20	3.438	3.348	5.004	0.084	**0.031**#	**0.027**#
Polygonum capitatum Ham.	20.00	53.33	40.00	0.67	1.00	0.53	2.990	4.147	2.760	0.167	**0.035**#	**0.033**#
Polygonum filicaule Wall.	13.33	53.33	33.33	0.40	0.67	0.47	1.909	3.697	2.329	0.225	**0.023**#	**0.042**#
Potentilla atrosanguinea Lodd.	13.33	33.33	26.67	0.20	0.53	0.40	1.529	2.468	1.898	0.113	**0.048**#	0.056
Psilocarya scirpoides Torrey	66.67	53.33	33.33	3.40	2.13	1.33	12.203	5.677	3.453	0.077	0.075	0.120
Swertia chirayita (Roxb. Ex Fleming) Karsten	NA	40.00	66.67	NA	0.67	1.20	NA	2.998	5.004	NA	**0.042**#	**0.027**#
Veronica sp.	20.00	33.33	66.67	0.33	0.80	1.80	2.357	2.828	5.782	0.083	0.072	**0.041**#
Viola sp.	NA	40.00	73.33	NA	2.20	3.67	NA	5.068	8.547	NA	0.138	0.068

Low – low elevation site, Medium – medium elevation site, High- high elevation site.

Table 3.2. Continued.

Name of the species	Frequency (%)			Density			IVI			Whitford's index		
	Low	Medium	High	Low	Medium	High	Low	Medium	High	Low	Medium	High
Shrub species												
Acer palmatum Thumb	46.67	33.33	NA	1.87	1.00	NA	7.567	3.098	NA	0.086	0.090	NA
Anemone sp.	13.33	33.33	53.33	0.27	1.33	2.67	1.656	3.548	6.216	0.150	0.120	0.094
Aster salsuginosus Richardson	40.00	53.33	33.33	1.20	2.67	3.00	5.727	6.398	5.614	0.075	0.094	0.270
Berberis wallichiana DC.	20.00	33.33	46.67	0.60	1.33	1.87	2.863	3.548	4.834	0.150	0.120	0.086
Cnicus sp.	20.00	33.33	33.33	0.40	1.00	1.20	2.484	3.098	3.280	0.100	0.090	0.108
Daphne papyracae	13.33	NA	6.67	0.67	1.20	0.20	2.415	3.718	0.604	0.375	0.075	0.450
Dipsacus inermis Wall.	6.67	13.33	20.00	0.13	0.33	0.67	0.828	1.149	1.899	0.300	0.188	0.167
Elaegnus sp.	20.00	13.33	NA	0.40	0.13	NA	2.484	0.879	NA	0.100	0.075	NA
Euphorbia wallichii	NA	33.33	46.67	NA	0.80	1.20	NA	2.828	3.970	NA	0.072	0.055
Gentiana sp.	NA	13.33	33.33	NA	0.80	2.67	NA	1.779	5.181	NA	0.450	0.240
Litsea citrata Bl.	20.00	6.67	NA	0.60	0.13	NA	2.863	0.530	NA	0.150	0.300	NA
Lyonia ovalifolia	20.00	53.33	6.67	0.40	1.20	0.13	2.484	4.417	0.518	0.100	**0.042**[#]	0.300
Lyonia sp.	40.00	26.67	13.33	1.20	0.47	0.20	5.727	2.029	0.949	0.075	0.066	0.113
Mahonia leschenaultic Tak.	60.00	46.67	6.67	1.80	1.60	0.07	8.590	4.608	0.431	**0.050**[#]	0.073	0.150

Low – low elevation site, Medium – medium elevation site, High- high elevation site.

Table 3.2. Continued.

Name of the species	Frequency (%)			Density			IVI			Whitford's index		
	Low	Medium	High	Low	Medium	High	Low	Medium	High	Low	Medium	High
Meliosma dilleniaefolia Wall.	53.33	40.00	6.67	1.40	1.13	0.07	7.256	3.628	0.431	**0.049**[#]	0.071	0.150
Prunus bukhariensis	53.33	33.33	6.67	0.80	0.47	0.07	6.117	2.378	0.431	**0.028**[#]	**0.042**[#]	0.150
Rhododendron arboreum	NA	60.00	40.00	NA	1.80	1.33	NA	5.577	3.798	NA	**0.050**[#]	0.083
Rhododendron thomsonii	NA	60.00	53.33	NA	2.07	1.40	NA	5.937	4.574	NA	0.057	**0.049**[#]
Rhododendron fulgens	NA	40.00	66.67	NA	1.27	2.20	NA	3.808	6.300	NA	0.079	**0.050**[#]
Rhododendron tawangensis	NA	66.67	26.67	NA	2.33	1.20	NA	6.647	2.935	NA	0.053	0.169
Rubus alpestris Blume	40.00	26.67	NA	0.60	0.40	NA	4.588	1.939	NA	**0.038**[#]	0.056	NA
Rubus paniculata Smith	53.33	33.33	NA	0.53	0.40	NA	5.610	2.288	NA	**0.019**[#]	**0.036**[#]	NA
Rumex nepalensis Spreng	60.00	53.33	33.33	2.40	1.80	1.00	9.729	5.227	3.021	0.067	0.063	0.090
Sambucus ebulus Linn.	NA	40.00	26.67	NA	0.87	0.60	NA	3.268	2.157	NA	0.054	0.084
Sarcococca *saligna* Muell.Arg.	20.00	40.00	NA	0.60	1.33	NA	2.863	3.898	NA	0.150	0.083	NA
Schefflera sp.	20.00	6.67	NA	0.67	0.13	NA	2.990	0.530	NA	0.167	0.300	NA
Senecio chrysanthemoides DC.	NA	33.33	66.67	NA	0.80	2.20	NA	2.828	6.300	NA	0.072	**0.050**[#]
Viburnum stellulatum Wall.	46.67	33.33	NA	1.00	0.47	NA	5.922	2.378	NA	**0.046**[#]	**0.042**[#]	NA

Low – low elevation site, Medium – medium elevation site, High- high elevation site.
[†] Species having highest IVI, [#] Species in random distribution NA – Not applicable

be due to the increase in the bamboo clump density and closer forest canopy at the lower elevation. In case of shrubs, the density was highest at the medium elevation site (29.2 per 25 m^2), followed by the high elevation site (23.9 per 25 m^2) and lowest at the low elevation site (17.3 per 25 m^2). Highest number of herb and shrub species was observed at the medium elevation site followed by the high and low elevation sites. Species richness and Shannon-Wiener indices also showed highest value at the medium elevation site followed by the high and low elevation sites (Table 3.3).

3.8 PHYSICAL PROPERTIES OF SOIL

Soil samples were collected in April, July, October and January during 2001, 2002 and 2003, representing spring, rainy, autumn and winter season. From each elevation site, nine replicate samples were collected using a steel corer (6.5 cm diameter and 30 cm height) from three soil depths (0-10, 10-20 and 20-30 cm). The replicate samples of a given depth were thoroughly mixed to obtain one composite sample. The samples were air dried, sieved through a 2 mm mesh sieve to remove stone particles and gravels and then passed through 0.5 mm mesh screen for the determination of physical and chemical properties.

Soil samples were analysed once for texture, bulk density, water holding capacity, and soil porosity, whereas soil moisture, pH, organic carbon and soil nutrients were analysed on seasonal basis through periodic sampling. Soil texture and bulk density were determined by Bouyoucos hydrometer method and gravimetric method, respectively (Allen *et al.* 1974). Soil porosity was determined using the bulk density data following the methodology given by Allen *et al.* (1974). Water holding capacity (WHC) was determined by

Table 3.3. Number of family, genera and species of herbs and shrubs; species richness and diversity indices at the three elevation sites

Elevation sites	Family	Genera	Herb species	Shrub species	Total species	Species richness index (D)	Species diversity index $(\overline{H})$
Low (2400-2800)	20	26	14	21	35	12.079	1.285
Medium (2800-3200)	25	45	26	28	54	17.730	1.570
High (3200-3600)	23	43	28	21	49	16.322	1.558

Keen's box method using copper cups of 5.6 cm internal diameter and 1.6 cm height (Piper 1942). Soil moisture content was determined gravimetrically by taking 10 g of fresh unsieved soil and the result expressed on oven-dry weight basis. pH was determined electrometrically by a digital pH meter (SYSTRONICS-335) in 1:2.5 suspension of soil in deionized water (Anderson and Ingram 1993).

The data were statistically analysed using multiway ANOVA to study the effect of altitudinal variation, season/ sampling period and soil depth on edaphic variables.

3.8.1 Soil moisture

Differences in soil moisture content at different soil depths, three elevation sites and sampling periods were significantly different (F = 62.61, 117.81 and 101.12 respectively, P< 0.001). It was significantly higher at the medium elevation site at all the three depths compared to the low and high elevation sites, which was due to the higher precipitation through rainfall and snowfall. Maximum soil moisture content was observed during July at the low elevation site, while two peaks of soil moisture (during July and January) were recorded at the medium and high elevation sites due to high snowfall during winter. Minimum soil moisture content was noticed during April at all the elevation sites. It had a great impact on the induction of new shoots resulting in low yield. There was a significant decrease in soil moisture content with the increase in soil depth at all the three elevation sites. Mean soil moisture content in the surface soil (0-10 cm depth) at the low, medium and high elevation sites was recorded as 46.5%, 56.5% and 42.8% respectively. At 10-20 cm depth, it was 42.8% 52.4% and 38.8% respectively, whereas at the

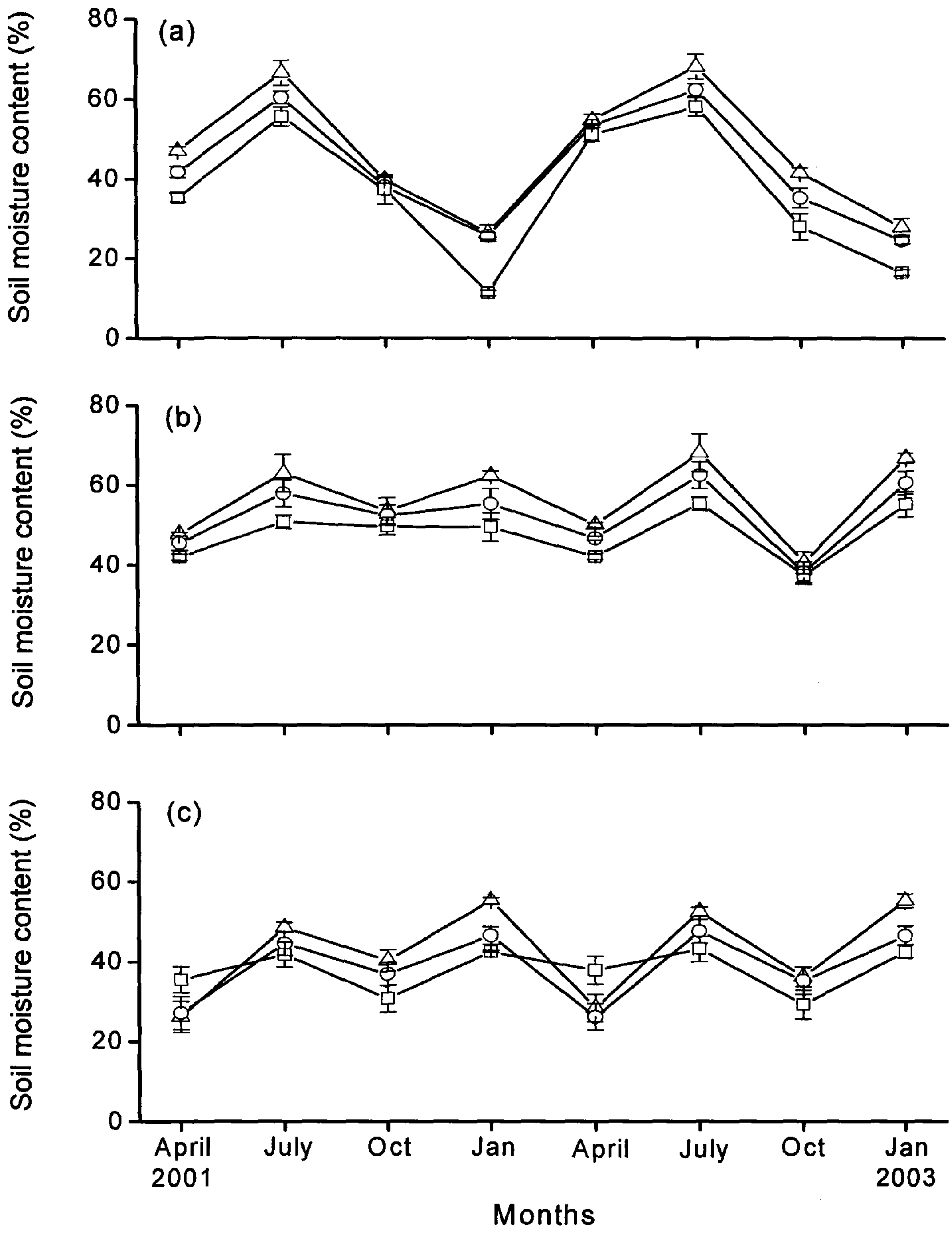

Figure 3.6. Temporal variation in soil moisture content at three soil depths (-△-, 0 - 10 cm;-○-, 10 -20 cm;-□-, 20 -30 cm) at the low (a), medium (b) and high (c) elevation sites. Vertical line bar indicates ± SE.

lowest depth (20-30 cm), moisture content was observed to be 36.7%, 47.7% and 37.9% respectively at the low, medium and high elevation sites (Fig. 3.6).

3.8.2 Soil pH

Soil at all the elevation sites was acidic. It may be due to the accumulation of cations in biomass causing anionic imbalance, and anion leaching loss due to heavy rainfall and snowfall. It was significantly different among the soil depths, elevation sites and seasons ($F = 39.37$, 92.46 and 209.80 respectively, $P < 0.001$). At all the elevation sites, soil pH was highest during autumn season and lowest during spring. There was a decline in soil pH from surface layer to sub surface layers during the study period at all the elevation sites, except during 2001-2002, when the surface soil (0-10 cm) at the low elevation site was more acidic than the two subsurface soil layers (10-20 and 20-30 cm depths). Soil pH at the medium elevation site was significantly higher compared to the other two elevation sites with mean pH 5.46, 5.41 and 5.35 respectively at 0-10, 10-20 and 20-30 cm depth. The soil pH was lowest at the high elevation site, which might have been caused due to the soil erosion and leaching loss of basic cations due to heavy rainfall and snowfall (Fig. 3.7).

3.8.3 Bulk density and Soil porosity

Bulk density of soil at different depths at the three elevation sites varied significantly ($F = 20.05$ and 80.50 respectively, $P < 0.001$). The high elevation site having open bamboo forest showed higher values which gradually declined at the medium and low elevation sites that had better vegetation cover. Bulk density increased with the increase in soil depth at all the elevation sites, which implies the increase in soil compactness. The soils

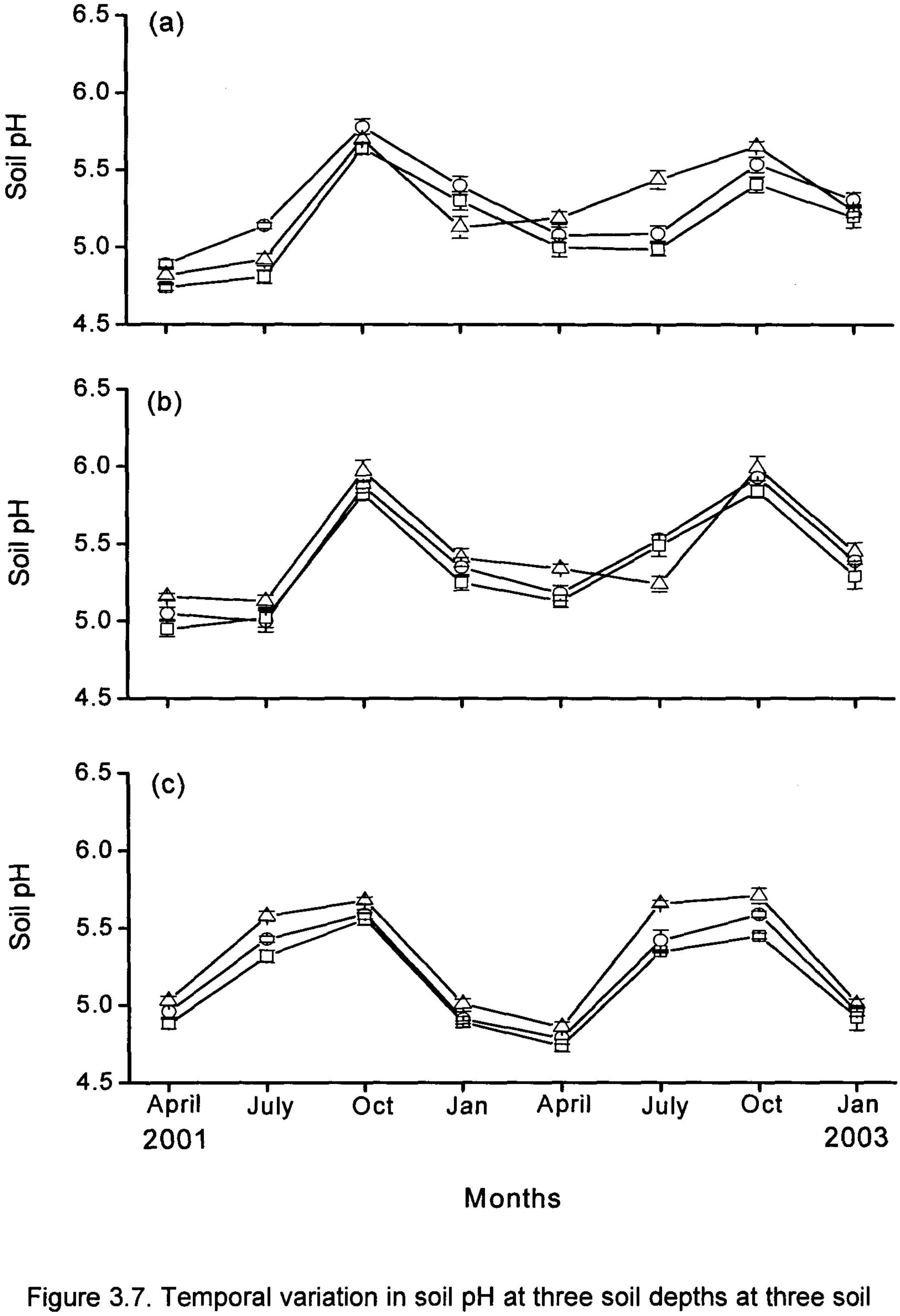

Figure 3.7. Temporal variation in soil pH at three soil depths at three soil depths (-△-, 0 - 10 cm;-○- 10 -20 cm;-□- 20 -30 cm) at the low (a), medium (b) and high (c) elevation sites. Vertical line bar indicates ± SE.

at the low elevation site were more porous compared to the medium and high elevation sites (Table 3.4).

3.8.4 Water holding capacity

Water holding capacity did not differ significantly among the three soil depths, however, it differed significantly among the three elevation sites ($F = 22.087$, $P < 0.001$). Soil of the middle depth (10-20 cm) showed maximum water holding capacity at the low and medium elevation sites, while at high elevation site, it was greater in the surface soil than the sub surface soil. The medium elevation site had the highest water holding capacity (Table 3.4).

3.8.5 Texture

The texture of the soil was sandy at the high and low elevation sites, whereas it was loamy sand at the medium elevation site. Silt and clay percent was significantly higher at the medium elevation site compared to the other two elevation sites (Table 3.4).

3.9 SOIL NUTRIENT STATUS

Soil organic carbon was determined by rapid titration method (Walkley and Black 1934). Total kjeldahl nitrogen (TKN) was determined by digesting air-dried soil samples with concentrated sulphuric acid using Kjeltab (TECATOR) as catalyst, on a block digester followed by distillation and titration in a KEL PLUS distillation system and Schott Titro Line easy (ELITE EX) respectively. Available phosphorus was determined by molybdenum blue method (Allen *et al.* 1974) after extracting the soil phosphorus in 0.5 M sodium bicarbonate solution. Soil potassium was determined by using flame photometer after digesting the soil samples with tri-acid following the

Table 3.4. Physical properties of soil at three depths at the three elevation sites.

Elevation sites	Soil depth (cm)	BD ($g\ cm^{-3}$)	Porosity (%)	WHC (%)	Percentage of soil particles			Textural class
					Sand	Silt	Clay	
Low (2400- 2800m asl.)	0-10	0.24 ± 0.03	90.82 ± 1.01	70.54 ± 9.54	94.19 ± 1.24	4.50 ± 0.03	1.31 ± 0.03	S
	10-20	0.29 ± 0.02	88.93 ± 0.88	65.96 ± 2.56	93.13 ± 1.71	5.10 ± 0.02	1.77 ± 0.02	S
	20-30	0.31 ± 0.02	88.24 ± 0.83	54.82± 6.88	92.96 ± 0.63	5.51 ± 0.03	1.53 ± 0.12	S
Medium (2800-3200m asl.)	0-10	0.23 ± 0.03	91.26 ± 0.96	64.66 ± 9.54	80.71 ± 0.57	17.00 ± 1.18	2.29 ± 0.03	LS
	10-20	0.26 ± 0.02	90.31 ± 0.81	67.44 ± 8.17	79.38 ± 2.04	18.11 ± 0.51	2.51 ± 0.04	LS
	20-30	0.29 ± 0.02	88.99 ± 0.82	63.46 ± 6.60	77.63 ± 1.15	19.44 ± 0.03	2.93 ± 0.03	LS
High (3200-3600m asl.)	0-10	0.40 ± 0.02	84.78 ± 0.75	59.44 ± 5.60	94.75 ± 2.60	4.00 ± 0.30	1.25 ± 0.05	S
	10-20	0.50 ± 0.02	81.19 ± 0.75	53.98 ± 3.20	93.72 ± 1.26	4.56 ± 0.21	1.72 ± 0.04	S
	20-30	0.56 ± 0.03	78.87 ± 1.07	47.07 ± 6.76	92.92 ± 1.55	4.61 ± 0.20	2.47 ± 0.05	S

BD – Bulk density; WHC – Water holding capacity; S – Sandy; LS – Loamy Sand, ± indicates the SE (n = 3).

methodology given by Allen *et al.* (1974). Each analysis was performed in triplicate and the final results are expressed on oven-dry weight basis.

All the data were statistically analysed using multiway ANOVA to study the effect of altitudinal variation, season and soil depth on soil nutrient.

3.9.1 Organic carbon

Soil organic carbon (SOC) showed significant difference among the three soil depths, three elevation sites and sampling periods (F = 410.34, 478.02 and 556.97 respectively, P< 0.001). SOC decreased with the increase in soil depth and was greater during October, while it was minimum during April at all the three elevation sites. There was no significant difference in SOC between the two consecutive years during the study period, although an insignificant increase was observed in the surface soil. SOC at two sub surface soil layers (10-20 and 20-30 cm) increased during April and July, and it declined during October and January (Table 3.5).

3.9.2 Soil total nitrogen

Soil total nitrogen differed significantly among the three soil depths, elevation sites and sampling periods (F = 14.96, 87.64 and19.90 respectively, P< 0.001). The soil of the surface layer had higher total nitrogen concentration which gradually declined in the sub surface layers. Maximum total soil nitrogen was observed at the low elevation site and minimum at the high elevation site. It attained peak value during July at the low and medium elevation sites, whereas at the high elevation site, it peaked during October. Minimum soil total nitrogen concentration was found during April at all the elevation sites. An increase in total soil nitrogen concentration was observed at the low elevation site during the study period, while there was no significant

Table 3.5. Temporal variation in soil organic carbon (%) at the three elevation sites.

Elevation sites	Soil depths (cm)	2001 - 2002					2002 - 2003				
		April	July	October	January	Mean	April	July	October	January	Mean
Low	**0-10**	6.85 ± 0.02	8.20 ± 0.06	12.80 ± 0.03	9.20 ± 0.03	**9.26**	7.30 ± 0.03	8.24 ± 0.04	14.70 ± 0.03	9.29 ± 0.03	**9.88**
	10-20	4.90 ± 0.02	7.80 ± 0.04	11.70 ± 0.05	8.00 ± 0.09	**8.10**	5.80 ± 0.08	7.71 ± 0.04	11.00 ± 0.02	7.10 ± 0.04	**7.90**
	20-30	4.00 ± 0.07	5.00 ± 0.04	10.70 ± 0.02	6.70 ± 0.03	**6.60**	4.40 ± 0.05	5.60 ± 0.07	9.00 ± 0.06	5.60 ± 0.02	**6.15**
Medium	**0-10**	8.48 ± 0.02	10.20 ± 0.03	14.70 ± 0.07	11.70 ± 0.02	**11.27**	9.20 ± 0.06	11.00 ± 0.05	16.00 ± 0.07	11.70 ± 0.05	**11.98**
	10-20	6.50 ± 0.06	9.80 ± 0.05	13.50 ± 0.05	10.70 ± 0.03	**10.13**	7.30 ± 0.04	10.50 ± 0.06	11.30 ± 0.05	8.50 ± 0.04	**9.40**
	20-30	5.50 ± 0.05	8.00 ± 0.06	12.50 ± 0.03	7.06 ± 0.03	**8.27**	6.70 ± 0.04	9.20 ± 0.06	10.70 ± 0.05	7.60 ± 0.05	**8.55**
High	**0-10**	5.40 ± 0.03	7.40 ± 0.04	10.70 ± 0.05	8.20 ± 0.05	**7.93**	6.40 ± 0.05	8.00 ± 0.04	10.70 ± 0.06	8.90 ± 0.03	**8.50**
	10-20	3.30 ± 0.04	6.00 ± 0.01	9.20 ± 0.06	7.40 ± 0.04	**6.48**	4.40 ± 0.06	6.70 ± 0.05	7.00 ± 0.04	5.30 ± 0.04	**5.85**
	20-30	2.50 ± 0.02	4.50 ± 0.02	7.60 ± 0.03	4.30 ± 0.04	**4.73**	3.30 ± 0.02	6.10 ± 0.05	6.30 ± 0.06	3.00 ± 0.07	**4.68**

± Indicates the SE (n = 3).

change at the medium elevation, but at the high elevation site there was a gradual decrease in N concentration (Table 3.6).

3.9.3 Soil available phosphorus

Concentration of soil available phosphorus (P) was significantly higher at the medium elevation site ($F = 16.154$, $P < 0.001$), and lowest at the high elevation site. It differed significantly among the three soil depths and sampling periods ($F = 31.867$ and 29.953 respectively, $P < 0.001$). Surface soil of the three elevation sites had higher P concentration, which gradually decreased with the increase in soil depth. Concentration of available P had two peaks *i.e.* during July and January at all the three elevation sites. Highest P concentration at the low elevation site was observed during July, whereas at the medium and high elevation sites highest values were recorded during January. Lowest concentration of available P was noticed during October. A gradual increase in available phosphorus was observed during the study period at all the elevation sites (Table 3.7).

3.9.4 Soil total potassium

Concentration of soil total potassium did not differ significantly among the soil depths, elevation sites and seasons. It was higher in the middle soil layer (10-20 cm) at all the three elevation sites. At the low and medium elevation sites, maximum K concentration was observed during July, while at the high elevation site it was maximum during October. Minimum K concentration was observed during April at the low elevation site, whereas at the medium and high elevation sites, minimum concentration was recorded during January (Table 3.8).

Table 3.6. Temporal variation in soil total nitrogen (%) at the three elevation sites.

Elevation sites	Soil depths (cm)	2001 - 2002					2002 - 2003				
		April	July	October	January	Mean	April	July	October	January	Mean
Low	0-10	0.54 ± 0.046	0.96 ± 0.012	0.93 ± 0.012	0.62 ± 0.006	**0.76**	0.76 ± 0.005	1.37 ± 0.012	1.17 ± 0.029	0.66 ± 0.046	**0.99**
	10-20	0.51 ± 0.006	0.87 ± 0.006	0.69 ± 0.035	0.55 ± 0.023	**0.66**	0.66 ± 0.008	1.20 ± 0.023	0.73 ± 0.012	0.57 ± 0.012	**0.79**
	20-30	0.42 ± 0.012	0.82 ± 0.006	0.60 ± 0.012	0.52 ± 0.069	**0.59**	0.60 ± 0.012	1.07 ± 0.006	0.64 ± 0.046	0.56 ± 0.006	**0.72**
Medium	0-10	0.34 ± 0.006	0.95 ± 0.006	0.44 ± 0.012	0.49 ± 0.017	**0.56**	0.46 ± 0.046	0.70 ± 0.006	0.49 ± 0.023	0.51 ± 0.006	**0.54**
	10-20	0.30 ± 0.005	0.77 ± 0.012	0.36 ± 0.023	0.44 ± 0.012	**0.47**	0.39 ± 0.017	0.65 ± 0.012	0.39 ± 0.006	0.46 ± 0.023	**0.47**
	20-30	0.18 ± 0.029	0.53 ± 0.029	0.29 ± 0.006	0.42 ± 0.017	**0.36**	0.31 ± 0.003	0.53 ± 0.046	0.31 ± 0.046	0.43 ± 0.012	**0.40**
High	0-10	0.41 ± 0.046	0.22 ± 0.006	0.54 ± 0.012	0.48 ± 0.017	**0.41**	0.21 ± 0.012	0.36 ± 0.003	0.56 ± 0.017	0.47 ± 0.006	**0.40**
	10-20	0.38 ± 0.012	0.21 ± 0.006	0.47 ± 0.017	0.41 ± 0.006	**0.37**	0.10 ± 0.029	0.25 ± 0.023	0.51 ± 0.012	0.42 ± 0.012	**0.32**
	20-30	0.33 ± 0.012	0.17 ± 0.017	0.41 ± 0.012	0.34 ± 0.017	**0.31**	0.08 ± 0.005	0.21 ± 0.017	0.43 ± 0.006	0.36 ± 0.017	**0.27**

± Indicates the SE (n = 3).

Table 3.7. Temporal variation in soil available phosphorus (µg g^{-1}) at the three elevation sites.

Elevation sites	Soil depths (cm)	2001 - 2002					2002 - 2003				
		April	July	October	January	Mean	April	July	October	January	Mean
Low	**0-10**	3.58 ± 1.49	11.94 ± 1.70	6.32 ± 3.65	10.54 ± 0.07	**8.10**	5.69 ± 0.08	14.25 ± 0.38	8.67 ± 0.09	12.90 ± 0.13	**10.38**
	10-20	1.76 ± 0.98	8.28 ±1.85	2.36 ± 1.36	6.26 ± 0.07	**4.67**	3.87 ± 0.08	10.59 ± 0.48	4.71 ± 1.21	8.62 ± 0.07	**6.95**
	20-30	1.74 ± 0.72	3.70 ± 0.48	1.16 ± 0.09	2.86 ± 0.01	**2.36**	3.85 ± 0.15	6.01 ± 0.61	3.51 ± 3.65	5.22 ± 0.25	**4.65**
Medium	**0-10**	10.56 ± 0.66	10.92 ± 1.04	4.90 ± 1.21	13.62 ± 0.67	**10.00**	12.67 ± 0.16	13.23 ± 0.62	7.25 ± 0.23	15.98 ± 0.01	**12.28**
	10-20	9.66 ± 0.20	6.28 ± 0.61	1.68 ± 0.38	12.20 ± 0.25	**7.46**	11.77 ± 0.20	8.59 ± 0.82	4.03 ± 0.81	14.56 ± 0.06	**9.74**
	20-30	6.26 ± 0.16	5.80 ± 0.82	1.40 ± 0.23	8.90 ± 0.13	**5.59**	8.37 ± 0.66	8.11 ± 1.85	3.75 ± 3.50	11.26 ± 0.24	**7.87**
High	**0-10**	6.25 ± 0.15	6.94 ± 1.07	5.70 ± 0.81	8.04 ± 0.24	**6.73**	8.36 ± 0.72	9.25 ± 1.70	8.05 ± 0.81	10.40 ± 0.07	**9.02**
	10-20	4.76 ± 0.08	6.40 ± 0.62	5.30 ± 3.67	7.26 ± 0.30	**5.93**	6.87 ± 0.98	8.71 ± 0.82	7.65 ± 1.36	9.62 ± 0.25	**8.21**
	20-30	5.88 ± 0.08	6.00 ± 0.38	4.80 ± 3.50	6.50 ± 0.06	**5.80**	7.99 ± 1.49	8.31 ± 1.04	7.15 ± 3.67	8.86 ± 0.67	**8.08**

± Indicates the SE (n = 3).

Table 3.8. Temporal variation in soil total potassium (%) at the three elevation sites.

Elevation sites	Soil depths (cm)	2001 - 2002					2002 - 2003				
		April	July	October	January	Mean	April	July	October	January	Mean
Low	**0-10**	0.041 ± 0.001	0.055 ± 0.001	0.050 ± 0.005	0.051 ± 0.001	**0.049**	0.042 ± 0.001	0.064 ± 0.004	0.050 ± 0.002	0.051 ± 0.004	**0.052**
	10-20	0.049 ± 0.001	0.053 ± 0.001	0.061 ± 0.007	0.052 ± 0.004	**0.054**	0.051 ± 0.003	0.065 ± 0.001	0.056 ± 0.001	0.052 ± 0.002	**0.056**
	20-30	0.048 ± 0.002	0.053 ± 0.003	0.052 ± 0.005	0.054 ± 0.003	**0.052**	0.047 ± 0.004	0.061 ± 0.002	0.052 ± 0.003	0.054 ± 0.004	**0.054**
Medium	**0-10**	0.047 ± 0.001	0.054 ± 0.001	0.054 ± 0.002	0.041 ± 0.001	**0.049**	0.049 ± 0.002	0.058 ± 0.003	0.054 ± 0.004	0.047 ± 0.001	**0.052**
	10-20	0.051 ± 0.001	0.057 ± 0.002	0.053 ± 0.004	0.045 ± 0.005	**0.052**	0.054 ± 0.001	0.064 ± 0.001	0.053 ± 0.005	0.050 ± 0.001	**0.055**
	20-30	0.051 ± 0.002	0.057 ± 0.001	0.055 ± 0.001	0.045 ± 0.003	**0.052**	0.054 ± 0.004	0.059 ± 0.001	0.055 ± 0.001	0.044 ± 0.003	**0.053**
High	**0-10**	0.045 ± 0.003	0.052 ± 0.003	0.056 ± 0.003	0.046 ± 0.002	**0.050**	0.049 ± 0.002	0.051 ± 0.002	0.056 ± 0.002	0.042 ± 0.001	**0.049**
	10-20	0.046 ± 0.001	0.052 ± 0.001	0.065 ± 0.001	0.048 ± 0.002	**0.053**	0.051 ± 0.001	0.049 ± 0.003	0.065 ± 0.001	0.047 ± 0.002	**0.053**
	20-30	0.050 ± 0.002	0.052 ± 0.002	0.055 ± 0.002	0.046 ± 0.001	**0.051**	0.047 ± 0.003	0.050 ± 0.001	0.050 ± 0.004	0.041 ± 0.001	**0.047**

± Indicates the SE (n = 3).

CHAPTER IV

BIOLOGY, SITE-SPECIFICITY, POPULATION STRUCTURE AND GROWTH PERFORMANCE OF *ARUNDINARIA MALING*

4.1 BIOLOGY

4.1.1 Systematic position of *A. maling*

The genus *Arundinaria* occurs at higher elevation in the Himalayan tracts between 600 to 3700 m asl. Among the species of the genus *Arundinaria*, *Arundinaria maling* is one of the most important, rare and endemic temperate bamboo. It belongs to the subfamily Bambusoideae of Gramineae family. According to Keng (1991), taxonomic position of *Arundinaria maling* is as follows:

Family	: Gramineae
Sub-family	: Bambusoideae
Super-tribe	: Arundinariatae Keng et Keng f.
Tribe	: Arundinarieae Steud.
Sub-tribe	: Arundinariinae Keng
Genus	: *Arundinaria* Michaux
Species	: *Maling* Gamble

4.1.2 Description

Arundinaria maling was first described by Gamble in the "*Bulletin of miscellaneous information, Royal Botanic Gardens*" (p. 139), Kew in 1912. Gamble also described it in *Indian Bamboo*, p. 9, *et* ap. Earlier, in 1896, it was reported and described as *Arundinaria racemosa* by Munro in Trans. Linn. Soc., p.26, p.p. 17. Few workers have also reported and described this bamboo species in different publications (Camus, *Les Bambusees*, 1913, p. 31. p.p. 16. Fig. A; Ray, *Indian Forester,* 1952, p. 89, Fig.A - H; Varmah and Bahadur, 1980, *Indian Forest Records (Botany)* p. 1; Bor, Flora of Assam, 1982, vol. 5, p. 24 and Naithani, 1987, *Ph D. Thesis*, p. 22-25, Fig.7, p.p. 18).

Arundinaria maling is an erect shrubby bamboo; rhizomes - stout, subterranean and sympodial-creeping with long neck, producing single culms at intervals. *Culms* - 3 to 9 m tall, slender, fistular with 2-4 cm diameter, wall *ca.* 5 mm thick. *Internodes* - 20 to 40 cm long, scabid above. *Culm sheaths* - *ca.* 32 cm x 10 cm, straw-coloured, chartaceous, coriaceous, striate, sparsely yellowish-hispid; margins ciliate, attenuate at the top, broadly auricled. Auricles - furnished with long, patent, rigid cilia; blade - imperfect, 6-7 cm long, erect or reflexed, scabid inside; ligule - *ca.* 1 cm long, fimbriate. *Leaves* - linear lanceolate, 5-10 cm x 8-20 cm, chartaceous, setaceous, acuminate at the apex; attenuate into a short petiole, glabrous on both surfaces, glaucescent beneath; margins minutely scabrous; veins - three pairs, intermediate *ca.* 6-9 cm; transverse veinlets conspicuous, tessellate; sheaths - striate, glabrous, except for a few cilia at the mouth and on the back; ligule - short, truncate, pubescent. *Inflorescence* is a decompound panicle, *ca.* 10 cm long supported at the base by spathaceous bracts; rachis glabrous, angular, pedicels - filiform sinuate, 1-2 cm long. Spikelets 10-20, distichous, ca. 3-5 cm long, 7-9 flowered, alternate, uppermost empty. Rachilla joints clavate, curved, flattened on the inner surface, pubescent and ciliate, 5-6 cm long. Glumes - 2, ovate, scabidly setaceous - acuminate. Lemma - 1 to 1.3 cm long, ovate, 7-9 nerved with transverse nerves, scabidly setaceous - acuminate. Palea - 7 to 8 mm long, bifid at the apex, 2-keeled, and keels ciliate, between the keels 2-3 nerved with a few transverse veinlets. Lodicules - 3, ovate, obtusely acute, ciliate, narrowed at the base, 2-2.5 mm long. Stamens - 3, anthers 5-6 mm long, yellow, bifid at the apex. Ovary - ovoid; style short, slender; stigmas - 3, long - plumose. *Caryopsis* - ca. 9.7 mm long, dorsally furrowed. *Seeds* – albuminous (Plate 8).

4.1.3 Distribution of *A. maling*

Worldwide, a total of 150 species of the genus *Arundinaria* has been reported. More than 26 species have been reported from India, in which, 10 species are recorded from north-east (Biswas 1988). According to Varmah and Bahadur (1980) and Bedell (1997), the distributional pattern of the species of *Arundinaria* in India vary along the altitudinal gradients e.g. *A. hookeriana* - 600 to 1524 m asl., *A. polystachya* - 914 to 1524 m, *A. falconeri* - 1828 to 2438 m, *A. maling* - 1800 to 3658 m, *A. griffithiana* and *A. pantlingi* - 2438 to 3048 m, *A. aristata* - 3048 to 3658 m, *A. clarkei* and *A. hirsuta* -1525 to 3000 m, *A. manii* - 700 to 1000 m, *A. microphylla* - 2400 to 3100 m, *A. rolloana* - 1525 to 2300 m asl. A number of *Chimonobambusa* spp. occurring in India were originally identified as *Arundinaria,* which occur in Arunachal Pradesh, Khasi hills, Naga hills, Manipur and Sikkim from 1200 to 2280 m asl.

Arundinaria maling was reported from India (Arunachal Pradesh, Sikkim and hilly areas of North Bengal), Bhutan and Nepal. Biswas (1988) reported the occurrence of *A. maling, A. gracilis and A. racemosa* (the three indigenous and endemic bamboo species) in Arunachal Pradesh. The occurrence and distribution of *A. maling* Gamble in Arunachal Pradesh was reported only from three localities where it was found in fairly large numbers. The three natural habitats identified were - Eagle's nest Wildlife Sanctuary,

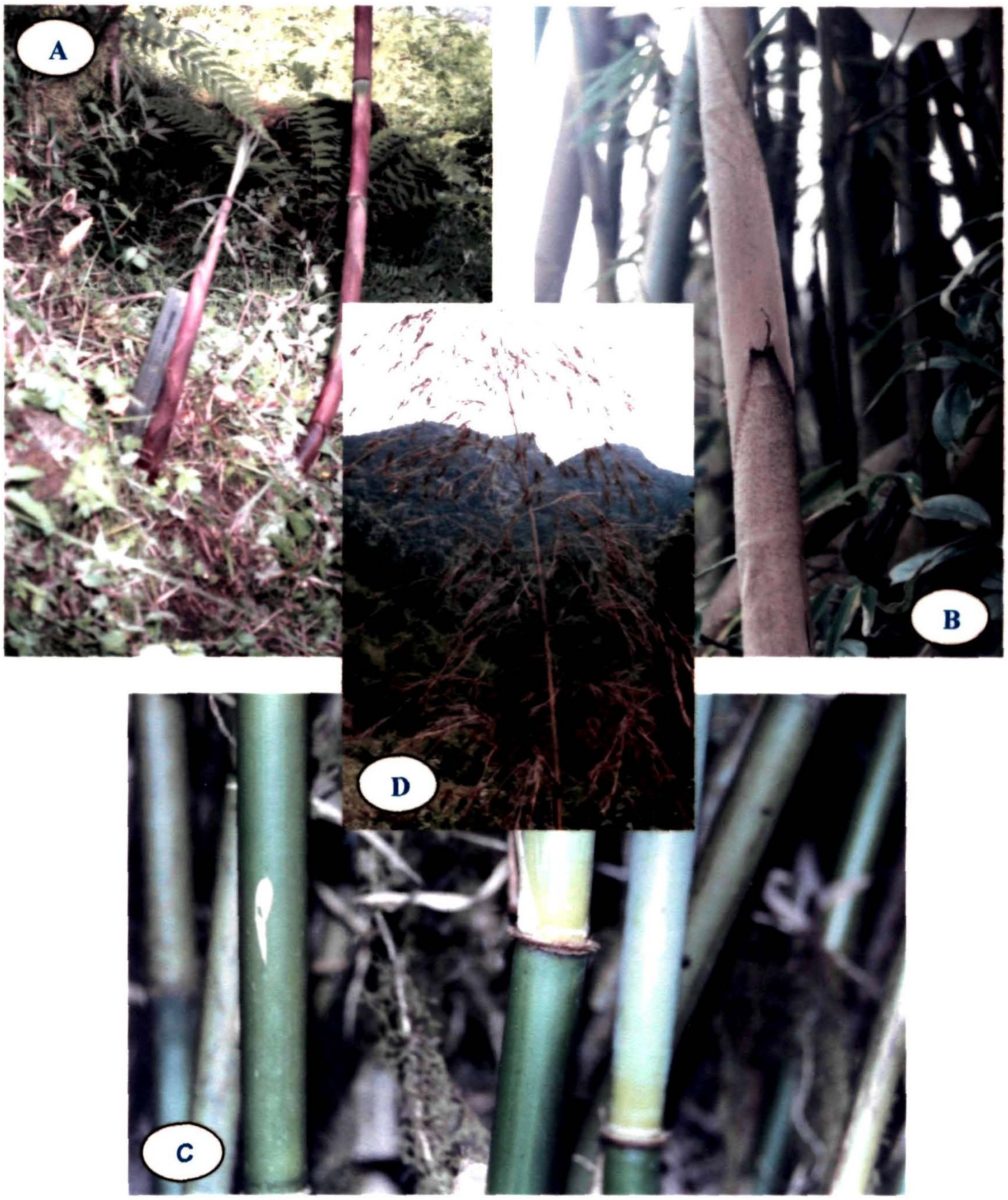

Plate 8. (A) A four days old and a seven days old new individuals of 'Rui' bamboo, (B) A culm wrapped with sheaths showing blade and auricle, (C) Nodes with brown hairy rings above and (D) A completely defoliated individual of 'Rui' bamboo with inflorescence.

Bomdila and Peri la of West Kameng District (Haridashan and Deori 1987, Naithani 1987). Jang area of Tawang district, where the present study was carried out, is the fourth and the largest natural habitat of *A. maling* reported so far from Arunachal Pradesh.

4.1.4 Phenology of *A. maling*

Flowering in bamboo is periodic as in case of *Melocanna baccifera* (*ca.* 45 yrs), *Arundinaria racemosa* (*ca.* 30 yrs) or annual as in *Indocalamus wightiana, Bambusa attra* and gregarious, sporadic or both (Tewari 1992). Thus, majority of the bamboos fall between these two extremes and the flowering cycle ranges from a few to 120 years (Janzen 1976, Gaur 1987, Koshy and Pushpangadan 1997). The longest cycle *i.e.* 120 years was recorded in *Phyllostachys bambusoides* by Soderstrom and Calderon (1979) from the United States. There are only three reports that could be traced back on the flowering incidences of *A. maling.* According to Gamble (1912) and Blatter (1929-30), *A. maling* had flowered at Mt. Tanglo, Sikkim during 1904. Ray (1952) stated that it had gregariously flowered during February-May 1951 in Sanchal Range all around Tiger hills, Darjeeling (North Bengal).

In spite of the occurrence of *A. maling* in Arunachal Pradesh, no such reports on its flowering or phenology are available. During the present study, it is learnt from the villagers that *A. maling* flowered gregariously in Jang area during 1940s and died *en masse*. Natural regeneration of *A. maling* after gregarious flowering took place in few pockets inside the bamboo forest, and in due course of time a good bamboo forest developed. It took around fifteen years to establish a mature bamboo forest with normal commercial sized culms.

During the study period, sporadic flowering of *A. maling* in few clumps of the same forest was observed (Plate 8D). Blooms were initiated during February, 2002 and flowering continued till May, 2002. Seed formation and seed maturation was observed during July - August of the same year. No seedlings or saplings could be noticed in those clumps after sporadic flowering, which may be due to the low soil as well as air temperature. There were no symptoms of mites, rodents or other organisms which consume the seeds of *A. maling* in canopy or after seed set. Seeds that had fallen on the ground decayed. New shoots emerged only at the onset of rainy season (Plate 8A). More than 80% of the new shoots were induced within a very short period, *i.e.*, between the last week of June to the second week of July. Further, emergence of new shoots continued till the last week of July. Induction of new branches took place at the age of nine months during spring season, whereas emergence of new leaves was observed during rainy season at the age of twelve months. Leaf senescence and defoliation were noticed throughout the year with the maximum rate during rainy season.

4.2 SITE-SPECIFICITY

Restricted distribution of bamboo species in nature is highly influenced by altitude, topography, agro-climatic and edaphic variation, and anthropogenic pressures (Numata 1987, Uchimura 1987). Rainfall plays a very important role in the distribution and growth of different bamboo species (Gamble 1896, Numata 1987). Climatically, bamboos prefer regions of high annual rainfall ranging from ca. 1270 to 6350 mm (Bedell 1997, Banik 2000, Huberman 2003), although in India species like *Dendrocalamus strictus* also occurs in dry deciduous forests with low annual rainfall (ca. 760-1000 mm) in

Rajasthan. Usually, bamboos prefer well-drained soils but it is also found on swampy or wet streambeds. No bamboo is reported on saline soils. Different species require a set of optimum condition for their growth and development such as temperature, rainfall, humidity, soil structure, drainage, soil moisture, soil nutrients, altitude and physiographic features (Varmah and Bahadur 1980, Bedell 1997, Tewari 1992). As individual bamboo species have well-defined habitats, it may be considered as indicators of different forest types. Under Indian conditions (Deogun 1937, Sen Gupta 1952), *Dendrocalamus strictus* does well in open, mixed deciduous forest or in open areas on stony hillside soils, and extends into drier conditions. *Bambusa arundinacea* occurs on rich moist soil such as alluvial stretches along streams. Loose and fertile soil with high organic matter content, good water holding ability and water permeability facilitate rhizome growth. Rhizomes lie in soils 20-50 cm deep and determined by the horizontal geotropism of the rhizomes, and 80% of the roots of a well-grown clump of *Bambusa tulda* were reported to be present in the upper 33 cm (White and Childers 1945). The textural variation and soil depth do not interfere in the normal growth of bamboo, provided the drainage, rainfall and temperature conditions are favourable (Qureshi *et al.* 1969).

Soil pH from 5.0 to 6.5 is the most suitable for bamboo growth, whereas some species may grow even at pH 3.5. According to Uchimura (1980), soils rich in N, P, and K promote the growth of bamboo culms. Soil nitrogen and phosphorus content are the most important factors affecting bamboo growth, but soil organic matter, texture, aeration and depth are also important (He and Ye 1987).

In general, there is a reduction in bamboo culm size with the increase in latitude and altitude, which is presumed to be the reason why each species occupies a characteristic habitat and rarely occurs mixed with other species of bamboo, exceptions being *Bambusa tulda* in association with *Cephalostachyum capitatum* and *Oxytenanthera* spp. with some reeds (Qureshi and Deshmukh 1962). Bamboos become luxuriant on deep loamy soils, sandy loams, and fertile clayey-loams though some species such as species of *Oxytenanthera* occupy hill tops and plateaus, with a rather depleted soil layer (Bedell 1997). Bamboo species like *Dendrocalamus strictus* and *Bambusa arundinacea* flourish along riverbanks, brooks, streams and low-level depressions. *Dendrocalamus longispathus* prefers to grow along ravines, while *Cephalostachyum pergracile* prefers sites between dry and moist, and *Teinistachyum helferi* prefers moist humid valleys in evergreen forests (Bedell 1997).

The agro-climatic and edaphic conditions of Jang area such as its peculiar physiography with hilly terrain and mountainous slope, with 2400-3600 m altitude, moderate annual rainfall (1894-1996 mm), moderate snowfall (215-1736 mm), high relative humidity (62-87%), moderate air temperature (5-11^{0}C), high wind velocity (1-5 km hr^{-1}) and moderate to high light intensity (20500-88400 Lux) have been responsible for the distribution of *A. maling* in this area. Soil physico-chemical parameters like moderate to low mean soil temperature (2-8^{0}C), high soil moisture content (40-52%), high water holding capacity (54-65%), low bulk density (0.20-0.40 g cm^{-3}) with high porosity (84-92%), moderately acidic soil with pH 5.26-5.46, higher level of soil total nitrogen (0.41-0.88%), available phosphorus (6-8.82 µg g^{-1}), soil total potassium (0.052%) and soil organic carbon (6.36-9.93%) are conducive for the distribution and growth of *A. maling* at Jang area (Chapter III). Such types of limiting factors for the distribution of many bamboo species have been reported by several workers (Yadav 1964, 1969, Uchimura 1978, 1981, Chung and Ramm 1990, Tewari *et al.* 1994, Wang *et al.* 1998).

Due to the long intermast period with long flowering and fruiting cycle, regeneration of bamboo species including *A. maling* takes place through subterranean rhizomes. The long intermast period is considered to be one of the most important limiting factors resulting in restricted distribution of *A. maling.* Anthropogenic pressures like human interference by land encroachment for construction and agricultural practices, road construction, mass harvest for fuel and fodder, and grazing of new shoots by domestic animals from the periphery of the forest also resulted in the restricted distribution and growth of the species (Plate 9). The reports available on flowering of *A. maling* are not sufficient to predict its flowering cycle. The period of gregarious flowering so far reported from Sikkim and West Bengal (Darjeeling) did not match, and it also differed from that of other parts of Arunachal Pradesh, where *A. maling* occurs. The information gathered through this study could provide an idea of its flowering and fruiting nature. After sixty-two years of gregarious flowering with a long intermast period, *A. maling* has initiated sporadic flowering at Jang area of Tawang District of Arunachal Pradesh. The initiation of sporadic flowering in bamboo is considered to be a symptom of the forthcoming gregarious flowering (Banik 1989). Sporadic flowering occurred at the high elevation site during the study period, which resulted in the production of some viable seeds, which could not germinate in natural habitat on account of unsuitable micro-climatic condition

Plate 9. Anthropogenic threats – (A and B) Mass harvest of 'Rui' bamboo for the use in road construction, (C) Grazing and destruction of tender shoots by domestic animal (Yak), and (D) Land slide and erosion of soil as well as 'Rui' bamboo due to road construction inside the bamboo forest.

particularly the prevailing low soil temperature.

4.3 GROWTH PERFORMANCE AND POPULATION STRUCTURE OF *A. MALING*

Growth and population structure of *A. maling* at the three elevation sites in Jang bamboo forest was studied by determining the culm height, diameter at breast height (DBH), internode length, basal area, clump area, clump density and number of new shoots produced per unit area. Influence of elevation and site characteristics like climate and soil on the growth of *A. maling* was also analysed. The study was carried out during April 2001-April 2003 at three months interval. Three belt transects of 300 m length and 30 m width were laid down in each of the three elevation sites along the altitudinal gradient (2400-3600 m asl), one each at the northern and southern part and one in the middle of the *A. maling* forest (Figure 3.1b). Within each belt, three quadrats each of 30 m x 30 m were laid randomly at the three elevation sites covering the base, middle and the top of the bamboo forest of each elevation site. Two clumps in each quadrat were permanently earmarked for studying the temporal changes in population structure and growth performance of *A. maling*. Number of *A. maling* individuals of different ages viz., <1yr. old (new) and ≥1yr. old (old) was found out by counting the available stock in the earmarked clumps in the permanent quadrats at each elevation site. The number of individuals extracted by the local people was estimated by counting the bamboo individuals lost from these clumps. Diameter of eighteen randomly selected clumps was recorded for each elevation site. During the shoot emergence period (*i.e.*, during the last week of June 2001), new shoots that had developed from the fifty-four earmarked clumps and had similar emergence time, were tagged. A total of eighteen randomly selected new bamboo individuals (<1yr. old) were harvested from the ground level from the earmarked clumps of each elevation site. Measurements on height, diameter at breast height (DBH), basal diameter and internode length were made at three months interval beginning at the age of one month, and presented on the basis of culm age (in months) for two consecutive years. Further, these harvested individuals were used for the determination of dry matter content (Chapter V), and N, P and K distribution and accumulation studies in *A. maling* (Chapter VI). Leaves were produced after one year of shoot emergence. Hence, leaves for area measurement were sampled during July 2003 from the bamboo individuals of two age groups *i.e.*, 2 years and three years old, bearing one year and two years old leaves respectively. From each elevation site, fifty leaves were randomly sampled from the top, middle and lower canopy from randomly selected new and old culms of a clump. Three such replicates were maintained in each elevation site. Leaf area was measured using portable leaf area meter (LICOR 3000A). Total leaf area per culm as well as per clump was worked out by leaf area and leaf weight method. Leaf area index (LAI) was calculated using total leaf area and clump area (ground area) on per clump basis.

Multi-way analysis of variance was done to compare the data on growth parameters and population structure of *A. maling* growing in the three elevation sites. Linearized curvilinear regression model (Woodwell and Whittaker 1968) was applied to prepare regression plots and to generate logarithmic regression equations between the culm age versus culm height and DBH. Simple-linear regression equations for height versus DBH classes of all the three-elevation sites, and equations considering low to high elevation sites were also established. To understand the influence of climatic variables and soil physico-chemical parameters on growth of *A. maling*, correlation and simple linear regression analyses were done through SYSTAT software version-6.

4.3.1 Growth performance of *A. maling* in Jang bamboo forest

The culm height, DBH, basal area and internode length of *A. maling* revealed that, this bamboo species also follows the logarithmic growth, as reported in other bamboo species (Shanmughavel and Francis 2001). Most of the height, DBH, basal area and internode length was achieved during the first three months of growth. Table 4.1 depicts the clump characteristics and culm density of *A. maling* at the three elevation sites of Jang bamboo forest.

Culm height

Culm height was significantly different among the three elevation sites ($F = 25217.56$, $P < 0.001$), among culm age ($F = 2960.12$, $P < 0.001$) as well as among the same age group at different elevation sites ($F = 74.02$, $P < 0.001$). The culms were significantly taller at the medium elevation site as compared to the low and high elevation sites. 66% of the culm height achievable at the age of 24 months was achieved at the age of one month at the medium elevation site, whereas at the high and low elevation sites it was 61% and 59% respectively. The culms at the medium elevation site achieved 99% of the total height at the age of three months and no significant height increment was recorded during the rest twenty-one months of the study period. At the high elevation site, 89% of the total culm height was achieved by the age of three months, and it gradually increased until the age of twenty-four months to reach the optimum height. At the low elevation site, it could

Table 4.1. Clump characteristics and culm density of *Arundinaria maling* Gamble at the three elevation sites in the Jang bamboo forest (Mean ± SE).

Parameters	Low elevation	Medium elevation	High elevation
No. of clumps/ quadrat*	28.0 ± 0.6	18.0 ± 0.7	14.1 ± 0.5
No. of clumps/ ha	311 ± 6.3	200 ± 7.9	156 ± 5.8
Clump diameter (m)	4.95 ± 0.2	5.56 ± 0.1	3.36 ± 0.1
Clump area (m^2)	19.22 ± 1.6	24.23 ± 0.7	8.87 ± 0.7
No. of new shoots/ clump	59.2 ± 1.8	115.2 ± 2.5	19.3 ± 1.4
No. of new shoots/ quadrat*	1,658 ± 1.4	2,063 ± 79.8	263 ± 18.1
No. of new shoots/ ha	18,431 ± 716.7	22,931 ± 886.2	2,928 ± 201.5

*Size of quadrat = 30m x 30 m.

achieve 87% of the total height at the age of three months (Fig. 4.1). Logarithmic relationship between the culm age and culm height along with regression equations of *A. maling* at the three individual elevation sites are presented in Fig. 4.2 and 4.3. The entire slope as well as intercept values are significant ($P < 0.001$) and the mean values lie significantly on the log curve or nearest to the curve ($P < 0.001$). Among the climatic variables, annual rainfall, air temperature and light intensity had significant positive influence on height growth of *A. maling*, whereas snowfall and wind velocity had significant negative influence. Rainfall alone accounted for 81% of the variation in culm height, whereas 51% was influenced by snowfall, 87% by wind velocity and 14-19% by air temperature (Table 4.2). All the soil physical parameters studied had significant influence on the growth of *A. maling*. Soil moisture content at 0-10 cm and 10-20 cm depth accounted for 94% variation, while bulk density at the same depth influenced 78% and 83% variation in culm height. Water holding capacity at 10-20 cm and 20-30 cm depth influenced 48% and 45% variation in culm height respectively. 79% variation in culm height was accounted by sand and silt particles on surface and subsurface soil whereas clay content influenced 80% variation (Table 4.3). Among the soil chemical components studied, soil available phosphorus at 0-10 cm depth and soil organic carbon content at all the three soil depths accounted for 99% variation in culm height growth. Soil pH at 10-20 cm and 20-30 cm depth influenced 97% and 76% variation respectively, while soil total nitrogen content at 10-20 cm accounted for 10% variation in culm height. Soil potassium content and C/N ratio at 20-30 cm depth also influenced culm height growth (Table 4.4).

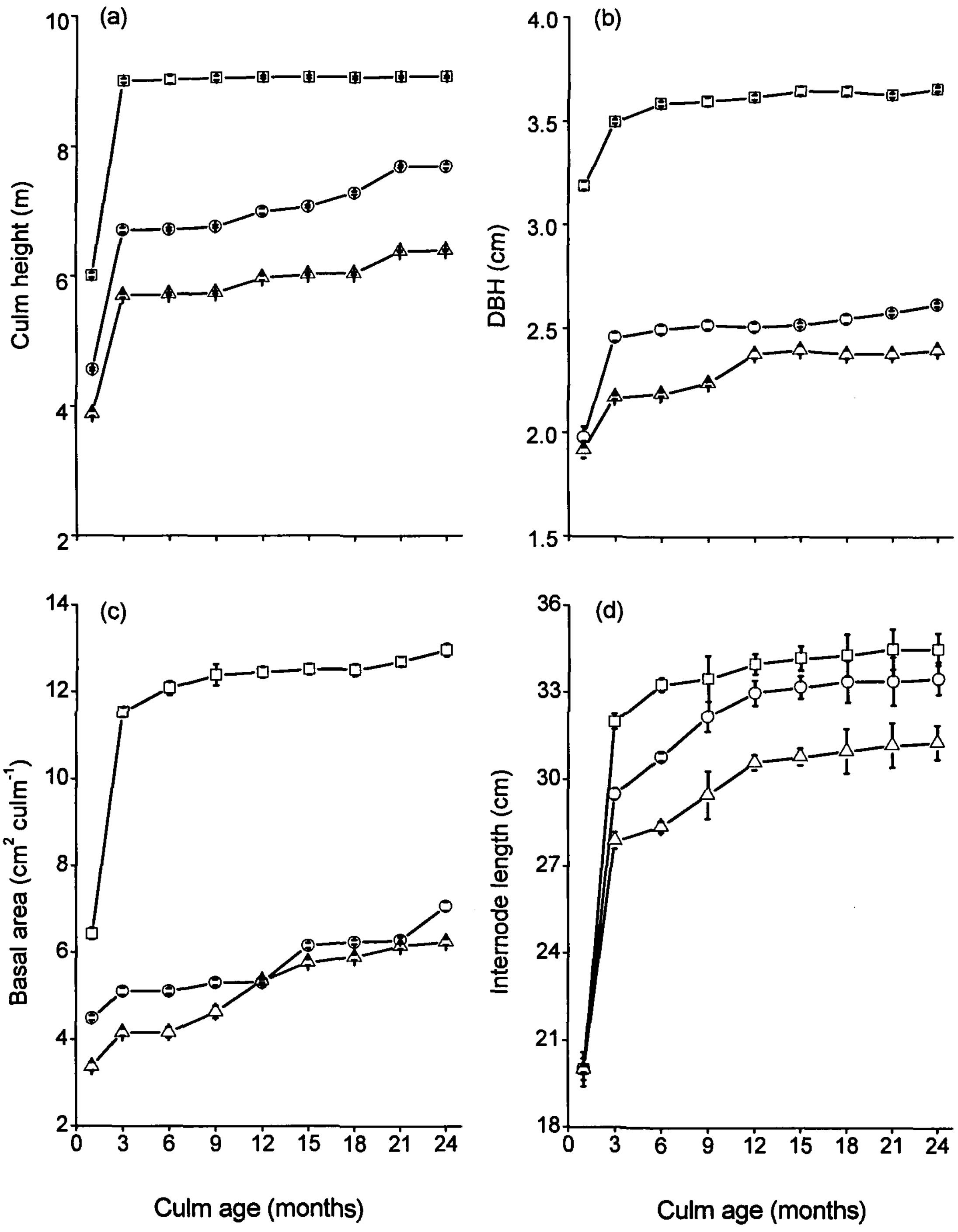

Figure 4.1. Culm height (a), DBH (b), basal area (c) and internode length (d) of *A. maling* at different culm age at the low (-O-), medium (-□-) and high (-△-) elevation sites. Vertical line bars indicate ± SE.

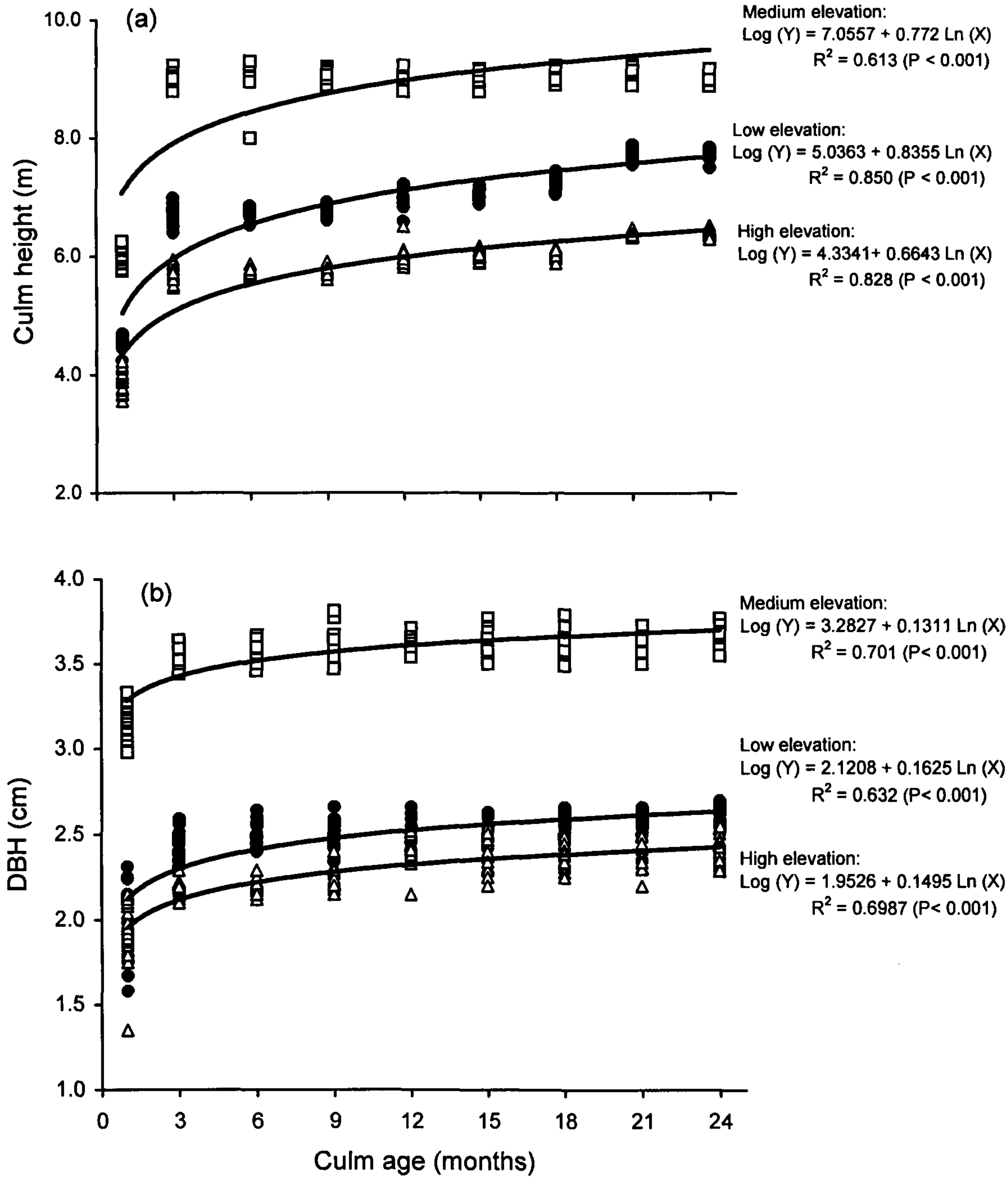

Figure 4.2. Logarithmic relationship between culm age with culm height (a) and DBH (b) of each elevation site. The degrees of freedom in each case are 160.

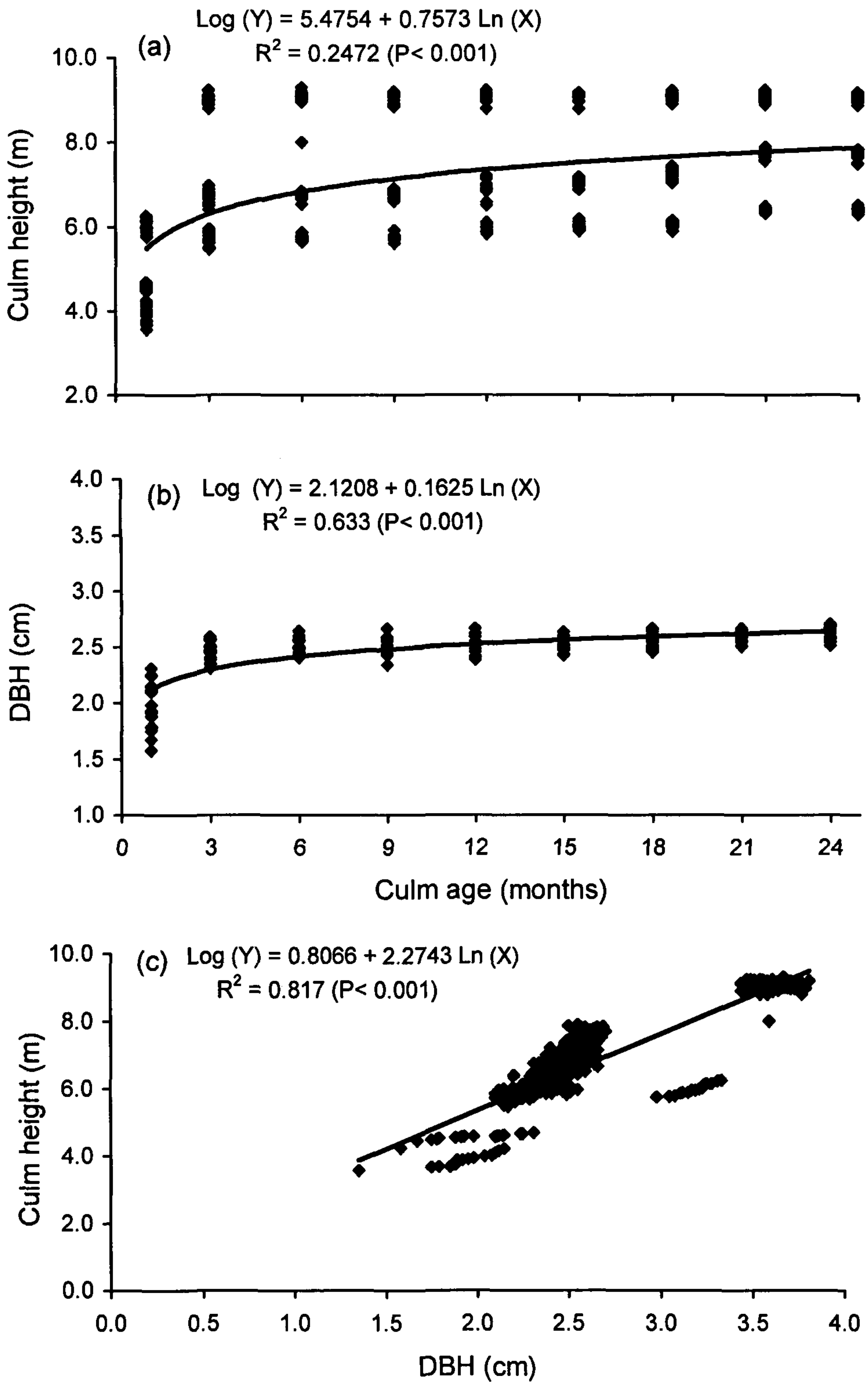

Figure 4.3. Logarithmic relationship between culm age with culm height (a), culm age with DBH (b) and linear relationship between DBH and culm height (c) of *A. maling*, considering all the three elevation sites (Degrees of freedom in each case = 484).

Table 4.3. Influence of soil physical parameters on the growth performance of *A. maling.*

Growth parameters	Soil depth (cm)	Soil moisture		Bulk density		Water holding capacity		Sand (%)		Silt (%)		Clay (%)		Soil temperature	
		R^2	F	R^2	F	R^2	F	R^2	F	R^2	F	R^2	F	R^2	F
Culm height	0-10	0.943	845.68*	0.776	179.73*	0.295	21.72*	0.789	194.50*	0.788	193.30*	0.802	210.50*	0.234	15.90*
	10-20	0.947	935.20*	0.825	244.77*	0.483	227.23*	0.790	195.57*	0.789	194.48*	0.806	215.94*	0.342	26.99*
	20-30	0.674	107.75*	0.551	63.93*	0.444	41.52*	0.712	128.77*	0.760	164.67*	0.114	6.67**	0.382	32.09*
	0-30	0.886	402.53*	0.731	141.29*	0.822	240.48*	0.770	174.33*	0.779	183.22*	0.523	56.96*	0.314	23.75*
DBH	0-10	0.975	2035.8*	0.447	42.10*	0.626	86.95*	0.972	1825.07*	0.972	1824.5*	0.976	2119.76*	0.026	1.37^{NS}
	10-20	0.973	1841.4*	0.509	53.93*	0.495	50.92*	0.973	1844.21*	0.962	1330.3*	0.977	2223.30*	0.076	4.30**
	20-30	0.924	629.08*	0.223	14.96*	0.141	8.53**	0.942	850.64*	0.969	1628.4*	0.400	34.68*	0.100	5.77**
	0-30	0.988	4297.9*	0.396	34.12*	0.506	53.20*	0.966	1481.48*	0.976	2119.7*	0.828	249.53*	0.061	3.39^{NS}
New shoot production	0-10	0.939	797.74*	0.684	112.68*	0.355	28.67*	0.820	236.20*	0.819	234.81*	0.830	254.58*	0.166	10.34**
	10-20	0.942	841.57*	0.737	145.63*	0.725	137.07*	0.820	237.44*	0.820	236.17*	0.834	260.79*	0.261	18.36*
	20-30	0.720	133.42*	0.458	43.92*	0.355	28.65*	0.753	158.73*	0.795	201.39*	0.162	10.06**	0.297	22.01*
	0-30	0.898	457.04*	0.638	91.48*	0.734	143.56*	0.804	212.73*	0.811	223.11*	0.580	71.67*	0.236	16.03*
Clump area	0-10	0.540	60.97*	0.640	92.37*	0.073	4.09**	0.389	33.08*	0.388	32.96*	0.400	34.61*	0.315	23.93*
	10-20	0.546	62.45*	0.658	99.83*	0.654	98.218*	0.390	33.18*	0.389	33.07*	0.403	35.11*	0.396	34.14*
	20-30	0.300	22.25*	0.530	58.77*	0.465	45.248*	0.328	25.35*	0.365	29.88*	0.007	0.54^{NS}	0.424	38.29*
	0-30	0.477	47.35*	0.621	85.33*	0.657	99.459*	0.373	30.97*	0.380	31.92*	0.198	12.80**	0.376	31.34*

*, **- Significant at < 0.001 and < 0.05 probability level respectively. NS - values are not significant.

Table 4.4. Influence of soil chemical parameters on the growth performance of *A. maling.*

Growth parameters	Soil depth (cm)	Soil pH		Total Nitrogen		Available phosphorus		Potassium		Organic carbon		C/N ratio	
		R^2	F	R^2	F	R^2	F	R^2	F	R^2	F	R^2	F
Culm height	0-10	0.479	47.85*	0.075	4.19**	0.988	4419.98*	0.000	0.00^{NS}	0.984	3275.54*	0.013	0.67^{NS}
	10-20	0.971	1715.79*	0.102	5.92**	0.314	23.75*	0.015	0.00^{NS}	0.993	7701.97*	0.007	0.38^{NS}
	20-30	0.760	164.67*	0.050	2.73^{NS}	0.001	0.07^{NS}	0.499	51.88*	0.993	7139.14*	0.119	7.03**
	0-30	0.798	205.76*	0.076	4.27**	0.349	27.93*	0.234	15.90*	0.993	7220.14*	0.037	1.98^{NS}
DBH	0-10	0.794	200.90*	0.004	0.23^{NS}	0.919	587.63*	0.000	0.00^{NS}	0.930	689.40*	0.193	12.46**
	10-20	0.953	1050.90*	0.000	0.02^{NS}	0.645	94.60*	0.124	7.34**	0.856	309.05*	0.172	10.80**
	20-30	0.962	1330.30*	0.014	0.73^{NS}	0.090	5.15**	0.182	11.54**	0.898	456.80*	0.408	35.88*
	0-30	0.975	2030.73*	0.004	0.217^{NS}	0.681	110.93*	0.026	1.37^{NS}	0.897	453.71*	0.260	18.23*
New shoot production	0-10	0.538	60.57*	0.038	2.03^{NS}	0.961	1270.37*	0.009	0.45^{NS}	0.960	1256.04*	0.035	1.87^{NS}
	10-20	0.955	1105.49*	0.052	3.21^{NS}	0.375	31.15*	0.408	35.81*	0.950	978.58*	0.026	1.36^{NS}
	20-30	0.795	201.39*	0.021	1.10^{NS}	0.002	0.08^{NS}	0.166	10.34**	0.959	1219.21*	0.168	10.51**
	0-30	0.827	249.16*	0.034	2.08^{NS}	0.411	36.26*	0.000	0.00^{NS}	0.959	1216.53*	0.069	3.86^{NS}
Clump area	0-10	0.171	10.73**	0.168	10.47**	0.613	82.53*	0.000	0.00^{NS}	0.604	79.27*	0.011	0.59^{NS}
	10-20	0.579	71.40*	0.197	12.76**	0.082	4.64**	0.034	1.83^{NS}	0.650	96.55*	0.017	0.87^{NS}
	20-30	0.365	29.88*	0.138	8.34**	0.052	2.85^{NS}	0.500	51.95*	0.628	87.92*	0.008	0.44^{NS}
	0-30	0.397	34.17*	0.169	10.58**	0.100	5.75**	0.315	23.93*	0.629	88.07*	0.002	0.084^{NS}

★, ★★- Significant at < 0.001 and < 0.05 probability level respectively. NS - values are not significant.

Table 4.2. Influence of climatic variables on the growth performance of *A. maling*.

Growth parameters	Temperature (max)		Temperature (min)		RH		Rainfall		Snowfall		Wind velocity		Light intensity	
	R^2	F- Value	R^2	F- Value	R^2	F- Value	R^2	F- Value	R^2	F- Value	R^2	F- Value	R^2	F- Value
Culm height	0.140	8.470**	0.198	12.822**	0.015	0.809^{NS}	0.809	220.048*	0.509	53.948*	0.869	345.739*	0.098	5.629**
DBH	0.002	0.083^{NS}	0.014	0.718^{NS}	0.047	2.574^{NS}	0.488	49.647*	0.189	12.144**	0.571	69.267*	0.375	31.177*
New shoot production	0.088	4.987**	0.135	8.112**	0.002	0.107^{NS}	0.720	133.496*	0.417	37.236*	0.7861	90.993*	0.144	8.721**
Clump area	0.234	15.888*	0.285	20.750*	0.087	4.976**	0.652	97.484*	0.506	53.207*	0.670	105.747*	0.004	0.209^{NS}

★, ★★- Significant at < 0.001 and < 0.05 probability level respectively.
NS - values are not significant.

Culm diameter at breast height (DBH) and basal area

Figure 4.1b shows the culm diameter at breast height at different ages of *A. maling* in the Jang bamboo forest. The culms at the medium elevation site had significantly larger DBH (F= 10744, P< 0.001) and basal area per culm (F= 9743, P< 0.001). DBH and basal area among the different age groups at the same elevation site were significantly different (195.29, P< 0.001; F= 407.43, P< 0.001, respectively). It was also significantly different among the same age group at different elevation sites (F= 5.394, P< 0.001; F= 407.43, P< 0.001, respectively). During the peak growth phase (*i.e.*, 10-90 days after new shoot emergence), at the age of one month, 87% of the DBH of 24 months old culm was achieved at the medium elevation site. It was followed by the high elevation site with 80% and the low elevation site with 76%. By the age of three months, DBH achieved by the culms at the medium, low and high elevation sites respectively was 96%, 94% and 90% of that achieved by the two yr. old culms. There was a very slow increase in DBH at all the three elevation sites during the rest twenty-one months of the study period. More than 70% of the basal diameter achieved by the two yr. old culms was achieved at the age of one month and more than 82% at the age of three months. Logarithmic relationship between culm age and culm DBH along with regression equations of *A. maling* at the three elevation sites is presented in Figure 4.2b. The regression equations considering all the three elevation sites were also worked out together and are presented in Fig. 4.3b. The entire slope as well as intercept values are significant (P< 0.001) and the mean values lie significantly on the log curve or nearest to the curve (P< 0.001). Regression analyses revealed that among the climatic variables studied, annual rainfall and light intensity accounted for 50% and 38% variation in DBH respectively, whereas snowfall and wind velocity had 19% and 57% influence, respectively (Table 4.2). Except soil temperature at the surface soil, all other soil physical parameters studied had significant influence on the variation of DBH of *A. maling* at Jang area. Soil moisture, sand, silt and clay content at all the three soil depths accounted for 97% variation in DBH, while bulk density and water holding capacity at 10-20 cm depth influenced 50% variation (Table 4.3). Among the soil chemical parameters studied, soil pH at 10-20 cm and 20-30 cm depth accounted for 95% variation in DBH, while 91% and 65% variation was influenced by soil available phosphorus at 0-10 and 10-20 cm depth respectively. Soil potassium content at 10-20 cm and 20-30 cm depth accounted for 12% and 18% variation in DBH, whereas 93%, 86% and 90% variation in DBH was influenced by soil organic carbon content at 0-10, 10-20 and 20-30 cm, respectively. The C/N ratio at the 20-30 cm depth accounted for 38% variation in DBH (Table 4.4).

Figure 4.3 depicts the linear relation between the culm DBH and culm height of *A. maling* growing at Jang area. The slopes as well as the intercept values are significant ($P < 0.001$) and the mean values lie on the line or distributed nearest to the line ($P < 0.001$).

Basal area per culm of *A. maling* differed significantly among the different sites ($F = 9743.869$, $P < 0.001$), age groups ($F = 407.439$, $P < 0.001$) and at different sites within same age groups ($F = 55.478$, $P < 0.001$). It was highest at the medium elevation site followed by the values at the low elevation and high elevation sites (Fig. 4.1c).

Internode length

Figure 4.1d shows the differences in the length of internode and the mode of increment in culms of different ages at the three elevation sites. The length of internode was also significantly different among the elevation sites and longest internode was recorded at the medium elevation site (F= 89.03, P< 0.001). It was also significantly different among the different age groups (F= 188.5, P< 0.001) and among the same age group at different elevation sites (F= 1.885, P< 0.05). More than 58% of the internode length achieved by the 24 months old culm was achieved at the age of one month and 88-92% at the age of three months.

Clump density

Number of clumps per quadrat (30 m x 30 m) was significantly greater (F= 137.15, P< 0.001) at the low elevation site, and it declined with the increase in elevation. Statistical analysis revealed that the climatic variables like relative humidity, air temperature and annual rainfall had significantly strong positive correlation with clump density (r = 0.909, 0.912 and 0.599 respectively, P< 0.001), while snowfall, wind velocity and light intensity had significant negative correlation (r = -0.790, -0.538 and -0.767 respectively, P< 0.001). Soil temperature and WHC had significant positive correlation with clump density (r = 0.868 and 0.586, P< 0.001), while bulk density had significant negative correlation (r = -0.661, P< 0.001). Among the soil chemical parameters, soil nitrogen at all the three depths had strong positive correlation (r = 0.918, P< 0.001) with the clump density (Table 4.1).

Clump area

Clump area at the three elevation sites was significantly different

(F= 53.77, P< 0.001); clumps at the medium elevation site showing larger area than at the low and high elevation sites (Table 4.1). Regression analyses revealed that 65% of the variation in clump area was accounted by annual rainfall, 51% by snowfall, 67% by wind velocity and 26% by air temperature (Table 4.2). Soil physical parameters like moisture content, bulk density, water holding capacity, soil texture and soil temperature had significant influence on the clump size (Table 4.3). Bulk density alone accounted for 64% of the variation in clump size in the 0-10 cm soil depth, 66% in the 10-20 cm and 53% in the 20-30 cm soil depth. Soil moisture content attributed 54% variability in clump size in the 0-10 cm depth, 55% in the 10-20 cm and 30% in the 20-30 cm soil depth. Water holding capacity also influenced 65% variation in the 10-20 cm soil depth and 47% in the 20-30 cm depth. Soil organic carbon was found to have a highly significant effect. It attributed 60% of variability in clump size in the 0-10 cm soil depth, 65% in the 10-20 cm and 62% in the 20-30 cm soil depth. Soil available phosphorus in the surface soil accounted for 61% variation, soil potassium 50% in the 20-30 cm depth, soil nitrogen 19% in the 10-20 cm depth and by soil pH at the 10-20 cm depth accounted for 58% variability in the clump size of *A. maling* (Table 4.4).

Production of new shoots

Table 4.1 depicts the new shoot production pattern at the three elevation sites. The rate of annual young shoot production was significantly different among the three elevation sites (F= 269.95, P< 0.001). The highest number of young shoots per clump was produced at the middle elevation site and lowest at the high elevation site. Although the clump density was significantly higher at the lower elevation site, the number of young shoots produced per hectare per year was significantly higher at the medium elevation site (F= 246.617, P< 0.001). Annual rainfall, snowfall and wind velocity accounted for 72%, 42% and 79% of the variation respectively in the annual young shoot production. Influence of light intensity and minimum air temperature were also observed to explain 14% variability in new shoot production (Table 4.2). All the soil physical parameters studied had significant influence on the production of new shoots. Soil moisture content at 0-10 cm and 10-20 cm depth accounted for 94% and moisture content at the 20-30 cm depth influenced 72% of the variation. Bulk density at 0-10 cm, 10-20 cm and 20-30 cm soil depth accounted for 68%, 74% and 46% variability, while water holding capacity at 0-10 cm and 20-30 cm soil depth influenced 36% each, whereas 10-20 cm depth accounted for 73% variation. 82% variation in new shoot production could be explained by sand and silt content at 0-10 and 10-20 cm depth, while 83% variation was influenced by clay (Table 4.3). The influence of soil chemical parameters is presented in Table 4.4. Soil organic carbon alone explained 96% of variation in new shoot production in all the three soil depths. Available soil phosphorus in 0-10 cm and 20-30 cm depth accounted for 96% and 38% variation in shoot production, while 41% was influenced by soil potassium at 10-20 cm soil depth. Soil pH influenced 96% variability in the new shoot production at 10-20 cm depth, 80% at 20-30 cm depth and 54% at 0-10 cm depth.

Leaf area and leaf area index (LAI)

Mean leaf area per leaf, number of leaf per culm as well as leaf area index (LAI) were observed to be significantly different among the three elevation sites (F= 35.23, P< 0.001 and F= 94.49, P< 0.001). The mean maximum leaf area (15.67 cm^2/ leaf) was observed at the medium elevation site followed by the low elevation (10.95 cm^2/ leaf) and high elevation site (9.19 cm^2/ leaf). LAI at the medium elevation site was also observed to be significantly greater (7.98) than at the low (4.11) and high elevation site (1.99).

4.3.2 Variation in population structure of *A. maling* in Jang bamboo forest

Figure 4.4 & 4.5 depicts the population structure of *A. maling* of <1yr. old (new), ≥1yr. old (old) and number of individuals extracted during different sampling period at Jang bamboo forest. Population of new individuals per clump as well as per hectare was significantly different at the three elevation sites ($F = 32.684$ and 32.310, $P < 0.001$ respectively), but it did not differ with the sampling periods. As the new shoots are produced during June-July, the highest population of <1yr. old individuals was observed during July at all the three elevation sites and it gradually declined afterwards of the yr. and the lowest population was observed during April at all the three elevation sites. During the year 2001-2002, maximum population of <1yr. old was observed at the medium elevation site with 95 individuals per clump (19,000 individuals ha^{-1}), followed by the low elevation site with 49 individuals per clump (15,301 individuals ha^{-1}) and lowest at the high elevation site with 12 individuals per clump (1,872 individuals ha^{-1}). During the year 2002-2003, the population of <1yr. old individuals increased to 69 individuals per clump (21,583 individuals ha^{-1}), 135 individuals per clump (27,000 individuals ha^{-1}) and 26 individuals per clump (4,056 individuals ha^{-1}) at the low, medium and high elevation sites, respectively. The variation in population of ≥1yr. old individuals per clump as well as per hectare was also significantly different at different elevation sites ($F = 86.353$ and 128.027, $P < 0.001$), but it did not vary

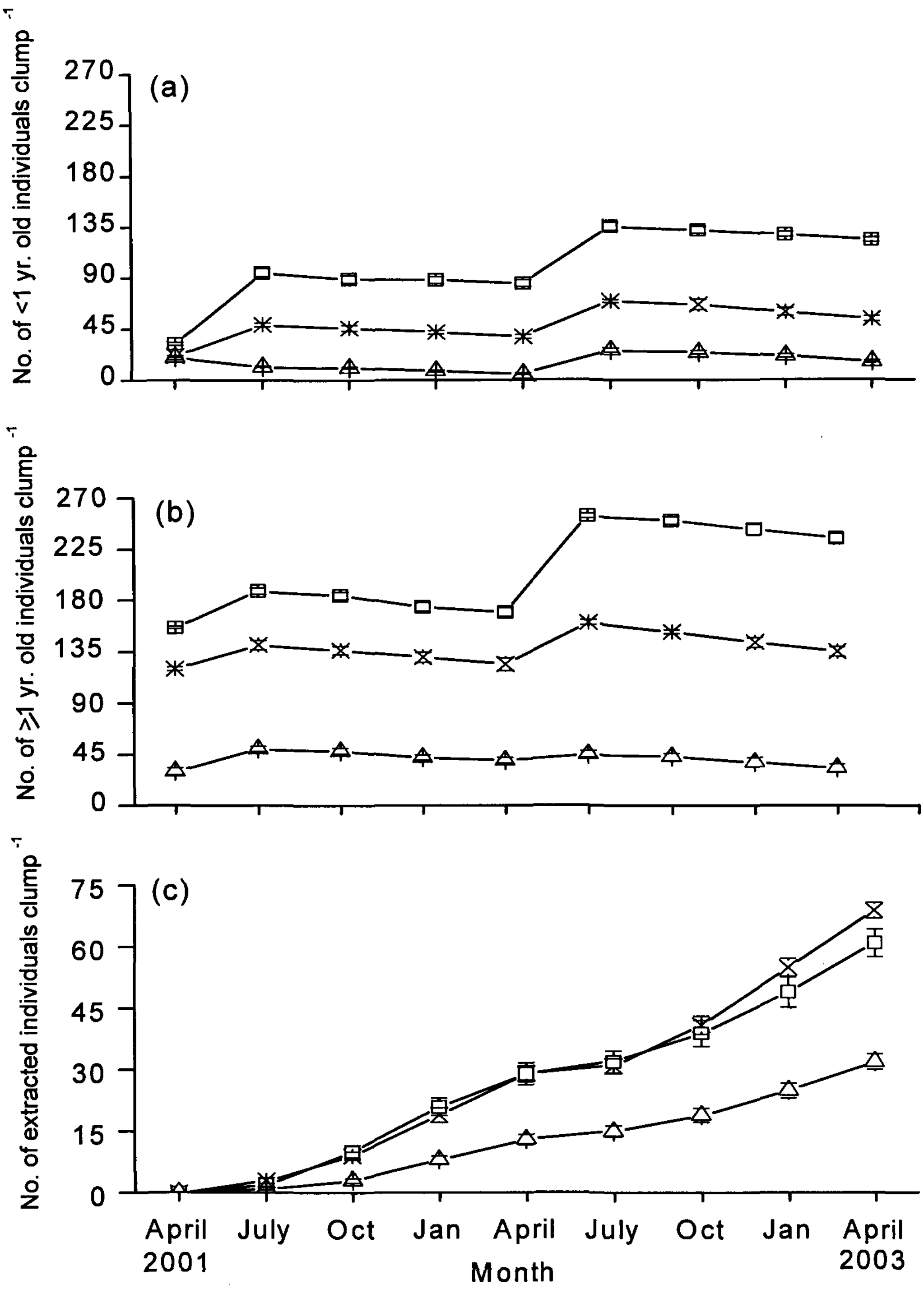

Figure 4.4. Temporal variation in population (No. of individuals clump^{-1}) of <1yr. old (a), ≥1yr. old (b) and individuals extracted (c) at the low (-✕-), medium (-□-) and high (-△-) elevation sites. Vertical line bars represent ± SE.

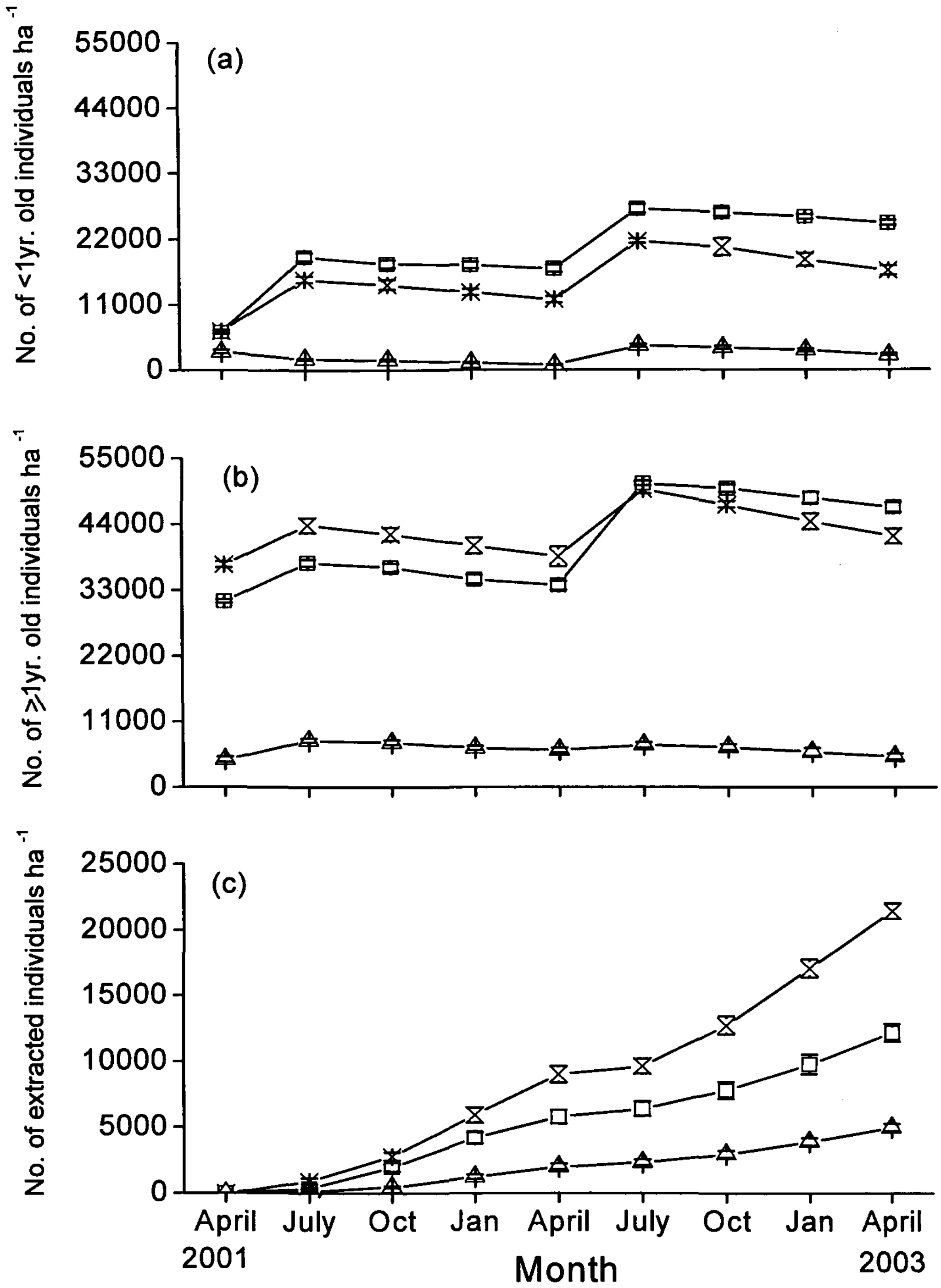

Figure 4.5. Temporal variation in population (No. of individuals ha^{-1}) of <1yr. old (a), ≥1yr. old (b) and individuals extracted (c) at the low (-X-), medium (-□-) and high (-△-) elevation sites. Vertical line bars represent ± SE.

significantly at different sampling periods. Highest population of ≥1yr. old individuals was observed during July at all the three elevation sites, and it gradually declined during the consecutive sampling periods. During the study period, population of ≥1yr. old individuals per clump was higher at the medium elevation site followed by low and high elevation sites throughout the sampling periods with 188, 141 and 50 individuals per clump during 2001-2002. It increased considerably during 2002-2003 with 160, 254 and 45 individuals per clump at the low medium and high elevation sites. Population of ≥1yr. old individuals per hectare was significantly high at the low elevation site ($F = 128.027$, $P < 0.001$) throughout the sampling periods during 2001-2002, whereas during 2002-2003, the population of ≥1yr. old individuals was highest at the medium elevation site (Fig. 4.4 & 4.5). During the first year, maximum population at the low, medium and high elevation sites was 43,851, 37,600 and 7,800 individuals per hectare, respectively. It increased considerably during 2002-2003 with 49,760, 50,800 and 7,020 individuals per hectare respectively at the low, medium and high elevation sites. The cumulative population of extracted bamboo individuals is also presented in Figure 4.4 & 4.5. It was significantly different at the three elevation sites ($F = 35.597$, $P < 0.001$) and sampling periods ($F = 16.708$, $P < 0.001$). At the low elevation site, the rate of extraction of bamboo individuals was significantly higher compared to that of medium and high elevation sites ($F = 35.597$, $P < 0.005$). It was also significantly different at different sampling periods ($F = 16.708$, $P < 0.001$). Lowest rate of extraction was observed at the high elevation site throughout the sampling periods.

Table 4.5 depicts the population flux of *A. maling* at different

Table 4.5. Population flux of *Arundinaria maling* at different elevation sites in Jang bamboo forest during the year 2001-2003 (Mean ± SE).

Parameters per hectare basis	Low elevation	Medium elevation	High elevation
No. of individuals at the beginning of the study	43851 ± 746	37600 ± 540	7800 ± 746
No. of individuals produced during the study period	36822 ± 933	46000 ± 1460	5928 ± 374
No. of individuals extracted	21459 ± 591	12200 ± 680	4992 ± 296
No. of individuals recorded at* the end of the study period	61982 ± 2364	73200 ± 1360	9984 ± 874
No. of individuals recorded** during the study period	80673 ± 1679	83600 ± 2000	13728 ± 1120
Net change***	18131 ± 1618	35600 ± 820	2184 ± 128
% Annual harvest****	13.3	7.3	18.2
Growth index of population*****	0.84	1.22	0.76

*No. of individuals recorded at the end of the study period =
[{No. of individuals at the beginning of the study} + {Number of individuals produced during the study period}] – {No. of individuals extracted}

** No. of individuals recorded during the study period =
{No. of individuals at the beginning of the study} + {Number of individuals produced during the study period}

*** Net change =
{No. of individuals recorded at the end of the study period} – {No. of individuals at the beginning of the study}

**** % Annual harvest = $\dfrac{\text{No. of individuals extracted X 100}}{\text{No. of individuals recorded during the study period X 2}}$

***** Growth index of population = $\dfrac{\text{No. of individuals produced during the study period}}{\text{No. of individuals at the beginning of the study}}$

elevation sites of Jang bamboo forest over a period of two years i.e., from 2001 to 2003. The number of bamboo individuals at the beginning of the study was highest at the low elevation site with 43,851 individuals per hectare followed by the medium and high elevation sites with 37,600 and 7,800 individuals per hectare respectively, whereas the number of individuals produced during the study period was greater at the medium elevation site with 46,000 individuals per hectare, followed by low and high elevation sites with 36,822 and 5,928 individuals respectively. Total number of culms extracted during the two-year period was maximum at the low elevation site with 21,459 individuals per hectare, followed by the medium and high elevation sites with 12,200 and 4,992 individuals, respectively. Total number of individuals recorded at the end of the study period was highest at the medium elevation site with 73,200 individuals per hectare, which was followed by the low and high elevation sites with 61,982 and 9,984 individuals, respectively. The net change was maximum at the medium elevation site with 35,600 individuals per hectare, which was followed by the low and medium elevation sites having 18,131 and 2,184 individuals respectively. The percent annual harvest was observed to be highest at the high elevation site followed by the low elevation site and medium elevation site (Table 4.5). The growth index of population was higher at the medium elevation site with 1.22 followed by the low and high elevation sites with 0.84 and 0.76, respectively.

4.4 DISCUSSION

Unlike trees, where extension and radial growth are continuous activities throughout the life cycle of the species, in bamboos, these activities mostly occur in the initial phase of ramet production. Higher the length number of internode, taller is the culm. The fast growing phase in *A. maling* ('Rui' bamboo) was limited to 3-4 months, which is similar to that of other tropical and subtropical bamboo species reported so far (Liese and Wiener 1995, Chua *et al.* 1996). The height increment of *A. maling* was almost terminated after the age of 21 months at all the elevation sites as is the case with other bamboo species (Londoño 1992). It is presumed that under the agro-climatic conditions prevailing in Jang area, *A. maling* can attain its maximum height at the age of 24 months. Statistical analyses of the data revealed significant influence of most of the climatic and soil parameters on growth performance of *A. maling*. Better growth performance in terms of height and diameter growth was observed at the medium elevation site in the Jang area, which may be due to the suitable climatic conditions and soil physico-chemical characteristics of the area. Among the climatic variables, higher annual rainfall (1996 mm), moderate air temperature (mean maximum 16^0C and mean minimum 0^0C), low wind velocity (2.84 km hr^{-1}), moderate relative humidity (66%), annual snowfall (581 mm) and higher light intensity (88400 Lux) are the most important parameters favouring the growth of 'Rui' bamboo at the medium elevation site. Many workers have reported that distribution as well as growth of bamboo is highly influenced by annual precipitation (Koyama and Uchimura 1995, Biswas 1988). Qiu *et al.* (1992) established a highly significant relationship between annual precipitation and annual timber yield for *Phylostachys pubescens* in China. Kigomo and Kamiri (1985) found a similar functional dependency for *Oxytenanthera abyssinica* in Kenya. Aggarwal *et al.* (1994) and Lin (1995) reported that irrigation promotes shoot and culm growth when rainfall is insufficient. High wind velocity had significant negative influence on growth of *A. maling* at the low and high elevation sites, whereas low wind velocity at the medium elevation site had positive influence on its growth in Jang area. It may partially be due to the constant removal of water from the plant tissues, which leads to less expansion of cell walls in the absence of turgidity and increased rate of transpiration by quick removal of humid air layer just above the leaf surface (Numata 1987, Zhou *et al.* 1991, Ambasht and Ambasht 1999). The overall effect of smaller size of cells is to bring about decreased total height and DBH of plant (Ambasht and Ambasht 1999). Whitehead (1956) has also demonstrated experimentally that wind limits the growth of plants in exposed mountain locations. Influence of other climatic variables reported so far on growth of bamboo are, higher air temperature (Sun and Yang 1988, Lan 1990), optimum light intensity (Hassan 1966, Yang *et al.* 1991, Elgi and Schmid 1999) and moderate to high relative humidity (Farrelly 1984). Statistical analysis revealed that all the soil physical parameters studied in the *A. maling* forest at Jang area had significant influence on the growth of 'Rui' bamboo, which is in agreement with the findings of Yadav (1969) and Chung and Ramm (1990). Greater soil moisture availability at 0-30 cm depth throughout the year (45-60%), loose soil with low bulk density (0.26 g cm^{-3}) and high porosity (90.21%), higher silt (18.18%) and clay (2.58%) content and moderate soil temperature (-2 to 10^0 C) at the medium elevation site are among the important physical parameters favouring the growth of *A. maling* at this elevation. Qing *et al.* (2004) reported better growth of *Pleioblastus maculata* at higher soil moisture availability, and Li *et al.* (1998c) reported similar trend at higher soil porosity in China. It is well known that bamboo can grow even on highly acidic soils (pH 3.5), but most of them prefer to grow between pH 5 to 6.5 (Uchimura 1978, Hassan *et al.* 1988). The soil at medium elevation site was less acidic (pH ranging from 5.26 to 5.51) which might have led to better nutrient assimilation and microbial activities at this elevation, resulting in better growth of *A. maling*. Soil with higher available phosphorus (8.82 $\mu g\ g^{-1}$) and organic carbon (9.94%) at this elevation site also accounted for best growth. Totey and co-workers (1989) reported the influence of soil phosphorus on growth performance of *Denrocalamus strictus*. Reports on the association of vesicular-arbuscular mycorrhizal (VAM) fungi with many bamboo species, reflected significant influence of soil phosphorus on bamboo growth (Appasamy and Ganapathi 1992). Bamboos with the mycorrhizal association have been reported to show greater production and better growth than the non-associated ones (Ravikumar *et al.* 1997, Jamaluddin *et al.* 1998, Singh *et al.* 1999, Paroha *et al.* 1999).

Soil total nitrogen was more at the low elevation site (0.76%), although it did not influence height and diameter growth as also reported by many workers (Adamson *et al.* 1978, Patil *et al.* 1980, Shi *et al.* 1987, Qiu and Maoyi 1987, Raina *et al.* 1988, Thomas 1990) rather, it resulted into higher clump density at this elevation site. There are evidences of the increase in belowground rhizome length and development of new clumps in close proximity, through the belowground runners at low moisture availability and in the presence of sufficient soil nitrogen (Quing *et al.* 2004). Another reason for the poor growth of *A maling* at this elevation may be the higher nitrogen level in the soil, which has exhibited lodging as a result of the decreased thickness of the cell walls, or owing to the poor development of mechanical tissues of culm/rhizome or both as reported by Kanwar (1976). Similar effects of excess nitrogen on the growth characteristics in *Poplus* species have also been reported by Deol and Khosla (1983).

This study also revealed that soil potassium content was not significantly different among the three elevation sites and soil depths. Concentration of potassium was higher in the subsurface soil than the surface layer. It may be due to the capability of the root system of *A. maling* to accumulate and conserve soil potassium as reported by many workers in different bamboo species (Toky and Ramakrishnan 1982, Rao and Ramakrishnan 1989, Joshi *et al.* 1991, Mailly *et al.* 1997, Shanmughavel and Francis 1997, Lin and Lin 1998). Availability of soil potassium in the sub surface soil layer has a significant influence on growth performance of *A. maling*. Potassium alone does not influence growth of plants although it acts as a booster element in uptake and transport of other nutrients like NO_3 from source to the sink (Marschner *et al.* 1996), and also improves the hardiness of plants (Qiu and Maoyi 1987). Though the topography of *A. maling* forest was hilly terrain with steep slope, the concentration of soil nutrients especially potassium and nitrogen was high compared to that of tropical bamboo forests. This reflects the soil nutrient conservation potentiality of *A. maling* which is a temperate bamboo.

Though nitrogen, phosphorus and potassium are the three major mineral elements reported to be closely related to the growth of bamboo, the demand for them is not the same during different growth phases. Huang (1987) stated that during the shoot induction period, bamboo consumes more nitrogen than phosphorus and potassium, but during the period of shoot growth and rhizome running, it requires more phosphorus and potassium than nitrogen.

Soil moisture is very important for bamboo growth and production. Wet seasons increase shoot production of bamboos (Pearson *et al.* 1994), and bamboo is not suitable commercial species for areas where sufficient water is usually not available (Siddiqui 1994). Higher soil moisture availability and low bulk density with high water holding capacity at the medium elevation site resulted into the production of greater young shoot compared to the low and high elevation sites depicting the crucial role of soil moisture and porosity.

The presence of higher soil organic matter content and sufficient quantity of plant litter (bamboo as well as herb and shrub), on the forest floor maintained the soil moisture and temperature at the medium elevation site as also reported by He and Ye (1987). The presence of high level of organic carbon in the 0-10 and 10-20 cm soil layers coupled with the tremendous biological activity of fibrous roots and living organisms at the medium elevation site, manifested in the quantum of water stable macro aggregates. Clay content being very low seems to play only a minor role in the formation and stabilization of aggregates. The formation and maintenance of the stable aggregates make the soil loose, friable and porous permitting free movement of water and air and unobstructed root and new shoot growth. The detrimental effects of drought but positive effects of irrigation during the shoot production and culm growth phase were reported by Chu and Xu (1988), Li and Zhang (1987), Aggarwal *et al.* (1994), Lin (1995).

The rate of annual new shoot production of *A. maling* at Jang area ranged from 19 to 115 per clump (2928 to 22931 per ha.), the maximum shoot production being recoded at the medium elevation site. It is well known that the production of new shoots varies with bamboo species and is much higher for smaller-diameter species than for medium and large-diameter species (Yang and Huang 1981, Zhang and He 1997, Dart 1999). The optimum level of soil nitrogen, phosphorus and potassium was observed to increase new shoot production rate in *A. maling* at Jang area. The maximum shoot production was observed at the medium elevation site. Similar trend of young shoot production in *Phyllostachys pubescens* was reported by many workers (Fu *et al.* 1991, Zhou *et al.* 1991, Koyama and Uchimura 1995, Li *et al.* 1998a, Wang e*t al.* 1998). In India, such type of influence of N, P and K was reported in many bamboo species like, *Bambusa tulda, B. balcooa*, *Dendrocalamus strictus, D. hamiltonii, Dendrocalamus longispathus, Melocanna baccifera* (Raina *et al.* 1988, Patil and Patil 1990, Shanmughavel and Francis1996, Banik 2000, Jha and Lalnunmawia 2003).

Larger clump area observed at the medium elevation site was due to the selective harvest of large-sized mature culms by the inhabitants of Jang area, which favourably influenced the production of young shoot and expansion of clump area. *A. maling* produced healthy and larger leaves at the medium elevation site. Due to the distant location and transportation problem, only culms are removed from the medium elevation site and the leaves are left on the forest floor. Hence, the nutrients accumulated in the leaves and branches are reincorporated in the bamboo forest. Many workers have reported similar trend of selective harvest resulting in higher new shoot production and increase of clump area (Basio *et al.*1988, Carcallus *et al.* 1988, Virtucio *et al.* 1992, Banik 2000).

Growth of *A. maling* at Jang area in terms of height, DBH and production of new shoots is significantly influenced by leaf area index (LAI) and light intensity. LAI accounted for 97% variation in culm height ($F = 1798$, $P < 0.001$) and 95% variation in DBH ($F = 1014$, $P < 0.001$) and new shoot production ($F = 1121$, $P < 0.001$). Light intensity at different elevation sites also accounted significant variation in culm height with 10% ($F = 5.629$, $P < 0.05$), 38% variation in DBH (31.171, $P < 0.001$) and 14% variation in production of new culm ($F = 8.721$, $P < 0.05$). Similar influence of light intensity and LAI on growth and new shoot production of several bamboo species have been reported by other workers (Lin *et al.* 1979, Liao 1986, Yang *et al.* 1988, Qiu *et al.* 1992, Ishagi *et al.* 1993, Banik 1997, Wang *et al.* 1998).

The higher extraction of 'Rui' bamboo at the low elevation site in Jang area was due to the easy accessibility of this resource to the villagers. Although the culms at this elevation site were comparatively narrow, yet they were harvested in large numbers throughout the year for household and home garden applications. The medium elevation site was dominated by the larger culms but they were not easily accessible due to long distance (8-10 km) from the village area and steep slope except during the dry season. The distance of the high elevation site is 18 km from the human habitation and hence, maximum extraction of culms from this site is done for road construction purpose and by the defence personnel. The large-scale harvesting from the roadside clumps is very common phenomenon observed at all the three elevation sites.

As the rate of young shoot production was significantly higher at medium elevation site, due to more suitable climatic and soil conditions as well as larger clump area, the standing stock of population of *A. maling* at Jang area was significantly higher at this elevation. Selective harvest by the villagers and low anthropogenic pressure due to longer distance of the site from the human habitation might have also favoured the higher induction of young shoots at this particular elevation site. The lower production of new shoots at the low elevation site might have resulted due to the non-systematic harvest as well as culm congestion (Banik 2000). The standing stock of *A. maling* at Jang area with 9,984-73,200 individuals ha^{-1} was very high comparatively to that reported worldwide (900-52,500 individuals ha^{-1}) in many bamboo species in tropical and temperate ecosystems (Kleinhenz and Midmore 2001). The standing stock of *Phyllostachys pubescens*, a non-clump forming bamboo in China, was only 7,100 individuals ha^{-1} during 1991 (Isagi *et al.* 1997). According to Embaye (2003), in Ethiopia, the average stocking in low land with clump forming bamboo species was 8,000 individuals ha^{-1}, whereas it was 6,000 individuals ha^{-1} in high land with non clump forming bamboo species. The yield of *A. maling* at Jang bamboo forest was to the tune of 2964-23000 individuals ha^{-1} yr^{-1}, which is much higher than the other species reported till date (Kleinhenz and Midmore 2001). Comparatively higher growth indices of bamboo population with low annual harvest rate at all the three elevation sites, revealed the better status and long term sustainability of the *Arundinaria maling* forest in Jang area.

CHAPTER V

BIOMASS AND PRODUCTIVITY OF *A. MALING* FOREST

5.1 INTRODUCTION

Biomass is the total quantity of organic matter per unit area present in an ecosystem at a given time and may relate to a particular species, group of species or a community as a whole. Primary producers in an ecosystem convert the solar energy into organic matter and accumulate it after respiratory utilization in the above and belowground parts. The accumulated organic matter or the standing crop of the biomass serves as an important structural characteristic of the ecosystem (Golley and Leith 1972, Odum 1971) and regulates the overall energy flow and nutrient cycling within the ecosystem. The biomass determinations are employed to measure the biological productivity and at times the economic productivity. Biomass of plants in an ecosystem depends on species composition and community structure. Biomass of herbaceous community fluctuates greatly with seasons.

Net primary productivity refers to the rate of organic matter-storage in plant tissues in excess of the respiratory utilization during the measurement period. According to Egunjobi (1957), it may be considered as the rate of net primary production of organic matter left after respiration but including all loses from litterfall, grazing etc. Productivity is one of the most important functional attributes of an ecosystem and provides basic energy and matter for all other biotic components of the ecosystem (Billore and Mall 1977). It is also an index of fertility of an ecosystem for the organic matter production.

Microclimate of the habitat plays a key role in limiting the biomass and productivity of an ecosystem.

Bamboo acts as a very active and efficient CO_2 fixer. It is reported that one ha of bamboo stand can absorb about 17 tonnes of CO_2 per year, and if it is not burnt and converted into long term durable products, long term capture of CO_2 can be assured (Isagi 1994, Rawat and Pal 2004). Due to its fast growing nature, it can accumulate maximum amount of biomass with higher productivity, for which it may be considered as ideal species to establish carbon sinks. In general, the dry weight of all the aboveground components of bamboo increases consistently with the increase in age up to six years and then it declines considerably (Shanmughavel and Francis 2001). The total biomass increase may be proportional to diameter, height and the culm age. The world's annual production of bamboo biomass has been estimated as more than 20 million tonnes (Sharma 1980).

Productivity and bamboo biomass are species-specific, and also depend on the stock density and age. Induction of new shoots increases up to a certain age and gradually decreases, which is also reported to be species-specific, and is dependent on soil and climatic condition (Banik 2000, Shanmughavel and Francis 2001). In case of species having short-necked rhizome, annual systematic harvest is reported to be most important, as much crowdedness and congested condition result in scarcity of room as well as water and nutrient (Kondas 1981, Banik 2000). Many workers reported that supply of nutrients considerably increases growth and biomass production (Anonymous 1961, Adamson *et al.* 1978, Hussain 1980, Shi *et al.* 1987 and Patil and Patil 1990). The influence of nutrients and water availability in the as well as in plant parts on primary productivity in an ecosystem has been reported by several workers (Uchimura 1980, Kinhal 1985, Huang 1987).

Biomass studies on bamboo in India and abroad are especially concerned with the tropical and subtropical species possibly due to their larger size with high commercial value. Such studies on bamboos in natural forest stands are very meager, although a few studies were made in tropical forests of India and few in temperate forests of China, Japan, Java and America. Among the workers who have contributed to bamboo biomass studies are Lu and Liu (1982), Kigomo and Kamiri (1987), Othman (1993), Lakshmana, (1994), Tewari *et al.* (1994), Tripathi and Singh (1994), Shanmughavel (1995), Chandrashekara (1996), Christanty *et al.* (1996), Manipula *et al.* (1996), Isagi *et al.* (1997), Singh and Singh (1999), Yamamoto *et al.* (1999), Banik (2000), Uniyal and Avasthi (2000) etc.

This chapter deals with biomass and productivity of *A. maling* at three elevation sites in Jang area within the range of 2400-3600 m asl. Results on the variation in aboveground dry matter accumulation at different age and biomass accumulation in the aboveground bamboo parts over a period of twenty-four months are presented in this chapter. Regression equations for the prediction of biomass of *A. maling* through height, DBH and basal area have been generated through different regression models. Temporal variation in the aboveground biomass and productivity of *A. maling* and litter production is also presented. Aboveground biomass of herb and shrub and their contribution to the total aboveground biomass of *A. maling* forest was also studied and will be discussed in this chapter.

5.2 MATERIALS AND METHODS

5.2.1 Biomass determination

Biomass determination was done by destructive sampling technique (Milner and Hughes 1968). The sampling was started during April 2001 at the three elevation sites in the *A. maling* forest at Jang area, and continued till April 2003 at three-month interval over a period of two years. Bamboo sampling was done from eighteen earmarked clumps (two each from the nine permanent quadrats of 30 m x 30 m), laid at each elevation site for growth study (Chapter IV). During the first sampling period (April 2001), thirty-six bamboo individuals (18 <1yr. and 18 ≥1yr. old) were randomly harvested from the ground level from the eighteen permanent clumps at each elevation site for growth determination. In addition to the bamboo individuals harvested for growth studies (Chapter IV), eighteen more bamboo individuals of ≥1yr. old were harvested during July, October, January and April of 2001-2002 for biomass studies, and the same number of bamboo individuals of <1yr. old were harvested during the sampling periods of 2002-2003. Harvested bamboos were separated into culm, branch and leaf and their fresh weight was worked out in the field itself. A total of 18 samples for each bamboo part from each elevation site was transported to the laboratory. The samples were oven-dried at 80^0 C for 48 hours to constant weight and then weighed. Biomass of <1yr. old and ≥1yr. old 'Rui' bamboo was determined by multiplying the respective mean dry weight per individual with average culm density per clump. Finally they were added together to give the biomass per clump. Total biomass per hectare was determined by multiplying mean dry weight per clump and the number of clumps per hectare. As the biomass of only the aerial bamboo parts was determined, the biomass values represent the aboveground biomass only.

5.2.2 Pattern of dry matter production at different ages of *A. maling*

The dry matter of different bamboo parts of the individuals sampled at different culm ages for growth measurement were used to study the dry matter allocation pattern at different culm ages. Rate of dry matter accumulation in bamboo individuals of different ages were computed, considering the total dry matter accumulated per individual during the two year of study period.

5.2.3 Determination of herb and shrub biomass

Herb and shrub biomass was determined at three months interval during the bamboo-sampling months through harvest method. Sampling for the herb and shrub biomass was done from the ten randomly laid quadrats of 1 m x 1 m size at each elevation site within the three belts, laid for studying growth performance of *A. maling*. In this study, only the aboveground biomass of herb and shrub was determined.

5.2.4 Sampling of bamboo leaf litter

Litter production was studied on monthly basis by randomly placing ten litter traps of 0.5 m x 0.5 m x 0.15 m size within the permanent quadrats (30 m x 30 m) laid in each elevation site. The data on litter production was presented for two consecutive years i.e., 2001-2002 and 2002-2003.

5.2.5 Productivity measurement

The aboveground primary productivity of *A. maling* at different elevation sites was determined by the "difference method" (Egunjobi 1957, Odum 1971). Similarly, aboveground primary productivity of herb and shrub was also determined by the difference method. Aboveground net primary productivity (ANP) of *A. maling* forest at different elevation sites was computed by the method "sum of positive increment in biomass plus mortality" as outlined by Singh and Yadava (1974). Thus for computing annual productivity, the positive increment in <1yr. old and ≥1yr. old individuals at successive sampling dates for one year period were summed up for respective elevation sites. Similarly, annual herb and shrub productivity was measured by summing the positive increment in biomass on successive sampling dates for one year period. The data on productivity are presented per three months as well as on annual basis for two consecutive years i.e., 2001-2002 and 2002-2003. Annual litter production and annual bamboo biomass extracted from the *A. maling* forest at different elevation sites were added to the values of bamboo and herb and shrub productivity to give aboveground net primary productivity (ANP) of *A. maling* forest.

Two-way analysis of variance was done to compare the data on biomass and productivity of *A. maling* growing at the three elevation sites. Linearized curvilinear regression model (Woodwell and Whittaker 1968) was applied to prepare regression plots and to generate exponential and logarithmic regression equations between the biomass versus culm height, DBH and basal area of individual culm. To understand the influence of climatic variables and soil physico-chemical parameters on dry matter accumulation of *A. maling*, correlation and simple linear regression analyses were done through SYSTAT software version-6.

5.3 RESULTS

5.3.1 Aboveground biomass of *A. maling* forest at Jang area

5.3.1.1 Aboveground biomass of *A. maling*

Table 5.1 depicts the status of standing crop of *A. maling* at different sampling dates at the low, medium and high elevation sites. It was significantly different among the three elevation sites (F = 93.767, P< 0.001), whereas the difference was insignificant among different sampling dates, although the standing crop increased considerably with age at all the three elevation sites. During the initial sampling period (April 2001), the standing crop at the low, medium and high elevation sites was 72.46 tonnes ha^{-1} (232.90 kg $clump^{-1}$), 81.32 tonnes ha^{-1} (406.60 kg $clump^{-1}$) and 8.53 tonnes ha^{-1} (54.70 kg $clump^{-1}$), respectively. After one year, the standing crop increased to 79.84 tonnes ha^{-1} (256.72 kg $clump^{-1}$), 104.60 tonnes ha^{-1} (523.03 kg $clump^{-1}$) and 8.74 tonnes ha^{-1} (56.04 kg $clump^{-1}$) at the three elevation sites respectively. Finally at the end of the study period (April 2003) the standing crop was observed to be 90.54 tonnes ha^{-1}, (291.10 kg $clump^{-1}$), 146.57 tonnes ha^{-1} (732.90 kg $clump^{-1}$) and 8.66 tonnes ha^{-1} (55.55 kg $clump^{-1}$), respectively at the low, medium and high elevation sites. There was a sudden decline in standing crop of *A. maling* at the low elevation site during October and during October and April at the high elevation site.

Temporal variation in biomass of different bamboo parts of *A. maling* at different elevation sites is presented in Figure 5.1. The difference in biomass of culm, branch and leaf was insignificant at different sampling dates, whereas it differed significantly among the three elevation sites, where highest values were observed at medium elevation site with F ratios of 95.83, 37.366

Table 5.1. Temporal variation in the standing crop of *A. maling* at the three elevation sites in Jang bamboo forest.

Sampling date	Age group of culm	Low elevation		Medium elevation		High elevation	
		Kg $clump^{-1}$	Tonnes ha^{-1}	Kg $clump^{-1}$	Tonnes ha^{-1}	Kg $clump^{-1}$	Tonnes ha^{-1}
April 2001	<1yr. old	20.58 ± 0.88	6.40 ± 0.27	52.48 ± 2.30	10.50 ± 0.46	15.40 ± 1.46	2.40 ± 0.23
	≥1yr. old	212.40 ± 2.66	66.06 ± 0.83	354.12 ± 2.83	70.82 ± 0.57	39.30 ± 3.93	6.13 ± 0.61
	Total	232.98 ± 3.54	72.46 ± 1.10	406.60 ± 5.13	81.32 ± 1.03	54.70 ± 5.39	8.53 ± 0.84
July	<1yr. old	14.76 ± 0.51	4.59 ± 0.16	48.45 ± 1.84	9.69 ± 0.37	2.52 ± 0.15	0.39 ± 0.02
	≥1yr. old	231.24 ± 6.56	71.91 ± 2.04	415.48 ± 6.18	83.09 ± 1.23	63.00 ± 2.90	9.83 ± 0.45
	Total	246.00 ± 7.07	76.50 ± 2.20	463.93 ± 8.02	92.78 ± 1.60	65.52 ± 3.05	10.22 ± 0.47
October	<1yr. old	31.74 ± 1.79	9.87 ± 0.56	84.55 ± 3.14	16.91 ± 0.63	4.84 ± 0.40	0.76 ± 0.06
	≥1yr. old	202.94 ± 5.37	63.12 ± 1.67	384.56 ± 6.69	76.91 ± 1.24	52.32 ± 2.83	8.15 ± 0.44
	Total	234.68 ± 7.16	72.99 ± 2.23	469.11 ± 9.83	93.82 ± 1.87	57.16 ± 3.23	8.91 ± 0.50
January	<1yr. old	34.44 ± 1.31	10.71 ± 0.41	105.60 ± 3.48	21.12 ± 0.70	4.16 ± 0.36	0.65 ± 0.06
	≥1yr. old	210.60 ± 6.97	65.50 ± 2.17	375.84 ± 7.99	75.17 ± 1.60	52.08 ± 2.97	8.12 ± 0.46
	Total	245.04 ± 8.28	76.21 ± 2.58	481.44 ± 11.47	96.29 ± 2.30	56.24 ± 3.33	8.77 ± 0.52
April 2002	<1yr. old	37.24 ± 1.67	11.58 ± 0.52	139.40 ± 4.92	27.88 ± 0.98	4.16 ± 0.46	0.65 ± 0.07
	≥1yr. old	219.48 ± 9.56	68.26 ± 2.97	383.63 ± 8.03	76.72 ± 1.61	51.88 ± 3.28	8.09 ± 0.51
	Total	256.72 ± 11.23	79.84 ± 3.49	523.03 ± 12.95	104.60 ± 2.59	56.04 ± 3.74	8.74 ± 0.58

(Mean ± SE)

Table 5.1. Continued.

Sampling date	Age group of culm	Low elevation		Medium elevation		High elevation	
		Kg clump^{-1}	Tonnes ha^{-1}	Kg clump^{-1}	Tonnes ha^{-1}	Kg clump^{-1}	Tonnes ha^{-1}
July	<1yr. old	20.82 ± 0.39	6.47 ± 0.12	68.85 ± 1.89	13.77 ± 0.38	5.46 ± 0.36	0.85 ± 0.06
	≥1yr. old	262.40 ± 3.60	81.61 ± 1.12	561.34 ± 4.42	112.26 ± 0.89	56.70 ± 3.78	8.84 ± 0.59
	Total	283.22 ± 3.99	88.08 ± 1.24	630.19 ± 6.31	126.03 ± 1.27	62.16 ± 4.14	9.69 ± 0.65
October	<1yr. old	45.68 ± 3.24	14.21 ± 1.01	125.40 ± 3.04	25.08 ± 0.61	10.56 ± 0.75	1.65 ± 0.12
	≥1yr. old	226.48 ± 2.54	70.43 ± 0.79	522.50 ± 6.69	104.50 ± 1.34	46.87 ± 3.49	7.31 ± 0.53
	Total	272.16 ± 5.78	84.64 ± 1.80	647.90 ± 9.73	129.58 ± 1.95	57.43 ± 4.24	8.96 ± 0.65
January	<1yr. old	48.71 ± 2.79	15.15 ± 0.87	153.60 ± 2.52	30.72 ± 0.50	10.92 ± 0.83	1.70 ± 0.13
	≥1yr. old	231.49 ± 6.97	72.00 ± 2.17	522.72 ± 10.15	104.55 ± 2.02	47.12 ± 4.96	7.35 ± 0.77
	Total	280.20 ± 9.76	87.15 ± 3.04	676.32 ± 12.67	135.27 ± 2.52	58.04 ± 5.79	9.05 ± 0.90
April 2003	<1yr. old	52.33 ± 2.45	16.28 ± 0.76	201.72 ± 3.44	40.34 ± 0.69	12.32 ± 0.85	1.92 ± 0.13
	≥1yr. old	238.77 ± 7.08	74.26 ± 2.20	531.18 ± 8.90	106.23 ± 1.78	43.23 ± 4.32	6.74 ± 0.67
	Total	291.10 ± 9.53	90.54 ± 2.96	732.90 ± 12.34	146.57 ± 2.47	55.55 ± 5.17	8.66 ± 0.80

(Mean ± SE)

Clump density: Low elevation= 311, medium elevation= 200, high elevation= 156 (clumps per ha)

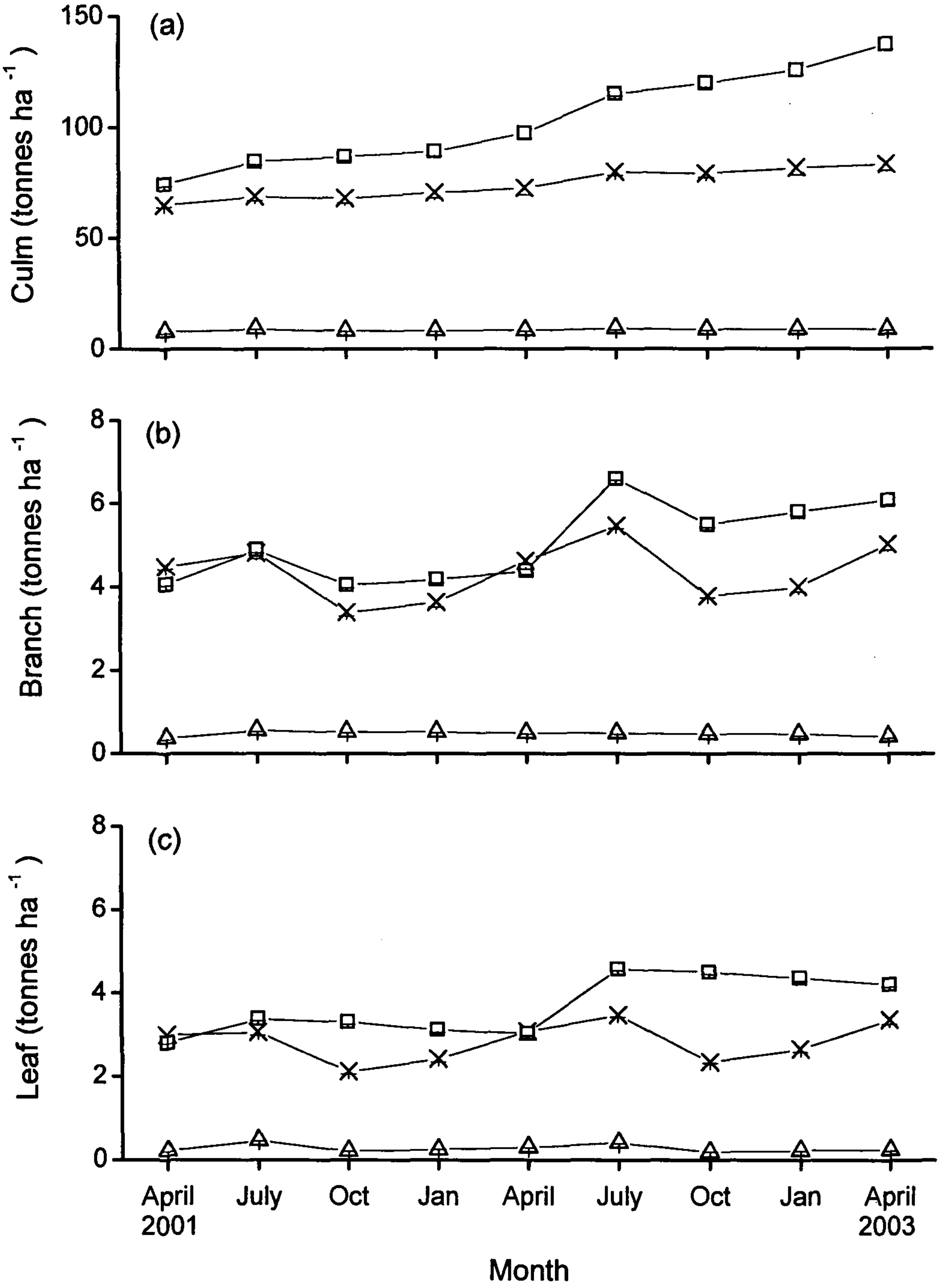

Figure 5.1. Temporal variation in standing biomass of culm (a), branch (b) and leaf (c) of *A. maling* at the low (-X-), medium (-□-) and high (-△-) elevation sites. Vertical line bars represent ± SE.

and 129.504 (P< 0.001), respectively. The variation in aboveground biomass of *A. maling* at different sampling dates was insignificant, although a higher biomass was recorded during July at the low and high elevation sites, whereas at the medium elevation site it was recorded during January. Lowest aboveground biomass of *A. maling* was recorded during April at all the three elevation sites (Fig.5.2).

The mean standing biomass of *A. maling* in Jang area was highest at the medium elevation site (107.46 tonnes ha^{-1}) followed by the low (79.73 tonnes ha^{-1}) and high (9.11 tonnes ha^{-1}) elevation site. The percent contribution of culm, branch and leaf to the total bamboo biomass was in the ratio of 91:5:4 at the low elevation site, and 92:5:3 at the medium and high elevation sites (Table 5.2).

5.3.1.2 Aboveground herb and shrub standing biomass

The aboveground biomass of herbs and shrubs was significantly different among the three elevation sites (F = 147.378, P< 0.001) and sampling dates (F = 11.789, P< 0.005). Maximum biomass was observed during July followed by October and lowest biomass was observed during January at all the three elevation sites (Table 5.3). The mean aboveground biomass of herbs and shrubs was higher (2.68 tonnes ha^{-1}) at the medium elevation site than the low (1.70 tonnes ha^{-1}) and high (2.45 tonnes ha^{-1}) elevation sites.

5.3.1.3 Total aboveground biomass of *A. maling* forest

Total aboveground standing biomass (biomass of bamboo plus biomass of herbs and shrubs) of *A. maling* forest in Jang area was significantly different at the three elevation sites (F = 90.901, P< 0.001),

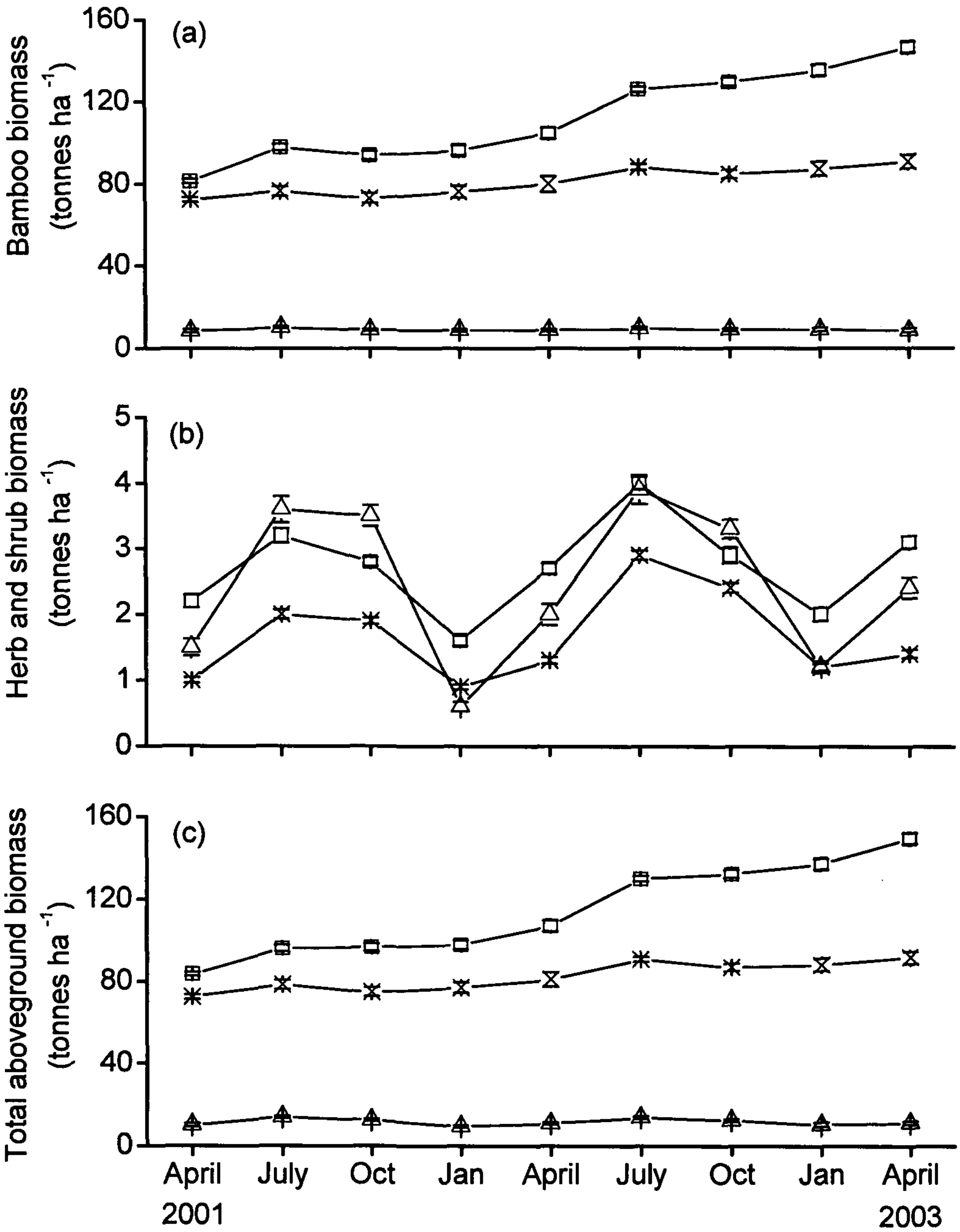

Figure 5.2. Temporal variation in aboveground biomass of *A. maling* (a), herbs and shrubs (b) and total aboveground biomass (c) at the low (-✕-), medium (-□-) and high (-△-) elevation sites of *A. maling* forest. Vertical line bars represent ± SE.

Table 5.2. Biomass (tonnes ha^{-1}) of different bamboo parts at the three elevation sites in *A. maling* forest. Values in the parentheses represent percent contribution to the total bamboo biomass.

Site	Bamboo parts			Total biomass
	Culm	Branch	Leaf	
Low elevation	72.53 ± 2.11 (91)	4.36 ± 0.11 (5)	2.84 ± 0.07 (4)	79.73 ± 2.29
Medium elevation	98.70 ± 1.90 (92)	5.06 ± 0.08 (5)	3.70 ± 0.06 (3)	107.46 ± 2.04
High elevation	8.34 ± 0.64 (92)	0.48 ± 0.03 (5)	0.29 ± 0.02 (3)	9.11 ± 0.69

(Mean ± SE)

Table 5.3. Temporal variation in herb and shrub biomass at the three elevation sites in *A. maling* forest.

Site	Units	April 2001	July	October	January	April 2002	July	October	January	April 2003
Low elevation	Kg m^{-2}	0.10 ± 0.01	0.20 ± 0.02	0.19 ± 0.01	0.09 ± 0.01	0.13 ± 0.01	0.29 ± 0.02	0.24 ± 0.02	0.12 ± 0.01	0.14 ± 0.01
	Tonnes ha^{-1}	1.00 ± 0.10	2.00 ± 0.20	1.90 ± 0.10	0.90 ± 0.10	1.30 ± 0.10	2.90 ± 0.20	2.40 ± 0.20	1.20 ± 0.10	1.40 ± 0.10
Medium elevation	Kg m^{-2}	0.22 ± 0.02	0.32 ± 0.02	0.28 ± 0.01	0.16 ± 0.02	0.27 ± 0.02	0.40 ± 0.02	0.29 ± 0.02	0.20 ± 0.02	0.31 ± 0.02
	Tonnes ha^{-1}	2.20 ± 0.20	3.20 ± 0.20	2.80 ± 0.10	1.60 ± 0.20	2.70 ± 0.20	4.00 ± 0.20	2.90 ± 0.20	2.00 ± 0.20	3.10 ± 0.20
High elevation	Kg m^{-2}	0.15 ± 0.01	0.36 ± 0.02	0.35 ± 0.02	0.06 ± 0.01	0.20 ± 0.02	0.39 ± 0.02	0.33 ± 0.02	0.12 ± 0.01	0.24 ± 0.02
	Tonnes ha^{-1}	1.50 ± 0.10	3.60 ± 0.20	3.50 ± 0.20	0.60 ± 0.10	2.00 ± 0.20	3.90 ± 0.20	3.30 ± 0.20	1.20 ± 0.10	2.40 ± 0.20

(Mean ± SE)

whereas the variation was insignificant at different sampling dates (Fig. 5.2). The total aboveground biomass was highest during July at the low (84.74 tonnes ha^{-1}) and high (13.71 tonnes ha^{-1}) elevation sites, whereas at the medium elevation site it was recorded during January (117.58 tonnes ha^{-1}). Lowest aboveground biomass was observed during April at the low (77.30 tonnes ha^{-1}) and medium (95.41 tonnes ha^{-1}) elevation sites, whereas biomass was lowest during January at the high elevation site (9.81 tonnes ha^{-1}).

The total aboveground biomass of *A. maling* forest in Jang area was highest (110.14 tonnes ha^{-1}) at the medium elevation site followed by the low elevation site (81.43 tonnes ha^{-1}) and high elevation site (11.56 tonnes ha^{-1}) (Table 5.4). The percent contribution of the bamboo to the total aboveground biomass at the low, medium and high elevation sites was 98% at the low and medium elevation sites and 79% at the high elevation site, whereas herbs and shrubs contributed 2% at the low and medium elevation sites and 21% at the high elevation site.

5.3.2 Dry matter accumulation in 'Rui' bamboo and its dry matter prediction equations

Figure 5.3 depicts dry matter accumulation in different bamboo parts and total dry matter accumulation at different ages of *A. maling* at different elevation sites. At the low elevation site, there was a 6.5 fold increase in dry matter from its initial one-month old individuals (0.30 kg) to 24 months old individuals (1.95 kg). At the medium elevation site, the increase was of 4.75 fold (2.42 kg $individual^{-1}$), whereas at the high elevation site, the increase was observed to be 7.52 fold (0.90 kg $individual^{-1}$). There was a considerable increase in total dry matter as the branches and leaves began to

Table 5.4. The aboveground biomass (tonnes ha $^{-1}$) of the bamboo and herbs and shrubs at the three elevation sites in *A. maling* forest. Values in the parentheses represent percent contribution to the total aboveground biomass.

Elevation sites	Bamboo	Herb and shrub	Total
Low	79.73 ± 2.28 (98)	1.70 ± 0.22 (2)	81.43 ± 2.50
Medium	107.46 ± 7.62 (98)	2.68 ± 0.24 (2)	110.14 ± 7.86
High	9.11 ± 0.18 (79)	2.45 ± 0.40 (21)	11.56 ± 0.58

(Mean ± SE)

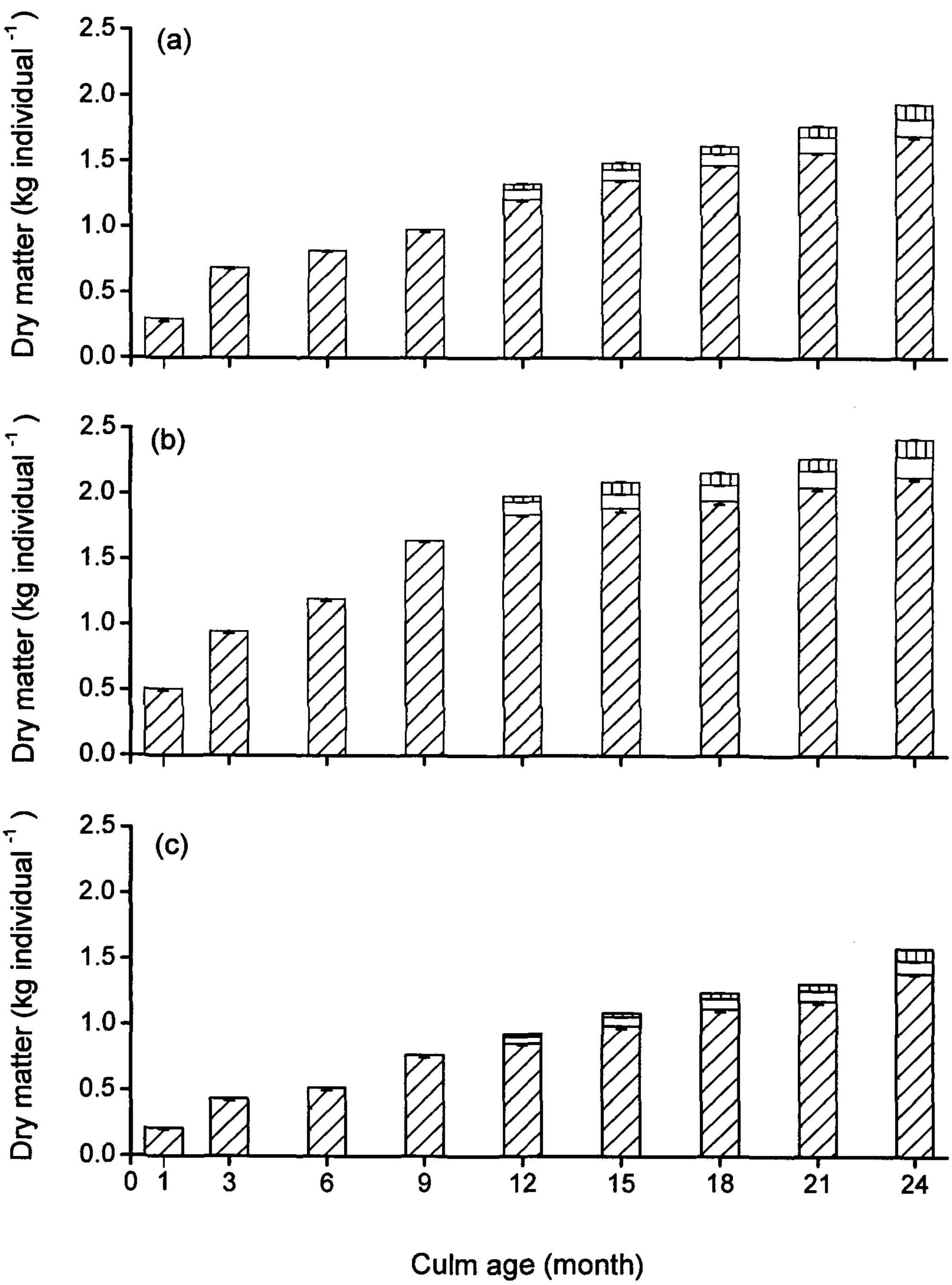

Figure 5.3. Aboveground dry matter accumulation in culm (▨), branch (□) and leaf (▥) of *A. maling* at different ages at the low (a), medium (b) and high (c) elevation sites. Vertical line bars represent ± SE.

develop at the age of twelve months at all the three elevation sites. Total dry matter accumulation per individual was significantly higher at the medium elevation site ($F = 3757$, $P < 0.001$) than the low and high elevation sites. Dry matter accumulation in the culm, branch and leaf was also significantly higher at medium elevation site ($F = 112.976$, $P < 0.001$; $F = 693.294$, $P < 0.001$, $F = 825$, $P < 0.001$) as compared to the other two sites. There was a considerable variation among the dry matter accumulation in different bamboo parts.

The percent contribution of culm, branch and leaf to the total dry matter of 12-24 months old *A. maling* were in the ratio of 90:6:4 at the low elevation site, 91:5:4 at the medium elevation site, and 91:6:3 at the high elevation site. In the culms of less than nine months age in which the branch buds were yet to be developed, the moisture content in culm was 53-80% at the high elevation site, 57-65% at the low elevation site and 57-61% at the medium elevation site (Fig. 5.4). Variation in moisture content in the branches and leaves at the three elevation sites was not significant, although the values decreased considerably with the increase in culm age.

The rate of dry matter accumulation was significantly higher at the medium elevation site ($F = 142.949$, $P < 0.001$) with a maximum value of 17 g individual^{-1} day^{-1} during the first month. It was followed by the low elevation site (10.13 g individual^{-1} day^{-1}) and high elevation site (6.93 g individual^{-1} day^{-1}) (Fig. 5.5). The effect of interaction among sites and age on the rate of dry matter accumulation was also significant ($F = 61.336$, $P < 0.001$). During the second peak, the dry matter production at the low, medium and high elevation sites was 3.81, 4.93 and 2.77 g individual^{-1} day^{-1}. The rate of dry matter accumulation gradually decreased with the increase in age.

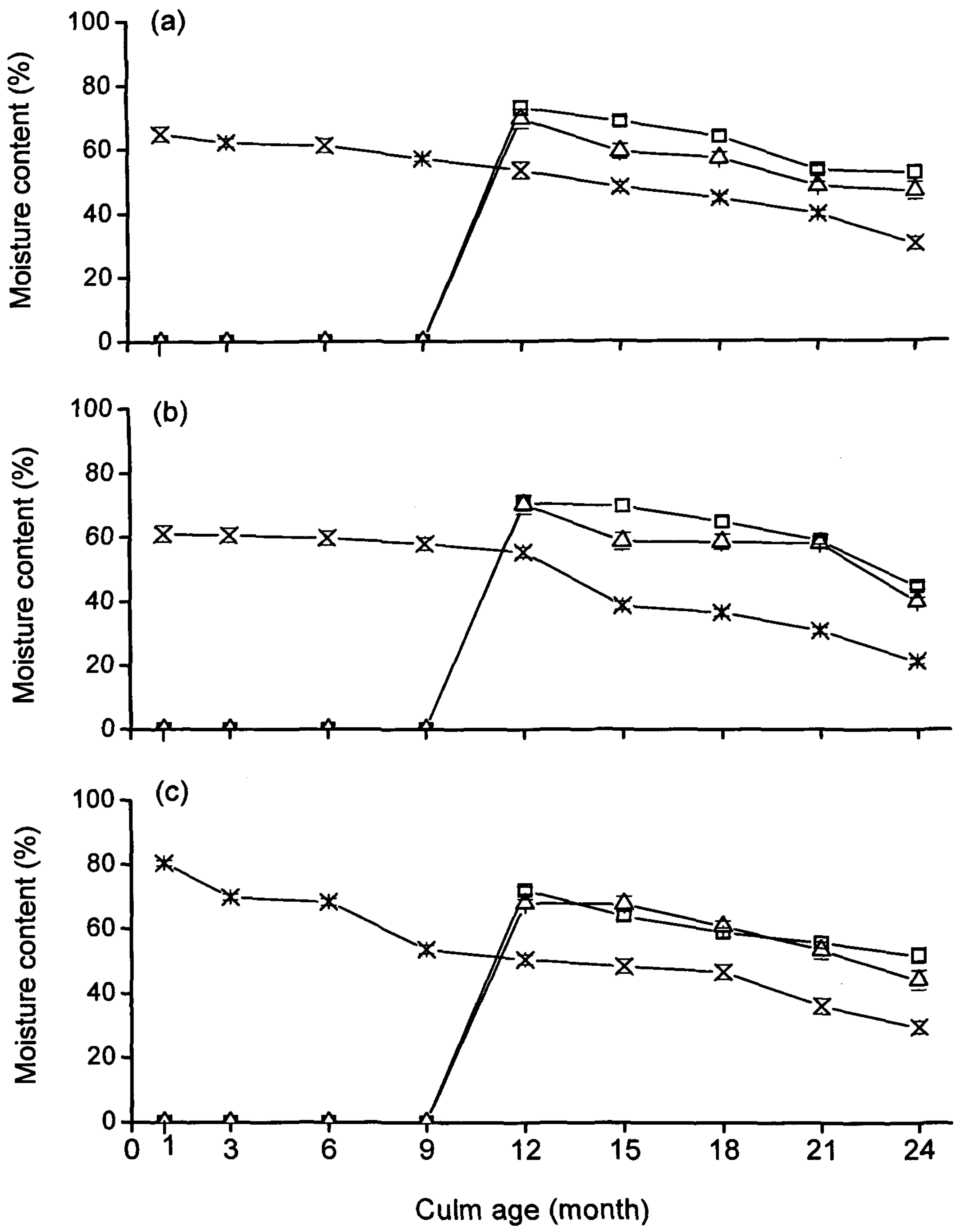

Figure 5.4. Changes in moisture content (%) in culm (-X-), branch (-□-) and leaf (-△-) of *A. maling* with the increase in culm age at the low (a), medium (b) and high (c) elevation sites. Vertical line bars represent ± SE.

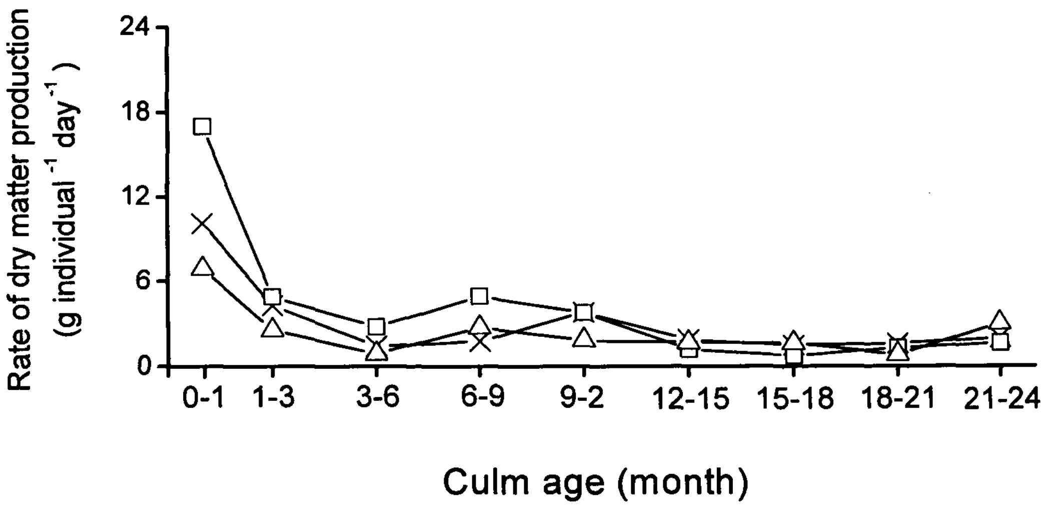

Figure 5.5. Variation in the rate of aboveground dry matter accumulation at different ages at the low (-X-), medium (-□-) and high (-△-) elevation sites. Vertical line bars represent ± SE.

Biomass predicting equations were established through regression models and are presented in Figure 5.6. Aboveground standing biomass of *A. maling* at the low, medium and high elevation sites can be predicted through the equations generated in Figure 5.6, considering the culm height, DBH and basal area per culm as independent variable. All the equations were fitted in exponential model and are significant at $P < 0.001$. At the low elevation site, culm height was having a strong correlation with the bamboo dry matter ($r = 0.94$), whereas at the medium elevation site, correlation coefficient was higher with DBH ($r = 0.89$). At the high elevation site, a stronger correlation was observed between bamboo dry matter and basal area ($r = 0.95$). Logarithmic regression equations were also established considering all the three elevation sites together for the prediction of standing biomass of *A. maling* (Fig. 5.6d), where culm height was observed to have stronger relation with bamboo dry matter ($r = 0.81$). It was followed by basal area per culm ($r = 0.78$) and DBH ($r = 0.69$). Equations were also generated to predict biomass of individual parts of *A. maling* (Fig. 5.6e-g), where culm biomass may be best predicted using culm height ($r = 0.84$) followed by basal area ($r = 0.80$) and DBH ($r = 0.73$). Similarly, branch and leaf biomass can be best worked out by considering culm height as independent variable.

5.3.2.1 Influence of climatic variables and edaphic factors on biomass

Table 5.5 depicts the influence of climatic variables and soil physico-chemical parameters on dry matter accumulation per individual and the correlation coefficients among growth parameters including biomass. Except relative humidity, all other climatic variables were observed to influence the biomass accumulation with different degree. Among the

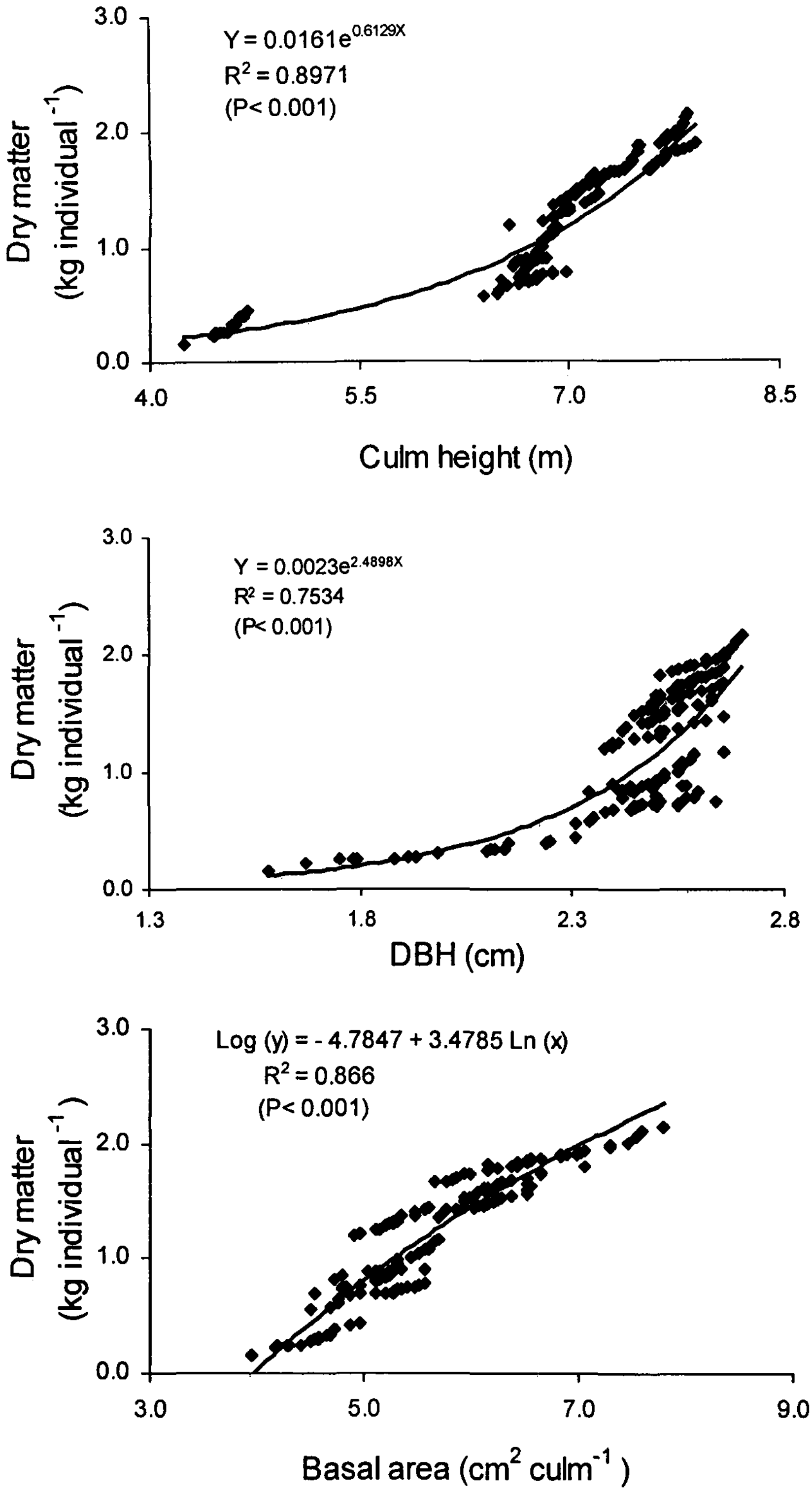

Figure 5.6a. Exponential relationship between bamboo dry matter with culm height, DBH and basal area per culm at the low elevation site. The degrees of freedom in each case are 160.

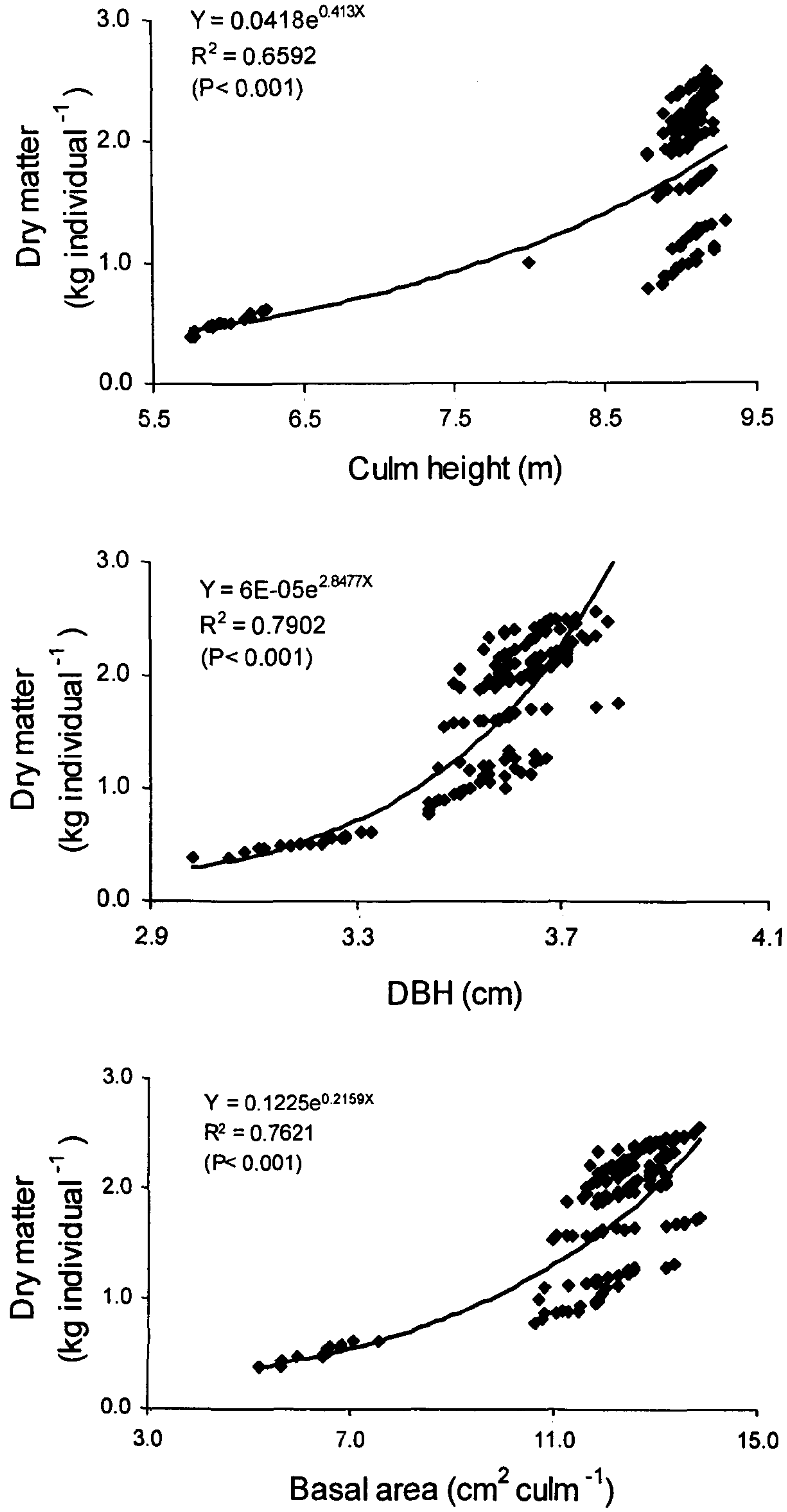

Figure 5.6b. Exponential relationship between bamboo dry matter with culm height, DBH and basal area per culm at the medium elevation site. The degrees of freedom in each case are 160.

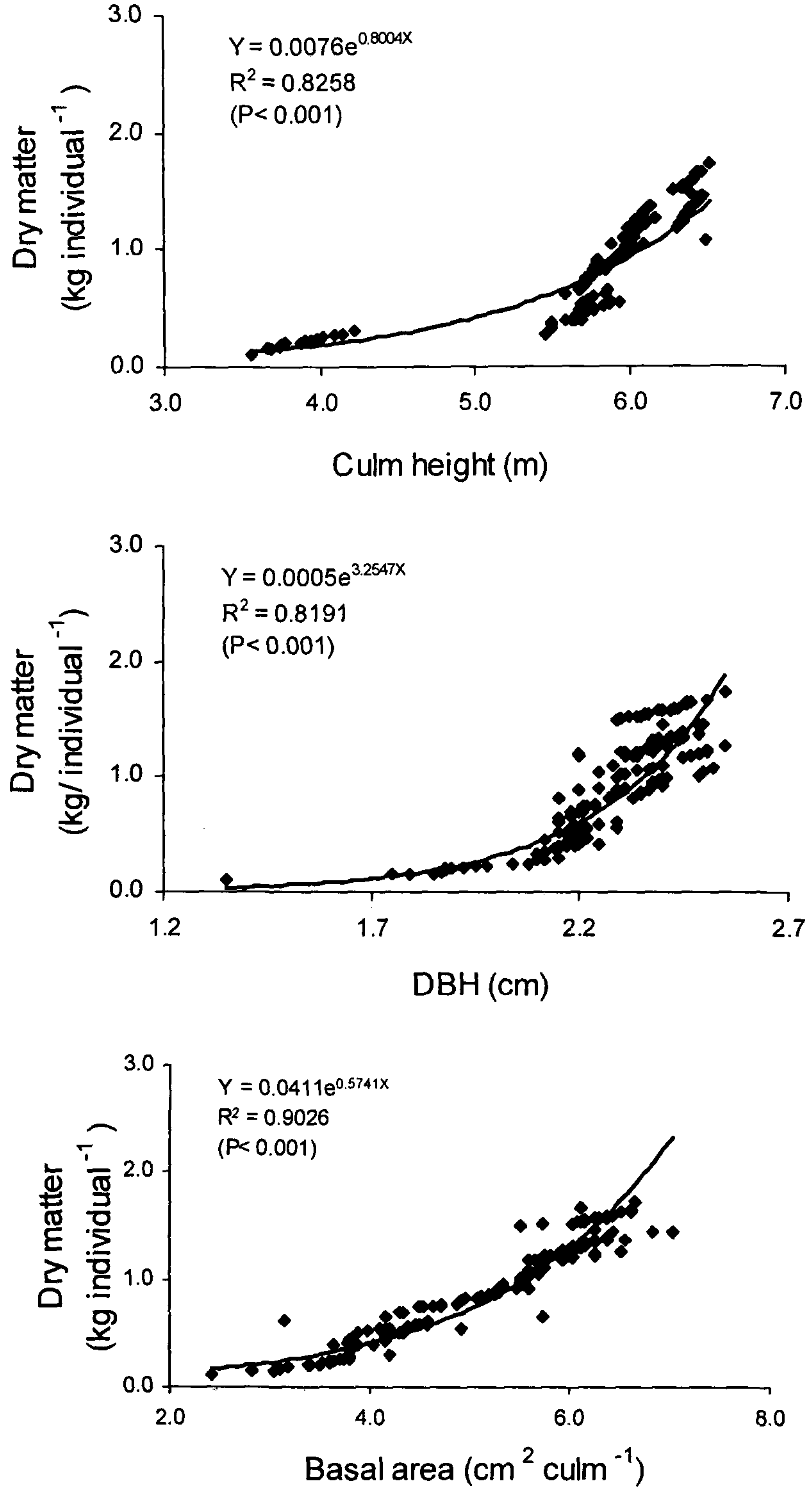

Figure 5.6c. Exponential relationship between bamboo dry matter with culm height, DBH and basal area per culm at the high elevation site. The degrees of freedom in each case are 160.

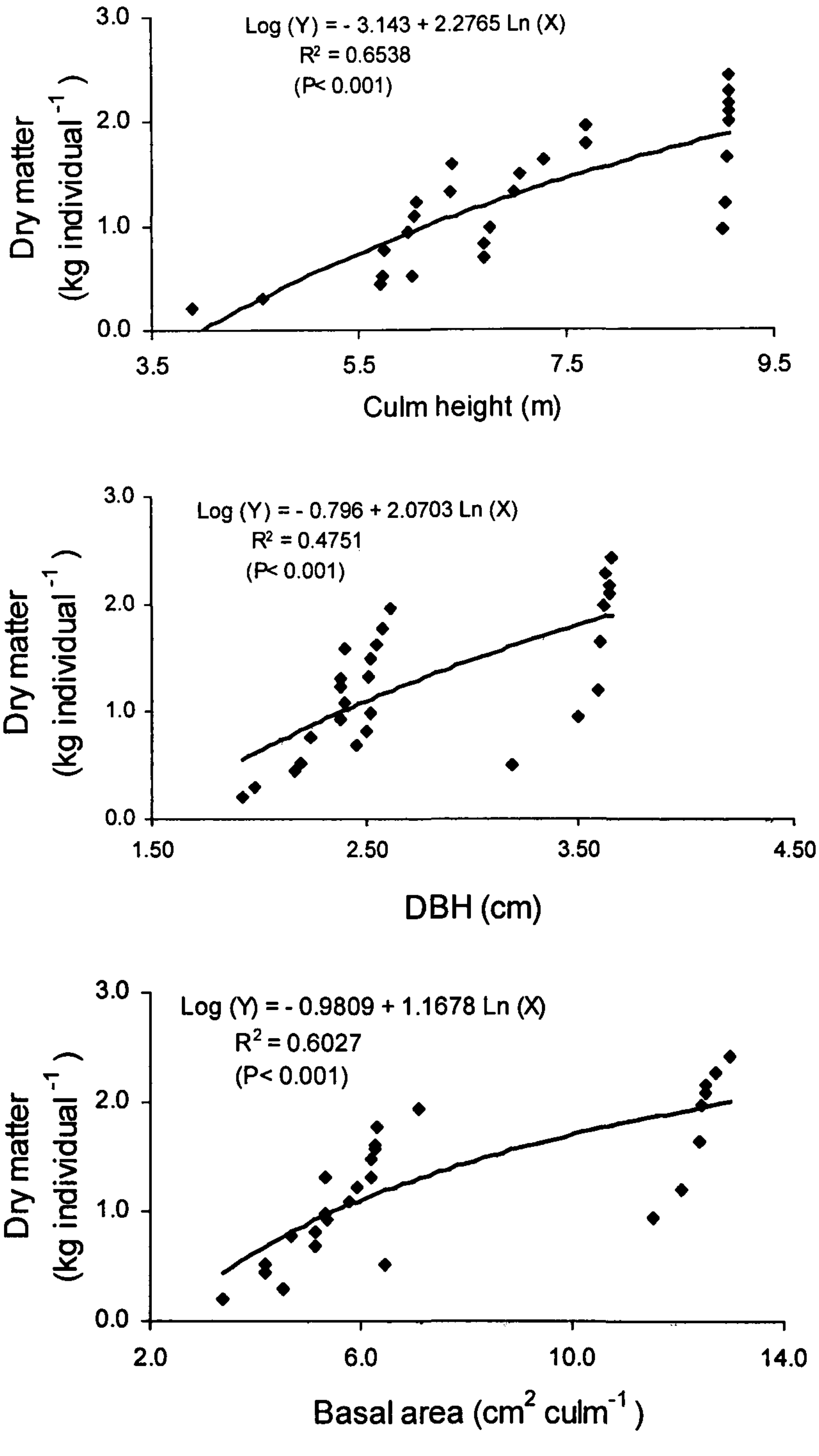

Figure 5.6d. Logarithmic relationship between bamboo dry matter with culm height, DBH and basal area per culm of *A. maling* at Jang bamboo forest (considering all the three elevation sites). The degrees of freedom in each case are 25.

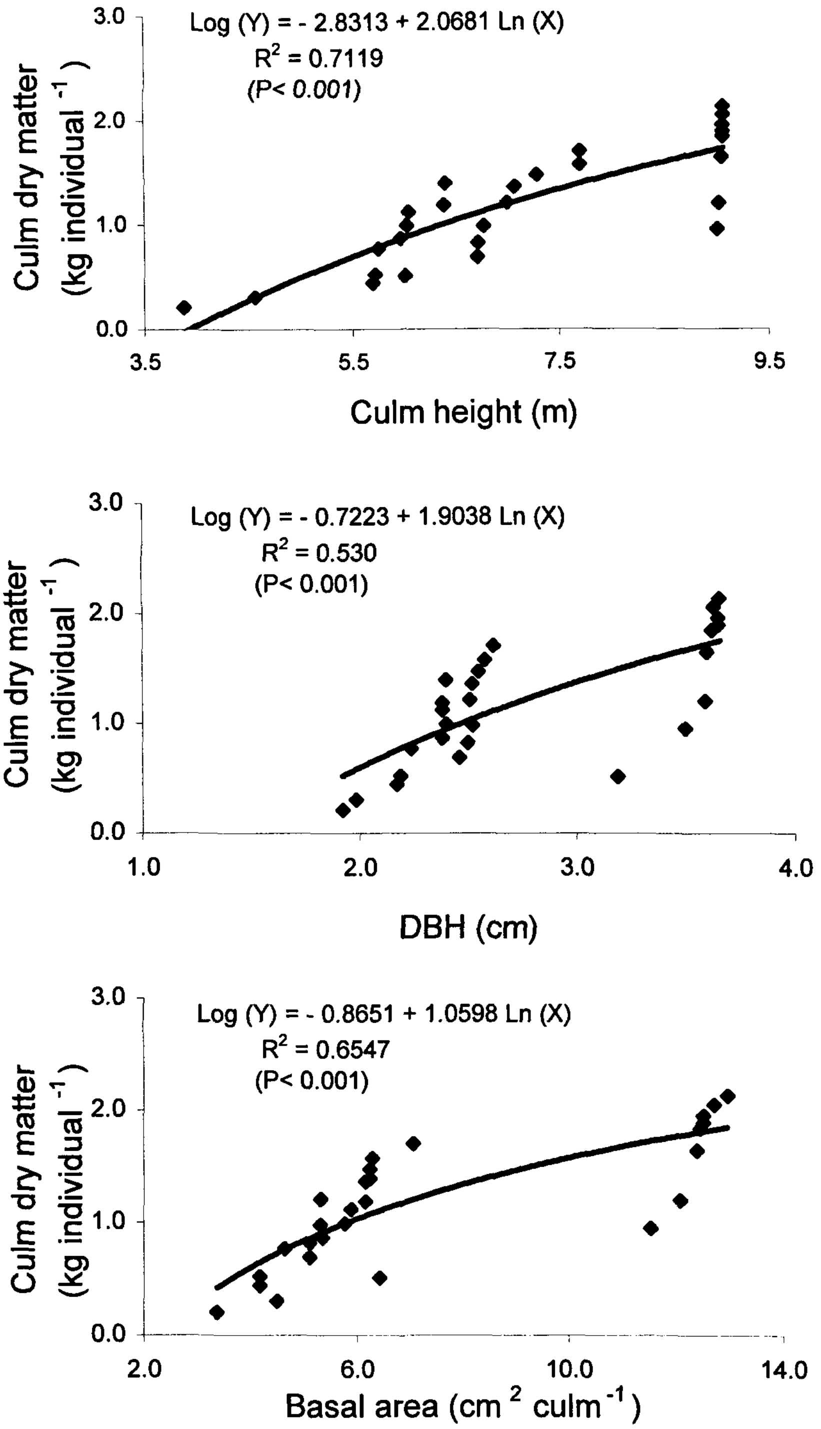

Figure 5.6e. Logarithmic relationship between culm dry matter with culm height, DBH and basal area per culm of *A. maling* at Jang bamboo forest (considering all the three elevation sites). The degrees of freedom in each case are 25.

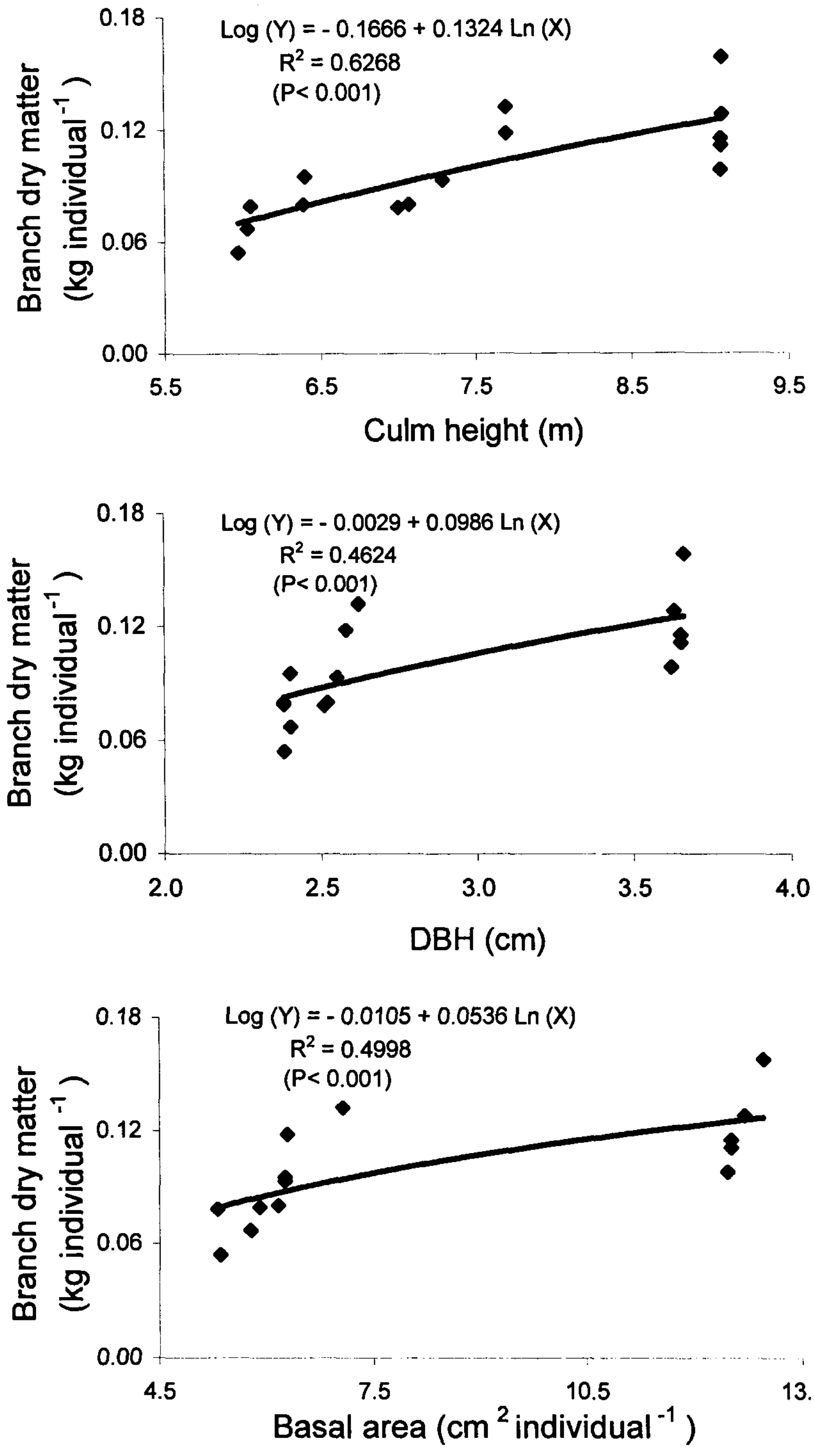

Figure 5.6f. Logarithmic relationship between branch dry matter with culm height, DBH and basal area per culm of *A. maling* at Jang bamboo forest (considering all the three elevation sites). The degrees of freedom in each case are 25.

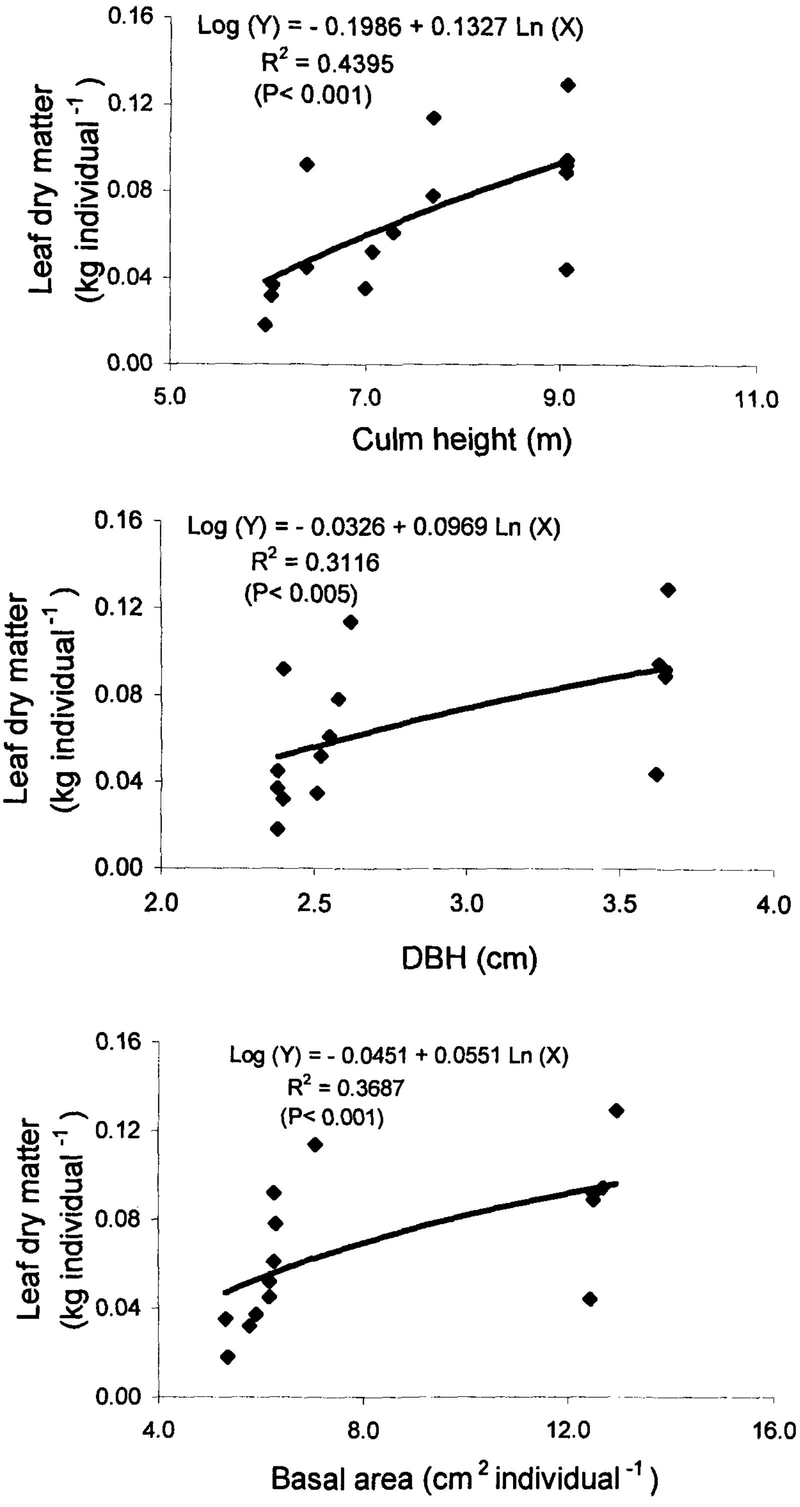

Figure 5.6g. Logarithmic relationship between leaf dry matter with culm height, DBH and basal area per culm of *A. maling* at Jang bamboo forest (considering all the three elevation sites). The degrees of freedom in each case are 25.

parameters, annual rainfall accounted for 72.9% variation with strong positive correlation, while snowfall and wind velocity accounted for 43.6% and 79.1% variation, respectively with negative correlation (Table 5.5a).

All the soil physical parameters were observed to influence the bamboo biomass accumulation. Except soil temperature at 0-10 cm depth, and clay content at 20-30 cm depth, the influence of other parameters at all soil depths was observed to be highly significant (Table 5.5b). Except sand content and bulk density, other parameters were having positive correlation with biomass accumulation. Soil moisture content at 0-10 cm and 10-20 cm depth caused 91.3% and 96.6% variation in bamboo biomass. Water holding capacity at 10-20 cm depth accounted for 73.4% variation, whereas soil temperature at 10-20 cm and 20-30 cm accounted for 18.3% and 28% variation in bamboo biomass accumulation. Bulk density at 0-10 cm and 10-20 cm depth had high negative influence with 69.5% and 74.5% on bamboo biomass accumulation, whereas sand and silt content at 0-10 cm and 10-20 cm depth accounted 78.5%. Clay content at 0-10 cm and 10-20 cm depth caused 80% variation in bamboo biomass accumulation (Table 5.5b).

Among the soil chemical parameters studied, soil pH at 10-20 cm and 20-30 cm depth, soil available phosphorus at 0-10 cm depth and organic carbon at all the three soil depths and soil potassium at 20-30 cm depth were observed to have significant influence on biomass accumulation (Table 5.5c). On the other hand, the effect of soil nitrogen on biomass accumulation was found to be insignificant. Available phosphorus at 0-10 cm alone accounted for 94.2% variation in the rate of biomass accumulation, while soil pH at 10-20

Table 5.5a. Influence of climatic variables on biomass accumulation in *A. maling.*

Temperature (max)		Temperature (min)		RH		Rainfall		Snowfall		Wind velocity		Light intensity	
R^2	F- Value	R^2	F- Value	R^2	F- Value	R^2	F- Value	R^2	F- Value	R^2	F- Value	R^2	F- Value
0.151	9.258**	0.102	5.876**	0.005	0.269^{NS}	0.729	139.658*	0.436	40.128*	0.791	197.034*	0.123	7.283**

⋆, ⋆⋆ Significant at < 0.001 and < 0.05 probability level respectively.

NS - values are not significant.

Table 5.5b. Influence of soil physical parameters on biomass accumulation in *A. maling.*

Soil depth (cm)	Soil moisture		Bulk density		Water holding capacity		Sand (%)		Silt (%)		Clay (%)		Soil temperature	
	R^2	F	R^2	F	R^2	F	R^2	F	R^2	F	R^2	F	R^2	F
0-10	0.913	545.713*	0.695	118.466*	0.324	24.902*	0.785	190.362*	0.785	89.346*	0.797	203.723*	0.183	11.652**
10-20	0.916	570.654*	0.745	151.911*	0.734	143.274*	0.786	191.265*	0.785	190.338*	0.800	208.192*	0.280	20.195*
20-30	0.683	112.173*	0.476	47.156*	0.374	31.084*	0.717	132.028*	0.760	164.579*	0.140	8.463**	0.361	24.055*
0-30	0.868	341.158*	0.650	96.684*	0.742	149.823*	0.769	173.049*	0.777	180.741*	0.543	61.820*	0.254	17.717*

⋆, ⋆⋆ Significant at < 0.001 and < 0.05 probability level respectively.

NS - values are not significant.

Table 5.5c. Influence of soil chemical parameters on biomass accumulation in *A. maling.*

Soil depth (cm)	Soil pH		Total Nitrogen		Available phosphorus		Potassium		Organic carbon		C/N ratio	
	R^2	F	R^2	F	R^2	F	R^2	F	R^2	F	R^2	F
0-10	0.502	52.438*	0.048	2.608 NS	0.942	849.554*	0.000	0.000 NS	0.941	824.879*	0.025	1.339 NS
10-20	0.933	721.372*	0.070	3.913 NS	0.342	27.076*	0.004	0.223 NS	0.937	772.24*	0.017	0.919 NS
20-30	0.760	164.579*	0.029	1.534 NS	0.000	0.008 NS	0.426	38.623*	0.943	857.099*	0.146	8.660**
0-30	0.793	199.796*	0.049	2.685 NS	0.377	31.532*	0.183	11.652**	0.943	856.657*	0.055	3.027 NS

*, ** Significant at < 0.001 and < 0.05 probability level respectively.

NS - values are not significant.

Table 5.5d. Pearson correlation matrix for the relationship among growth parameters and bamboo biomass accumulation in *A. maling* at the three elevation sites.

Parameters	Bamboo biomass	Culm height	DBH	Clump area	LAI
Bamboo biomass	1.000				
Culm height	0.967	1.000			
DBH	0.921	0.934	1.000		
Clump area	0.772	0.802	0.683	1.000	
LAI	0.966	0.986	0.975	0.762	1.000

n = 54; all r-values are significant at < 0.001 probability level.

cm accounted for 93.3% variation and total soil potassium at 20-30 cm depth accounted for 42.6% variation in the bamboo biomass accumulation.

Table 5.5d depicts the Pearson's correlation matrix for the relationship among growth parameters and bamboo biomass. The correlation co-efficient of bamboo biomass and culm height was highest (0.967) followed by leaf area index (0.966) and DBH (0.772).

5.3.3 Aboveground productivity of *A. maling* forest at Jang area

5.3.3.1 Aboveground productivity of 'Rui' bamboo

Temporal variation in the dry matter production of *A. maling* at different elevation sites is presented in Table 5.6. The productivity (kg clump^{-1} per three months and tonnes ha^{-1} per three months) was significantly different at the three elevation sites ($F = 51.018$, $P < 0.001$) and different sampling dates ($F = 19.072$, $P < 0.001$).The effect of interaction between the elevation sites and sampling dates also differed significantly ($F = 7.325$, $P < 0.005$). The highest value of bamboo productivity was observed during April-July at all the three elevation sites, where medium elevation site had the largest value (16.45 tonnes ha^{-1} per three months). At the low elevation site, lowest bamboo productivity was recorded during October-January, and there was a negative value of productivity during July-October. Lowest bamboo productivity at the medium elevation site was recorded during July-October, whereas at the high elevation site lowest value was observed during October-January. There was negative productivity during July-October and January-April at the high elevation site. The annual productivity of 'Rui' bamboo increased significantly from the first year to the second year *i.e.*, 2001-2002 to

Table 5.6. Temporal variation in the dry matter production of *A. maling* at the three elevation sites in Jang bamboo forest.

Site	Unit	2001 - 2002					2002 - 2003					2001 - 2003
		April-July	July-Oct	Oct-Jan	Jan-April	**Annual productivity**	April-July	July-Oct	Oct-Jan	Jan-April	**Annual productivity**	**Mean annual productivity**
Low elevation	Kg $clump^{-1}$	3.02 ± 3.90	N	10.36 ± 2.08	11.68 ± 2.95	**35.06 ± 8.93**	26.5 ± 5.96	N	8.04 ± 4.88	10.90 ± 4.68	**45.44 ± 15.52**	**40.25 ± 5.19**
	Tonnes ha^{-1}	4.04 ± 1.21	N	3.22 ± 0.65	3.63 ± 0.91	**10.89 ± 2.77**	8.24 ± 1.85	N	2.51 ± 1.52	3.39 ± 0.14	**14.14 ± 3.51**	**12.52 ± 1.63**
Medium elevation	Kg $clump^{-1}$	57.93 ± 3.35	5.18 ± 1.30	12.33 ± 0.34	41.59 ± 1.48	**117.03 ± 3.12**	107.16 ± 3.61	17.71 ± 1.15	28.42 ± 3.98	56.58 ± 2.33	**209.87 ± 11.07**	**163.45 ± 46.42**
	Tonnes ha^{-1}	11.46 ± 0.66	1.04 ± 0.26	2.47 ± 0.07	8.31 ± 0.29	**20.81 ± 0.62**	21.43 ± 0.72	3.55 ± 0.23	5.69 ± 0.79	11.30 ± 1.88	**41.97 ± 3.62**	**31.39 ± 9.35**
High elevation	Kg $clump^{-1}$	10.82 ± 1.03	N	N	N	**10.82 ± 1.03**	6.12 ± 0.60	N	0.61 ± 1.55	N	**6.73 ± 2.15**	**8.78 ± 2.05**
	Tonnes ha^{-1}	1.69 ± 0.16	N	N	N	**1.69 ± 0.16**	0.95 ± 0.09	N	0.09 ± 0.25	N	**1.04 ± 0.34**	**1.37 ± 0.33**

(Mean ± SE); N - indicates the negative values of productivity which are excluded in determining the annual productivity.

2002-2003 with a mean productivity of 12.52, 31.39 and 1.37 tonnes ha^{-1} yr^{-1}, respectively at the low, medium and high elevation sites.

Temporal variation in the bamboo extraction revealed that, largest bamboo biomass was extracted during January-April at all the three elevation sites, whereas lowest extraction was recorded during April-July. Largest bamboo biomass was extracted from the low elevation site (18.47 tonnes ha^{-1} yr^{-1}) compared to that of medium (15.28 tonnes ha^{-1} yr^{-1}) and high elevation site (3.40 tonnes ha^{-1} yr^{-1}). The annual bamboo extraction increased from the year 2001-2002 to 2002-2003 at the low and high elevation sites, whereas it decreased from the first year to the second year at the medium elevation site (Table 5.7).

5.3.3.2 Productivity of herbs and shrubs in 'Rui' bamboo forest at Jang area

Temporal and annual variation in the dry matter production of herbs and shrubs is presented in Table 5.8. The dry matter production at three months period was significantly different at the three elevation sites ($F = 87.657$, $P < 0.001$), and different sampling dates ($F = 177.370$, $P < 0.001$). Productivity of herbs and shrubs was highest during April-July at all the three elevation sites, whereas it was lowest during January-April. Dry matter production of herbs and shrubs increased considerably from the year 2001-2002 to 2002-2003. Productivity of herbs and shrubs was highest at the high elevation site (3.30 tonnes ha^{-1} yr^{-1}), and decreased with the decrease in elevation.

5.3.3.3 Temporal variation in litter production at Jang bamboo forest

Table 5.9 depicts the temporal and annual variation in litter production at Jang bamboo forest. Litter production differs significantly at the

Table 5.7. Temporal variation in the extraction of bamboo biomass from the *A. maling* forest during 2001-2003.

Site	Unit	2001 - 2002					2002 - 2003					2001 - 2003
		April-July	July-Oct	Oct-Jan	Jan-April	**Annual harvest**	April-July	July-Oct	Oct-Jan	Jan-April	**Annual harvest**	**Mean annual harvest**
Low elevation	Kg $clump^{-1}$	4.92	8.79	16.95	18.08	**48.74**	2.70	13.35	28.09	25.88	**70.02**	**59.38**
	Tonnes ha^{-1}	1.53	2.73	5.27	5.62	**15.15**	0.84	4.15	8.74	8.05	**21.78**	**18.47**
Medium elevation	Kg $clump^{-1}$	4.42	16.68	23.86	44.51	**89.47**	1.59	13.99	21.99	25.68	**63.25**	**76.36**
	Tonnes ha^{-1}	0.88	3.34	4.77	8.90	**17.89**	0.32	2.80	4.40	5.14	**12.66**	**15.28**
High elevation	Kg $clump^{-1}$	1.26	1.94	6.47	10.17	**19.84**	2.52	2.58	9.15	9.42	**23.67**	**21.76**
	Tonnes ha^{-1}	0.20	0.30	1.01	1.59	**3.10**	0.39	0.40	1.43	1.47	**3.69**	**3.40**

Table 5.8. Temporal variation in the productivity of herbs and shrubs in Jang bamboo forest.

Site	Unit	2001 - 2002					2002 - 2003					2001 - 2003
		April-July	July-Oct	Oct-Jan	Jan-April	**Annual productivity**	April-July	July-Oct	Oct-Jan	Jan-April	**Annual productivity**	**Mean annual productivity**
Low elevation	Kg m^{-2}	0.10	N	N	0.04	**0.14**	0.16	N	N	0.02	**0.18**	**0.16**
	Tonnes ha^{-1}	1.00	N	N	0.40	**1.40**	1.60	N	N	0.20	**1.80**	**1.60**
Medium elevation	Kg m^{-2}	0.10	N	N	0.11	**0.21**	0.13	N	N	0.11	**0.24**	**0.23**
	Tonnes ha^{-1}	1.00	N	N	1.10	**2.10**	1.30	N	N	1.10	**2.40**	**2.25**
High elevation	Kg m^{-2}	0.21	N	N	0.14	**0.35**	0.19	N	N	0.12	**0.31**	**0.33**
	Tonnes ha^{-1}	2.10	N	N	1.40	**3.50**	1.90	N	N	1.20	**3.10**	**3.30**

N- indicates the negative values of productivity which are excluded in determining the annual productivity.

Table 5.9. Temporal variation in the litter production in Jang bamboo forest.

Site	Unit	2001 - 2002					2002 - 2003					2001 - 2003
		April-July	July-Oct	Oct-Jan	Jan-April	**Annual litterfall**	April-July	July-Oct	Oct-Jan	Jan-April	**Annual litterfall**	**Mean annual litterfall**
Low elevation	Kg m^{-2}	0.20	0.06	0.18	0.18	**0.62**	0.25	0.07	0.19	0.19	**0.70**	**0.66**
	Tonnes ha^{-1}	2.00	0.60	1.78	1.78	**6.16**	2.48	0.72	1.90	1.91	**7.01**	**6.59**
Medium elevation	Kg m^{-2}	0.18	0.10	0.13	0.16	**0.57**	0.21	0.12	0.14	0.18	**0.65**	**0.61**
	Tonnes ha^{-1}	1.76	1.04	1.34	1.59	**5.73**	2.14	1.23	1.43	1.78	**6.58**	**6.16**
High elevation	Kg m^{-2}	0.17	0.13	0.21	0.14	**0.65**	0.21	0.15	0.22	0.16	**0.74**	**0.70**
	Tonnes ha^{-1}	1.72	1.28	2.09	1.40	**6.49**	2.13	1.50	2.20	1.62	**7.45**	**6.97**

three elevation sites ($F = 10.374$, $P < 0.001$), different sampling dates ($F = 163.083$, $P < 0.001$) and the effects of interaction between sites and sampling dates ($F = 33.311$, $P < 0.001$). The litter production (per three months) was highest during April-July at all the three elevation sites, whereas litter production was lowest during July-October. Litter production was maximum at the high elevation site (6.97 tonnes ha^{-1} yr^{-1}) followed by the low (6.59 tonnes ha^{-1} yr^{-1}) and the medium elevation sites (6.16 tonnes ha^{-1} yr^{-1}).

5.3.3.4 Annual biomass accumulation, net aboveground primary production and biomass accumulation quotient in *A. maling* forest at Jang area

Highest bamboo biomass was accumulated at the medium elevation site followed by the low and high elevation sites, while largest quantity of bamboo biomass was extracted from the low elevation site. Highest rate of herbs and shrubs biomass accumulation was recorded at the high elevation site followed by the medium and low elevation sites. The annual litterfall was higher at the high elevation site as compared to the other two elevation sites. The net aboveground primary productivity (NPP) of *A. maling* forest at Jang area was larger at the medium elevation site from that of low and high elevation sites. The biomass accumulation quotient was higher at the low elevation site followed by the medium and high elevation sites (Table 5.10).

5.4. DISCUSSION

Bamboo biomass differs from species to species according to their size and specific gravity. Standing crop of *A. maling* at Jang bamboo forest was highly influenced by topography, climate, soil and anthropogenic pressure. *A. maling* at Jang area was flourished well within the elevation

Table 5.10. Rate of biomass accumulation, litterfall and aboveground net primary production at the low, medium and high elevation sites in Jang 'Rui' Bamboo forest.

Parameters	Low elevation	Medium elevation	High elevation
Standing biomass of bamboo (tonnes ha^{-1})	79.73	107.46	9.11
Rate of bamboo biomass accumulation (tonnes ha^{-1} yr^{-1})	12.52	31.39	1.37
Rate of herb and shrub biomass accumulation (tonnes ha^{-1} yr^{-1})	1.60	2.25	3.30
Total litterfall (tonnes ha^{-1} yr^{-1})	6.59	6.16	6.97
Bamboo biomass extracted (tonnes ha^{-1} yr^{-1})	18.47	15.28	3.40
Net aboveground primary production (NPP) (tonnes ha^{-1} yr^{-1})	39.18	55.08	15.04
Biomass accumulation quotient (Standing biomass/NPP)	2.03	1.95	0.61

range of 2400-3600 m asl., although the medium elevation site with 2800-3200 m asl. was found most suitable for growth and biomass performance. Studies on temporal variation on bamboo standing crop at natural habitats are very meager. The seasonal variation in standing crop of *A. maling* in Jang area was insignificant, but it increased significantly from the first year to the second year at all the three elevation sites. During the wet season, villagers of Jang area did not have an easy access to the bamboo resource due to wild animals and insect problem. There was a sudden decline in bamboo standing crop during dry season at all the three elevation sites, which was due to the massive extraction of bamboo culms during this period. As there was no other bamboo species and any other suitable timber tree except *Cephalotaxus griffithi* and few *Rhododendron* species, which were protected by the State Forest Department, people fully depend on this bamboo forest for fuel wood and other household needs.

The standing crop of *A. maling,* a narrow temperate bamboo species (height: 6.4-9.5 m; DBH: 2.40-3.66 cm) was 67.71 tonnes ha^{-1} (11.56-110.14 tonnes ha^{-1}) is comparatively higher than the biomass of most of the large and narrow tropical and subtropical bamboo species reported by many authors (APPENDIX V-A). In India, the standing crop of *Bambusa bambos*, a large tropical bamboo species (height: 20-30 m; DBH: 5-8.5 cm) was reported to be 122-287 tonnes ha^{-1} (Shanmughavel and Francis 1996), whereas in case of *Dendrocalamus strictus*, another tropical to sub-tropical medium size bamboo (height: 8-16 m; DBH: 2.5-8 cm), it was 4-22 tonnes ha^{-1} (Tripathi and Singh 1994). However, in the improved plantation stands of *Dendrocalamus strictus*, the standing crop was reported to be 144.34 tonnes

ha^{-1} (Singh *et al.* 2004), which is much higher compared to the values reported by Tripathi and Singh (1994). The standing crop of *Chusquea tessellata*, a temperate and alpine bamboo species reported from Colombia, was 26.25 tonnes ha^{-1} (Gerrit and Antoine 1994), which is much less compared to that of *A. maling*. *Gigantochloa scortechnii* produced 71.9 tonnes biomass per hectare in natural stand and 36.36 tonnes ha^{-1} in a three year old plantation in Malaysia (Othman 1992), which is lower than that of *A. maling* at the low elevation site (81.43 tonnes ha^{-1}). The standing crop of *A. maling* at the medium elevation site in Jang area was more or less equal to that of *Phyllostachys bambusoides* and *P. pubescens*, the two most important multipurpose bamboo species of China and Japan which produced 112 and 139 tonnes of biomass per hectare (Isagi *et al.* 1993, 1997). Aboveground biomass of bamboo species growing in jhum lands was 0.08-6.2 tonnes ha^{-1} as reported by Rao (1986) which is much less in comparison to the biomass of *A. maling* found in the present investigation. The aboveground biomass of *A. maling* is well comparable to the biomass of other fast growing tree species, such as *Eucalyptus globules* (8.6 tonnes ha^{-1} in 4 year old plantation, Cromer and Williams 1982), *Leucaena leucocephala* (47 tonnes ha^{-1} in 5 year old plantation, Pandey *et al.* 1989) and *Pinus caribaea* (87 tonnes ha^{-1} in six year old plantation, Madgwick *et al.* 1977). If the standing crop of these trees is compared with that of *A. maling* at the medium elevation site of the present investigation, there is a 1.2-12 fold greater dry matter accumulation in *A. maling*. Thus, total aboveground biomass of *A. maling* including other bamboo species reported by Kleinhenz and Midmore (2001) and Embaye (2003) were fairly much within the expected range for woody biomass. It appears that the amount and distribution of bamboo biomass differs from that for tree biomass by degree only. The key differences are the smaller piece size and higher number of 'stems' typical of a bamboo plantation and that bamboo biomass never seems to approach the very high figures possible in some tree stands.

Dry matter allocation in culm, branch and leaf of the standing crop of *A. maling* in the present investigation (91-92%, 5% and 3-4% respectively) was well within the range reported for other bamboos (APPENDIX V-C). The biomass contained in culm (98.70 tonnes ha^{-1}), branch (5.06 tonnes ha^{-1}) and leaf (3.70 tonnes ha^{-1}) at the medium elevation site was comparatively higher than those of *Phyllostachys bambusoides* reported by Isagi *et al.* (1993) and *P. pubescens* reported by Li *et al.* (1998a).

Aboveground biomass of herb and shrub was significantly different among the three elevation sites, which might have resulted due to the different climatic and soil conditions of the study sites. Maximum biomass was observed during July and October and which could be due to high moisture availability and relatively warmer weather. The minimum biomass observed during January and April might be due to the chilling stress and low moisture availability. In tropical cropland, Boral (1993) has reported similar trend. The medium elevation site supported better growth of woody herbs and shrubs with higher plant diversity and density (Chapter III). And hence, highest biomass was recorded at the medium elevation site. The aboveground herb and shrub biomass in *A. maling* forest at Jang area with 1.70-2.68 tonnes ha^{-1} was comparatively higher than the Himalayan high altitude grasslands reported by Joshi *et al.* (1991) and the cropland of Meghalaya reported by Boral (1993).

The mean total aboveground biomass of *A. maling* forest (bamboo biomass plus herbs and shrubs biomass) at Jang area was 67.71 tonnes ha^{-1} which is comparable with that of many bamboo forests of tropical to alpine ecosystems, whereas the total aboveground biomass at medium elevation site (110.14 tonnes ha^{-1}) is comparatively higher than many of the temperate as well as tropical bamboo forests reported by Kleinhenz and Midmore (2001) and Embaye (2003). Santa Regina and Tarazona (2001) reported that total biomass ranged from 132.7 tonnes ha^{-1} in sea beach stands to 152.1 tonnes ha^{-1} in the pine stands in Northern Spain. The highest aboveground biomass of *A. maling* forest observed during July at the low and high elevation sites might be due to the production of new shoots during June-July, and partially due to the highest biomass of herbs and shrubs during this sampling period. Highest aboveground biomass of *A. maling* forest observed during January at the medium elevation site may be explained due to the highest dry matter accumulation rate in different bamboo parts with large population. Extraction of largest bamboo biomass during January-April associated with less herbs and shrubs biomass, might have resulted to the lowest standing biomass of *A. maling* forest during April at all the three elevation sites.

The quantity of dry matter accumulation in bamboo varies greatly among the species and habitat. In general, bamboo species, which occur in tropical and subtropical zones, are larger in size with larger quantity of dry matter accumulation, whereas bamboos of temperate and alpine zones are smaller in size and produce less biomass. Mean aboveground dry matter accumulation in one-year old *A. maling* at Jang bamboo forest varied from 0.93-1.98 kg $individual^{-1}$ (considering all the three elevation sites) and at the age of two years, it accumulated 1.58-2.42 kg individual^{-1}. Tropical bamboo species, such as *Bambusa bambos* can accumulate larger quantity of dry matter (52-72 kg individual^{-1}) during the first year (Shanmughavel and Francis 2001) in comparison to *A. maling*. On the other hand, subtropical bamboo species like *Phyllostachys glauca*, *P. nigrahexonis* and *P. viridis* accumulated 1.82, 1.67, and 2.16 kg biomass individual^{-1}, respectively (Othman and Shamsudin 2002). *P. heteroclada* accumulated 1.03 kg individual^{-1} (Sun *et al.* 1987), which is much less compared to that of *A. maling*.

Unlike other woody perennials, bamboos attain maximum growth within a very short period during the culm elongation phase, in which, highest rate of biomass accumulation takes place in both tropical and temperate ecosystems. The aboveground biomass was reported to be maximum at the age of six year in case of *Bambusa bambos* (Banik 2000, Shanmughavel and Francis 2001). In *A. maling*, the maximum growth rate of height and DBH was observed during the first month after shoot emergence (Chapter IV). There was a gradual increase in height and DBH of *A. maling* after the culm elongation phase till the end of the study period. In tropical and subtropical large-sized bamboo species, culm elongation phase lasts for only 60-90 days depending on bamboo species and habitat (Mc Clure 1966, Ueda 1981, Shanmughavel 1995, Banik 2000, Shanmughavel and Francis 2001). The first and the foremost peak of dry matter accumulation rate in *A. maling* was seen during the first month of culm elongation phase, which gradually declined. Finally, another peak was observed at the age between 9 to 12 months, which resulted due to the induction of branches and leaves, in addition to its normal dry matter accumulation in the culm. The highest rate of dry matter accumulation was recorded during the first month after shoot emergence from the ground, whereas in tropical and subtropical large-sized bamboos the highest rate of dry matter accumulation has been reported between 3-6 months (Shanmughavel and Francis 2001). Dry matter accumulation was highest at the medium elevation site with 17.00 g day^{-1} $individual^{-1}$ whilst at the low and high elevation sites the biomass accumulation was much lower (10.13 and 6.93 g day^{-1} $individual^{-1}$ respectively). Moisture content in the culm of *A. maling* was maximum during the first month with 61-81%, which gradually declined with the increase in age, and at the age of 24 months (almost mature condition), it was only 21-30%. Banik (2000) reported high moisture content during the first month and decrease in moisture content with age in *Bambusa tulda, Dendrocalamus longispathus, Melocanna baccifera, Ochlandra nigrocilata* and *Schizostachyum dullooa*. The low moisture content in culm, branch and leaf at the medium elevation site, compared to the low and high elevation site revealed that there might be higher rate of deposition of starch and other organic compounds in bamboo parts at this elevation. At the age of two years *A. maling* allocated 87-88% dry matter to its culm, 6-7% to the branch and 5-6% to leaf. The allocation pattern is similar to that reported by Kleinhenz and Midmore (2001) and many other workers (APPENDIX V-C) while it is quite different from tropical clump forming species reported by Shanmughavel and Francis (2001).

This study has revealed a significant influence of topography, climate and soil on growth as well as biomass accumulation in *A. maling* in Jang area. Many workers have reported higher dry matter accumulation on high annual precipitation in several bamboo species (Kigomo and Kamiri

1985, Biswas 1988, Qiu *et al.* 1992, Aggarwal *et al.* 1994, Koyama and Uchimura 1995, Lin 1995). The wind velocity had negative influence on biomass accumulation by *A. maling* as also reported by Zhou *et al.* (1991), Ambasht and Ambasht (1999) in other bamboo species. The larger biomass accumulation by *A. maling* on higher light intensity was similar as reported in other bamboo species (Hasan 1966, Yang *et al.* 1991, Elgi and Schmid 1999).

Loose soil with loamy sand texture characterized by higher silt but low clay content at the medium elevation site might have a positive influence on bamboo growth and biomass accumulation at this elevation. A similar effect was reported by Yadav (1969) and Chung and Ramm (1990). At the low and high elevation sites, soil with sandy texture, might have negative effects resulting in poor growth and less biomass accumulation in *A. maling*. Greater soil moisture availability at 0-30 cm depth throughout the year (45-60%), loose soil with low bulk density (0.26 g cm^{-3}) and high porosity (90.21%) and moderate soil temperature (-2 to 10^0 C) at the medium elevation site are among the important physical parameters which might have resulted in greater biomass accumulation at this elevation. Soil moisture at 0-10 and 10-20 cm depth accounted for maximum variation (91%) in bamboo biomass accumulation followed by soil texture and bulk density. Similar trends were reported by Qing *et al.* (2004) on growth and biomass accumulation in *Pleioblastus maculata* for higher soil moisture availability, and by Li *et al.* (1998c) for higher soil porosity in China. Influence of soil pH at 10-20 cm depth on biomass accumulation in *A. maling* was significantly high accounting for 93.3% variation in biomass accumulation.

The soil pH of Jang *A. maling* forest was within the suitable range (5.22- 5.41) for the best bamboo growth and biomass performance as reported by Uchimura (1978), Hassan *et al.* (1988) and Rao (1993). Soil at the medium elevation site was less acidic, pH ranging from 5.26 to 5.51, which might have supported better nutrient assimilation at this elevation resulting in better growth and biomass accumulation of *A. maling*. Soil available phosphorus at 0-10 cm depth and organic carbon at all the three soil depths accounted more than 94% variation in bamboo biomass accumulation, and hence, these two nutrients may be considered as the most important nutrients limiting the growth as well as biomass accumulation in *A. maling*. In addition to other factors, soil with higher available phosphorus (8.82 µg g^{-1}) and organic carbon (9.94%) at the medium elevation site might have contributed to greater biomass accumulation. Totey and co-workers (1989) have reported similar positive influence of soil phosphorus on biomass performance of *Dendrocalamus strictus*. Reports on the association of vesicular-arbuscular mycorrhizal (VAM) fungi with many bamboo species like *Bambusa bambos*, *Dendrocalamus strictus, Ochlandra scriptoria* and *O. travancorica*, reflected significant influence of soil phosphorus on bamboo growth and biomass accumulation (Appasamy and Ganapathi 1992). Singh *et al.* (1999) has reported seven fold increase in biomass accumulation in *Dendrocalamus strictus,* when it was inoculated with VAM fungi. He and Ye (1987) reported soil organic matter as one of the most important factors influencing plant growth. Sun and Ye (1988) also reported the positive role of soil organic matter in biomass accumulation by increasing soil porosity and water holding capacity, and proper nourishment to the microbes, which mineralize and release the nutrients locked in the plant residues.

Soil nitrogen content at all the three elevation sites was much higher (0.76%, 0.46% and 0.31% at 0-30 cm depth at the low, medium and high elevation sites, respectively) compared to other subtropical and temperate bamboo stands as reported by Shi *et al.* (1987) in *Phyllostachys pubescens* stands and by Yadav (1963) in *Bambusa bambos* and *Dendrocalamus strictus* stands. It is a well-known fact that nitrogen plays a key role in plant growth and biomass performance. Soil total nitrogen was much higher at the low elevation site compared to the medium and high elevation sites, but it did not cause any significant influence on biomass accumulation of *A. maling*. As *A. maling* forest stand had a high concentration of soil total nitrogen at all the three elevation sites due to high organic matter accumulation, all the elevation sites might have attained the optimum level of nitrogen required for growth and survival of *A. maling*. Other workers have also reported insignificant role of soil nitrogen in such a situation on growth and biomass accumulation of many bamboo species (Adamson *et al.* 1978, Patil *et al.* 1980, Shi *et al.* 1987, Qiu and Maoyi 1987, Raina *et al.* 1988, Thomas 1990).

The difference in soil potassium content was insignificant among the three elevation sites. The soil had a higher concentration of potassium indicating that *A. maling* growing at the three-elevation sites has helped in conserving soil potassium as has also been reported by Toky and Ramakrishnan (1982) and Rao and Ramakrishnan (1989) in the case of other bamboos. The concentration of potassium was higher in the subsurface soil than the surface layer, while the soil nitrogen and phosphorus contents were low in the sub soil. It may be due to the capability of the root system of *A. maling* to accumulate and conserve soil potassium as reported by many workers in different bamboo species (Toky and Ramakrishnan 1982, Rao and Ramakrishnan 1989, Joshi *et al.* 1991, Mailly *et al.* 1997, Shanmughavel and Francis 1997, Lin and Lin 1998). Greater availability of soil potassium in the sub-surface soil had a significant influence on biomass performance of *A. maling*, which agrees with the findings of Marschner *et al.* (1996) and Qiu and Maoyi (1987). Growth parameters like culm height, DBH, basal area per culm and leaf area index (LAI) had significant positive correlation with the biomass accumulation of *A. maling* as also reported by Banik (2000) and Shanmughavel and Francis (1997) in other bamboo species. The leaf area index of *A. maling* at the medium elevation site (7.98) is comparable to *Phyllostachys pubescens* (8.02) and *P. bambusoides* (11.6), the two most important and efficient bamboo species found in China, Japan and Thailand (Isagi *et al.* 1993).

Biomass prediction equations generated from different regression models revealed that at the low elevation site, the equation $Y = 0.0161e^{0.6129X}$ ($R^2 = 0.8971$) may most suitable for the culm height, followed by basal area per culm ($R^2 = 0.866$) and DBH ($R^2 = 0.7534$). At the medium elevation site, the equation was best derived with DBH as $Y = 6E\text{-}05e^{2.8477X}$ ($R^2 = 0.7902$) followed by basal area ($R^2 = 0.7621$) and culm height ($R^2 = 0.6592$), whereas at the high elevation site, basal area per culm was noticed to be the most significant parameter for biomass prediction, $Y = 0.0411e^{0.5741X}$ ($R^2 = 0.9026$) followed by culm height (0.8258) and DBH (0.8191). The equation to predict bamboo biomass of *A. maling* considering all the three elevation sites was best derived with culm height as Log Y = -3.143 + 2.2765 Ln (X), (R^2 = 0.6538) followed by basal area (R^2 = 0.6027) and DBH (R^2 = 0.4751). The last equation implied that biomass of *A. maling* growing along an altitudinal gradient is highly influenced by culm height. Many workers have derived such biomass prediction equations, which are species-specific. For the prediction of accumulated dry matter in culm, branch and leaf of *A. maling*, culm height was most suitable followed by basal area and DBH. Leaf area index also had a highly significant positive influence on the dry matter accumulation in *A. maling* (r = 0.966). Shanmughavel and Francis (2001) has derived total aboveground bamboo biomass prediction equation for *Bambusa bambos* as Log Y = -0.8838 + 3.1908 Ln (X) (R^2 = 0.9878), considering culm height for the determination of total biomass.

Many workers have reported that individual bamboo species has its own site specificity for distribution and growth performance, where topography, agro- climatic conditions and soil play key roles (Gamble 1896, Qureshi and Deshmukh 1962, Varmah and Bahadur 1980, Numata 1987, Uchimura 1987, Tewari 1992, Bedell 1997). The greater dry matter accumulation in *A. maling* at the medium elevation site might be due to the more suitable micro-climatic and soil conditions at this site compared to the other two sites.

The rate of annual bamboo biomass accumulation in *A. maling* forest (15.09 tonnes ha^{-1} considering all the three elevation sites) was much higher than the reported annual productivity of bamboo forests in India (0.33 tonnes ha^{-1}), China (1.25 tonnes ha^{-1}) and Japan (2.41 tonnes ha^{-1})

1989). It is interesting to note that, *A. maling* forest in Jang area has much greater annual biomass accumulation as compared to other tropical, subtropical and temperate bamboo species reported so far by Veblen *et al.* (1980), Tripathi and Singh (1994) and Isagi *et al.* (1997), which ranged between 1.8-20 tonnes^{-1} ha^{-1}. The rate of biomass accumulation in *A. maling* may also be well compared with many tropical and temperate woody species. The values are comparatively higher than those reported for poplar (Heilman and Xie 1993, Stanley and Montagnini 1999), *Acacia auriculiformis* and *Pinus caribaea* (Kadeba 1991), with 5.2-22 tonnes ha^{-1} yr^{-1}. In addition to this, the annual biomass production of A. *maling* at Jang area was much pronounced at the medium elevation site with 31.89 tonnes ha^{-1} yr^{-1}, which is very high compared to the low and high elevation sites, as well as most of the bamboo and woody forests in the world.

The annual rate of litterfall in the *A. maling* forest (6-7 tonnes ha^{-1}) was comparatively higher to those reported in different bamboo species occurring in tropical to temperate forests by many authors (APPENDIX V-C), except *Bambusa bambos* (Shanmughavel and Francis 1996), where it was 9.2-11.8 tonnes ha^{-1}. In the Jang *A. maling* forest, the rate of litterfall was significantly higher at the high elevation site than the low and medium elevation sites, which might be due to the prevailing climatic variables like low temperature, low to high light intensity, high snowfall, low relative humidity and high wind velocity.

The greater extraction of 'Rui' bamboo at the low elevation site in Jang area was due to the easy accessibility of this resource to the villagers. Although the culms at this elevation site were comparatively narrow, yet they were harvested in large numbers throughout the year for household and home garden applications. As the medium elevation site was dominated by the larger culms but they were not easily accessible due to long distance from the village area and steep slope except during the dry season. The distance of the high elevation site is 18 km from the human habitation and hence, maximum biomass extraction from this site is done for road construction purpose and by defence personnel.

The net aboveground primary production (NPP) of Jang bamboo forest with 36.43 tonnes ha^{-1} yr^{-1} is comparatively higher in global context (APPENDIX V-B). It was much higher from those reported in subtropical to temperate stands of *Phyllostachys bambusoides* (Isagi *et al.* 1993), *P. pubescens* (Isagi *et al.* 1997) and *Thyrostachys siamensis* (Suwannapinunt 1983). It was also higher from *Dendrocalamus strictus*, a tropical species worked out in India (Tripathi and Singh 1994) and close enough to *Bambusa bambos* (Shanmughavel 1995). If the medium elevation site is considered, the NPP (55.08) exceeds to all bamboo forests reported by many authors (APPENDIX V-B).

It can be concluded that largest biomass, productivity and net primary productivity of *Arundinaria maling* forest at the medium elevation site (2800-3200 m asl) of Jang area might be due to the suitable physiography, climatic and soil condition at this particular elevation range. It can serve as a rich biomass resource and can compete successfully with other tropical large-sized bamboo species. The estimated total land area of Jang bamboo forest is 3169 ha which represents only 0.40% of the total bamboo forest area (780 thousand hectares) of Arunachal Pradesh. The calculated 47.8 thousand tonnes annual production of 'Rui' bamboo in Jang area represents 23.9% of the state's total bamboo production out of 200 thousand tonnes reported earlier (Trivedi and Tripathi 1984, Tewari 1992, Hore 1998). This available resource may be exploited scientifically and used to run bamboo based small scale industries for the development of the socio-economic condition of Jang area and the Tawang district as well.

CHAPTER VI

DISTRIBUTION OF N, P AND K AND LEAF CHLOROPHYLL CONTENT IN *ARUNDINARIA MALING*

6.1 INTRODUCTION

Plants absorb nutrients and transport them to various growing parts for the production of organic compounds and their incorporation into biomass (Kramer and Kozlowski 1960). Nitrogen, phosphorus and potassium (N, P and K) are the three amongst the essential macro elements that limit the growth and productivity of plant communities, and play an important role in functioning of the ecosystem (Uchimura 1980, Kinhal 1985, Huang 1987). In addition to the knowledge on the status of N, P and K in soil, studies on their distribution in the vegetation subsystem and its inputs and outputs in various components and compartments are essential for complete understanding of N, P, K cycling within the ecosystem.

Nitrogen is the basic component of most of the organic compounds of living beings, as building block of amino acids, proteins, nucleic acids etc. Phosphorus acts as biological energy for physiological metabolism and in nature, it occurs as orthophosphate (PO_4^{3-}) bound to different compounds. It is also one of the essential elements for all living cells, as a component of nucleic acids, phospholipids, sugar phosphates and molecules with an energy-rich pyrophosphate bond (e.g. ATP). In the vegetative tissues of higher plants, most inorganic phosphate (Pi) is located in vacuole. P deficiency depresses plant growth. The leaf area of the plant is significantly reduced, while chlorophyll content is usually not affected or even increased, making the leaves darker in colour, a symptom of P deficiency (Marschner 1995). Plants take up P as hydrogenated orthophosphate ions (H_2PO4^- or HPO_4^{2-}) from the soil solution in an active energy dependent process (Rao *et al.* 1999). Potassium is a versatile nutrient involved in plants in many metabolic processes such as enzyme activation, osmotic control of the water economy, carbohydrate production and partitioning and the anion/cation balance. Potassium alone does not influence growth and biomass of plants, although it acts as a booster element in uptake and transport of other nutrients like NO_3 from the roots to the shoot and carbon from the shoot to the roots, storage organs like grains, and tubers (Marschner *et al.* 1996). It also improves the hardiness of plants (Qiu and Maoyi 1987). Potassium travels as counter-ion together with NO_3 in the xylem to the shoot (Marschner *et al.*, 1996). Lack of potassium, however, restricts the NO_3 transport, which leads to nitrate reduction in the roots and accumulation of amino acids.

Chlorophyll is the green photosynthetic pigment present in chloroplasts, which provides the energy necessary for photosynthesis. It is capable of channeling the energy of sunlight into chemical energy through the process of photosynthesis. In this process the energy absorbed by chlorophyll transforms carbon dioxide and water into carbohydrates and oxygen. Chlorophyll-a participates directly in the light requiring reactions of photosynthesis, whereas chlorophyll-b acts indirectly as an accessory pigment in photosynthesis by transferring the light it absorbs to chlorophyll a. Nutritional status in the plant parts, chlorophyll content and the age of the plant play key roles in photosynthetic capacity of leaves that reflect on growth and productivity of plants. Being an extremely fast growing species, bamboo can be expected to consume larger quantities of nutrients than the other plants.

This chapter deals with effect of the age of *A. maling* and temporal variation on N, P and K content in different parts of *A. maling* and in leaf litter at different elevation sites. Effect of leaf age on leaf chlorophyll content at different elevation sites has also been analyzed and discussed. Aboveground standing state of N, P and K in the aboveground bamboo parts and their removal through culm harvest and return through leaf litter at different elevation sites have also been computed and discussed in this chapter.

6.2 MATERIALS AND METHODS

Culm, branch and leaf samples of *A. maling* collected from the three elevation sites at three months interval over a period of two years were air-dried. Branch and leaf samples were oven-dried at 70^0 C for 24 hours and ground in a Wiley mill, whereas saw dusts were collected after cutting the culms and ground. All the powdered materials were stored in polythene bags for determining N, P and K. Nitrogen, phosphorus and potassium contents of the powdered samples starting from April 2001 to July 2003 were determined following the methodology given by Allen *et al.* (1974). Plant nitrogen was determined by digesting powdered samples with concentrated sulphuric acid using Kjeltab (TECATOR) as catalyst, in a block digester. Distillation and titration were done in a KEL PLUS distillation system and Schott Titro Line easy (ELITE EX) respectively. Plant phosphorus was determined by an UV-visible spectrophotometer through molybdenum blue method (Allen *et al.* 1974). Potassium was determined through flame photometer after digesting the samples with tri-acid following the methodology of Allen *et al.* (1974). Each analysis was performed in triplicate and the final results are expressed on oven-dry weight basis.

During the plant sampling period, fresh bamboo leaves were collected from three canopy layers of the crown, and brought to the laboratory for the determination of chlorophyll. Chlorophyll a, b and total chlorophyll were determined after extracting through 80% acetone following the methodology of Arnon (1949).

N, P and K accumulation in the aboveground bamboo parts was worked out using their biomass values and corresponding nutrient concentrations at different sampling dates. As leaves and branches are left in the forest during harvest, nitrogen, phosphorus and potassium loss through culm removal was computed considering only the culm biomass. N, P and K return in the *A. maling* forest through leaf litter was computed considering periodic leaf litter production and their nutrient concentration at respective sampling periods.

Multi-way analysis of variance was done to compare the N, P, and K content in different bamboo parts, their accumulation, return through litter, lost through culm harvest and leaf chlorophyll content of *A. maling* growing at the three elevation sites. To understand the influence of soil N, P, and K pool on their translocation to different bamboo parts, correlation analyses were done through SYSTAT software version-6.

6.3 RESULTS

6.3.1 Effect of the age of *A. maling* on N, P and K content in its culm, branch and leaf

The concentration of nitrogen in different bamboo parts of *A. maling* is presented in Figure 6.1. Nitrogen content differed significantly among different bamboo parts (F = 1270.237, P< 0.001) and with the age (F = 390.894, P< 0.001), whereas the variation in N - content among the three elevation sites was insignificant. The variation due to interaction values between bamboo parts and elevation sites, parts and age, sites and age as well as parts, sites and age was also significant (F = 17.279, 292.484, 5.866 and 6.439 respectively; P< 0.001). Nitrogen concentration in the bamboo culms at all the three elevation sites was highest during the initial stage, *i.e.*, during the first month of the new shoot emergence. Branch bud on the culms appeared during the 9th month, and nitrogen content was highest at this age, whereas leaf proliferation took place at the age of 12 month during which nitrogen concentration was highest in the leaves. Significantly higher level of nitrogen concentration was observed in the leaves followed by branch and culm at all the three elevation sites. In one month old leaves, the highest nitrogen concentration was recorded at the medium elevation site (2.67%) followed by the high (2.44%) and low elevation site (2.43%). There was a sudden decline in leaf nitrogen concentration with the increase in age at the high and low elevation sites, and the lowest leaf N concentration was observed in the 18th month of culm age. During the 21st month of culm age, there was another peak of leaf nitrogen concentration at all the three elevation sites. A similar trend of ageing effect was observed in branch and culm nitrogen concentration at all the three elevation sites. In the branch, nitrogen

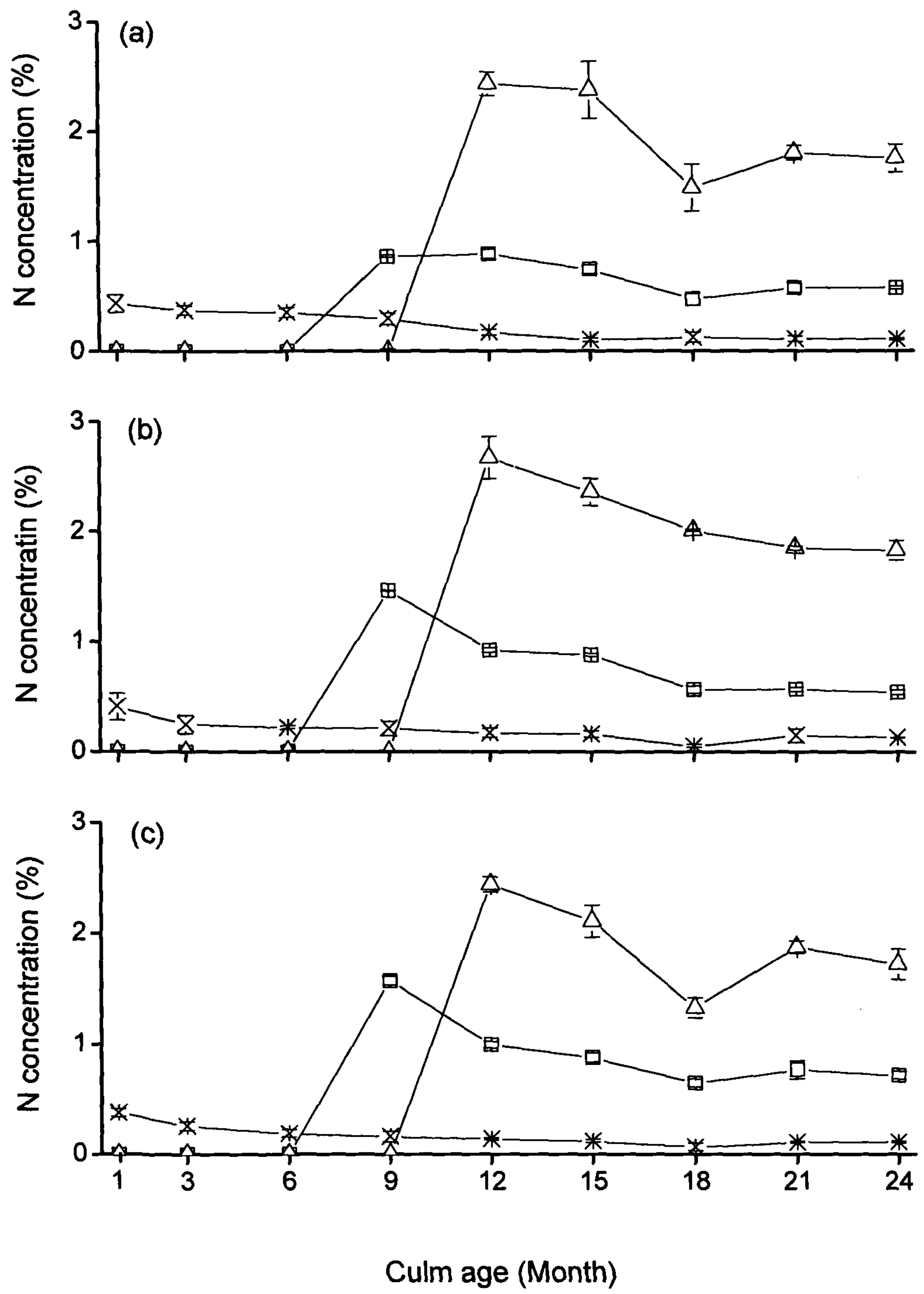

Figure 6.1. Effect of the age of *A. maling* on nitrogen concentration in its culm (-X-), branch (-□-) and leaf (-△-) at the low (a), medium (b) and high (c) elevation sites. Vertical line bars represent ± SE.

concentration was maximum at the high elevation site (1.57%) followed by the medium (1.47%) and low elevation sites (0.86%), whereas in the culm, it was highest at the low elevation site (0.43%) followed by the medium (0.41%) and high elevation sites (0.38%). At the age of 24 months the culm nitrogen concentration decreased to 0.11%, 0.13% and 0.11% at the low, medium and high elevation sites, respectively. At this age, nitrogen concentration in the branch declined to 0.57%, 0.54% and 0.72%, whereas in the leaves it was 1.75%, 1.83% and 1.72%, respectively. The mean percent decrease in nitrogen concentration (considering all the three elevation sites) in culm, branch and leaf of *A. maling* at the age of 24 months was 0.29%, 0.69% and 0.74%, respectively.

Figure 6.2 depicts the effect of the age of *A. maling* on phosphorus concentration in its culm, branch and leaf at the low, medium and high elevation sites. Difference in phosphorus concentration was significant among different bamboo parts (F = 222.010, P< 0.001), where highest concentration was observed in the branch at all the three elevation sites. It was also significantly different at different elevation sites (F = 58.956, P< 0.001) and different age of *A. maling* (F = 38.268, P< 0.001). The values of interaction between bamboo parts and elevation sites, parts and age, sites and age as well as parts, sites and age were also significant (F = 30.927, 74.289, 3.076 and 5.376, respectively; P< 0.001). Among the three bamboo parts, the highest phosphorus concentration was observed in the branch followed by culm and leaf at all the three elevation sites. Phosphorus concentration in the culm increased up to six months, with 0.228%, 0.245% and 0.155% during the peak period at the low, medium and high elevation sites, respectively, and it

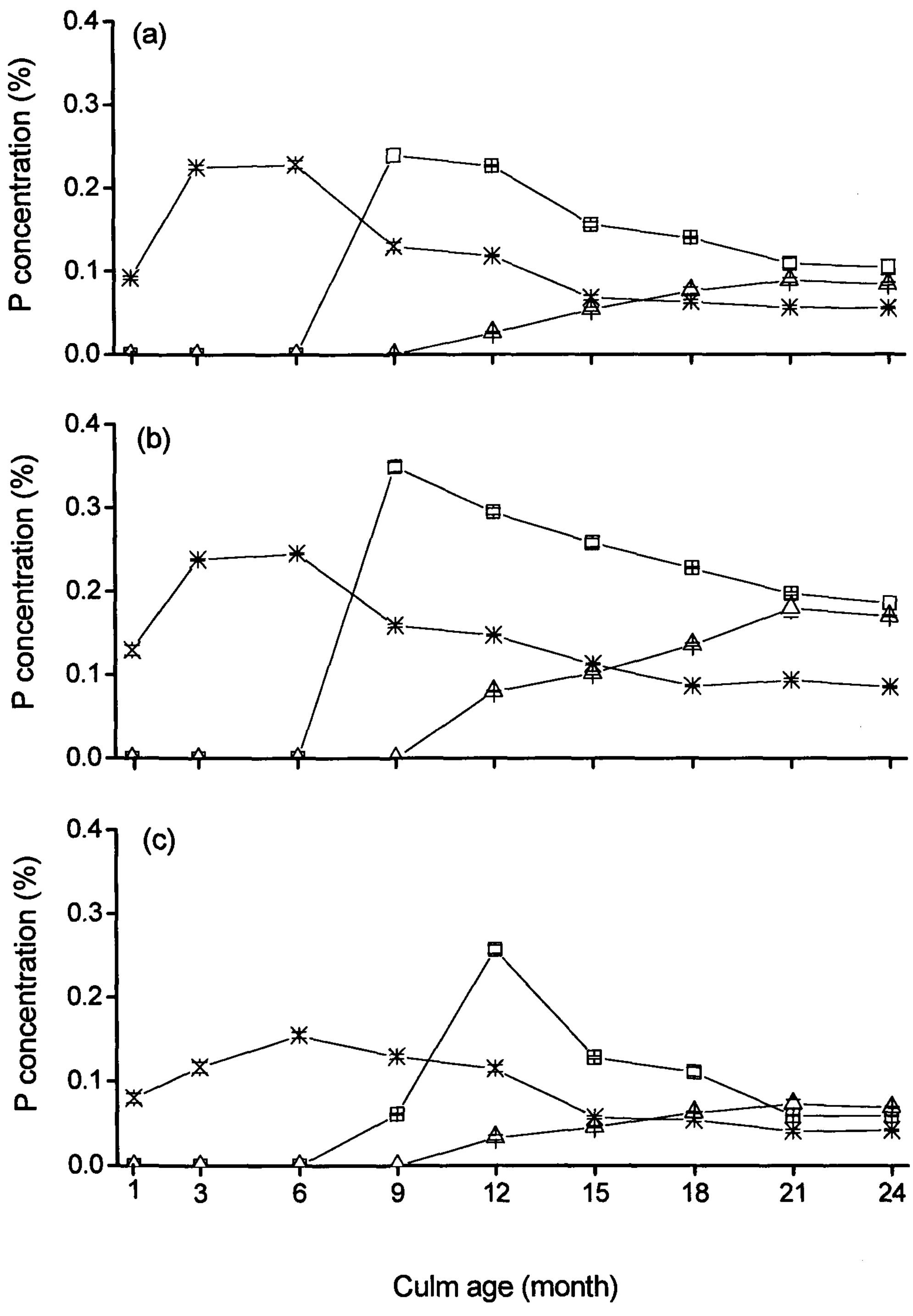

Figure 6.2. Effect of the age of *A. maling* on phosphorus concentration in its culm (-X-), branch (-□-) and leaf (-△-) at the low (a), medium (b) and high (c) elevation sites. Vertical line bars represent ± SE.

gradually declined. In branch, the phosphorus concentration was highest during the bud stage *i.e.* in nine month old culms at the low and medium elevation sites, whereas at the high elevation site the highest P concentration was recorded at the age of 12 months. A similar trend of phosphorus concentration was recorded in branches with 0.349%, 0.239% and 0.061% at the medium, low and high elevation sites, respectively. In leaves, there was a gradual increase in phosphorus concentration since the initial (one month old) stage till twenty-one months of culm age. There was a great variation in phosphorus concentration of leaves. The leaves at the medium elevation site had 0.180% P concentration followed by the low and high elevation sites with 0.094% and 0.059%, respectively. There was an insignificant variation in leaf phosphorus concentration between 21 and 24 months old individuals at all the three elevation sites. The mean percent decrease in phosphorus concentration in culm and branch of *A. maling* from the initial sampling periods to the final sampling period was 0.039% and 0.100% respectively, whereas the mean increase in phosphorus concentration in bamboo leaves was 0.063% considering all the three elevation sites together.

Potassium content in different parts of *A. maling* at different ages and elevation sites are presented in Figure 6.3. Potassium concentration differed significantly among different bamboo parts ($F = 563.346$, $P < 0.001$), with the highest concentration recorded in the leaf at all the three elevation sites. It was also significantly different at the three elevation sites ($F = 14.036$, $P < 0.001$) and different ages of *A. maling* ($F = 222.623$, $P < 0.001$). The values of interaction between bamboo parts and elevation sites, parts and age, sites and age as well as parts, sites and age were also significant ($F = 7.736$,

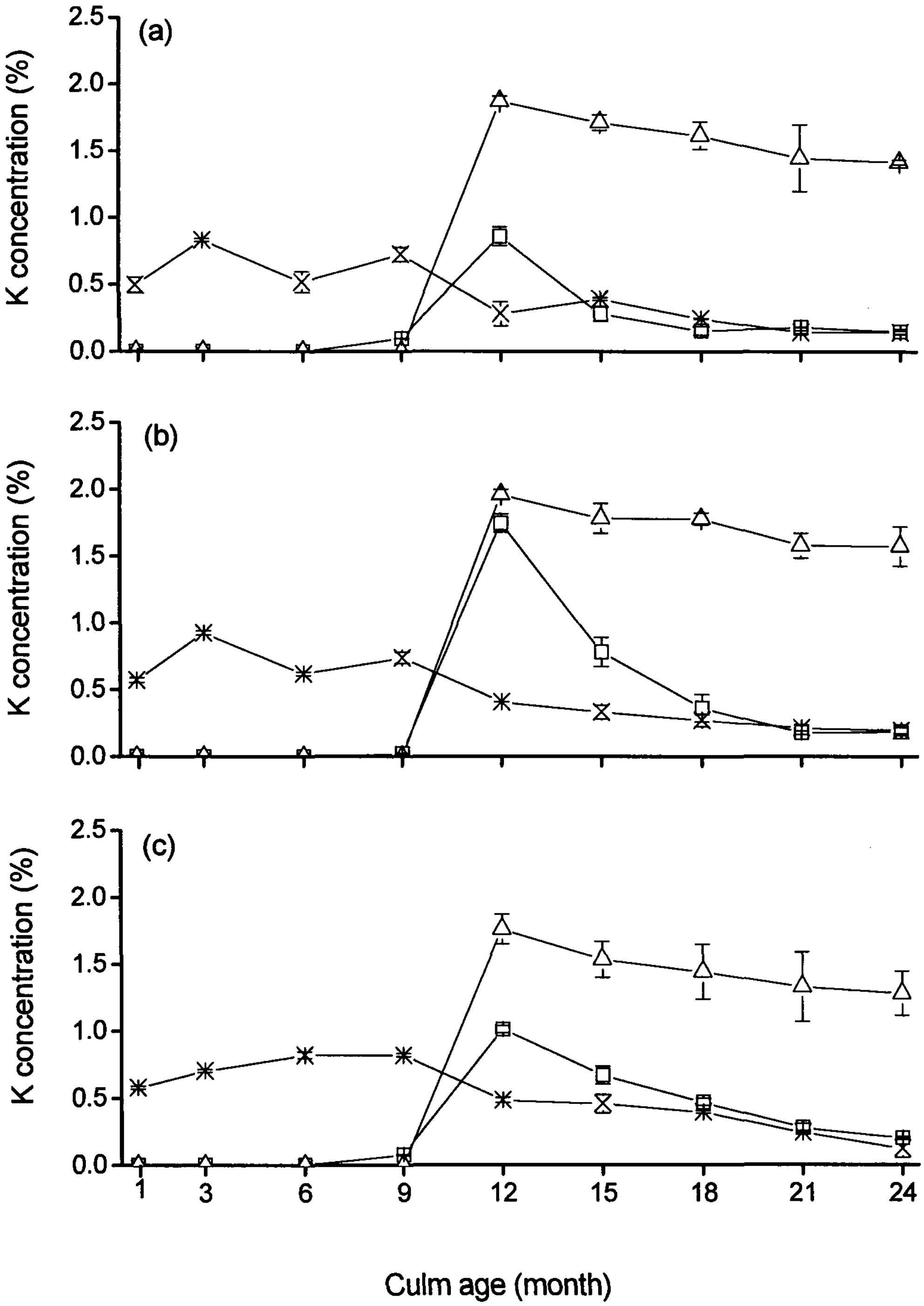

Figure 6.3. Effect of the age of *A. maling* on potassium concentration in its culm (-X-), branch (-□-) and leaf (-△-) at the low (a), medium (b) and high (c) elevation sites. Vertical line bars represent ± SE.

194.326, 2.929 and 3.138 respectively; P< 0.001). Potassium concentration in the culm at the low and medium elevation sites increased up to three months, whereas at the high elevation site it increased up to nine month of the culm age and then decreased. During the peak period, highest potassium concentration (0.925%) was recorded at the medium elevation site. A sharp decline in culm potassium concentration was observed when the branches and leaves were induced. Mean potassium concentration in the culm was observed to be highest (0.513%) at the high elevation site followed by the medium (0.475%) and low elevation sites (0.420%). In branch and leaf, potassium concentration was highest in the three month old branches and one month old leaves. Mean potassium concentration in branch and leaf was observed to be highest at the medium elevation site.

6.3.2 Effect of the age of *A. maling* on leaf chlorophyll content

Figure 6.4 depicts the effect of the bamboo age on leaf chlorophyll content of *A. maling* at the three elevation sites. Chlorophyll-a content differed significantly at the three elevation sites (F = 22.744, P< 0.001) and in leaves of different age (F = 10.155, P< 0.001). The interaction between the site and age on chlorophyll-a content was also significant (F = 14.644, P< 0.001). Chlorophyll-a content was highest in the one-month old leaves at the medium and high elevation sites with 2.09 and 1.80 mg g^{-1} fresh tissue. At the low elevation site, it was recorded in the three month old leaves with 1.88 mg g^{-1} fresh tissue. After the initial peak, there was a gradual decrease in chlorophyll-a content, while a sharp increase was recorded in the twelve month old leaves at the medium and high elevation sites. The mean chlorophyll-a content in one to twelve month old leaves was observed to be

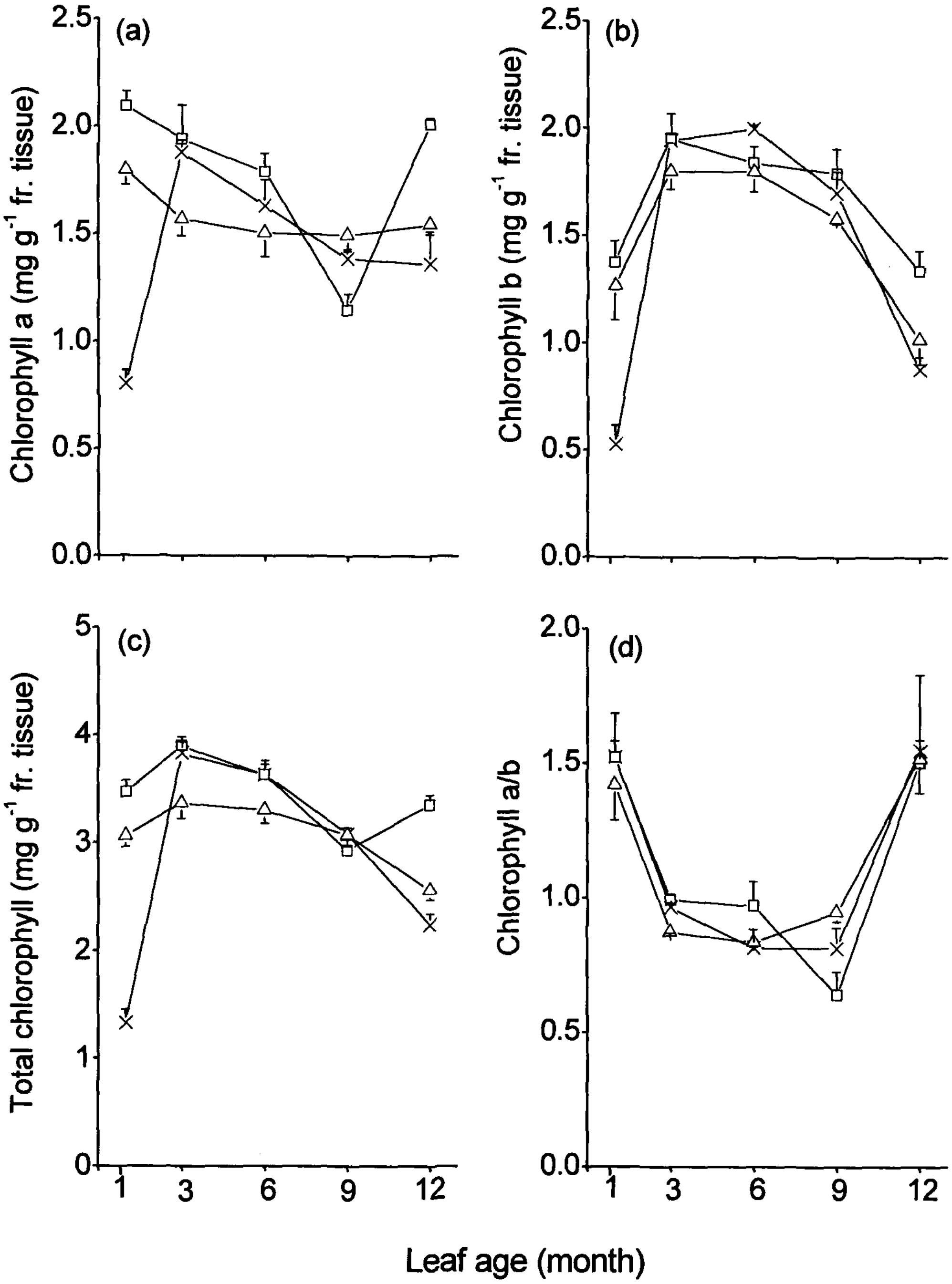

Figure 6.4. Effect of the age of *A. maling* on chlorophyll-a (a), chlorophyll-b (b), total chlorophyll content (c) and chlorophyll a/b ratio (d) in *A. maling* leaf at the low (-X-), medium (-□-) and high (-△-) elevation sites. Vertical line bars represent ± SE.

highest at the medium elevation site, followed by high and low elevation sites with 1.80, 1.58 and 1.41 mg g^{-1} fresh tissue (Fig. 6.4a). Chlorophyll-b content also differed significantly at different elevation sites ($F = 9.385$, $P < 0.005$), at different leaf age ($F = 61.906$, $P < 0.001$) and the interaction between site and age ($F = 6.325$, $P < 0.001$). Chlorophyll-b content in the leaves increased up to six month at the low and high elevation sites and decreased with the increase in leaf age. At the medium elevation site, it increased up to three month and gradually declined later. The mean chlorophyll-b content of 1-12 month old leaves was observed to be highest at the medium elevation site, followed by the high and low elevation site with 1.66, 1.49 and 1.41 mg g^{-1} fresh tissue (Fig. 6.4b). Total chlorophyll content in the leaves of *A. maling* was significantly different at the three elevation sites and at different age of the leaf ($F = 17.682$ and 50.054, $P < 0.001$). It was highest in the three month old leaves at all the three elevation sites, and gradually declined with the increase in leaf age. At the medium elevation site, there was a sharp increase in total chlorophyll content of leaves at the age of twelve month (Fig. 6.4c). Variation in the ratio of chlorophyll a to chlorophyll b was insignificant at the three elevation sites, whereas it differed significantly with the leaf age ($F = 33.611$, $P < 0.001$). Highest mean chlorophyll a/b ratio was observed at the low elevation site followed by the medium and high elevation sites (Fig. 6.4d).

6.3.3 Temporal variation in N, P and K content in culm, branch and leaf of *A. maling*

Temporal variation in nitrogen concentration in culm, branch and leaf of *A. maling* (<1yr. old and ≥1yr. old individuals) at the low, medium and high elevation sites are presented in Figure 6.5. Nitrogen concentration differed significantly in different aboveground bamboo parts, at the three

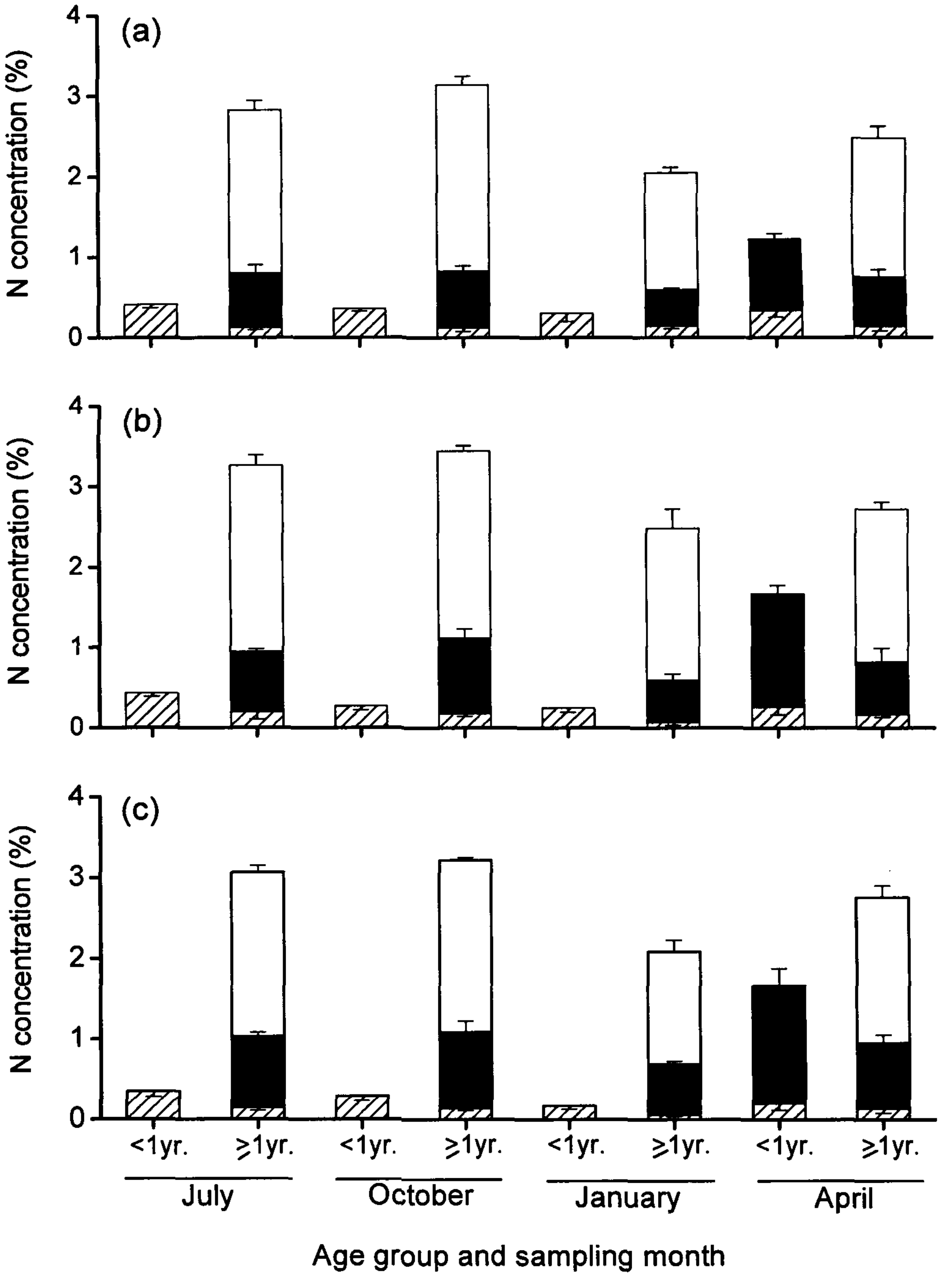

Figure 6.5. Temporal variation in nitrogen concentration (%) in culm (hatched), branch (black) and leaf (open) of <1yr. old and ≥1yr. old individuals of *A. maling* at the low (a), medium (b) and high (c) elevation sites. Vertical line bars represent ± SE.

elevation sites, and at different sampling dates (F = 1550, 17.88 and 125.88 respectively, P< 0.001). Differences in nitrogen concentration in the new individuals (<1yr. old) were significant in different aboveground bamboo parts (F = 495.86, P< 0.001) and in different sampling dates (F = 481.97, P< 0.001), whereas values were insignificantly different at the three elevation sites. The highest culm nitrogen concentration at the low, medium and high elevation sites was observed during July with 0.41%, 0.43% and 0.35% respectively, whereas the lowest was recorded during January with 0.30%, 0.25% and 0.17%, respectively. The mean culm nitrogen content in <1yr. old individuals was highest at the low elevation site (0.35%) followed by the medium (0.31%) and high elevation sites (0.25%). Branch formation in <1yr. old individuals was observed only during April, when the highest nitrogen concentration was recorded at the high elevation site with 1.47% followed by the medium and low elevation sites with 1.41% and 0.89%, respectively. There was no leaf formation in less than one yr. old individuals.

Values for nitrogen concentration in ≥1yr. old individuals were significantly different in various aboveground bamboo parts (F = 3104.83, P< 0.001), different elevation sites (F = 15.585, P< 0.001) and for different sampling dates (F = 57.294, P< 0.001). Highest culm nitrogen concentration was observed during July at the medium and high elevation sites (0.20% and 0.14%) and lowest during January. At the low elevation site, it was highest during January (0.14%) and lowest during October (0.12%). Culms at the medium elevation site had highest nitrogen content (0.15%) followed by the low and high elevation sites which had 0.13% and 0.15% nitrogen content respectively. Branch nitrogen content in ≥1yr. old individuals was highest during October with 0.70%, 0.94% and 0.95% at the low, medium and high elevation sites respectively, whereas the lowest was recorded during January with 0.46%, 52% and 63%, respectively. The mean nitrogen content in branch was highest at the high elevation site (0.82%) followed by the medium (0.72%) and low elevation sites (0.61%). Nitrogen content in leaves of ≥1yr. old individuals at the low, medium and high elevation sites was highest during October with 2.32%, 2.33% and 2.13%, respectively and lowest during January with 1.45%, 1.89% and 1.4%, respectively. The mean leaf nitrogen concentration was highest at the medium elevation site (2.11%) followed by the low (1.88%) and high (1.85%) elevation sites. Nitrogen concentration in ≥1 yr. old individuals was in the order of leaf > branch > culm.

Temporal variation in phosphorus concentration in culm, branch and leaf of <1yr. and ≥1yr. old individuals of *A. maling* at the low, medium and high elevation sites are presented in Figure 6.6. Variations in phosphorus concentration were highly significant in different bamboo parts, elevation sites and sampling dates ($F = 3182.12$, 1773.24 and 216.88, respectively; $P < 0.001$). Variations in phosphorus concentration in <1yr. old were significantly different in different aboveground bamboo parts ($F = 9052.05$, $P < 0.001$), at the three elevation sites ($F = 828.25$, $P < 0.001$) and sampling dates ($F = 1280.64$, $P < 0.001$). Highest culm phosphorus concentration at the medium and high elevation sites was observed during January with 0.233% and 0.119% respectively, whereas the lowest was recorded during July with 0.133% and 0.079%, respectively. At the low elevation site, the highest culm P was recorded during October with 0.228% and lowest during July with 0.096%. The mean culm phosphorus concentration in <1yr. old individuals

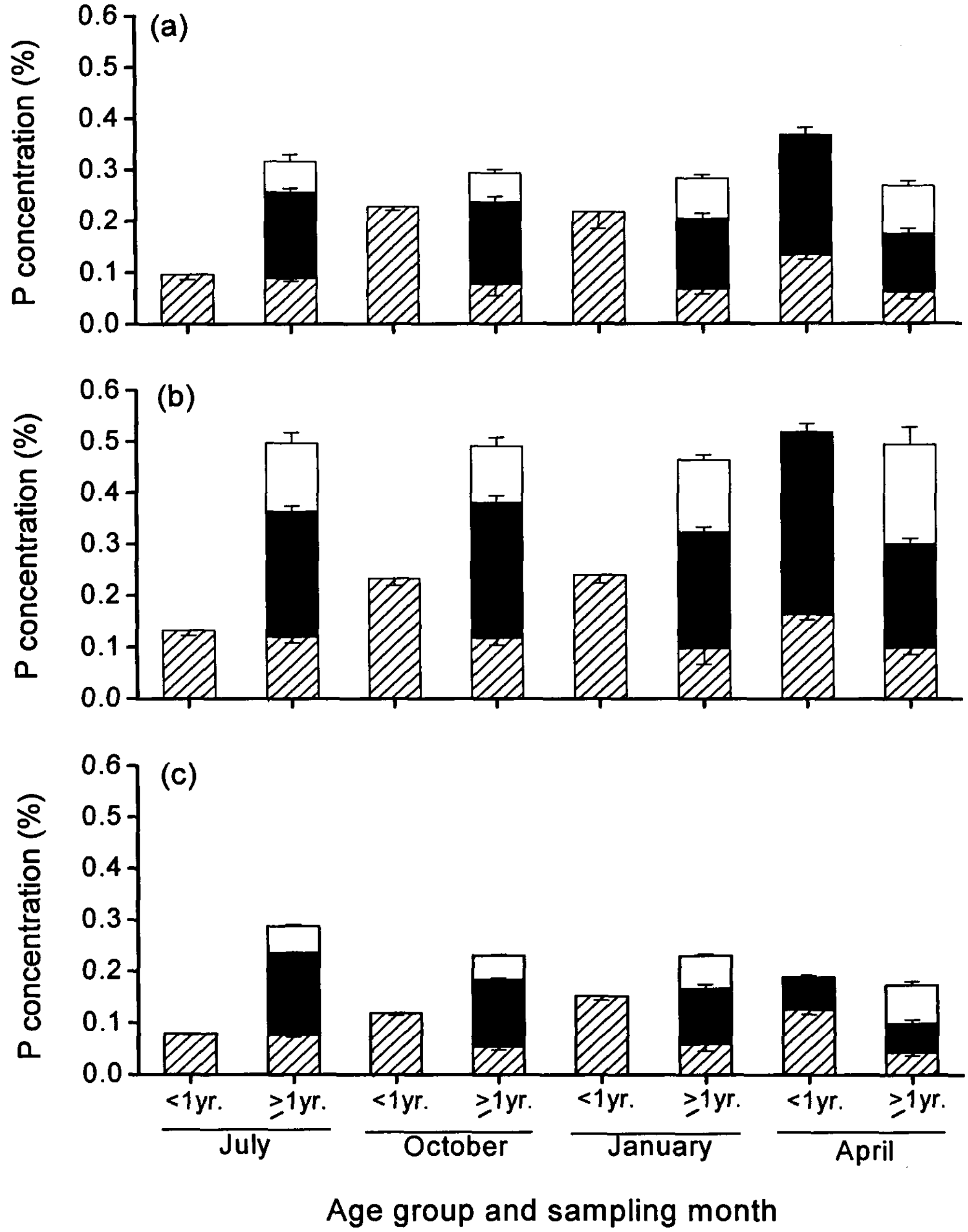

Figure 6.6. Temporal variation in phosphorus concentration (%) in culm (hatched), branch (black) and leaf (white) of <1yr. old and ≥1yr. old individuals of *A. maling* at the low (a), medium (b) and high (c) elevation sites. Vertical line bars represent ± SE.

was highest at the medium elevation site (0.192%) followed by the low (0.168%) and high elevation sites (0.119%). Highest phosphorus concentration (0.355%) in branch was recorded during April at the medium elevation site followed by the low elevation site with 0.234% and high elevation site with 0.063%.

Phosphorus concentration in ≥1yr. old individuals also varied significantly in different aboveground bamboo parts ($F = 1186.81$, $P < 0.001$), at different elevation sites ($F = 1138.91$, $P < 0.001$) and different sampling dates ($F = 28.33$, $P < 0.001$). The highest phosphorus concentration in the culm was recorded during July at the medium and high elevation sites (0.20% and 0.14%) and lowest during January, whereas at the low elevation site, it was highest during January (0.14%) and lowest during October (0.12%). The older culms (≥1yr. old) at the medium elevation site had the highest mean phosphorus content (0.108%) followed by the low and high elevation sites with 0.073% and 0.058%, respectively. Phosphorus content in branch of ≥1yr. old individuals was highest during July at the low elevation site (0.168%) and high elevation site (0.159%), whereas at the medium elevation site, it was highest during October (0.263%). During April, phosphorus concentration in branch was lowest at all the three elevation sites. The mean phosphorus concentration in branch of ≥1yr. old individuals was highest at the medium elevation site (0.233%) followed by the low (0.144%) and high (0.113%) elevation sites. Phosphorus content in leaves of ≥1yr. old individuals at the low, medium and high elevation sites was highest during April (0.093%, 0.193% and 0.075%, respectively) and lowest during October (0.057%, 0.109% and 0.047%, respectively). The mean leaf phosphorus concentration was highest at the medium elevation site (0.143%) followed by the low (0.072%) and high (0.060%) elevation sites. Phosphorus concentration in ≥1 yr. old individuals was in the order of branch > culm > leaf during July and October, whereas the order was changed to branch > leaf > culm during January and April.

Temporal variation in potassium concentration in culm, branch and leaf of <1 yr. and ≥1 yr. old individuals of *A. maling* at the low, medium and high elevation sites are presented in Figure 6.7. Potassium concentration varied significantly in different bamboo parts, at the three elevation sites and sampling dates (F = 188.07, 7.201 and 8.173 respectively; $P< 0.005$).

Values for potassium concentration in <1yr. old individuals varied significantly in different aboveground bamboo parts (F = 2393.58, $P< 0.001$), at the three elevation sites (F = 4.48, $P< 0.05$) and sampling dates (F = 21.70, $P< 0.001$). Highest potassium concentration in culm at the low and medium elevation sites was observed during October (0.856% and 0.937% respectively), whereas at the high elevation site, the highest concentration (0.841%) was recoded during April. Lowest potassium concentration in the culm at the low and high elevation sites was observed during July, whereas at the medium elevation, the lowest concentration was recorded during January. The mean culm potassium concentration in <1yr. old individuals was highest at the medium elevation site (0.775%) followed by the high (0.743%) and low elevation sites (0.661%). Highest potassium concentration in branch (0.119%) during April was recorded at the low elevation site followed by the high elevation site (0.095%) and medium elevation site (0.072%)

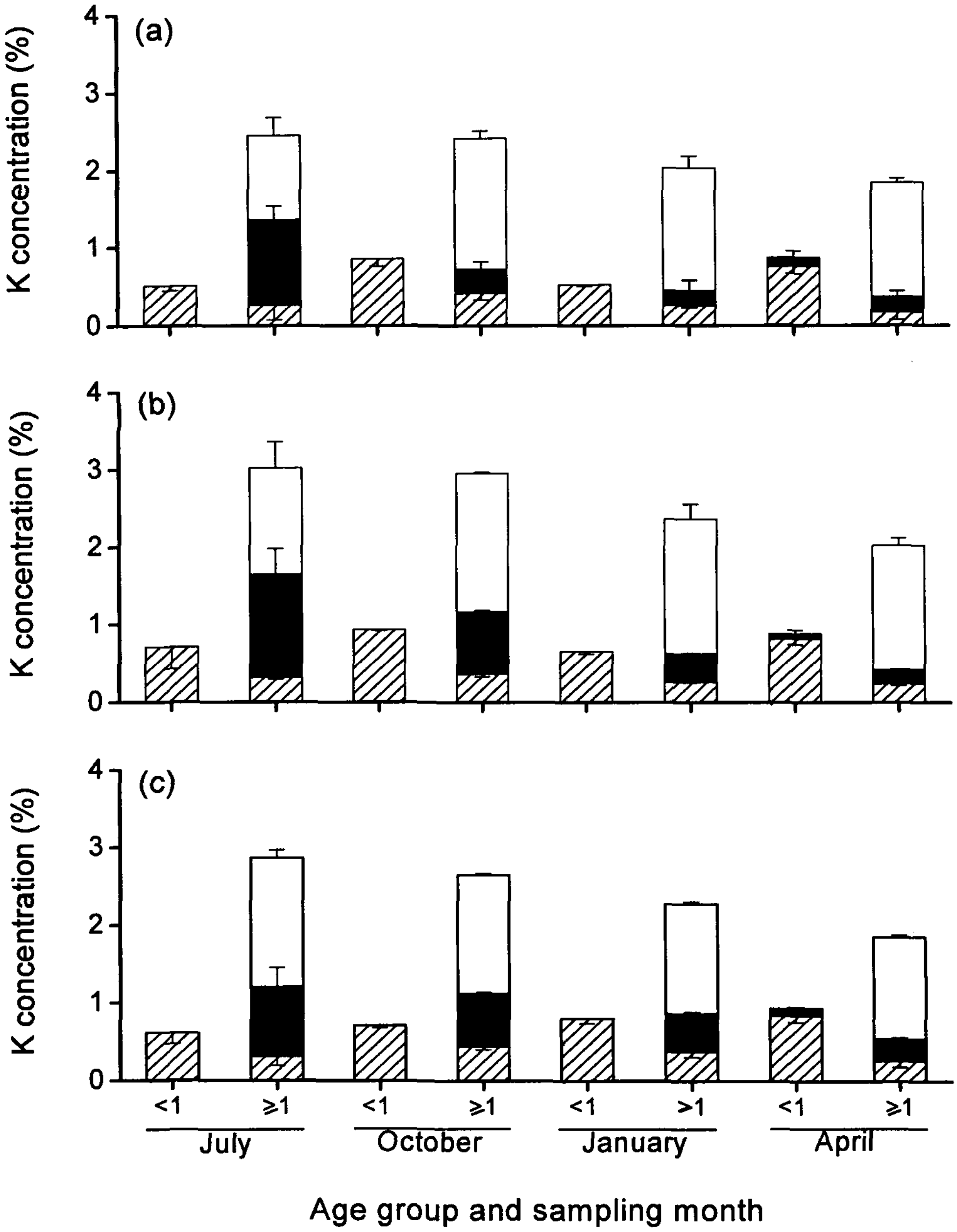

Figure 6.7. Temporal variation in potassium concentration (%) in culm (▨), branch (■) and leaf (□) of <1yr. old and ≥1yr. old individuals of *A. maling* at the low (a), medium (b) and high (c) elevation sites. Vertical line bars represent ± SE.

Potassium concentration in ≥1yr. old individuals varied significantly in different aboveground bamboo parts (F = 359.83, P< 0.001), elevation sites (F = 4.27, P< 0.05) and sampling dates (F = 11.14, P< 0.001). In ≥1yr. old individuals, the highest potassium concentration in culms was observed during October at all the three elevation sites and lowest during April. Mean potassium content in ≥1yr. old culm was highest at the high elevation site (0.349%) followed by the medium (0.297%) and low (0.275%) elevation sites. Potassium content in branch of ≥1yr. old individuals was highest during July (1.099%, 1.325 and 0.893% at the low, medium and high elevation sites, respectively), and lowest during April. Mean potassium concentration in branch of ≥1yr. old individuals was highest at the medium elevation site (0.669%) followed by the high (0.589%) and low elevation sites (0.449%). Potassium concentration in leaves of ≥1yr. old individuals at the low and medium elevation sites was highest during October (1.694% and 1.788% at low and medium elevation sites, respectively) and lowest during July (1.091 and 1.381%, respectively). At the high elevation site, K concentration was highest during July (1.655%) and it gradually declined showing lowest value (1.303%) during April. The mean leaf potassium concentration was highest at the medium elevation site (1.642%) followed by the high (1.471%) and low (1.459%) elevation sites. Potassium concentration in ≥1yr. old individuals was in the order of leaf > branch > culm.

Figure 6.8 depicts the temporal variation in N, P and K concentration in leaf litter of *A. maling* at the low, medium and high elevation sites in Jang area. Nitrogen content in leaf litter varied significantly among different sampling periods (F = 3.754, P< 0.05), whereas the differences were

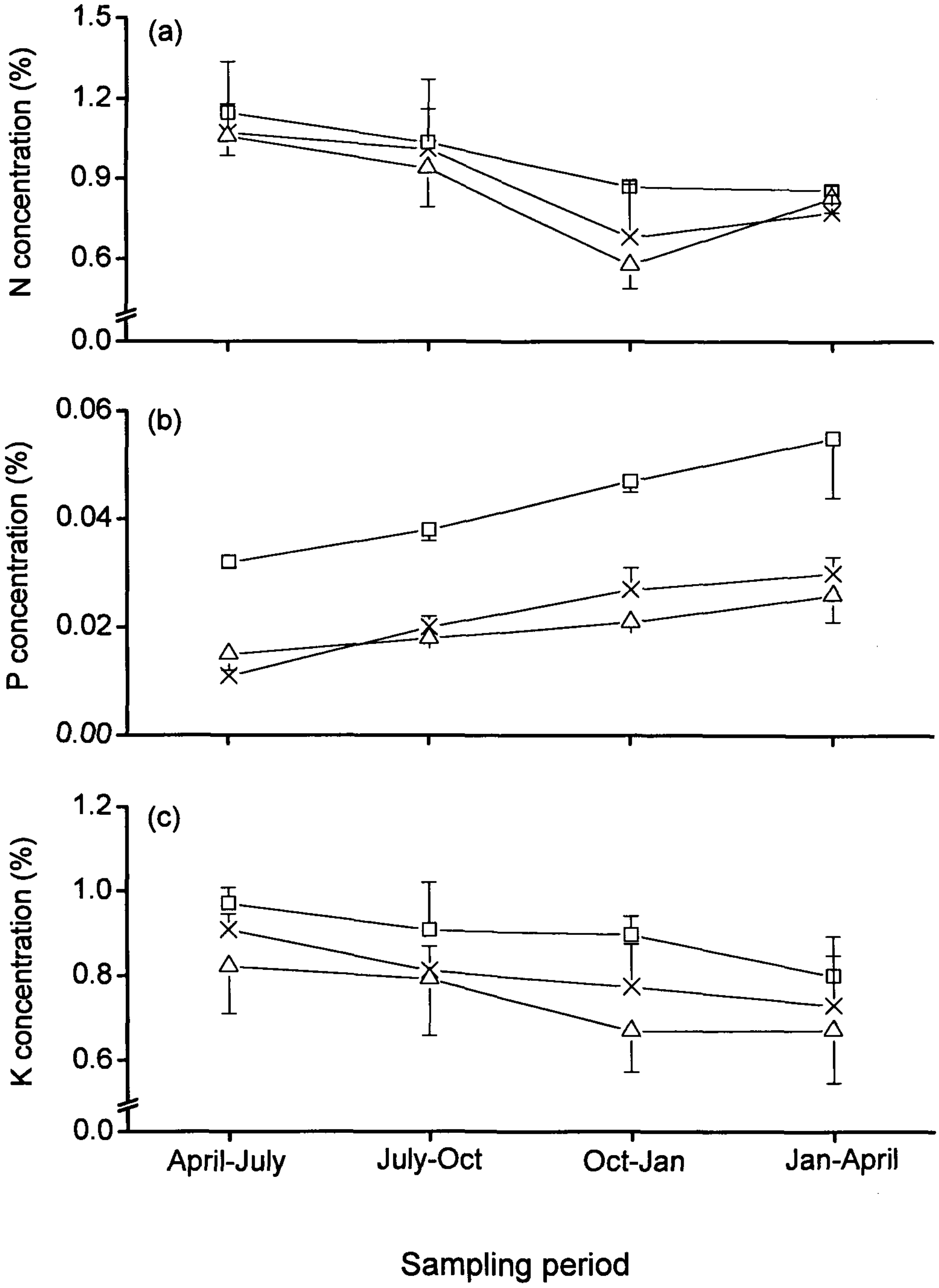

Figure 6.8. Temporal variation in nitrogen (a), phosphorus (b) and potassium (c) concentration (%) in leaf litter of *A. maling* at the low (-X-), medium (-□-) and high (-△-) elevation sites. Vertical line bars represent ± SE.

insignificant at the three elevation sites and between the two years of investigation. The highest nitrogen content in leaf litter was observed during April-July, whereas the lowest concentration was recorded during October-January at all the three elevation sites (Fig. 6.8a). Mean nitrogen concentration in leaf litter was highest at the medium elevation site (0.98%) followed by the low (0.88%) and high elevation sites (0.85%).

Variation in phosphorus concentration in leaf litter was significant at the three elevation sites ($F = 23.901$, $P < 0.001$) and sampling periods ($F = 6.629$, $P < 0.005$. The highest phosphorus content in leaf litter was observed during January-April, whereas lowest level was recorded during April-July at all the three elevation sites. The mean phosphorus concentration in leaf litter was highest (0.043%) at the medium elevation site followed by the low elevation site (0.022%) and high elevation site (0.020%).

The concentration of potassium in the leaf litter did not vary significantly at the three elevation sites and sampling periods. Potassium content in leaf litter was highest during April-July, decreased gradually showing the lowest concentration during January-April at all the three elevation sites. The mean potassium content was highest at the medium elevation site (0.894%) followed by the low elevation site (0.806%) and high elevation site (0.739%).

6.3.4 Temporal variation in standing state of N, P and K in culm, branch and leaf of *A. maling*, and their contribution to the total N, P and K accumulation

Figure 6.9 depicts the temporal variation in standing state of nitrogen *i.e.,* N accumulation in different bamboo parts of <1yr. old and ≥1yr. old individuals of *A. maling* at the low, medium and high elevation sites.

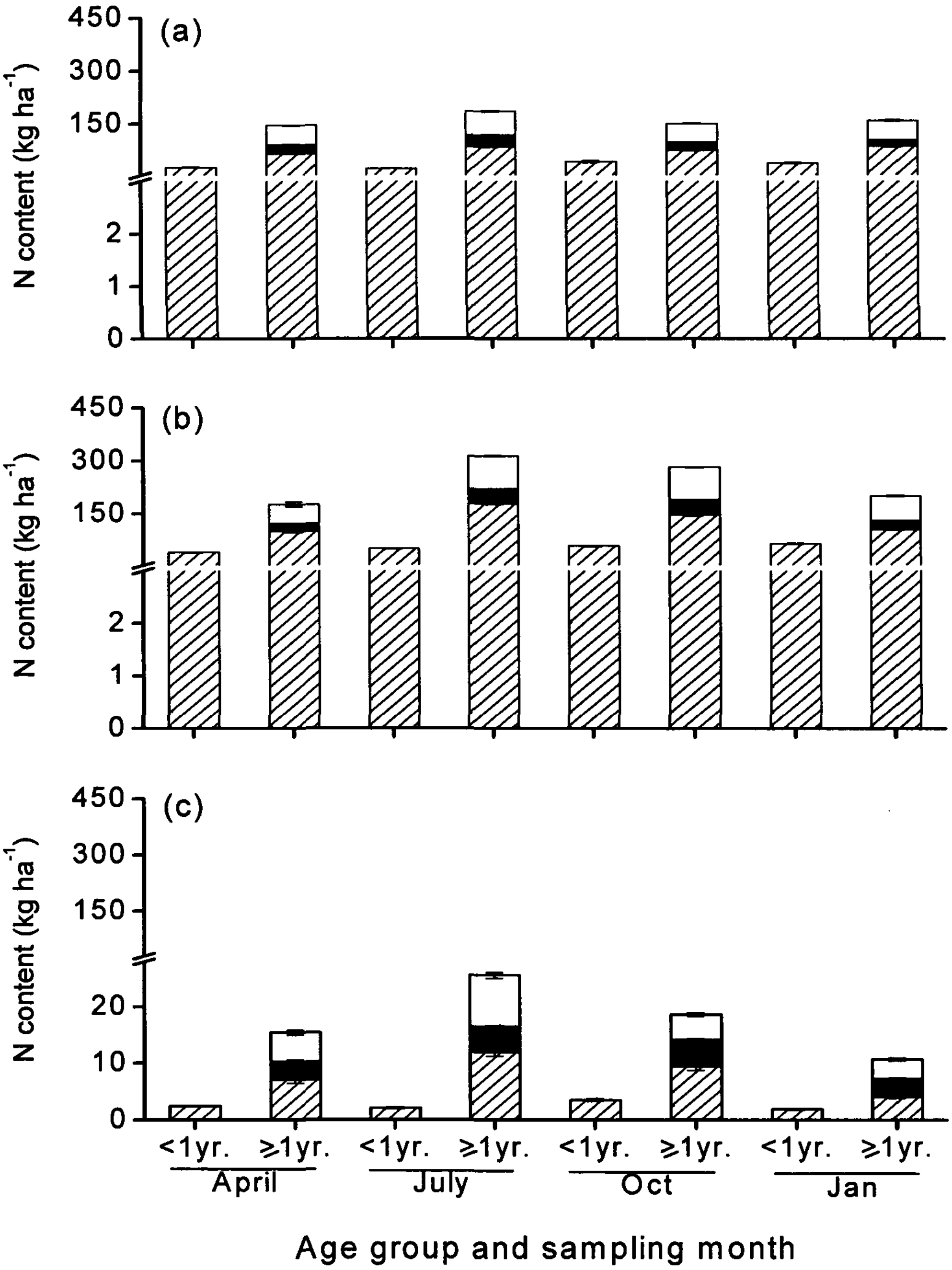

Figure 6.9. Temporal variation in standing state of nitrogen (kg ha^{-1}) in culm (▨), branch (■) and leaf (□) in <1yr. old and ≥1yr. old individuals of *A. maling* at the low (a), medium (b) and high (c) elevation sites. Vertical line bars represent ± SE.

Nitrogen accumulation in *A. maling* was significantly different at the three elevation sites (F = 14.641, P<0.001) and sampling dates (F = 28.33, P< 0.001). Nitrogen accumulation in <1yr. old individuals was highest during October at all the three elevation sites (42.56, 64.60 and 3.53 kg ha^{-1} at the low, medium and high elevation sites, respectively), whereas N accumulation in ≥1yr. old individuals at all the three elevation sites was highest during July (184.94, 313.23 and 25.56 kg ha^{-1}, respectively at the low, medium and high elevation sites). The lowest N accumulation in both <1yr. old and ≥1yr. old individuals was observed during April at the low (26.17 kg ha^{-1} in <1yr. old and 145.20 kg ha^{-1} in ≥1yr. old) and medium (40.11 kg ha^{-1} in <1yr. old and 176.81 kg ha^{-1} in ≥1yr. old) elevation sites, whereas N accumulation at the high elevation site was lowest during January (1.9 and 10.71 kg ha^{-1} in <1yr. old and ≥1yr. old individuals, respectively). The total N accumulation (<1yr. old plus ≥1yr. old individuals) in *A. maling* was significantly higher at the medium elevation site (F= 14.641, P< 0.001) (296.46 kg ha^{-1}), followed by the low (191.46 kg ha^{-1}) and high elevation sites (20.07 kg ha^{-1}). Temporal variation in the total N accumulation revealed that highest N accumulation in *A. maling* occurred during July and lowest during April at all the three elevation sites.

The contribution of aboveground bamboo parts to the total N accumulation was in the order of culm > leaf > branch throughout the study period at all the three elevation sites. The percent contribution of culm branch and leaf to the total N accumulation in ≥1yr. old individuals during the study period was 43-54%, 12-19% and 32-38%, respectively, at the low elevation site. At the medium elevation site, it was 49-60%, 13-16% and 31-35%

respectively, whereas at the high elevation site the percent contribution was 41-55%, 17-29% and 23-33%, respectively.

Figure 6.10 depicts the temporal variation in standing state of phosphorus in different bamboo parts of <1 yr. old and ≥1yr. old individuals of *A. maling* at the low, medium and high elevation sites. Variation in phosphorus accumulation in <1yr. old and ≥1yr. old individuals was significantly different at the three elevation sites ($F = 30.186$, $P < 0.001$) and sampling dates ($F = 5.067$, $P < 0.05$). Phosphorus accumulation in <1yr. old individuals was highest during January at all the three elevation sites, whereas in case of ≥1yr. old individuals, it was highest during July. The lowest P accumulation in <1yr. old individuals occurred during July, whereas in ≥1yr. old individuals P accumulation was lowest during April. Temporal variation in total P accumulation (<1yr. old plus ≥1yr. old individuals) in *A. maling* revealed that, P accumulation was highest during October at the low (80.72 kg ha^{-1}) and medium (162.50 kg ha^{-1}) elevation sites, whereas at the high elevation site, P accumulation was highest during July (8.02 kg ha^{-1}). Total P accumulation in *A. maling* was highest at the medium elevation site (142.30 kg ha^{-1}) followed by the low (71.82 kg ha^{-1}) and high (6.41 kg ha^{-}) elevation sites.

Among the aboveground bamboo parts, the contribution of culms towards the total P accumulation was maximum followed by branch and leaf. The percent contribution of culm, branch and leaf to the total P accumulation in the ≥1yr. old individuals during the study period was 81-88%, 10-12% and 2-7%, respectively at the low elevation site. At the medium elevation site, the contribution of culm, branch and leaf was 81-85%, 11-13% and 4-7%,

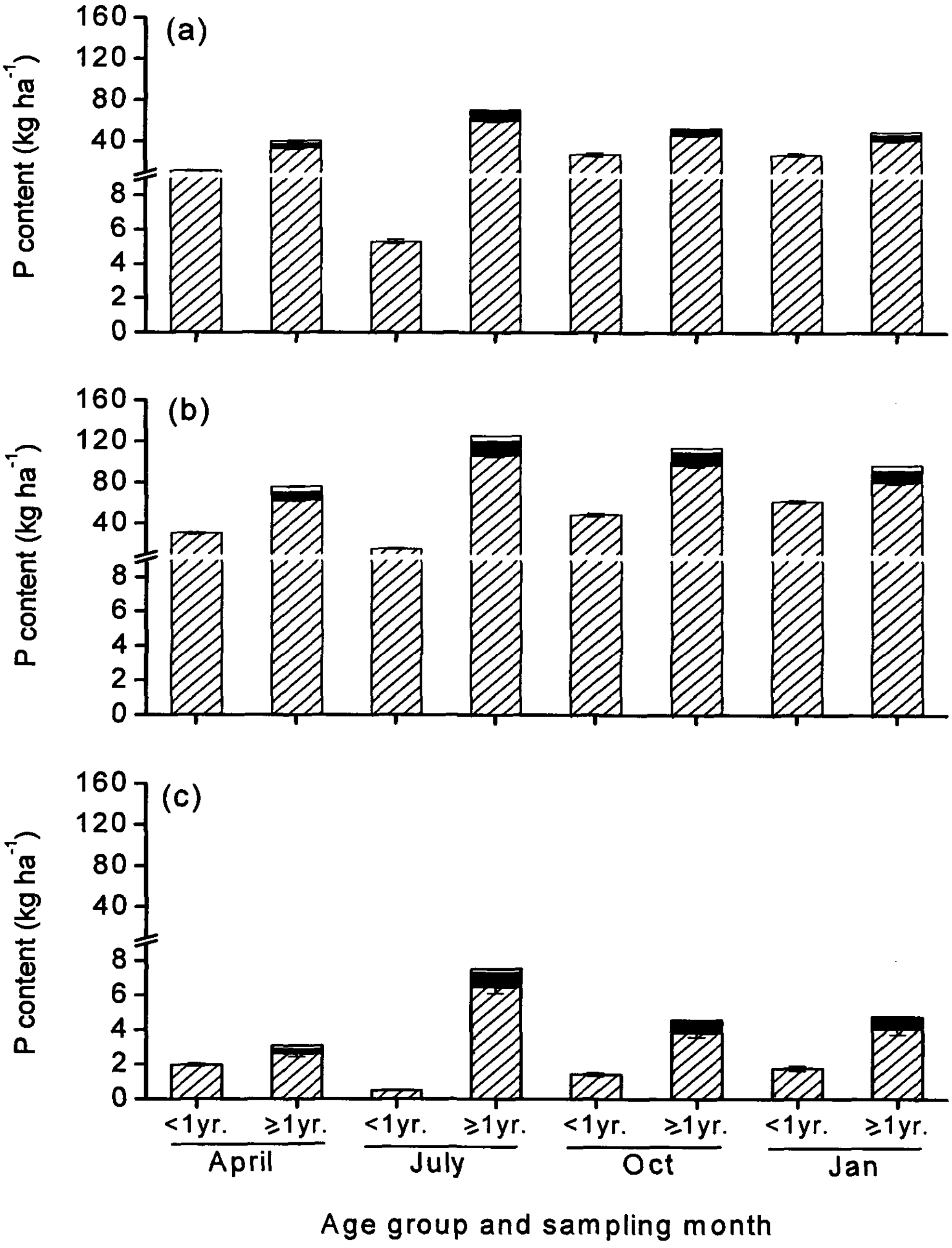

Figure 6.10. Temporal variation in standing state of phosphorus (kg ha^{-1}) in culm (▨), branch (■) and leaf (□) in <1yr. old and ≥1yr. old individuals of *A. maling* at the low (a), medium (b) and high (c) elevation sites. Vertical line bars represent ± SE.

respectively, whereas at the high elevation site the percent contribution was 83-87%, 8-15% and 2-6%, respectively.

Temporal variations in standing state of potassium in different bamboo parts of <1yr. old and ≥1yr. old individuals of *A. maling* at the low, medium and high elevation sites are presented in Figure 6.11. Potassium accumulation in <1yr. old and ≥1yr. old individuals varied significantly at the three elevation sites ($F = 16.012$, $P < 0.001$) and sampling dates ($F = 5.764$, $P < 0.01$). The highest K accumulation in <1yr. old individuals was observed during October at the low and medium elevation sites, whereas at the high elevation site, it was highest during April. In case of ≥1yr. old individuals, highest K accumulation occurred during October at the low elevation site, whereas at the medium and high elevation sites, highest K accumulation was observed during July. Lowest K accumulation in <1yr. and ≥1yr. old individuals was observed during July and April, respectively at all the three elevation sites. The total K accumulation (<1yr. old plus ≥1yr. old individuals) in *A. maling* was highest at the medium elevation site with 477.55 kg ha^{-1} followed by the low and high elevation sites with 301.88 kg ha^{-1} and 40.82 kg ha^{-1}, respectively. The temporal variation in the total K accumulation in *A. maling* showed to be highest during October (407.65, 610.20 and 46.61 kg ha^{-1} at the low, medium and high elevation sites, respectively) and minimum during April at all the three elevation sites (203.02, 337.96 and 32.74 kg ha^{-1} at the low, medium and high elevation sites, respectively).

The contribution of the aboveground bamboo parts to the total K accumulation varied with the sampling dates. The culms contributed maximum to the total K accumulation followed by leaves and branches

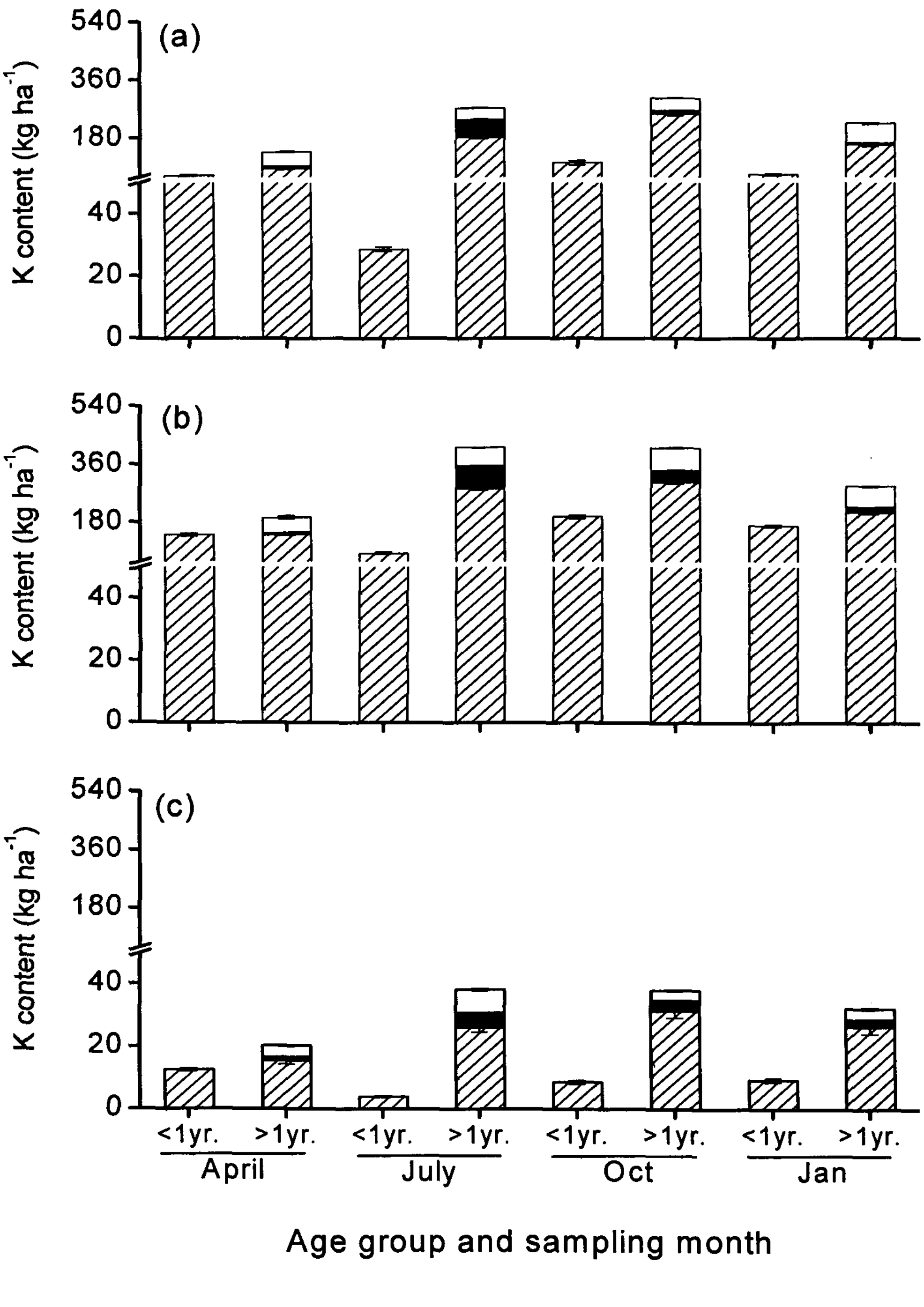

Figure 6.11. Temporal variation in standing state of potassium (kg ha $^{-1}$) in culm (▨), branch (■) and leaf (□) in <1yr. old and ≥1yr. old individuals of *A. maling* at the low (a), medium (b) and high (c) elevation sites. Vertical line bars represent ± SE.

throughout the study period except July month at all the three elevation sites. The percent contribution of culm, branch and leaf to the total aboveground K accumulation in mature individuals during the study period was 61-84%, 3-25% and 12-32%, respectively at the low elevation site; 66-75%, 4-24% and 10-24%, respectively at the medium elevation site and 67-83%, 6-14% and 8-20%, respectively at the high elevation site.

6.3.5 N, P and K removal from *A. maling* forest through culm harvest

Figure 6.12 depicts the temporal variation in loss of N, P and K from *A. maling* forest through culm removal. The quantity of N, P and K removal through culm harvest varied significantly at the three elevation sites ($F = 14.579$, 25.531 and 18.940, respectively for N, P and K; $P < 0.005$) and sampling dates ($F = 9.803$, 10.895 and 11.564, respectively for N, P and K; $P < 0.005$). Highest nitrogen removal was observed during the samplings made in April at the medium (11.21 kg ha^{-1}) and high (2.04 kg ha^{-1}) elevation sites, whereas at the low elevation site, highest N removal was recorded during the sampling made in January (9.80 kg ha^{-1}). Annual culm removal loss of N and K from the *A. maling* forest was highest at the low elevation site (25.07 kg ha^{-1} and 47.01 kg ha^{-1}, respectively for N and K) followed by the medium elevation site (23.42 kg ha^{-1} and 41.46 kg ha^{-1}, respectively) and low elevation site (3.65 and 10.99 kg ha^{-1}, respectively). The loss of phosphorus through culm removal was highest at the medium elevation site (15.59 kg ha^{-1}) followed by the low (12.60 kg ha^{-1}) and high (1.80 kg ha^{-1}) elevation sites.

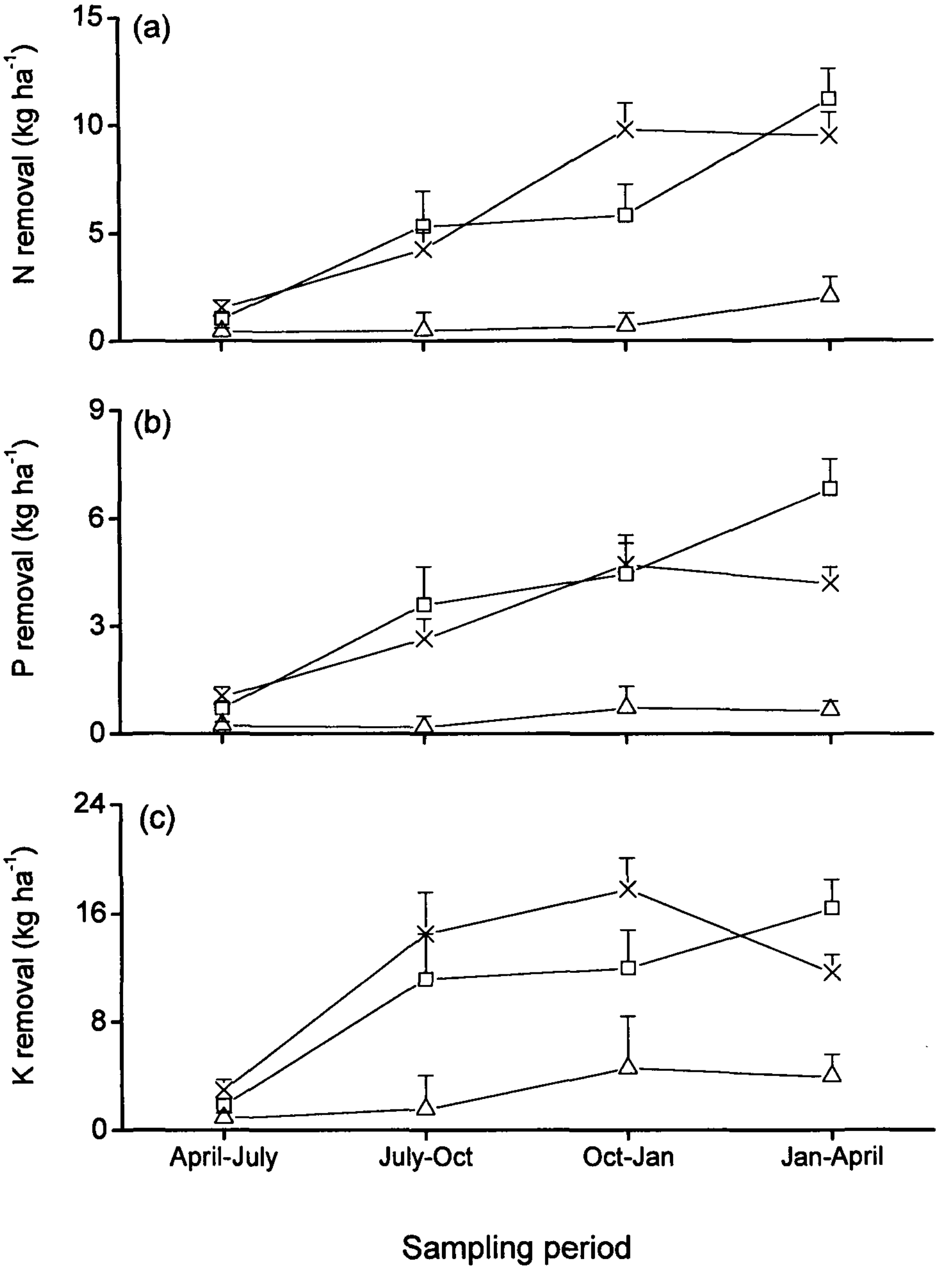

Figure 6.12. Periodic variation in nitrogen (a), phosphorus (b) and potassium (c) loss from *A. maling* forest through culm removal at the low (-X-), medium (-□-) and high (-△-) elevation sites. Vertical line bars represent ± SE.

6.3.6 N, P and K return through leaf litter in the *A. maling* forest.

Figure 6.13 depicts the variation in nitrogen, phosphorus and potassium returned through leaf litter of *A. maling* at different elevation sites in Jang bamboo forest. Variation in N and K return through leaf litter was significant at different sampling periods ($F = 56.777$, $P < 0.001$), but insignificant among the three elevation sites. Phosphorus return through leaf litter differed significantly at the three elevation sites ($F = 26.596$, $P < 0.001$) and sampling periods ($F = 19.405$, $P < 0.001$). Highest N and K return through leaf litter of *A. maling* was observed during the samplings made between April and July at all the three elevation sites, whereas highest P return was recorded during the samplings made between January and April. Annual N return through leaf litter of *A. maling* was highest at the high elevation site (61.24 kg ha^{-1}), whereas P and K return was highest at the medium elevation site (2.63 and 55.24 kg ha^{-1}, respectively for P and k).

6.3.7 Correlation between soil N, P and K pool and plant N, P and K

Correlation analysis between the soil N, P and K pool and N, P and K content in *A. maling* revealed that, soil phosphorus and potassium had significant positive correlation between the two nutrient pools (*i.e.*, source and sink), whereas the correlation between soil nitrogen content and plant nitrogen content was insignificant (Table 6.1).

6.4 DISCUSSION

Effect of the age of *A. maling* on N, P and K content in its aboveground parts of <1yr. old and ≥1yr. old individuals

At all the three elevation sites, N, P and K were observed to occur in higher concentrations in different aboveground parts of *A. maling* during the early stages and the concentrations gradually declined with the age. Bamboo

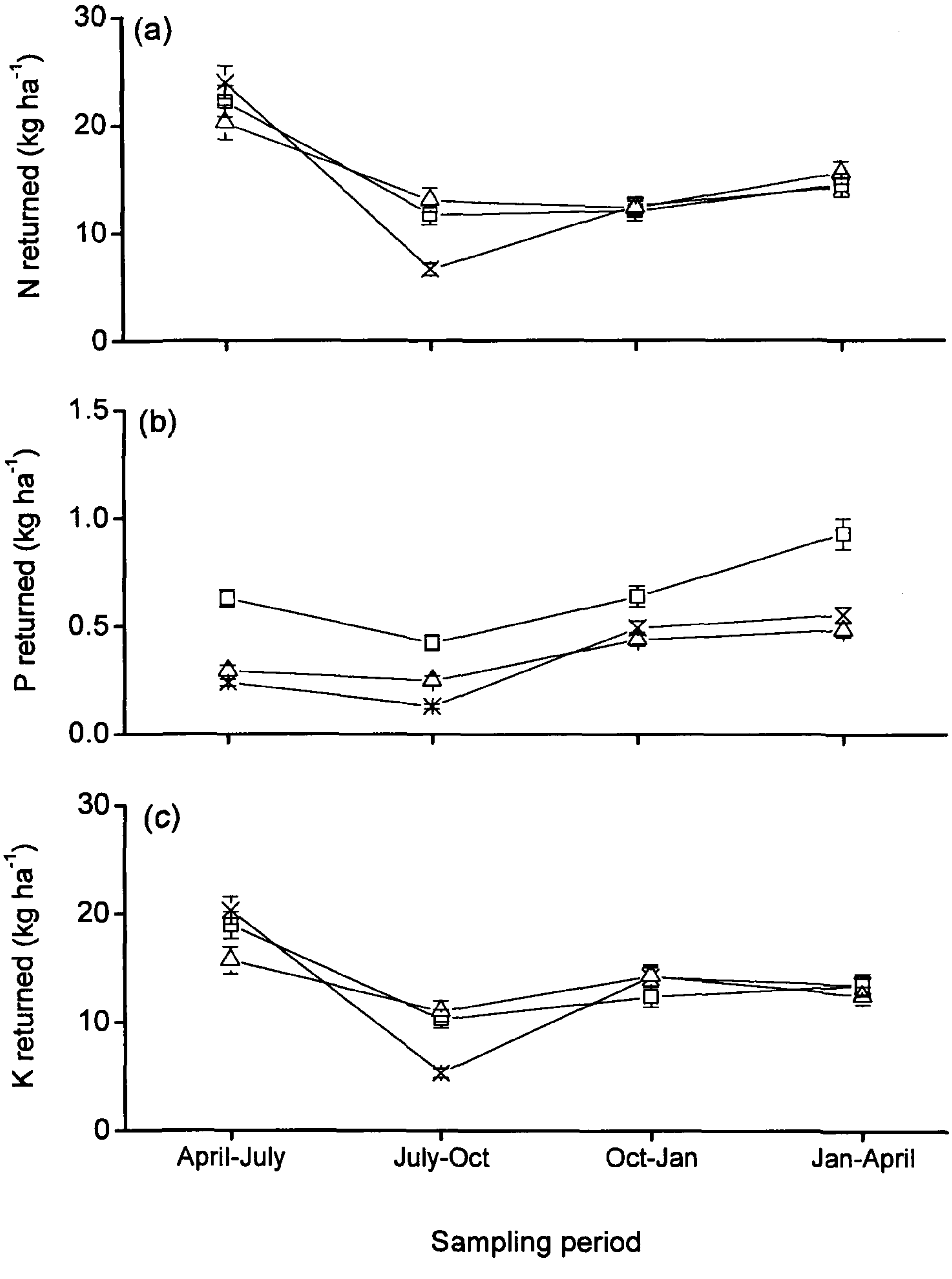

Figure.6.13. Periodic variation in nitrogen (a), phosphorus (b) and potassium (c) return through leaf litter of *A. maling* at the low (-X-), medium (-□-) and high (-△-) elevation sites. Vertical line bars represent ± SE.

Table 6.1. Pearson correlation matrix for the relationship between soil NPK pool and its concentration in *A. maling*.

	Soil N	Soil P	Soil K	Plant N	Plant P	Plant K
Soil N	1.000					
Soil P	0.025	1.000				
Soil K	0.101	-0.277	1.000			
Plant N	0.282	0.306	0.166	1.000		
Plant P	-0.382	0.367*	-0.420	0.196	1.000	
Plant K	-0.316	0.278	0.436*	0.207	-0.146	1.000

Soil N and soil K – Total pool

Soil P - Available form

* Significant at < 0.05 probability level.

Number of observations: 24

leaves with maximum concentration of nutrients remain the major sink for most of the nutrients. The observed higher N and K content in the leaf compared to the branch and culm in the present study agrees with the findings of several researchers working on tropical and temperate bamboo species (Toky and Ramakrishnan 1982, Huang 1987, Liang *et al.* 2000, Shanmughavel and Francis 2001, Kleinhenz and Midmore 2001, Embaye 2003). Higher N, P and K content in culm, branch and leaf of new bamboo individuals (<1yr. old) of *A. maling* compared to the older ones (≥1yr. old) might have resulted due to the active metabolic activities in newly growing parts, which showed a higher rate of water and nutrient translocation from the source. Such type of incidence was also reported by Shanmughavel and Francis (2001) in *Bambusa bambos*, where N, P and K content declined from the bud stage to organ expansion stage. Rodin and Bazilvitch (1968) also reported higher concentrations of many nutrients in actively growing regions in many tree species. Decline in N, P and K in different parts of two bamboo species viz. *Oxytenanthera abyssinica* Munro and *Yushane alpina* K.S. Lin. caused by ageing was also reported by Embaye (2003). Zhou and Wu (1997) reported a similar trend of decreasing N, P, and K concentrations in leaves of *Bambusa distegia* with increasing leaf age, and Li *et al.* (1998b) in *Phyllostachys pubescens*.

A steady decline in N, P and K levels during the growth phases as observed in 'Rui' bamboo has also been reported in tree species like *Eucalyptus tereticornis* Smith (Singh 1984) and *Quarcus leucotrichophora* (Lata and Bisht 1993). The sharp decline in N, P and K content in the culms of

A. maling at the age of nine and twelve months might have resulted due to their translocation to the newly growing branches and leaves.

The root causes of age-dependent decrease in N, P and K in *A. maling* are the same as reported in case of other bamboo species. Ageing of culms is associated with significant chemical and structural changes in parenchyma and fiber tissues, which include decrease in moisture content (Espiloy 1994, Sattar *et al.* 1994), cell wall thickening (Liese and Wiener 1995) and decrease in nutrient ions (Chen *et al.* 1987). In contrast to dicotyledonous plants, conducting tissues of bamboo have to function for many years without the formation of any new tissue (Liese 1995). Furthermore, dicotyledonous trees can shed metabolic residue substances with their bark or deposit them in special tissues such as heartwood, but such substances accumulate in meta-xylem vessels and sieve tubes of bamboo culms (Liese 1991). This progressively decreases the conductivity of the xylem for water and nutrients and that of phloem for assimilates, and finally leads to the breakdown of the transport system and death of culms (Liese and Wiener 1991, 1995).

The significant positive correlation observed during this study between soil available P and total K pool with their distribution in aboveground bamboo parts is well supported by the earlier findings showing that soil physical parameters and nutrient pool play a key role in nutrient distribution to the aboveground bamboo parts (Adamson *et al.* 1978, Uchimura 1978, Patil *et al.* 1980, Huang 1987, Shi *et al.* 1987, Qui and Maoyi 1987, Hassan *et al.* 1988, Raina *et al.* 1988, Totey *et al.* 1989, Thomas 1990, Rao 1993, Lin and Lin 1998). The correlation between total soil nitrogen and nitrogen content in aboveground bamboo parts was insignificant. Total soil N was lower at the medium elevation site than at the low elevation site, but N content in the aboveground bamboo parts at the medium elevation site was higher. This might have resulted due to the higher soil pH, moisture and potassium content, and higher N uptake efficiency of root systems at the medium elevation site. This is supported by the findings of Goldberg and Novoplansky (1997), Bazzaz and Grace (1997), Rorison and Robinson (1986) and Marschner *et al.* (1996). N, P and K content in culms, branches and leaves of *A. maling* in the present study is comparable to that of *Dendrocalamus strictus* reported by Joshi *et al.* (1991), whereas it was considerably higher to that of *Bambusa bambos*, reported by Shanmughavel and Francis (2001).

Effect of age on leaf chlorophyll content

The higher leaf chlorophyll content at the medium elevation site might be due to the suitable climatic variables as well as soil factors, which might have favoured growth and productivity of *A. maling* at this elevation site. The higher N, P and K in the leaves at the medium elevation site might have also played a key role in enhancing the chlorophyll content. Such findings are supported by many reports on the influence of plant nutrients in leaf chlorophyll content in *Phyllostachys pubescens* (Mengel and Kirkby 1987), *P. bambusoides* (Shi *et al.* 1987) and *Bambusa distegia* (Zhou and Wu 1997). In green plants, chlorophyll-a acts as the reaction center in photosynthesis; hence, its availability in grater quantity is of prime importance. Leaf chlorophyll-a content showed a gradual decrease with the leaf age at all the three elevation sites. However, there was an increase in chlorophyll-a content in leaf of twelve months age. This could be due to the induction of new leaves in the branches with higher chlorophyll-a content at all the three elevation sites. The content of chlorophyll-b, the accessory photosynthetic pigment in the *A. maling* leaves increased till the age of three months, after which it declined irrespective of elevation of the study sites. There was no significant addition of chlorophyll-b in the leaves of *A. maling* even during the leaf flush period. Total leaf chlorophyll of *A. maling* at all the elevation sites was well balanced throughout the twelve months of leaf age with better supported by higher chlorophyll-a content at the bud stage with extended support by chlorophyll-b when chlorophyll-a was declined during the mid age (3-9 months). When chlorophyll-b declined in the twelve months old leaves, second peak of chlorophyll-a again boosted the total chlorophyll maintaining the normalcy in bamboo growth and productivity. The age-dependent variation in chlorophyll-a and chlorophyll-b is well explained by chlorophyll a/b ratio, which showed a steady state in the leaves of 3-9 months age with two peaks, the first at the age of one month and second at the age of twelve months. There are also reports on the reduction of chlorophyll content in new leaves produced by the new individuals growing in the old bamboo stands (Shanmughavel *et al.* 1997). Chlorophyll content in *A. maling* is considerably higher as compared to *Bambusa bambos* reported by Shanmughavel and co-workers (1997).

Temporal variation in N, P and K content in <1yr. old and ≥1yr. old individuals of *A. maling*

The increase in N concentration in the aboveground bamboo parts from July to October and a sharp decline during January, indicated that precipitation, air and soil temperature, pH and soil moisture availability might have played an important role in nutrient uptake and translocation (Uchimura

1978, Numata 1987, Biswas 1988, 1994, Hassan *et al.* 1988, Koyama and Uchimura 1995, Banik 2000, Huberman 2003). The positive correlation between soil nutrient pool and plant nutrient concentration agrees with the findings of Bobbink and co-workers (1989). Generally, there is an ultimate increase in nutrient availability with the increase in soil moisture, pH and soil temperature due to higher microbial activity and nutrient return in available form to plants (Swift *et al.* 1979). The higher N concentration in the new individuals observed during July at all the three elevation sites, which was consisted with only culms, and as branch buds are produced during April, there was a sudden increase in N concentration in the aboveground bamboo parts during April. The higher N concentration in the ≥1yr. old individuals during July at all the three elevation sites might have been the result of an increased contribution of branch and leaf N to the total aboveground parts. Similar trend of higher N concentration during July in aboveground plant parts of grasses was reported by Singh (1981) in agro-ecosystems.

Phosphorus content was highest in the culm and branch of *A. maling* during April. The decline in P concentration in the mature individuals, at the low and high elevation sites might be due to the low P pool in the soil and age-dependent decrease in P uptake efficiency. At the medium elevation site P content was well maintained to support the metabolic activities occurring in the culms, branches and leaves. The highest P content in the branch at all the three elevation sites revealed that in *A. maling*, branch acts as the sink for phosphorus. The decrease in phosphorus in branches and its simultaneous increase in leaves indicates that P might have been transported to leaves as well as other growing regions from branches.

Potassium concentration in the young individuals increased with time. However, in January, due to the unsuitable ago-climatic and soil condition for the uptake as well as slow metabolic activities due to cold condition, there was an insignificant increase in K in this month. In mature individuals, the highest K content in the leaves of *A. maling* implies that leaves act as the sink of K, and highest uptake and translocation of K to the aboveground parts takes place during July at all the three elevation sites.

N, P and K content in leaf litter of *A. maling*

The lower N, P and K content in leaf litter of *A. maling* as compared to its fresh leaves at all the three elevation sites might be due to the ageing effect. Retranslocation of mobile plant nutrients from senescing leaves is a potential metabolic system through which plants reclaim nutrient loss from the senescing leaves (Killingbeck 1996, Young 1997, Mafongoya *et al.* 1998). Temporal variation in N, P and K content in leaf litter may also be explained due to the lower rate of nutrient uptake and their transport from the soil to the leaves in different months and seasons.

N, P and K accumulation in the aboveground bamboo parts

Nitrogen, phosphorus and potassium accumulation in the aboveground bamboo pats of *A. maling* was considerably higher than those reported in other bamboo stands of tropical and temperate zones (Mailly *et al.* 1997, Li *et al.* 1998b). The standing state of N, P and K in the *A. maling* forest was strongly influenced by the number of ≥1yr. old individuals. The higher N, P and K concentration, production of new individuals and induction of new branches and leaves in the ≥1yr. old individuals during July, contributed favourably to the standing state of N, P and K. Lowest culm harvesting by the

1996, Virtucio 1996, Mailly *et al.* 1997), but the rates of annual return of N, P and K are comparatively higher than the rates reported earlier. The larger quantity of mean annual N, P and K return through leaflitter at the high elevation site was due to the greater annual litterfall, whereas at the medium elevation site, the greater return of N, P and K could be attributed to their higher content in the leaf litter.

N, P and K loss through culm removal from the *A. maling* forest was higher during dry season compared to the rainy season. The higher N and K removal loss from the low elevation site compared to that of the medium and high elevation sites was due to the harvesting of greater number of culms with higher N and K concentrations, whereas harvesting of greater number of culms that accumulated larger quantity of P at the medium elevation site resulted highest P loss at this elevation site.

Except phosphorus content in the culm, nitrogen, phosphorus and potassium content in the aboveground parts and leaf chlorophyll content were highly influenced by the culm age showing a negative correlation with the latter. Phosphorus content in the culm of *A. maling* increased gradually with the increase in culm age up to twenty-four months. Variation in climatic condition and soil nutrient pool accounted for temporal variation in N, P and K content in aboveground bamboo parts, which caused variation in their periodic accumulation in the aboveground parts. Due to the sustainable culm harvest at the medium and high elevation sites, the N, P and K removal through annual culm harvest was negligible and the standing state of N, P and K was not much affected. Over-exploitation of the bamboo culms, branches and leaves due to human habitation and easy accessibility of the resource at the low elevation site, resulted in greater depletion of N, P and K pool in the aboveground parts of *A. maling* in Jang bamboo forest.

CHAPTER VII

GENERAL DISCUSSION

'Bamboo' being one of the most important and successful plant resource nowadays is in the limelight. Due to its unique ecological role, and several thousands of commercial applications, highest priority is given to this natural resource. The present study of *Arundinaria maling* Gamble has provided deep insights into its ecology. *Arundinaria maling* Gamble has been reported to be distributed in India, Nepal and Bhutan between 1800 to 3658 m asl. In Arunachal Pradesh it is restricted between 2400-3600 m asl. The present study revealed that the elevation range between 2800 to 3200 m asl. (*i.e.*, the medium elevation site) may be the most suitable for its growth and biomass production.

Arundinaria maling (locally called 'Rui' bamboo) is a narrow temperate bamboo which grows abundantly in the Jang area of Tawang district of Arunachal Pradesh. In Jang area, it flourishes between 2400 to 3600 m asl. forming a pure bamboo brake of *ca.* 25 sq. km. *A. maling* is a rare and endemic bamboo species of Eastern Himalaya. It can compete successfully in carbon sequestration with the large-sized tropical and subtropical bamboo species. The present study revealed that more than 80% of the new shoots were inducted within a very short period, *i.e.*, between the last week of June and the second week of July. The maximum emergence of new shoots during June and July revealed the importance and influence of rainfall on the induction of new shoots in *A. maling*. Similar positive influence of rainfall on the production of young shoots is also reported in many other bamboo species (Gamble 1896, Qureshi *et al.* 1969, Numata 1987, Bedell 1997, Banik 2000, Huberman 2003). The induction of new branches in *A. maling* at the age of nine months (during spring season) and the emergence of new leaves at the age of twelve months (during rainy season) are similar to many bamboo species as reported by Banik (2000).

Blooms in *A. maling* were initiated during February, 2002 and flowering continued till May, 2002. Seed formation and seed maturation were observed during July - August of the same year. Although sporadic flowering and seed formation were observed in certain clumps, the seedlings and saplings could not be noticed, which may be due to the low soil as well as air temperature. The initiation of sporadic flowering in *A. maling* after approximately sixty two years of gregarious flowering in Jang area may be considered as a symptom of the forthcoming gregarious flowering. Such incidence of sporadic flowering resulting into gregarious flowering was also reported by Banik (1989) in many other bamboo species. Natural regeneration of *A. maling* after gregarious flowering took around fifteen years to establish a mature forest and to produce culms of commercial size. Pande and Lohani (1963) also reported a similar trend of regeneration after gregarious flowering in *Dendrocalamus strictus*, where it required 12 years to produce commercial culms.

The restricted distribution of *A. maling*, in Jang area of Tawang district of Arunachal Pradesh is highly influenced by topography, climatic condition and soil. Due to the long intermast period of flowering and fruiting (more than sixty years), propagation of *A. maling* generally takes place through subterranean rhizomes. Steep slopes with rocky surface acted as a topographic obstacle and limited the natural propagation and extension growth of *A. maling* through subterranean rhizomes, resulting into the restricted distribution and localization of the species. Anthropogenic pressures like, human habitation and unscientific mode of exploitation in the periphery of the bamboo forest also restricted the further spread of *A. maling*. Grazing and trampling of young tender shoots by wild and domestic animals partially limited the survivality of the new individuals resulting in the reduction of productivity of *A. maling* in Jang bamboo forest. The agro-climatic and edaphic conditions of Jang area such as its peculiar physiography with hilly terrain and mountainous slope, high altitude (2400-3600 m asl.), moderate annual rainfall (1894-1996 mm), moderate snowfall (215-1736 mm), high relative humidity (62-87%), moderate air temperature (5-11^{0}C), high wind velocity (1-5 km hr^{-1}) and moderate to high light intensity (20500-88400 Lux) have been responsible for the distribution of *A. maling* in this area. Soil physico-chemical parameters like moderate to low mean soil temperature (2-8^{0}C), high soil moisture content (40-52%), high water holding capacity (54-65%), low bulk density (0.20-0.40 g cm^{-3}), high soil porosity (84-92%), moderately acidic soil with pH 5.26-5.46, higher level of soil nitrogen (0.41-0.88%), available phosphorus (6-8.82 µg g^{-1}), soil potassium (0.052%) and soil organic carbon (6.36-9.93%) are conducive for the distribution and growth of *A. maling* at Jang area (Chapter III). The above mentioned factors have been reported to limit the distribution and growth of many bamboo species (Yadav 1964, 1969, Uchimura 1978, Uchimura 1981, Chung and Ramm 1990, Tewari *et al.* 1994, Wang *et al.* 1998).

Among the study sites located at different elevations, the highest herb and shrub diversity and density were recorded at the medium elevation site, which may be due to the higher quantity of light reaching the ground and higher soil moisture content throughout the year at this site. Martins (2004) has reported a similar trend of colonization of herbs and shrubs in the gaps between bamboo clumps while studying influence of clump density and light intensity on herb and shrub diversity and density. Higher species diversity of herbs and shrubs at the medium elevation site may also be attributed to the transitional habitat, which supports the growth of species of both low and high elevation sites.

The high elevation site had lowest clump density, and due to the dense fog throughout the year, the forest floor at this elevation had lowest exposure to sunlight. This elevation site supported better diversity and density of annual herbs and shrubs compared to the low elevation site which might be due to the reduced competition for soil moisture and nutrients offered by *A. maling*. The lowest diversity and density of herbs and shrubs associated with *A. maling* at the low elevation site may be due to the low light intensity reaching the ground due to very high clump density and competitive exclusion of herbs and shrubs by *A. maling*.

Litter of herbs and shrubs had high annual nutrient turnover rate compared to that of bamboo litter due to the low lignin content in the former. Hence, herbs and shrubs associated with *A. maling* in Jang bamboo forest might have played a key role in enriching and maintaining the soil nutrient status. The highest diversity of herbs and shrubs at the medium elevation site indicates that the soil at this site is nutrient-rich compared to the other two elevation sites. Similar type of higher herb and shrub diversity in nutrient rich soils in different ecosystem is reported by Rorison and Robinson (1986), Bazzaz and Grace (1997) and Goldberg and Novoplansky (1997). The decrease in species density of herbs and shrubs with the decrease in elevation may be attributed to the increase in bamboo density and dense canopy of bamboo.

The fast growing phase in *A. maling* was limited to 3-4 months, which is similar to that of other tropical and subtropical bamboo species (Liese and Wiener 1995, Chua *et al.* 1996). The height increment of *A. maling* was almost terminated after the age of 21 months at all the elevation sites as is the case with other bamboo species (Londono 1992). It is presumed that under the agro-climatic conditions prevailing in Jang area, *A. maling* can attain its maximum height at the age of 24 months. Statistical analyses of the data revealed significant influence of most of the climatic and soil parameters on growth performance of *A. maling*. Better growth performance in terms of height and diameter growth was observed at the medium elevation site in the Jang area, which may be due to the suitable climatic conditions and soil physico-chemical characteristics of the area. Among the climatic variables, higher annual rainfall (1996 mm), moderate air temperature (mean maximum 16^0C and mean minimum 0^0C), low wind velocity (2.84 km hr^{-1}), moderate relative humidity (66%), annual snowfall (581 mm) and higher light intensity (88400 Lux) are the most important parameters favouring the growth of 'Rui' bamboo at the medium elevation site. Many workers have reported that distribution as well as growth of bamboo is highly influenced by annual precipitation (Koyama and Uchimura 1995, Biswas 1988). Qiu *et al.* (1992)

established a highly significant relationship between annual precipitation and annual timber yield of *Phylostachys pubescens* in China. Kigomo and Kamiri (1985) found a similar functional dependency for *Oxytenanthera abyssinica* in Kenya. The high wind velocity had significant negative influence on growth of *A. maling* at the low and high elevation sites, whereas the low wind velocity prevailing at the medium elevation site had positive influence on its growth in Jang area. Statistical analysis revealed that all the soil physical parameters studied in the *A. maling* forest at Jang area had significant influence on the growth of 'Rui' bamboo, which is in agreement with the findings of Yadav (1969) and Chung and Ramm (1990). It is well known that bamboo can grow even on highly acidic soils (pH 3.5), but most of them prefer to grow between pH 5 to 6.5 (Uchimura, 1978, Hassan *et al.* 1988, Rao 1993). The soil at the medium elevation site was less acidic (pH ranging from 5.26 to 5.51) which might have led to better nutrient assimilation and microbial activities at this elevation, resulting in better growth of *A. maling.* Soil with higher available phosphorus (8.82 $\mu g\ g^{-1}$) and organic carbon (9.94%) at this elevation site also accounted for best growth. Totey and co-workers (1989) reported the influence of soil phosphorus on growth performance of *Denrocalamus strictus.* Reports on the association of vesicular-arbuscular mycorrhizal (VAM) fungi with many bamboo species, reflected significant influence of soil phosphorus on bamboo growth (Appasamy and Ganapathi 1992). The total soil nitrogen was more at the low elevation site (0.76%), although it did not influence height and diameter growth as also reported by many workers (Adamson *et al.* 1978, Patil *et al.* 1980, Shi *et al.* 1987, Qui and Maoyi 1987, Raina *et al.* 1988, Thomas 1990) rather, it resulted into higher clump density at this elevation site. Soil potassium content was not significantly different among the three elevation sites and soil depths, although, the higher concentration of soil potassium in the subsurface layers of *A. maling* forest showed the capability of *A. maling* to accumulate and conserve soil K as reported by many workers in different bamboo species (Toky and Ramakrishnan 1982, Rao and Ramakrishnan 1989, Shanmughavel and Francis 1997, Lin and Lin 1998). The presence of higher soil organic matter content and sufficient quantity of plant litter (bamboo litter plus herb and shrub litter) on the forest floor maintained the soil moisture and temperature at the medium elevation site as also reported by He and Ye (1987). The maximum shoot production of *A. maling* at the medium elevation site in Jang area might be due to the optimum level of soil nitrogen, phosphorus and potassium. Similar type of influence of N, P and K on shoot production was reported in many bamboo species like, *Bambusa tulda, B. balcooa*, *Dendrocalamus strictus, D. hamiltonii, D. longispathus, Melocanna baccifera* (Raina *et al.* 1988, Patil and Patil 1990, Shanmughavel and Francis1996, Banik 2000, Jha and Lalnunmawia 2003). Larger clump area observed at the medium elevation site was due to the selective harvest of large-sized mature culms by the inhabitants of Jang area, which favourably influenced the production of young shoot and expansion of clump area. Many workers have reported similar trend of selective harvest resulting in higher new shoot production and increase of clump area (Basio *et al.*1988, Carcallus *et al.* 1988, Virtucio *et al* 1992, Banik 2000). Growth of *A. maling* at Jang area in terms of height, DBH and production of new shoots is significantly influenced by leaf area index (LAI) and light intensity, which agrees with the findings of many other workers in other bamboo species (Lin *et al.* 1979, Liao 1986, Yang *et al.* 1988, Qiu *et al* 1992, Ishagi *et al.* 1993, Banik 1997, Wang *et al.* 1998). The large-scale harvesting from the roadside clumps is a very common phenomenon observed at all the three elevation sites. The higher extraction of 'Rui' bamboo at the low elevation site in Jang area was due to the easy accessibility of this resource to the villagers. The less number of bamboos extracted from the medium and high elevation sites was due to long distance (8-18 km) from the village area and extractions made only during the dry season and not throughout the year. Due to the production of higher number of new shoots at the medium elevation site and larger clump area, the standing stock of population of *A. maling* was significantly higher at this elevation range. The standing stock of *A. maling* at Jang area with 9,984-73,200 individuals ha^{-1} was very high compared to that reported worldwide (900-52,500 individuals ha^{-1}) in many bamboo species in tropical and temperate ecosystems (Kleinhenz and Midmore 2001). The standing stock of *Phyllostachys pubescens*, a non-clump forming bamboo in China, was only 7,100 individuals ha^{-1} during 1991 (Isagi *et al.* 1997). The production of *A. maling* in Jang bamboo forest was to the tune of 2,964-23,000 individuals ha^{-1} yr^{-1}, which is much higher than the other species reported till date (Kleinhenz and Midmore 2001).

Standing crop of *A. maling* at Jang bamboo forest was highly influenced by topography, climate, soil and anthropogenic pressure. There was a sudden decline in bamboo standing crop during dry season at all the three elevation sites, which was due to the massive extraction of bamboo culms during this period. The standing crop of *A. maling* (67.71 tonnes ha^{-1}) is comparable with the biomass of most of the large and narrow tropical and subtropical bamboo species reported by many authors (APPENDIX V-A). The standing crop of *A. maling* at the medium elevation site was more or less equal to that of *Phyllostachys bambusoides* and *P. pubescens*, the two most important multipurpose bamboo species of China and Japan which produced 112 and 139 tonnes of biomass per hectare (Isagi *et al.* 1993, 1997). The aboveground biomass of *A. maling* compares well with the biomass of other fast growing tree species, such as *Eucalyptus globules* (Cromer and Williams 1982), *Leucaena leucocephala* (Pandey *et al.* 1989) and *Pinus caribaea* (Madgwick *et al.* 1977). The biomass contained in culm (98.70 tonnes ha^{-1}), branch (5.06 tonnes ha^{-1}) and leaf (3.70 tonnes ha^{-1}) at the medium elevation site was comparatively higher than those of *Phyllostachys bambusoides* (Isagi *et al.* 1993) and *P. pubescens* (Li *et al.* 1998a). Dry matter allocation in culm, branch and leaf of the standing crop of *A. maling* in the present investigation was well within the range reported for other bamboos (APPENDIX V-C). Maximum herb and shrub biomass observed during July and October and minimum during January and April might be due to high moisture availability and relatively warmer weather during July and October and the minimum biomass during January and April was due to chilling stress and low moisture availability. The aboveground herb and shrub biomass in *A. maling* forest at Jang area (1.70-2.68 tonnes ha^{-1}) was comparatively higher than the Himalayan high altitude grasslands reported by Joshi *et al.* (1991) and the cropland of Meghalaya reported by Boral (1993). The mean total aboveground biomass of *A. maling* forest (bamboo biomass plus herb and shrub biomass) at Jang area was 67.71 tonnes ha^{-1} which is comparable with that of many bamboo forests of tropical to alpine ecosystems, whereas the total aboveground biomass at the medium elevation site (110.14 tonnes ha^{-1}) is comparatively higher than many of the temperate as well as tropical bamboo forests (Kleinhenz and Midmore 2001 and Embaye 2003).

Mean aboveground dry matter accumulation in one-year old *A. maling* at Jang bamboo forest varied from 0.93-1.98 kg $individual^{-1}$ (considering all the three elevation sites) and at the age of two years, it accumulated 1.58-2.42 kg $individual^{-1}$. Tropical bamboo species, such as *Bambusa bambos* can accumulate larger quantity of dry matter during the first year (Shanmughavel and Francis 2001) in comparison to *A. maling*. On the other hand, subtropical bamboo species like *Phyllostachys glauca*, *P. nigrahexonis* and *P. viridis* accumulate similar quantity of dry matter as *A. maling* (Othman and Shamsudin 2002). *P. heteroclada* accumulated 1.03 kg $individual^{-1}$ (Sun *et al.* 1987), which is much less compared to that of *A. maling.* The highest rate of dry matter accumulation was recorded during the first month after shoot emergence from the ground, whereas in tropical and subtropical large-sized bamboos the highest rate of dry matter accumulation has been reported between 3-6 months (Shanmughavel and Francis 2001). Dry matter accumulation was highest at the medium elevation site compared to the other two elevation sites. Moisture content in the culm of *A. maling* was maximum during the first month which gradually declined with the increase in age. A similar trend in reduction of moisture content in culms with age is reported in many bamboo species by Banik (2000).

This study has revealed a significant influence of topography, climate and soil on growth as well as biomass accumulation in *A. maling* in Jang area. Many workers have reported higher dry matter accumulation in several bamboo species in response to high annual precipitation (Kigomo and Kamiri 1985, Aggarwal *et al.* 1994, Koyama and Uchimura 1995 and Lin 1995). The wind velocity had negative influence on biomass accumulation in *A. maling* as also reported by Zhou *et al.* (1991) and Ambasht and Ambasht (1999) in other bamboo species. The larger biomass accumulation by *A. maling* under high light intensity observed in the present study, agrees with the findings of other researchers in other bamboo species (Hassan 1966, Yang *et al.* 1991, Elgi and Schmid 1999). Loose soil with loamy sand texture characterized by higher silt but low clay content at the medium elevation site might have a positive influence on bamboo growth and biomass accumulation at this elevation. A similar effect was reported by Yadav (1969) and Chung and Ramm (1990). Greater soil moisture availability throughout the year, loose soil with low bulk density and high porosity, and moderate soil temperature at the medium elevation site are among the important physical parameters which might have resulted in greater biomass accumulation at this elevation. Soil available phosphorus and organic carbon accounted for more than 94% variation in bamboo biomass accumulation, and hence, these two nutrients may be considered as the most important nutrients limiting the growth as well as biomass accumulation in *A. maling*. Totey and co-workers (1989) have reported similar positive influence of soil phosphorus on biomass accumulation of *Dendrocalamus strictus*. Soil nitrogen content at all the three elevation sites was much higher compared to other subtropical and temperate bamboo stands as reported by Shi *et al.* (1987) in *Phyllostachys pubescens* stands and by Yadav (1963) in *Bambusa bambos* and *Dendrocalamus strictus* stands. The total soil nitrogen was much higher at the low elevation site compared to the medium and high elevation sites, but it did not cause any significant influence on biomass accumulation of *A. maling*. Similar insignificant role of soil nitrogen on growth and biomass accumulation of many bamboo species have been reported by many workers (Adamson *et al.* 1978, Patil *et al.* 1980, Shi *et al.* 1987, Qiu and Maoyi 1987, Raina *et al.* 1988 and Thomas 1990).

Biomass prediction equations generated from different regression models revealed that at the low elevation site, the equation $Y = 0.0161e^{0.6129X}$ ($R^2 = 0.8971$) may be most suitable for the culm height, followed by basal area per culm ($R^2 = 0.866$) and DBH ($R^2 = 0.7534$). At the medium elevation site, the equation was best derived with DBH as $Y = 6E\text{-}05e^{2.8477X}$ ($R^2 = 0.7902$) followed by basal area ($R^2 = 0.7621$) and culm height ($R^2 = 0.6592$), whereas at the high elevation site, basal area per culm was noticed to be the most significant parameter for biomass prediction, $Y = 0.0411e^{0.5741X}$ ($R^2 = 0.9026$) followed by culm height (0.8258) and DBH (0.8191). The equation to predict bamboo biomass of *A. maling* considering all the three elevation sites was best derived with culm height as $\text{Log } Y = -3.143 + 2.2765 \text{ Ln } (X)$, ($R^2 = 0.6538$) followed by basal area ($R^2 = 0.6027$) and DBH ($R^2 = 0.4751$).

The rate of annual bamboo biomass accumulation in *A. maling* forest (15.09 tonnes ha^{-1} considering all the three elevation sites) was much higher than the reported annual productivity of bamboo forests in India (0.33 tonnes ha^{-1}), China (1.25 tonnes ha^{-1}) and Japan (2.41 tonnes ha^{-1}) (Pathak 1989). It is interesting to note that, *A. maling* forest in Jang area has much greater annual biomass accumulation as compared to other tropical, subtropical and temperate bamboo species (Veblen *et al.* 1980, Tripathi and Singh 1994 and Isagi *et al.* 1997)

The annual rate of litterfall in the *A. maling* forest (6-7 tonnes ha^{-1}) was comparatively higher than those reported in different bamboo species occurring in tropical to temperate forests by many authors (APPENDIX V-C). The net aboveground primary production (NPP) of Jang bamboo forest with 36.43 tonnes ha^{-1} yr^{-1} is comparatively higher in global context and if the medium elevation site is considered, the NPP (55.08) exceeds to all bamboo forests reported by many workers (APPENDIX V-B). The calculated 47.8 thousand tonnes annual production of 'Rui' bamboo in Jang area represents 23.9% of the state's total bamboo production out of 200 thousand tonnes reported earlier (Trivedi and Tripathi 1984, Tewari 1992, Hore 1998).

Like other plants, bamboo leaves with maximum concentration of nutrients remain the major sink for most of the nutrients. Nitrogen, phosphorus and potassium were observed to occur in higher concentrations in different aboveground parts of *A. maling* during the early stages and the concentrations gradually declined with the age. Higher concentration of N, P and K in the newly growing parts is well supported by the findings of Rodin and Bazilvitch (1968). The higher N, P and K content in culm, branch and leaf of new bamboo individuals (<1yr. old) of *A. maling* compared to the older ones (≥1yr. old) might have resulted due to the active metabolic activities in newly growing parts, which showed a higher rate of water and nutrient translocation from the source. Such type of incidence with decline in N, P and K content from the bud stage to organ expansion stage was also reported by Shanmughavel and Francis (2001) in *Bambusa bambos* and in *Oxytenanthera* *abyssinica* and *Yushane alpine* by Embaye (2003). The significant positive correlation between soil available P and total K pool with their distribution in aboveground bamboo parts is supported by the earlier findings showing that soil P and K play a key role in nutrient distribution to the aboveground bamboo parts (Adamson *et al.* 1978, Shi *et al.* 1987, Huang 1987, Qui and Maoyi 1987, Hassan *et al.* 1988, Totey *et al.* 1989, Thomas 1990 and Lin and Lin 1998). Soil N was lower at the medium elevation site than at the low elevation site, but N content in the aboveground bamboo parts at the medium elevation site was higher. This might have resulted due to the higher soil pH, moisture and potassium content, and higher N uptake efficiency of root systems at the medium elevation site. This is supported by the findings of Goldberg and Novoplansky (1997), Bazzaz and Grace (1997), Rorison and Robinson (1986) and Marschner *et al.* (1996). The higher chlorophyll content in the leaves of *A. maling* at the medium elevation site might be due to the presence of N, P and K at optimum level at this elevation site. Similar findings were reported by Mengel and Kirkby (1987) in *Phyllostachys pubescens*, Shi *et al.* (1987) in *P. bambusoides* and Zhou and Wu (1997) in *Bambusa distegia* while working on the influence of plant nutrients in leaf chlorophyll content.

The increase in N and K concentration in the aboveground bamboo parts from July to October and a sharp decline during January to April, indicated that precipitation, air and soil temperature, pH and soil moisture availability might have played an important role in N uptake and translocation (Uchimura 1978, Numata 1987, Biswas 1988, Hassan *et al.* 1988, Koyama and Uchimura 1995, Banik 2000, Huberman 2003). Phosphorus content was highest in the culm and branch of *A. maling* during April. The decline in P concentration in the mature individuals, at the low and high elevation sites might be due to the low P pool in the soil and age-dependent decrease in P uptake efficiency. At the medium elevation site P content was well maintained to support the metabolic activities occurring in the culms, branches and leaves. The highest P content in the branch at all the three elevation sites revealed that in *A. maling*, branch acts as the sink for phosphorus. Potassium concentration in the young individuals increased with time. However, in January, due to the unsuitable climatic and soil conditions for the uptake of K as well as slow metabolic activities due to cold condition, there was an insignificant increase in K content of bamboo plants in this month. The lower N, P and K content in leaf litter of *A. maling* as compared to its fresh leaves at all the three elevation sites might be due to the retranslocation of mobile plant nutrients from senescing leaves which helped plants reclaim nutrient loss from the senescing leaves (Killingbeck 1996, Young 1997, Mafongoya *et al.* 1998).

Nitrogen, phosphorus and potassium accumulation in the aboveground bamboo parts of *A. maling* was considerably higher than those reported in other bamboo stands of tropical and temperate zones (Mailly *et al.* 1997, Li *et al.* 1998b), where number of ≥1yr. old individuals have strong influence on N, P and K accumulation. The temporal variation in standing state of N, P and K in the *A. maling* forest was highly influenced by culm harvest. Lowest culm harvesting by the people during July due to the threats from insects and wild animals allowed the accumulation of larger quantity of biomass and an increase in N, P and K content in plants during July. The lower N, P and K content and increase in culm removal from the three elevation sites during October to April resulted in sudden decline in standing state of N, P and K in the *A. maling* forest.

Leaf shedding in *A. maling* takes place throughout the year, but the maximum leaf litterfall occurred during May-July at all the three elevation sites. The greater leaf litterfall during May-July with high leaf N and K concentration resulted in a higher return of plant nitrogen and potassium to the soil during this period. The highest rate of N, P and K return to the soil through *A. maling* leaf litter at the medium elevation site in Jang bamboo forest reflects a better nutrient cycling process at this site compared to the low and high elevation sites. The rate of annual N return through leaf litter to the *A. maling* forest at Jang area was far greater compared to that of P and K. The annual return of P was the lowest. The N, P and K loss through culm removal from the *A. maling* forest was higher during dry season compared to the rainy season. The higher N and K removal from the low elevation site compared to that of the medium and high elevation sites was due to the harvesting of greater number of culms with higher N and K concentrations, whereas harvesting of culms with high P content at the medium elevation site resulted into the highest P loss at this elevation site.

Results of this study have pinpointed the possible abiotic and biotic factors responsible for the site specific distribution of *Arundinaria maling,* which grows in natural habitat between the elevation range from 2400 to 3600 m asl at Jang area of Tawang district of Arunachal Pradesh. The elevation range between 2800-3200 m asl. may be accredited as most suitable habitat for growth and biomass accumulation. *A. maling* did show sporadic flowering and produced viable seeds but the flowering cycle is assumed to be not less than 60 years. Topography, climatic variables and soil physico-chemical parameters play key roles in growth, biomass accumulation and productivity of *A. maling* as well as other plants. Comparatively higher growth indices with low annual harvest rate at all the three elevation sites, revealed better status with long-term sustainability of the *A. maling* forest in Jang area. It can be concluded that, *A. maling* may serve as a rich biomass resource, which can compete successfully with other tropical large-sized bamboo species. The calculated 47.8 thousand tonnes annual production of 'Rui' bamboo in Jang area represents 23.9% of the state's total bamboo production out of 200 thousand tonnes reported earlier (Trivedi and Tripathi 1984, Tewari 1992, Hore 1998). After the extraction by the inhabitants, there still remains a surplus of 6.8 thousand tonnes of bamboo biomass annually in the Jang bamboo forest. Thus, bamboo based small scale industries may be established for the welfare of the poor inhabitants of Jang area. Scientific mode of exploitation and proper utilization of 'Rui' bamboo may definitely be helpful in improving the socio-economic condition of Jang area, the Tawang district as well as Arunachal Pradesh. From ecological point of view, *A. maling* is identified as an endemic and rare bamboo species. Distribution and availability of this temperate bamboo species is limited only to a few pockets, the Jang area having the largest population size is one of those pockets. Hence, immediate action for the conservation of this precious resource may also be initiated through *in situ* as well as *ex situ* methods.

In future, studies on biomass and productivity of belowground compartment of *A. maling* as well as herbs and shrubs growing in *A. maling* forest in Jang area, should be undertaken to provide complete picture of the carbon sequestration by this forest. Studies on nutrient uptake and accumulation in the belowground compartment, and litter decomposition rate at different elevation zones also needed to be undertaken to decipher the effect of altitude on the organic matter and nutrient dynamics in the *A. maling* forest.

SUMMARY

Arundinaria maling Gamble (locally called 'Rui' bamboo) a temperate bamboo with narrow culm is a rare and endemic bamboo species. *A. maling* grows profusely covering *ca.* 3.17 x 10^3 hectare in Jang area of Tawang district of Arunachal Pradesh.

Present study analyses the site specificity, growth and productivity of 'Rui' bamboo and nutrient dynamics of 'Rui' bamboo forest in Jang area of Tawang district of Arunachal Pradesh. The study was carried out at three sites along an altitudinal gradient. The low elevation site ranges between 2400 to 2800 m asl., the medium elevation site between 2800-3200 m asl. and high elevation site ranges between 3200-3600 m asl. Studies on biology of *A. maling* including its phenology and growth (culm height, DBH, basal area), clump density, clump area, and production of new individuals were made from April 2001 to April 2003 at all the three elevation sites. Systematic position, description and distribution pattern of the genus *Arundinaria* as well as species have also been provided in this thesis. Studies were made on age-dependent variation in dry matter accumulation in *A. maling*, and biomass allocation to culm, branch and leaf to the total aboveground bamboo biomass. The biomass of herbs and shrubs was also determined during different seasons to understand their contribution to the total aboveground biomass of the Jang bamboo forest. Annual dry matter production of *A. maling* at the three elevation sites including periodic and annual leaf litter production and bamboo biomass extraction from *A. maling* forest were also determined. In

addition to the above, the temporal variation in distribution of N, P and K in culms, branches and leaves of *A. maling* at all the three elevation sites and age-dependent variation in leaf chlorophyll content were also studied. The influence of climatic variables and soil physico-chemical parameters on growth and biomass of 'Rui' bamboo, and N, P and K distribution in its aboveground parts at different elevation sites has also been studied. Salient findings of the present investigation are summarized as follows:

1. The pure *Arundinaria maling* brake occurring in Jang locality of Tawang district of Arunachal Pradesh (27^0 30′-27^0 35′ N latitude and 91^0 55′-92^0 E longitude) is a secondary successional forest, developed after the removal/overexploitation and destruction of *Taxus baccata* mixed forest. In Jang area, *A. maling* is restricted between 2400 to 3600 m asl., its maximum growth and biomass was recorded at the medium elevation site *i.e.*, between 2800 to 3200 m asl.
2. Annual rainfall was highest at the medium elevation site, whereas snowfall was maximum at the high elevation site. Mean maximum and mean minimum air temperature were highest at the low elevation site and the temperature decreased with the increase in elevation.
3. Soil temperature decreased with the increase in soil depth except during December and January at the high and medium elevation sites, where surface soil temperature was lower than the subsurface layers due to snow cover. Soil was sandy at the low and high elevation sites, whereas at the medium elevation site, it was loamy sand. The medium elevation site had higher water holding capacity compared to the other two elevation sites. Soil moisture content decreased with the increase in soil

depth and the maximum soil moisture content was observed at the medium elevation site. Bulk density increased significantly with the increase in soil depth, and it was lowest at the medium elevation site.

4. Soil at the medium elevation site was less acidic compared to that of the low and high elevation sites, and the acidity decreased with the increase in soil depth. Concentrations of soil organic carbon, total nitrogen and available phosphorus decreased with the increase in soil depth, whereas soil potassium content was highest at 10-20 cm depth. Mean soil organic carbon content was maximum at the medium elevation site.
5. Soil nitrogen content was highest at the low elevation site whereas soil available phosphorus was highest at the medium elevation site. Soil potassium content did not differ significantly among elevation sites.
6. A total of 29 species of herb and 28 species of shrub were recorded from the Jang *A. maling* forest, where highest number of species was observed at the medium elevation site, followed by the high and low elevation sites. *Eleocharis atropurpurea* of Cyperaceae, *Eragrostis ciliaris* of Poaceae and *Gnaphalium apiculatum* of Asteraceae family were the dominant species at the low, medium and high elevation sites, respectively. Species composition between the medium and high elevation sites had greater similarity in comparison to the similarity between medium and low, and between low and high elevation sites. Density of herbaceous species was highest at the high elevation site, whereas density of shrub species was highest at the medium elevation site. The values of species richness and Shannon-Wiener index were highest at the medium elevation site.

7. *A. maling* growing in Jang area flowered gregariously during 1940s and it regenerated through seeds in natural condition. Sporadic flowering which occurred at the high elevation site during the study period (2001-2003) caused production of viable seeds, but the latter did not develop into seedlings.
8. Emergence of new shoots took place during June-July with the onset of rainy season. Branches in the new individuals were induced at the age of nine months, whereas induction of new leaves took place at the age of twelve months.
9. Topography, climate and soil played a key role in the distribution of *A. maling* in Jang area. Anthropogenic pressures like unscientific mode of bamboo exploitation and human habitation at the periphery of the forest coupled with grazing and trampling of new shoots by wild and domestic animals also contributed to the restricted distribution of *A. maling.*
10. *A. maling* growing at the medium elevation site had significantly taller culms with larger diameter compared to the other two sites. The culm height and diameter were lowest at the high elevation site.
11. Regression equations to predict culm height and DBH of *A. maling* at different ages, irrespective of elevation sites were established as $Log(Y) = 5.4754 + 0.7573 Ln(X)$ and $Log(Y) = 2.1208 + 0.1625 Ln(X)$, respectively. Culm height prediction equation considering DBH was established as $Log(Y) = 0.8066 + 2.2743 Ln(X)$.
12. Clump density decreased with the increase in elevation. Clump area and new shoot production were maximum at the medium elevation site.

13. Climatic variables and soil physico-chemical parameters had positive influence on growth and biomass of *A. maling* at Jang area, whereas soil bulk density and wind velocity had strong negative influence.

14. Aboveground dry matter accumulation in two year old *A. maling* was 1.95, 2.42 and 0.90 kg/ individual, respectively at the low, medium and high elevation sites. The contribution of culm, branch and leaf to the total dry matter accumulation was in the ratio of 90%, 6% and 4%, respectively at the low elevation site, whereas it was 91%, 5% and 4% at the medium elevation site, and 91%, 6% and 3% at the high elevation site.

15. The rate of dry matter production in *A. maling* during the first month after shoot emergence at the low, medium and high elevation sites was 10.10, 17.00 and 6.93 g day^{-1} $individual^{-1}$, respectively.

16. Biomass prediction equations of *A. maling* through culm height, DBH and basal area per culm have been established as $Log (Y) = -3.143 + 2.2765 Ln (X)$, $Log (Y) = -0.796 + 2.0703 Ln (X)$ and $Log (Y) = -0.9809 + 1.1678 Ln (X)$, respectively.

17. The standing crop of *A. maling* was 79.73, 107.47 and 9.11 tonnes ha^{-1}, respectively at the low, medium and high elevation sites. The contribution of culm, branch and leaf to the total biomass was 92%, 5% and 3% at the medium and high elevation sites, and 91%, 5% and 4% at the low elevation site. The contribution of aboveground bamboo biomass towards the total aboveground biomass in the Jang forest area was 98% at the low and medium elevation sites and 79% at the high elevation site. The contribution of herbs and shrubs to the total aboveground biomass

was only 2% at the low and medium elevation sites and 21% at the high elevation site.

18. The rate of dry matter accumulation in *A. maling* was 12.52, 31.39 and 1.37 tonnes ha^{-1} yr^{-1}, respectively at the low, medium and high elevation sites, whereas biomass accumulation by herbs and shrubs was 1.6, 2.25 and 3.30 tonnes ha^{-1} yr^{-1}, respectively at the low, medium and high elevation sites.
19. The annual litterfall was 6.59, 6.16 and 6.97 tonnes ha^{-1} at the low, medium and high elevation sites, respectively and the bamboo biomass extraction was at the rate of 18.47, 15.28 and 3.40 tonnes ha^{-1}, respectively at the low, medium and high elevation sites.
20. The net aboveground primary production was highest at the medium elevation site with 55.08 tonnes ha^{-1} yr^{-1} followed by the low and high elevation sites with 39.18 and 15.04 tonnes ha^{-1} yr^{-1}, respectively.
21. Number of bamboo individuals recorded per hectare at the end of the study period at the low, medium and high elevation sites was 61982, 73200 and 9984, respectively while the number of individuals produced during 2001-2003 was 36822, 46000 and 5928 individuals ha^{-1} respectively, at the low, medium and high elevation sites. The percent annual harvest was 13.3, 7.3 and 18.2 at the low, medium and high elevation sites, respectively.
22. N, P and K content in the culms, branches and leaves of *A. maling* decreased with the age, and the highest concentration was recorded during the initial stage. The concentration of nitrogen and potassium in the aboveground parts of *A. maling* was in the order of leaf > branch >

culm, whereas in case of phosphorus, it was branch > leaf > culm. Leaf chlorophyll content decreased with the increase in leaf age, and leaves at the medium elevation site had maximum chlorophyll content.

23. The N, P and K content in leaf litter was highest at the medium elevation site (0.98%, 0.043% and 0.894%, respectively) followed by the low (0.88%, 0.022% and 0.806%, respectively) and high (0.85%, 0.020% and 0.739% respectively) elevation sites.
24. The N, P and K accumulation increased with the increase in stand age. The contribution of bamboo parts to N and K accumulation was in the order of culm > leaf > branch, and in case of P it was culm > branch > leaf. The aboveground N accumulation in *A. maling* was 191.96, 296.46 and 20.07 kg ha^{-1}, respectively at the low, medium and high elevation sites, whereas P accumulation was 71.82, 142.30 and 6.41 kg ha^{-1}, respectively and K was accumulated in the rate of 301.88, 477.55 and 40.82 kg ha^{-1}, respectively at the low, medium and high elevation sites.
25. The N, P and K lost through culm removal was 25.07, 12.60 and 47.01 kg ha^{-1}, respectively at the low elevation site, 23.42, 15.59 and 41.46 kg ha^{-1}, respectively at the medium elevation site and 3.65, 1.80 and 10.99 kg ha^{-1}, respectively at high elevation site.
26. The annual N, P and K return through *A. maling* leaf litter was 57.63, 1.42 and 53.38 kg ha^{-1}, respectively at the high elevation site, 60.41, 2.63 and 55.24 kg ha^{-1}, respectively at the medium elevation site and 61.24, 1.47 and 53.68 kg ha^{-1}, respectively at the low elevation site.

The present study on site specificity, growth and productivity of *Arundinaria maling* in Jang area of Tawang district of Arunachal Pradesh, revealed that localized distribution of *A. maling* is highly influenced by abiotic and biotic factors, where topography, climatic variables and soil physico-chemical parameters as well as anthropogenic pressures play key roles. Growth and biomass production was also highly influenced by both biotic and abiotic factors, where optimal performance was observed at 2800-3200 m asl *i.e.*, at the medium elevation site. Hence, it may be assumed that, the range of climatic and soil conditions prevailing at the medium elevation site is most suitable habitat for *Arundinaria maling* in Jang area of Arunachal Pradesh. Based on the scientific data collected during the present investigation, the potential areas to be brought under *A. maling* plantation can be located. Further, detailed studies on flowering and regeneration status, growth, biomass and nutrient distribution in belowground compartments of *A. maling* and soil, along with nutrient content in herbs and shrubs may provide a clear picture on the total biomass and productivity as well as nutrient dynamics in the *A. maling* forest in the Jang area. This may also provide strong indication regarding the site-specificity of *Arundinaria maling,* which may be helpful in the plantation and management of this bamboo resource.

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APPENDIX V-A. A Global scenario of total aboveground biomass of different bamboo species.

Species	Location (latitude)	Mean annual temperature and precipitation	Total biomass (t ha^{-1})	Special stand features (elevation; management)	References
Chusquea culeou	Chile (40^0 N)	8^0 C; 4000 mm	156-162	700 m asl	Veblen *et al.* (1980)
Chusquea tenuiflora	Chile (40^0 N)	6.5^0C; 5633 mm	13	1000 m asl	Veblen *et al.* (1980)
Dendrocalamus strictus	India (25^0 N)	26^0 C; 830 mm	4-22	N/A	Tripathi and Singh (1994)
Gigantochloa atter; G. verticilata	Indonesia (7^0 N)	28^0 C; 2000 mm	45	1100 m asl	Christanty *et al.* (1996)
Bambusa bambos	India (11^0 N)	31^0 C; 600 mm	122-287	N/A	Shanmughavel and Francis (1996)
Dendrocalamus strictus	India (24^0 N)	1069 mm	30-49	Plantation stand	Singh and Singh (1999)
Phyllostachys pubescens	Japan (34^0 N)	15^0 C; 1581 mm	138	N/A	Isagi *et al.* (1997)
Dendrocalamus latiflorus Munro	China (26^0 N)	20^0 C; 1700 mm	28.49	N/A	Lin *et al.* (2000)
Dendrocalamopsis oldhami	China (24^0 38′ -25^0 11′ N	20^0 C; 1448-2023 mm	134.49	N/A	Lin *et al.* (1998)
Bashania fangiana	China (32^0)	N/A	0.353	Panda bamboo	Zhou (1997)

N/A – Information not available.

APPENDIX V-B. A Global scenario of aboveground net primary productivity (ANPP) of bamboo stands (oven dry basis)

Location (Latitude)	Mean annual temperature and precipitation	Total ANPP (Maximum figure reported; t ha $^{-1}$ yr^{-1})	Aboveground wood productivity (Average reported; t ha $^{-1}$ yr^{-1})	Special stand features (elevation; management)	References
Southern India (11^0 N)	31^0 C; 600 mm	47.0	N/A	Highland (540m); fertilized and irrigated	Shanmughavel and Francis (1996)
Central Japan (35^0 N)	N/A	24.6	15.5	N/A	Isagi *et al.* (1993)
Japan	N/A	18.1	N/A	N/A	Isagi *et al.* (1997)
Georgia, USA (32^0 N)		N/A	9.1	Sustainable yield	Adamson *et al.* (1978)
Central Chile (40^0 S)	4000 mm	10.5	6.2	Montane (700 m)	Veblen *et al.* (1980)
Zhejiang, China (30^0 N)	16^0 C; 1800 mm	10.5	7.7	Managed by harvesting	Qiu *et al.* (1992)
Alabama, USA (32^0 N)	N/A	N/A	7.4	Probably fertilized	Sturkie *et al.* (1968)
Thailand (14^0 N)	28^0 C; 950 mm	8.1	N/A	N/A	Suwannapinunt (1983)
Northern India (25^0 N)	26^0 C; 830 mm	7.7	2.2	N/A	Tripathi and Singh (1994)
Central China (32^0 N)	1200 mm	4.5	3.1	Montane (2750 m)	Taylor and Qin (1987)

N/A – Information not available

APPENDIX V-C. A Global scenario of aboveground productivity of bamboo parts and litter (t ha^{-1} yr^{-1}, oven dry basis)

Species	Culm	Branch	Leaf	Litter	References
Chusquea culeou	127-130	N/A	25.0*	4.27	Veblen *et al.* (1980)
Chusquea tenuiflora	9.4	N/A	3.5*	0.09	Veblen *et al.* (1980)
Dendrocalamus strictus	7.8-30	N/A		4.1-1.2	Tripathi and Singh (1994)
Gigantochloa ater; G. verticilata	34.4	6.0	4.7	N/A	Christanty *et al.* (1996)
Bambusa bambos	93-243**	N/A	1.9-4.0**	9.2-11.8	Shanmughavel and Francis (1996)
Dendrocalamus strictus	24-38**	N/A	6.1-10.7**	N/A	Singh and Singh (1999)
Phyllostachys pubescens	116.5	15.5	5.9	4.4	Isagi *et al.* (1997)
Dendrocalamus latiflorus Munro	16.67	8.45	3.37	N/A	Lin *et al.* (2000)
Dendrocalamopsis oldhami	95.51	28.17	14.81	N/A	Lin *et al.* (1998)
Bashania fangiana	0.155	0.076	0.122*	N/A	Zhou (1997)

* Leaf biomass including culm sheath.
** Range of productivity at different stand age.
N/A – Information not available.

APPENDIX - CV

CURRICULUM VITAE

Name	: KSH. LAL BIHARI SINGHA
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Date of Birth	: 01.03.1973
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Educational Qualification:

Level	Degree	Year of Passing	Institution	Board/ Council/ University	Subjects/ Papers	Division & % of Marks
10^{th} Std.	HSLC	1989	Sonai Jubati High School	Board of Secondary education Assam	G. Science, G. Maths, English, Manipuri, Social Studies, Civics & Economics	II 57.47
12^{th} Std.	HSC	1992	Guru Charan College, Silchar, Assam	Assam Higher Secondary Education Council	Physics, Chemistry, Biology, English, Manipuri	II 53.20
Three Yrs. Degree Course	B.Sc. Botany Hons.	1996	Guru Charan College, Silchar, Assam	Assam (central) University Silchar, Assam	Botany Hon. Subjects, Zoology, Chemistry, English and Foundation Course	II 54.00
Post Graduate	M. Sc. Life Science (Botany)	1998	Assam University Silchar, Assam	Assam (central) University Silchar, Assam	Cell Biol., Immuno., Genetics, Biochem.& Mol. Biol., Env.& Cons. Biol., Tech. in Biology, Biostatistics & Computer applications, Microbiology, Biotechnology, Plant Diversity, Plant Morphology, Diff. & Taxonomy, Microbial Genetics, Plant Breeding, Pl. Pathology, Microbial ecology, Embryology, Advanced Plant Physiology, Bioenergetics	I 66.44
Master of Philosophy	M. Phil Life Sc.	2002	Department of Life Science, Assam (central) University Silchar, Assam	Assam (central) University Silchar, Assam	Research Techniques in Biology, Principles of Biostatistics & Computer Application, Fresh water systems & Management, Decomposition Biology	I 65.40

★ Academic Distinction: Stood First class 3^{rd} position in Masters of Science Examination 1998 in Life Science Botany.

Research experience

- Since 20th October 2000 to 15th May 2002 worked as Junior Research Fellow at North Eastern Regional Institute of Science & Technology, Itanagar, in an ICAR (NBPGR-NATP) funded Project entitled "Germplasm exploration, Collection, Evaluation and maintenance of Bamboo & Cane in North - Eastern Region of India.
- Since 17th May 2002 to 20th April 2005, worked as a Research Associate at Indian Council of Agricultural Research, Research Complex for North East Hill Region (Agroforestry Division), Umiam, Meghalaya under an A.P. CESS funded project on 'Germplasm Collection, Propagation and Young Shoot Production of Edible Bamboo Species available in North East India'.

A. Research papers published:

1. M.L. Khan, K. Upadhyaya, **L. B. Singha,** and A. Devi (2002). A plea for conservation of threatened tree fern (*Cyathea gigantea*). *Current Science*, 82 (4): 375-376 (India).
2. **Ksh. L.B. Singha**, M.H. Khan, M. Dash, and S.K. Panda (2002). Aluminium phytotoxicity in wheat: pigment alterations and oxidative damage. *Proceedings National Academy of Sciences*, India. Volume -72, Section -B (III) & (IV), pp 345-348 (India).
3. M.H. Khan, **Ksh. L. B. Singha** and S.K. Panda (2002). Changes in antioxidant levels in *Oryza sativa* L. roots subjected to NaCl- salinity stress. *Acta Physiologiae Plantarum*, 24(2): 145-148 (Poland).
4. **L.B. Singha,** B.P. Bhatt and M.L. Khan (2003). Flowering of *Bambusa cacharensis* Mazumder in the southern part of North-East India - a case study. *J. Bamboo and Rattan*, 2(1): 57-63 (The Netherlands).
5. B.P. Bhatt, **L.B. Singha,** K. Singh and M. S. Sachan (2003). Commercial edible bamboo species and their market potentiality in three Indian tribal states of North Eastern Himalayan Region. *J. Bamboo and Rattan*, 2(2): 111-133 (The Netherlands).
6. B.P. Bhatt, **L.B. Singha**, K. Singh and M. S. Sachan (2003). Some commercial edible bamboo species of North East India: Indigenous uses, Cost-benefit and Management Strategies. *Bamboo Science and Culture*, 17(1): 4-20 (USA).
7. S.K. Panda, **L. B. Singha** and M.H. Khan. (2003). Does Aluminium phytotoxicity induce oxidative stress in Green gram (*Vigna radiata*)? *Bulgarian J. of Plant Physiology,* 29(1-2): 77-86 (Bulgaria).
8. B.P. Bhatt, **L.B. Singha**, Kundan Singh and M. S. Sachan (2004). Distribution, growth and productivity of commercial edible bamboo species in the three states of Eastern Himalaya, India. *World Bamboo and Rattan,* 2 (3):22-32 (China).
9. B.P. Bhatt, **L.B. Singha**, K. Singh and M. S. Sachan (2004). Commercial edible bamboo species of North Eastern Himalayan Region, India. Part I: Young shoot sales. *J. Bamboo and Rattan*, 3(4): 337-365 (The Netherlands).
10. **L.B. Singha,** B.P. Bhatt, M. S. Sachan and K. Singh (2004). Market potentiality of edible bamboo shoots in North-eastern Hill Region of India. In: Proceedings of a regional seminar on *'the role Biodiversity and Environmental strategies in North East Indiafor Sustainable development',* Nov. 27-28, 2002 (Kharrakor, P., Diengdoh, C.R., james, N and Biswa, R. eds.), pp. 64-99. St. Mary,s College, Shillong (India).

11. B.P. Bhatt, **L.B. Singha**, K. Singh and M. S. Sachan (2005). Commercial edible bamboo species of North Eastern Himalayan Region, India. Part II: Fermented, roasted and boled bamboo shoots sales. *J. Bamboo and Rattan*, 4(1): 13-31 (The Netherlands).

B. Research papers accepted:

1. Kundan Singh, M.S. Sachan, **L.B. Singha**, Alka Singh and B.P. Bhatt. (2005). Edible Bamboo Species of NEH Region: A Potential Resource for Rehabilitation of Degraded Lands, Food Security and Employment Generation. *In:* Agroforestry in North east India: Opportunities and challenges, (Bhatt, B.P. *et al.* eds.), Indian Council of Agricultural Research (RC) for NEH Region, Meghalaya, India.

2. B.P. Bhatt, J.M.S. Tomar **L.B. Singha** and K.M. Bujarbaruah (2005). Growth Performance and Production Potential of Agrisilvicultural Practices in Meghalaya. *In:* Agroforestry in North east India: Opportunities and challenges, (Bhatt, B.P. *et al.* eds.), Indian Council of Agricultural Research (RC) for NEH Region, Meghalaya, India.

C. Research papers communicated:

1. B.P. Bhatt, **L.B. Singha,** K.K. Satapathy Y.P. Sharma and K.M. Bujarbaruah (Dec. 2004). Restoration of degraded lands through agroforestry models: A case study from North Eastern Hill Region, India. *Forests, Trees and Livelihoods J.* (UK).

2. **L.B. Singha** and B.P. Bhatt (Feb. 2005). Certain ecological parameters of selective commercial edible bamboo species of North east Hill Region of eastern Himalaya, India. *Forest Ecology and Management* (The Netherlands).

3. B.P. Bhatt, **L.B. Singha,** M. S. Sachan and K. Singh (April 2005). Ecology, Economics and Nutritional values of some edible bamboo species of North East Hill Region of India: an overview. *Acta Oecologica* (France).

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