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IMPROVED FODDER TREE MANAGEMENT IN THE AGROFORESTRY SYSTEMS OF CENTRAL AND WESTERN NEPAL

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Major professor

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# IMPROVED FODDER TREE MANAGEMENT IN THE AGROFORESTRY SYSTEMS OF CENTRAL AND WESTERN NEPAL

By

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ABSTRACT

IMPROVED FODDER TREE MANAGEMENT IN THE AGROFORESTRY SYSTEMS OF CENTRAL AND WESTERN NEPAL

By

**Madhav Bahadur Karki**

Ten, three year old, fodder tree species were evaluated at four on-station and three on-farm sites in Nepal. *Ficus semicordata* (Buchattam. ex Sm.) growth was found to be significantly higher (p=.01) than the rest in diameter and dry foliage weight values. Species were significantly (p=.01) different in height, diameter, and foliage and wood growth. Sites were significantly (p=.01) different in total height growth only. On-farm species evaluation indicated that *A.lakoocha* and *F.semicordata* had significantly higher growth.

Allometric regression equations were developed to predict foliage, total wood, and total biomass yield of *F. semicordata*, and *B.variegata*. Individual-tree models were developed based on the data collected from experimental plots and farmers' fields. Logarithmic transformations gave better fitted models. For *B.variegata*, diameter at 50 cm. and for *F.semicordata*, crown diameter and height gave the best fitted equations. Regression equations for three sites did not differ significantly (p=0.05) in their slopes and intercepts. Therefore, data were pooled and a common model

was estimated for each species. In on-farm regression models, height and crown diameter were the best predictors for *F.semicordata* and dbh gave the best fit for *B.variegata*. The models for the two species were used to construct regional fodder and fuelwood biomass tables.

An improved crop-livestock-fodder agroforestry system was designed for a village in Nepal, based on the research and survey data. Linear programming was used to demonstrate the use of a tool to optimize land allocation maximizing net returns while satisfying the supply of minimum needs of food, fodder, and fuelwood. The optimal solution indicated that, by improving the returns to labor and by applying more compost, the village should be able to increase the annual net farm returns from the current NRs. 2.94 million to an estimated NRs. 3.85 million. The food, fodder and fuelwood production levels were shown to increase by 17%, 130%, and 537% respectively. The labor and compost requirements were up by 138% and 59% respectively, over the five year period. The soil loss through run-off was estimated to decrease by about 15% over the same period.

To my parents,

Perm and Narindra Karki

One taught me about hard work,

the other about perseverance.

I'm deeply greatful to them both.

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My parents whose desire to educate their children made them struggle hard for their entire life have always been and will remain my constant source of inspiration, love, and dedication. I can not find suitable words to express my heartfelt thanks and gratitude to them.

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**IMPROVED FODDER TREE MANAGEMENT IN THE AGROFORESTRY SYSTEMS OF CENTRAL AND WESTERN NEPAL:**

# CHAPTER I

## GENERAL INTRODUCTION, BACKGROUND AND OVERVIEW

**Abstract**

Nepal's serious environmental concerns primarily stem from growing human and livestock population. Currently only two thirds of the total animal feed requirements are being met. Planting of fodder tree species (FTS) on farm lands is being encouraged to replace the forests as the traditional source of fodder. A review of the current FTS cultivation practices indicates that each farmer owns about 28 fodder trees belonging to more than ten species. *Ficus spp., Artocarpus lakoocha*, and *Bauhinia spp*. are the most commonly grown FTS in the Midhills and the Inner Tarai regions. The green foliage is fed to productive animals during dry season. Generally, easy to propagate and fast growing FTS with protein rich foliage are preferred by the farmers. However, an ideal tree, according to the farmers, should also fit in the existing farming system and tolerate active vegetation manipulations. The most important problem identified is the lack of information on the species evaluation, growth and yield, and crop-tree interactions. There is a need to standardize species evaluation techniques. Lack of fodder weight tables is also hampering the development of improved management plans. It is emphasized that to increase the contribution of FTS in fulfilling growing fodder needs, an improvement in the management of FTS is essential. A systematic approach should include appropriate species selection, individual-tree modeling, and an efficient land allocation techniques.

## 1.0 GENERAL INTRODUCTION

**1.1 Fragile hill-ecosystem:** Environmental degradation in Nepal due to population pressure and faulty land use practices is causing increasing concern over the long-term stability of fragile hill ecosystems. Nepal is estimated to have lost about 0.5 million ha. of forest area and half of its growing stock, at an annual rate of about 2.1 percent, between 1960 and 1980 (Wallace 1985; Wallace 1988; Upadhyaya

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1986). During 1990/91 alone it is reported to have lost about 76,000 ha. of prime forest land (Arab News 1991). Over exploitation of the forest is estimated to be equivalent to clear cutting of more than 100,000 ha. of natural forest a year (UNDP/World Bank 1983). At the current rate of depletion, several studies (World Bank 1978; FAO 1979) have concluded that there would be no accessible forests in the Middle Hills[1] by the end of this century.

Eighty three percent of Nepal is hilly and mountainous (Figure 1.1), where 56% (47.7% in the Middle Hills and 8.7% in the Mountains) of human population (10.7 million) and 63% (eight million) of ruminant animals live (APROSC 1986; MFSC 1988). The landscape is characterized by elaborate crop and livestock farming systems where cultivated plants, trees, shrubs, grassy vegetation and domesticated animals interact to generate a complex mix of primary and secondary production processes to fulfill the basic needs of the people. Forests cover 31% of the total country; another 28% is classified as wasteland; and cultivated areas occupy only 17 percent. Fifteen percent of the total area is under range vegetation[2], the bulk of which is inaccessible to grazing (Karki 1982).

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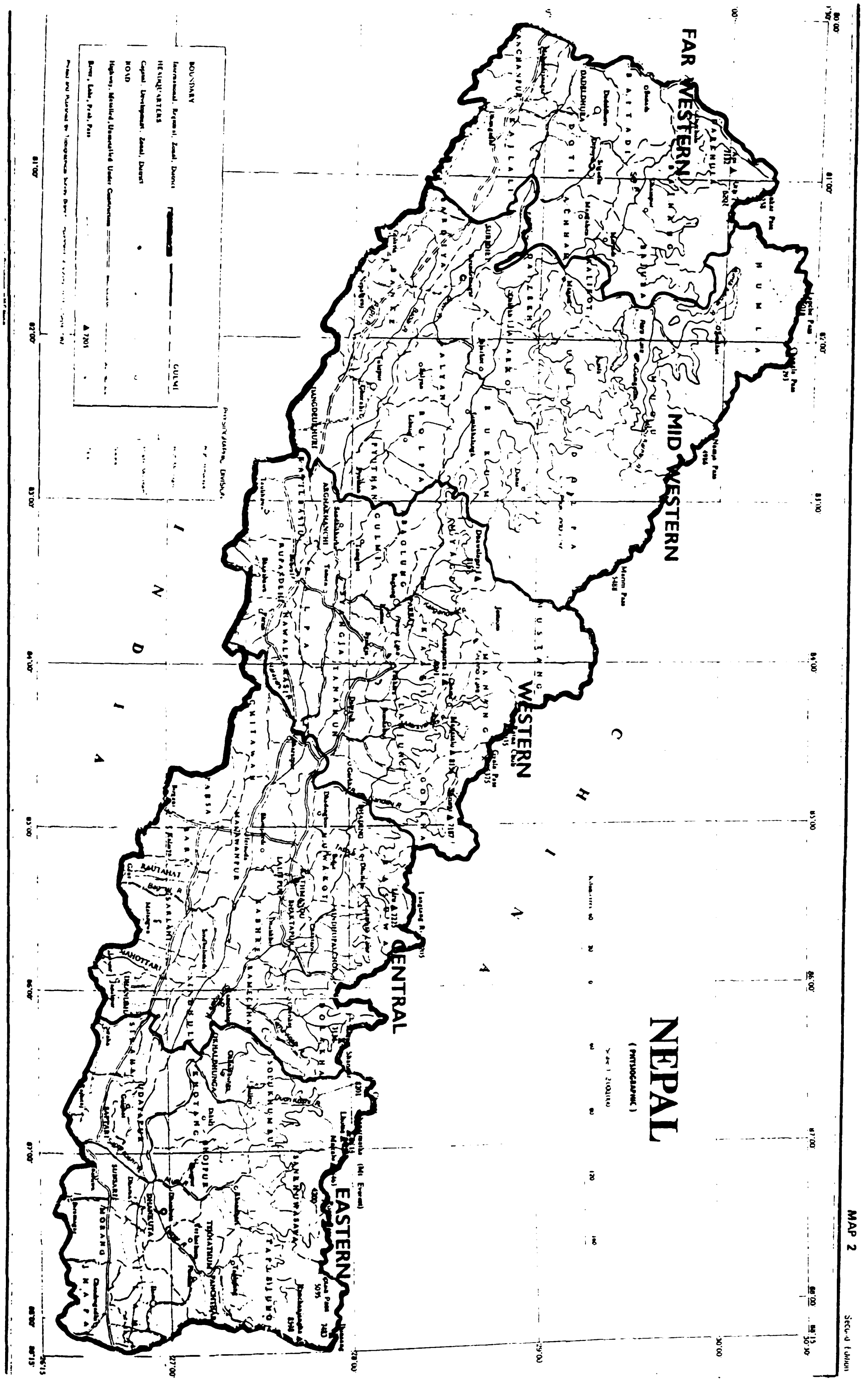
Nepal is geographically divided into four regions: the Mountains (> 4877 m asl); the Middle Hills (305-4877 m); the Inner Tarai (200-400 m); and the Tarai (< 200 m). The total area of the country is 147,181 sq. km. (CBS 1984).

land with natural herbaceous vegetation which is estimated to occupy 12% of the total land area in the country.

**Figure 1.1 Physiographic map of Nepal showing the ecological zones**



Animal husbandry is a major economic activity, second only to crop farming in the Middle Hills, and is the sole occupation of the people in the Mountains[3].

The most recent livestock population estimates are: 6.3 million cattle; 3.0 million buffalo; 5.32 million goats; and 0.73 million sheeps (APROSC 1986). The hilly regions are experiencing extreme pressure from: 1) the high ratio of population to cultivated land, approximately 16 persons per hectare (Wyatt-smith 1982); 2) the high rate of both human (2.6% per annum) and livestock (1.0% per annum) population growth; 3) a very large population of ruminant animals; and 4) shrinking supply of food, fodder, and fuelwood. These pressures have expressed themselves in the form of rapid deforestation for firewood and fodder, overgrazing, and clearing of steep slopes for cultivation. Resultant soil erosion rates are currently estimated at 300 million tons/year, roughly 20 tons/ha/year (Arab News 1991). A decline in agricultural productivity is causing extreme poverty. This vicious cycle has led to serious environmental degradation and deterioration in the quality of people's life.

**1.2 Declining Forests:** Forests are both extensively and intensively utilized for fuelwood, fodder, livestock grazing, timber production, forage, thatch grass cutting,

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Nepal's land area distribution is as follows: Tarai or Southern Plains - 17%, Middle Hills - 76%, and Mountains - 7%. (CBS 1984)

and occasional extraction of fruits, nuts and herbs. Based on the country's mountainous topography and subtropical to temperate climate, there are three major forest types in Nepal: highland conifer; mid-hills hardwood and mixed conifer; and lower hills/lowland hardwood forest. Half of the forests are classified as hardwood, 20% as conifer, and the rest as mixed type. Chir pine (*Pinus roxburghii*), deciduous mixed broadleafs (*Scheima* spp., *Quercus* spp.) and tropical mixed hardwoods (*Shorea robusta*, *Terminalia* spp.) are the major vegetation types. A large percentage of the forest land of Nepal is seriously understocked to meet growing demands for fuelwood, fodder, and small timber. Forty three percent of the forests have been estimated to be without tree crowns (or without healthy full grown trees) and 10% of the forest area is classified as shrubs (LRMP 1983). During 1979/80, only 47% of the total forest land was estimated to be covered by tree crowns ( > 10% crown cover), down 12% from 1964/65 estimate (Nield 1985). If percent crown cover is used to represent the growing stock, then there has been a reduction of about 25% in total forest stock in a 14 years period, for an annual loss of 2.1% (LRMP 1983).

**1.3 Problem statement:** Several studies have indicated that the exploitation of forest resources in Nepal is not intentional and reckless, but stems from understandable human needs and anxieties (FAO 1979; Mahat 1987; Gilmour

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1988). Forests and other vegetation supply some of the basic needs of rural life. These include tree foliage, grasses, and herbs as animal forage; fuelwood for cooking; fruits, nuts, honey and tubers for food; timber for building shelter; forest litter as compost; shrubs and vines as fencing materials; bamboo for cottage industries; thatch grasses for roofing materials; and herbs for medicine. Tree leaves, twigs, and succulent branches (tree fodder) make up about 40% of the annual feed of buffalo and 25% for cattle (Pandey 1982a). Uncontrolled grazing is common in the forests and is also considered to be one of the major reasons for plantation failure. Campbell and Bhattarai (1984a) reported that 33% of the people in the Middle Hills attributed uncontrolled grazing to be a major cause of seedling mortality in the community plantations.

**1.3.1 Limited land resources:** Recent government policies are based on the premise that increasing demands for fuelwood and fodder can only be met through intensive plantations of multipurpose trees on private land. The major goals of this program are: 1) to improve the supply of firewood, fodder, and small timber from both farmland and existing forests; and 2) to implement sound land use policies on sloping and degraded land. The government has also made it mandatory to plant at least 25% broadleaf species under community forestry plantations. This action will be implemented by the Department of the Forests (DOF), primarily to augment fodder production. There is an active policy to hand over responsibility of forest resources management to the local community. However, the major problem is the total lack of adequate governmental resources as well as usable lands to increase the supply of forest products.

The choice in forest development strategy lies in an intensive management of both public and private forests on a sustained basis. Given the poor resource endowment of the country, the only feasible approach to solve the shortage of food, fodder, and fuelwood is to increase productivity per tree or per unit land area.

**1.3.2 Shortage of animal feed:** It is estimated that an average household (HH) in Nepal owns about 10 trees (Campbell and Bhattarai 1984a). The average cultivated land per HH is one hectare (ha.). Currently only about 64% of the total feed requirements of the livestock are met in the Hills (Rajbhandari and Shah 1981; APROSC 1986). Pandey (1982a) estimated a deficit of 20 to 30% in fodder supply at the national level. One of the major reasons for the shortage is the continuing shrinkage in grazing and forest land. Good quality green fodder in adequate quantities is generally available only from June to November (the wet season). The major problem is the lack of green fodder during the long dry season (December-May). Farmers have traditionally tackled this problem by growing fodder trees on their farms and extracting tree fodder from the forests.

However, due to increasing population pressure, the latter source is shrinking. As a solution to this problem, experts (Wyatt-smith 1982; Pandey 1982a) have recommended stall feeding of livestock, the production of more fodder on individual farm holdings, and creation of more community forests composed of multipurpose tree species (MPTS). An analysis of the data gathered in western Nepal indicated that each family of five to six on an average farm holding of 1.25 ha. required, with present agricultural and forestry management practices, 3.5 hectares (ha.) of land for fodder, 0.3 to 0.6 ha. for fuelwood, and 0.4 ha. for timber to sustain current household level activities (Wyatt-smith 1982). However, the gross per capita availability of forest land is only 0.14 ha. (FAO 1979). In response, there is a need to increase the number of trees on private land. But since there are biological and physical limitations to planting significant numbers of additional trees, particularly on private farms, a more viable alternative is to improve the management of existing as well as future tree resources and increase their productivity.

**1.3.3 Environmental degradation:** Aside from direct consumption of fodder, grazing animals degrade fodder resources by feeding on tree seedlings, uprooting young grass shoots, and trampling both seedlings and new grasses. While fodder consumption alone does not directly reduce the forest area, it is the main cause of forest degradation

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leading to increased erosion as a result of depleted ground cover and soil compaction. One way of reducing environmental damage by animals is through stall feeding or confining the animals to corrals. Combined with this approach, if productivity of the fodder trees could be increased, and the associated tree fodder production better managed, the current deficit could be reduced substantially. Specifically, there is a need to assess the fodder potential of most commonly grown fodder tree species (FTS), develop biomass yield tables and growth functions, establish improved harvesting schedules and make this information available to the planners and extension personnel as quickly as possible. This points to the need to carry out species evaluation trials, accurately estimating their growth and yield, and developing local and regional FTS biomass tables. Utilization of such information in designing and implementing more productive agroforestry systems, especially in the Middle Hills, the Tarai and the Inner Tarai regions, is another challenge. This research project proposes to focus on these topics.

**1.4 Purpose of the research:** A comprehensive species evaluation and screening trial was conducted involving some of the most common FTS (including exotic species) in the Middle Hills and Tarai regions of Nepal. By analyzing growth data (height, diameter, crown height, crown diameter, and crown length) along with climatical and physical (soil, aspe

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aspect, and slope) variables from the fodder tree experimental plots, the study intended to develop growth and yield prediction models for the selected species included in the above mentioned trials. A second aim of the research was to construct biomass (both foliage and wood) tables by using allometric regression techniques and thereby estimate fodder and wood biomass production. Finally, the applicability of these models in improving the management of FTS in Nepal is examined by proposing an agroforestry development scheme in one of the study villages. This study is subject to the following limitations: it evaluates only a small list of FTS grown in Nepal, 2) it derives only preliminary growth functions for two of the most common fodder species; and 3) it makes reference to fodder trees generally found in the central Tarai and western Middle Hills of Nepal.

## 2.0 OVERALL OBJECTIVES:

The three major objectives of the research project described in Chapters II, III, and IV are as follows:

1. to evaluate the silvicultural characteristics of commonly grown native and exotic FTS over a wide geographical area (Chapter II);
2. to develop fodder and wood biomass tables for two top performing species in order to generate quantitative information about their growth potential (Chapter III); and
3. to study the impact of intensively cultivating the "best" performing species in the traditional agroforestry systems in the Middle Hills of Nepal (Chapter IV).

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**3.0 STUDY AREA DESCRIPTION:**

**3.1 Site selection:** The choice of site was governed by the: a) availability of suitable public and private land, b) ease of protection, c) representative of the average fodder trees growing areas, such as those being used by the farmers of each region, and d) all weather accessibility for regular monitoring and data recording. Acquiring private land of about one hectare size for a long-term research is rather difficult. Therefore, public agencies were approached for land to set up the experimental plots. Four sites - Karmaiya, Hetauda, Rampur, and Karmaiya were finally selected which best met the above criteria.

**3.2 Location:** The study area lies between latitudes 27° 05′ and 28° 05′ N and longitudes 84° 03′ and 86° 05′ E in central and western Nepal. Geographically, this area falls within the Central and the Western Development regions of Nepal (Figure 1.1). Ecologically, the scope of the study area covered the following three zones: 1. Middle Hills (305 - 4877 meters elevation); 2. Inner Tarai (200-400 m.); and 3. Tarai (< 200 m.). Climatically, the study area lies in the sub-tropical zone, but a wide range of climatic conditions exist due to altitudinal variation and topographical factors. The average annual temperature is 22.6°C, but temperatures of up to 40°C are not uncommon during May and early June before the onset of monsoon rains. Most of the rainfall (>90%) is received from June to

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September. A few scattered rains occur during the winter months. Average annual precipitation was estimated to be 2200 mm, however, the range is between 2000 to 4000 mm. A 20 year summary of temperature and rainfall information for all the four sites is provided in Table 1.1.

**Table 1.1. 20-year summary of climatic data in and around the four research sites in central and western Nepal.**

| Site | Ecological Zone | Temperature (°C) | | Precipitation (mm) | | Relative Humidity (%) | |
|---|---|---|---|---|---|---|---|
| | | Mean | SD | Mean | SD | Mean | SD |
| Simara[1] | Tarai | 23.68 | 0.71 | 1869.21 | 499.4 | 76.40 | 1.77 |
| Hetauda | Inn.Tarai | 22.68 | 0.89 | 2248.74 | 386.0 | 77.64 | 3.27 |
| Rampur | Inn.Tarai | 23.67 | 0.53 | 1990.92 | 293.0 | 81.81 | 1.87 |
| Pokhara | Midhills | 20.46 | 0.52 | 3558.73 | 426.6 | 80.75 | 3.86 |
| Study Area | | 22.62 | 1.52 | 2416.90 | 777.5 | 79.15 | 2.55 |

[1] Nearest meteorological station to the Karmaiya site.

The Midhill region is densely populated by both man and animals. Forests and agricultural lands in this area have a long history of intensive human intervention.

**3.3 Soils:** Soils in the Tarai are permeable, sandy loam in structure, and relatively more fertile than in the Midhills. In the hills, soils are coarse to loamy textured, stony, moderately acid, good structured, and generally deficient in major nutrients. The land is widely cultivated on slopes up to or greater than 30°. Land use is closely tied to elevation. The slope gradient determines the soil depth and soil stability (LRMP 1983). In general, the fertility on the arable land is maintained by applying up to 2-5 ton/ha/yr of compost. Geologically the soils are relatively young and wea

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weathering forces are strong. Table 1.2 provides a summary of their soil characteristics:

**Table 1.2. General soil characteristics of research sites in central and western Nepal**

| Soil Characteristics | Research Site | | | |
|---|---|---|---|---|
| | Pokhara | Rampur | Hetauda | Karmaiya |
| Texture | Silt Loam | Sandy Loam | Sandy Loam | Loam |
| Silt % | 47 | 19 | 30 | 42 |
| Clay % | 17 | 12 | 19 | 15 |
| Sand % | 34 | 69 | 58 | 43 |
| pH | 7.16 | 6.44 | 8.26 | 7.13 |
| EC us/cm | .08 | .05 | .07 | .06 |
| Na me/100gm | 0.0 | 0.0 | 0.0 | 0.0 |
| K " | 0.12 | 0.025 | 0.08 | 0.1 |
| CEC " | 4.95 | 4.90 | 3.72 | 4.78 |
| Organic C % | 1.31 | 1.61 | 0.77 | 0.78 |
| Total N% | 0.14 | 0.60 | 0.06 | 0.07 |
| Avail P | | | | |
| -ppm-Bray | 9.0 | - | 59.0 | - |
| -Olsen | - | 6.00 | - | 1.60 |

In terms of fertility status and $p^H$ values, the Rampur site (Inner Tarai) had relatively more favorable soil characteristics than the other four sites. Overall, all sites were deficient in major nutrients and have inadequate soil qualities with respect to the requirements of fodder tree seedlings.

## 4.0 LITERATURE REVIEW:

### 4.1 An overview of fodder cultivation in Nepal:

**4.1.1 Concepts:** The literal meaning of 'fodder' is 'dried animal feed'. However, in the agroforestry literature, 'fodder' generally refers to a type of animal feed primarily based on plant materials (e.g., forage grasses, tree shoots, crop residues, flowers, nuts and fruits). In Nepal this inc

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includes succulent twigs, fruits, branches, and tree bark with high palatative and nutritive values. In this review 'fodder' is used to refer to all edible plant parts (dried or green) from trees, shrubs, vines, grasses and food crops. FTS, however, refers to trees[4] on both private and public lands primarily managed for their green 'fodder' values.

**4.1.2 Definitions:** Different authors define fodder trees differently. Pandey (1982a) made a distinction between 'fodder trees' and 'tree fodder' by implying that the fodder trees are specific group of trees grown and/or managed primarily for their fodder products but 'tree fodder' are animal feed materials derived from any type of tree species. Mahat *et al* (1986) defined fodder as "dried food, hay, straw, etc., for stall feeding cattle but in the mixed farming system of Nepal it includes all of these as well as fresh grasses, herbage, ferns, and foliage from trees which are lopped for this purpose." However, FTS can be better understood in line with the definition of a multipurpose tree species (Von carlowitz and Burley 1984): "a tree grown deliberately or kept and managed primarily for fodder production or a tree that is raised or kept and maintained into an agroforestry system especially for the purpose of fodder production."

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A tree is defined here as "woody plants having one erect perennial stem or trunk at least three inches (7.5 cm. in diameter at breast height (4.5 ft. or 1.5 m), a more or less densely formed crown of foliage, and a height of at least 12 ft. (4 m)" (Little, 1953).

**4.2 Nature of tree cultivation:**

**4.2.1 Number of trees and size of land holding:** According to a survey by Campbell and Bhattarai (1984a), each Household (HH) in the Middle Hills of Nepal owned an average of 28 trees and 31 seedlings (trees under 5 years of age), of which 43% them were fodder trees. In general, fodder tree ownership tended to be higher in the Western and the Eastern regions (45% of total), and lower in the Central and far Western regions (41% of total). A separate study in the western Nepal (Karki and Karki 1987) found that 15 out of 60 trees planted (25%) by the farmers during the last ten years were fodder trees. Rusten (1989) reported that during a 10-year period an average of 58 trees were planted by each household in a village in western Nepal, out of which 24 (41%) were fodder trees. The number of FTS/HH is highly correlated with the size of land holding. In general, on land holdings up to 1.5 hectares, there is an inverse relationship between number of trees and size of land property.i.e, less land equates to a higher percentage of total trees, predominantly FTS (Karki 1987; and Shakya 1987).

**4.2.2 Number of trees and livestock units:** There are an average of five trees per livestock unit (LSU)[5] in most of the Middle Hills of Nepal, although figures range from two

Livestock Unit is defined as an equivalent to one adult female cow.

to eighteen (New Era 1980; Pandey 1982a; Hawkins and Malla 1983; Weise 1984; Shephard 1985; Shah 1980; Campbell and Bhattarai 1984a). Both big and small ruminants are fed with green fodder. However, milk animals and goats have been reported to require more fodder (Pandit and Karki 1987; Karki and Karki 1987; Rusten 1989)

**4.2.3 Key bio-physical factors:** The number of trees held by a HH primarily depends on the type of land and its ability to produce food grains. Campbell and Bhattarai (1984a) analyzed the association using multiple linear regression and found that the number of seedlings taken by the farmers from the government nurseries was strongly associated ($R^2 > 0.8$) with the amount of irrigated *khet* (low) land owned, but was not associated with the amount of *bari* (upland) owned. It was further noted that with 77% of the variation explained by one variable - irrigated land - it was possible to directly predict the number of seedlings taken by a HH by the amount of *khet* land owned. In other words, farmers capable of producing adequate food grains for home consumption tend to grow more FTS on their upland.

**4.3 Species used as fodder trees:**

**4.3.1: Number of species:** Pandey (1982b) reported that there were over 110 species of fodder trees in Nepal. Howland and Howland (1984) provided a checklist of 192 species, but 30 of these were herbs, shrubs, and climbers or of doubtful

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fodder value. Bajracharya *et al* (1985) carried out a study on feed values for 195 fodder plants found in the Kathmandu valley. The plants were identified as having good feed values on the basis of information provided by practicing farmers of the area, who regularly collected fodder from the forests for their livestock. Rusten (1989) listed 129 different species growing on private land, of which 70 species were potential sources of animal fodder. However, in his study only 28 species were noted as 'dedicated' fodder trees. Therefore, in any particular area there are likely to be only a small percentage of the reported total number of fodder species which are commonly used, grown or considered preferred sources of regular fodder. These are generally known by the generic name of fodder tree species (FTS). Mahato and Karki (1986) found 36 species exclusively managed for fodder products in a small area near Hetauda, central Nepal. Shah (1980) reported that 35 species were used as fodder species in the western region, and Dutt (1979) stated that 40 tree species were used for fodder in eastern Nepal. Hawkins and Malla (1983) found privately owned trees to consist of 8-10 species. However, the classification of fodder and non-fodder trees is a function of demand, supply, animal type, farmers' preferences and practices, and growing season.

**4.3.2 Reasons for large number of FTS:** There are several reasons for the use of a large number of tree species as

fodder. First, few species are able to supply fodder for the entire dry season. Some species are deciduous (*Morus alba, Symplocos crataegiodes*), and others (*Schima wallichii, Prunus cerasoides*) are only palatable at certain periods of the year (Rusten and Gold 1991). Not all species sprout at the same time and some sprout twice a year (*Garuga pinnata*). Farmers plant several species as a safeguard against pests and diseases and to ensure a sustained fodder supply during the dry season. There are other reasons for the large number of fodder trees: 1) The chemical composition of leaves vary by species and season of lopping. For example, farmers grow large number of species to meet varying nutritive needs of their mixed animal herd; 2) Moisture content in the fodder also varies by species and time, and therefore, farmers need a number of species to feed a balanced fodder diet; and 3) Not all species are equally palatable and the most highly palatable species do not provide adequate quantities of fodder, thus requiring a large number of fodder trees (Heuch 1986; Rusten and Gold 1991).

**4.3.3: Popular fodder tree species:** Farmers generally plant and manage high quality (as per their own perceived criteria) fodder species on their private farmland. The basic characteristics they look for in selecting species are: 1) ease of propagation; 2) site suitability; 3) effect on milk yield of animal; 4) palatability; 5) rapid growth; 6) minimal interference with crops both from roots and

crowns; 7) potential to supply fodder during the driest part of the year; 8) ease of harvesting by all family members; 9) type of animal to be fed; and 10) other possible uses such as fruit, bark, and stems (Heuch 1986; Rusten and Gold 1991). A host of factors are important in determining the frequencies of occurrences of fodder species. Based on available studies (Pandey 1982a; Mahato and Karki 1986; Gajurel *et al* 1987; and Rusten 1989), a list of commonly grown fodder tree species has been prepared (Table 1.3).

These trees are some of the most popularly grown fodder trees on the private farmlands in the lower elevations in the Middle Hills and parts of the Inner Tarai, the regions of focus in this study. The list is not comprehensive. There are generally separate lists of 'popular' FTS for cultivated land and forest land in most parts of Nepal. The species reported in Table 1.3 are often quite rare in the forest areas, which points towards their high preference. They have been overused and, therefore are gradually declining from forest land. *L. leucocephala*, an important exotic species, is also included in the above list despite its recent problems with psyllid (*Heteropsylla cubana*, Crawford) infestation. The above mentioned FTS are some of the most widely distributed species under the community forestry program (Shrestha 1987; Campbell and Bhattarai 1984a) but by no means are exclusive. Every ecological zone has a different list of common FTS.

**Table 1.3 Commonly grown FTS of central and western Nepal**

| Nepali Name | Scientific Name | Source |
|---|---|---|
| Badhar | *Artocarpus lakoocha* | Pandey (1982a); Gajurel *et al* (1987); Mahato and Karki (1986) |
| Koiralo | *Bauhinia variegata* | Pandey (1982a); Gajurel *et al* (1987) |
| Kutmiro | *Litsea monopetala* | Pandey (1982a); Gajurel *et al* (1987) |
| Pakhuri | *Ficus glaberrima* | Pandey (1982b); Gajurel *et al* (1987) |
| Nemaro | *Ficus auriculata* | Pandey (1982b); Gajurel *et al* (1987); Mahato and Karki (1986) |
| Kabro | *Ficus lacor* | Gajurel *et al* 1987 |
| Dudhilo | *Ficus nemoralis* | Pandey (1982b); Rusten (1989) |
| Khanayo | *Ficus semicordata* | Pandey (1982a); Mahato and Karki (1986) |
| Thotne | *Ficus hispida* | Kafle and Karki (1988); Gajurel *et al* (1987). |
| Ipil-Ipil | *Leucaena leucocephala* | Brewbaker (1983) |

## 4.4 Propagation techniques:

Both vegetative and seeding methods are used to propagate fodder trees. Eighty seven percent of farmers in the study area (Mahato and Karki 1986) have planted fodder trees with planting materials obtained from their own sources (mainly regenerated saplings collected from other farms as well as from the forest), and only 13% had used seedlings from public and private nurseries. Napier and Parajuli (1987) carried out a propagation trial under a 'stool bed system' using several fodder species. They reported that *F. semicordata* was the fastest growing species and *L. monopetala* was the slowest. Karki and Tuladhar (1988) found that stump cuttings were suitable to propagate *G. pinnata*, *Erythrina arborescens*, and *M. alba*, and that polythene-bag raised seedlings were best for *A. lakoocha*, *Ficus* spp., *L.*

*monopetala*, and *L. leucocephala*. The authors also noted a need to do further research on air layering which is widely practiced by farmers in some areas. *Leucaena* spp., which are exotic, are commonly propagated through seedlings and are the fastest growing exotic fodder species.

**4.5 Survival rates of FTS plantation:**

According to Campbell and Bhattarai (1984a) the survival rate for private planting averaged roughly over 60%, with higher rates for planting in wet years. Although the prime FTS of Nepal - *A. lakoocha* - recorded only 60% survival rate, over 75% survival rates have been recorded for other FTS such as *Prunus cerasoides* and *Ficus* spp. Several other research trials on survival performance are currently underway. Preliminary reports have indicated that *B. purpurea*, *L. leucocephala*, *Cordia dichotoma* (Napier and Parajuli 1987), *F. semicordata, F. auriculata, M. alba* (van der Dool 1987), *C. dichotoma, L. leucocephala, A. lakoocha*, and *Bauhinia* spp. (Neville 1987) achieve reasonable survival rates.

**4.6. The use of tree fodder:**

Once cut, fodder is bundled and carried to animal corrals. This process requires a variable amount of time and effort depending upon location. In eastern Nepal, an average HH was estimated to spend 15 hours/week making an average of 10 trips to collect fodder (Abell 1981). In central Nepal, Van Swinderen (1978) reported that on average 15 person-

days/month/family were spent collecting tree fodder. A study in western Nepal (APROSC 1980) estimated that in some villages trips to forest areas for fodder collection were taking up to 7 hours. A historical comparison of time taken to collect fodder in the Kaski district (Karki 1989) found that while it took less than one hour to collect fodder 50 years ago, it took more than 5 hours (mean = eight hours) to collect the same amount of fodder at the present time.

Tree fodder is mainly used during the dry season. Pandey (1982a) stated that more than 75% of tree fodder is used for period November to May. Van Swinderen (1978), Shrestha (1982), Fox (1983), and Rusten (1989) noted that farmers used tree fodder throughout the year. However, as cut grasses from terrace risers, marginal lands, and forest floors, and weeds from crop fields are readily available for fodder in the wet season, and combined with greater demands on family labor from crop farming, most farmers use less tree fodder during summer months. Less palatable tree species may also be rejected by animals in the monsoon when more palatable grasses are available (Heuch 1986). Rusten (1989) found that farmers used 'season' as one of the criteria of assessing fodder quality, implying that at certain periods of the year FTS produced **chiso** (moist) fodder which was less desirable and at other times produced **obano** (dry) fodder which was more desirable, especially by young cattle.

**4.7 Potential of FTS in improving the Hill farming system:**

Among the major constituents of hill farming systems of Nepal, livestock fodder for stall feeding, grazing, and browsing is perhaps the most important. Another equally important contribution of forestry to the hill farming system is the use of plant biomass as animal bedding or compost mixtures. Plant biomass, when mixed with animal excreta, yields organic compost manure which forms the principal source of soil nutrients for hill agricultural land. In fact, it provides the only manure/fertilizer nutrient inputs to crop production in hill farmland. Farmers are quite knowledgeable of the fact that agricultural yields decrease when fodder and leaf-litter are no longer available in sufficient quantities. Mahat (1985) estimated that 2.3 metric tons of litter and manure per ha. of cultivated land were used in eastern Nepal. However, since litter accumulation is decreasing by 50% annually in the forests (Khadka 1984), this valuable resource is also rapidly decreasing. LRMP (1983) indicated that the deterioration of soil fertility is the major cause for the decline in yield of major food crops. The overwhelming dependence of croplands on organic manuring derived from animal dung and tree leaf-litter needs no emphasis. Pandey (1982a) stated that "attacking the problem from the fodder angle alone covers only very limited sector of the ecological problem", and he recommended that research on fodder trees should be integrated with parallel efforts in all aspects of agriculture and forestry. The author specifically suggested linking fodder tree promotion with improvements in agriculture, forestry, and soil conservation. Robinson (1985) stressed the potential of native species in strengthening the farming system. Some of the characteristics of fodder trees to be considered in such research are (Heuch 1986; Rusten and Gold 1991):

1. capable of providing green fodder at times of scarcity.
2. high crude protein content (10 - 30%).
3. modified crown shading characteristics such as light crown and tall tapering shape.
4. ability to exploit nutrients from lower soil horizons.
5. fast growth to first harvest, amenable to vegetative propagation and to the application of manure.
6. ability to fit in the existing farming system especially to be able to provide quality fodder during dry season.
7. high crown height so as to render foliage out of reach of livestock (during fallow periods).
8. ability to tolerate active vegetation management in the form of pruning, pollarding, thinning, trimming, lopping.
9. good for milk production and palatable to animals.
10. foliage with low moisture contents (*Obano*) and/or one that causes few health problems.

Fonzen and Oberholzer (1984) felt that the inclusion of multipurpose trees on contour strips in the farming system cou

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could control erosion and produce multiple outputs. Planting more multipurpose tree species (MPTS) on contour strips is the suggested improvement strategy.

**4.8 Current management systems:**

**4.8.1: Lopping frequency:** Generally, time of lopping (chopping off the succulent leaves and branches) is a function of species type, fodder need, and amount of foliage growth. Pandey (1979); Pandey (1982a); Thapa *et al* (1985); Rusten (1989); and Mahato and Karki (1986) found that in the Inner Tarai the first lopping started when the tree completed its third year of growth. Branch size was often one of the criteria used to decide when to begin lopping. Fifty eight percent of the farmers reported lopping when the foliage branches reached thumb size (2 cm. or greater in diameter) (Mahato and Karki 1986). Half of the farmers sampled reported lopping annually and about half said they lopped the same tree every other year. Some species (*G. pinnata, Buddleja asiatica, F. semicordata, F. auriculata, F. glaberrima*, and *F. hispida*) were generally lopped twice a year and others (*A. lakoocha*) were lopped only once per year (Heuch 1986; Gajurel *et al* 1987). Several other factors also played important role in developing plant geometry. Savory (1979) reported a negative correlation between plant density and the number of branches per tree as well as the forage yield per branch. It is widely believed that farmers follow certain rules to decide on the frequency of lopping, but

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but so far there is no knowledge that can be generalized to a relatively large area within the Middle Hills. An equally challenging problem, from the management point of view, is how to estimate the production of fodder leaves, taking lopping or other management interventions into account.

**4.8.2: Lopping intensity:** Lopping intensities vary among species, regions, and farmers. Farmers generally lop tree fodder by cutting off leaves and small branches with a small sickle. However, Pandey (1982a) reported some farmers practicing deleafing by hand on some of the prized species (*A. lakoocha*), perhaps to avoid tree damage and enhance growth. On the whole, privately owned trees are lopped with more care than those on community owned land such as forests, but some of the variation seen may be attributable to differences in species composition of private and public fodder trees. Heuch (1986) stated that *A. lakoocha*, and *F. auriculata* were completely defoliated and *P. cerasoides*, and *Ficus glaberrima* were partially lopped in a village in western Nepal. In some trees (*Brassiopsis hainla*), a significant portion of branches are also harvested along with leaves. The possible reasons were: a lack of training on the part of the lopper, labor constraints, poor production of tree fodder, and shortage of firewood supply, but no definitive knowledge exists. Mahato and Karki (1986) found that about 73% of the trees in a village in the Inner Tarai were fully lopped and 21% were lopped to two-thirds of

their crown height. Gajurel *et al* (1987) reported that the amount of lopping in the Lamjung district of western Nepal varied according to species and availability of other fodder. In general, farmers reported carrying out heavy lopping when green forage from other sources was not available. Lopping frequencies and intensities are also known to be related to the lopping skills which vary among men, women, and children.

**4.9 Factors determining lopping practices:**

Several factors are known to influence lopping practices: 1) the immediate need for fodder; 2) the presence/absence of an adult male in the HH; 3) the presence/absence of lactating animal(s) in the house; and 4) the level of education of the HH members. Rusten (1989) noted that women in western Nepal were found to harvest fodder from up to five different trees in a single operation in order to select only desirable portions of the foliage. The author also reported that farmers considered the quality of fodder in terms of nutrients, digestibility to the animals, and type of animals to be fed while carrying out fodder lopping. For example, it was reported that farmers tended to avoid *chiso* or moist fodder for lactating and young animals and preferred *obano* or dry fodder. There were also gender-based differences in terms of selecting a particular species and/or portion of the tree for fodder for lopping and deleafing purposes. Women preferred *Ficus nemoralis* grown on farm, while men preferred *Quercus semicarpifolia* located in the forest (Rusten 1989).

**4.10: Share of tree fodder in animal diet:**

There exist several estimates on the contribution of tree fodder to the total animal feed budget. These estimates vary widely due to location, specific differences in fodder tree use and production. Pandey (1982a), based on his study in the Dolakha and the Sindhupalchok districts, reported that 42% of the total feed supply came from trees, 37% from forests, 7% from trees grown on farmland and remaining 14% from the crop residues. The author later stated (Pandey 1982b) that more than (35%) of the total feed was supplied from fodder trees. Brewbaker (1983) estimated that Nepal's animals derived 35% of their feed from trees. In a study near Palpa, western Nepal, Fonzen and Oberholzer (1984) reported that 43% of the total supply in two villages under study was met through privately owned trees. Pandit and Karki (1987) found that the share of tree fodder in the total feed supply of a village near Pokhara in western Nepal was 25%. Out of this 19% (i.e. 6% of the total supply) came from private fodder trees. Rusten (1989) quoted Weise (1984) and Alirol (1979) for their estimates of fodder tress to animal diets as 71%, 87%, and 90%. The contribution of private fodder trees alone, according to Rusten (1989), was over 50%. Mahat (1985) reported that 20% of feed came from tree leaves (of which 14% came from the forest and 6% from

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privately grown trees). A recent study by Kafle and Karki (1988) in the Tanahu district found that tree fodder contributed around 30% of the total fodder supply.

Above information indicate the increasing importance of fodder trees in substituting the traditional sources of animal feed such as forests. It is expected that within the next ten years, the contribution of fodder trees in total animal feed budget will be doubled.

**4.11 Fodder productivity:**

**4.11.1: Methods of assessment** - Different methods have been used by foresters and livestock specialists to estimate tree fodder production (Heuch 1986). Pradhan (1982) estimated fodder yield in terms of leaf and branch biomass weights. Sharma (1985) concentrated on utilizable fodder only, stressing that animal nutritionists are more interested in quality. But, as noted by Heuch (1986), 'both approaches are needed, but as yet research methods have not been devised that allow all the data needed to be collected simultaneously.' Several difficulties were noted by researchers in realistically estimating fodder productivity. Foresters and livestock personnel work under two different set-ups, thus often one over or under-estimates the other's perception. As an example, if leaves are separated from twigs to determine component yields (a common forestry practice), it is unrealistic to then feed the separated components to the livestock to determine a utilization

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index, as one major reason twigs are eaten is that they are attached to more palatable leaves (a common animal husbandry practice in the hills). Another difficulty is that lopping is a technique that is hard to emulate (as per farmers' practice) and replicate in trials, as the amount and method are often associated with the weight, height, and agility of the lopper. Several studies report attempts made to carry out lopping as realistically as possible so as to harvest only potential fodder from the trees (Wormald 1975; Pradhan 1982; Sharma 1985; Subba 1986). However, the general conclusion was that due to a large variation in lopping practices of the farmers, as well as in feeding behavior of animals, a large sample of both farmers and the animals were needed to yield an accurate estimate.

It is widely agreed that well developed fodder yield estimates are vital to manage fodder trees on a sustained basis. To date, no reliable data exists on the yield, volume, and rotation length of important fodder trees (Shah 1980). Karki and Tuladhar (1988) suggested standardization of the practice adopted by the farmers so that the quality of data expressed in local units could be improved and the prevailing units of measures more widely understood. For example a *bhari* (load), commonly used unit to express fodder weight in Nepal, may mean different amounts in different places within a small area. The problems gets further

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complicated as there is no standard weight and volume measurement system in rural areas.

**4.11.2 Measurement techniques:**

Shah (1980) has estimated average yields for individual trees in the Pokhara region, and Pandey (1982a) has reported yield by species in the Dolakha district. Both the authors used household level enquiries to estimate fodder yield. Although these data are useful as basic information, they do not allow comparisons of the potential performance of different species because the data ignored growth rates (Heuch 1986). Savory (1979) stated that the yields (forage) show a positive correlation with plant density in the case of *Leucaena* spp. There are also estimates based on farmers' recollection regarding fodder quantity (Pandit and Karki 1987; Mahato and Karki 1986). Research projects have utilized actual lopping and weighing techniques (Karki and Tuladhar 1988) as well as measuring height and growth to estimate productivity (Farm Forestry Project 1987). Van der Dool (1987), Neville (1987), and Napier and Parajuli (1987) have reported indirect measurements. While conversion of estimates to a common base is possible, it is prone to error due to a large variation between researchers and farmers.

There is also a need for standardizing the methods of estimating biomass at national, regional, and local levels. For example, the estimated annual fodder use per household has been found (Vega Condori 1985a and New Era 1980) to

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range from 13 to 27 metric tons. The estimate of Shephard (1985) was equivalent to seven tons (dry matter) per household per year. The apparent problem is that some estimates are in fresh weight (FW), others are in dry weight (DW), and there are many in-between estimates. Therefore, accurate estimates of fodder productivity and their actual usage are difficult without first knowing fodder species, animal types and numbers, feeding practices, survey methods, and measurement techniques.

**4.12 Research needs on fodder trees:**

**Research priorities:** Pandey (1982a) described three separate packages of research needs. The first was on improved fodder tree cultivation: site requirements, ecology, propagation and regeneration, diseases and parasites, lopping techniques, forest as fodder sources, competition with agricultural crops, fodder tree orchards, and optimum season of lopping. The second was on tree fodder chemical composition, storage techniques, and nutrient cycling. The final need was on extension, indigenous knowledge, communication, and motivation. More recently, Wyatt-Smith (1988), a consultant to the Master Plan for Forestry Sector Project (MPFSP), discussed research priorities (MFSC 1988). He identified "improved management of important fodder trees and shrubs in Tarai, Hills, and Mountains" as the most important research program with respect to improved land use, higher productivity and meeting the rural population

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ieeds. He recommended that research be restricted to as few species as possible and concentration on species with high rowth and yield in the production of nutritional fodder, specially during the March-May (premonsoon) period. mportant attributes of the selected species to be studied ccording to Wyatt-Smith (1988) are: 1) rapid growth rates nd high yield, 2) wide site adaptation; and 3) ease of ropagation. Heuch (1986) suggested research priorities be lecided in a multidisciplinary context to strengthen links mong the forest, pasture, and livestock researchers. 'inding means of increasing tree fodder supplies is an mportant area, but the author first recommends getting the esponse of farmers to such an increase. It may be possible hat farmers prefer to increase animal numbers, labor upply, and land area as opposed to planting more trees. eveloping a method to objectively compare species quality nd productivity is also suggested. Therefore, to manage ree fodder in line with the management of forests for imber and wood, a basic research data base needs to be eveloped. Gornov (1987) suggested a management approach imed at encouraging self-reliance of the villagers in anaging their forest resources on a sustained basis.

In summary, three important aspects of fodder tree esearch have been emphasized: 1) growth habit; 2) site laptation; and 3) improved management. I believe that the ntral focus of all research on FTS should be to increase fodd

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fodder productivity. This requires a better understanding of species potential, production patterns, and their ability to exist in complex farming systems as practiced by the farmers of Nepal. This study focuses on these three aspects of FTS cultivation in Nepal.

**5.0 GENERAL METHODOLOGY:**

Specific methods used in each chapter (II, III, and IV) are described in the respective chapters. However, a general overview of the methodology used to carry out the research project is described below:

**5.1 Species selection:** There are over 100 native FTS growing on the private farms of Nepal (Pandey 1982a; Bajracharya *et al* 1985). Including all of them in a single set of trials was not feasible. The focus of the study was limited to western Middle Hills and the central Tarai. Based on a reconnaissance survey of the area, 16 species were selected for inclusion in the trials. Out of this species pool, each site was allotted between eight to ten species depending upon each species' ecological requirements. At least seven species were included at all four sites.

**5.2 Research design:** Trial design was based on the treatments selected and land availability at each of the four sites. Since land was not limiting at Karmaiya and Hetauda, trial lay-out was arranged in a completely randomized block design (CRBD) involving 1200 trees per plot

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(Appendix 2, Figures 2.1). However, at Rampur and Pokhara, due to space limitations, three replications were arranged in a plot in a completely randomized design (CRD),(Appendix 2, Figure 2.2). On-farm research trials were also designed to complement the data expected from the research stations. The intent was also to carry out lopping management trials on the established trees on the farmer's field. Only on-farm trees of known age and previously unlopped crown were selected using each tree as a replicate, so as to arrange the trees in a CRD framework. The selected trees were leased from the concerned farmers and their growth was regularly monitored. Lopping intensity trials were carried out on these on-farm trees and the information derived was used as input to construct growth and yield models for commonly grown FTS by the farmers of the area.

Farmers in the study areas were intensively surveyed to find out the nature of their fodder cultivation methods, preferred species, and common problems related to FTS management. Attempts were made to find out the type of lopping regimes the villagers desired the research trials to test. Information was also collected on the topics related to the agroforestry systems prevailing in the area, particularly those related to crop and food grain production.

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## 6.0 OVERALL RESULTS:

Each of the three studies yielded specific results regarding the species selection, biomass modeling, and impact of proposed agroforestry systems. Specific results are detailed in chapters II, III, and IV. An overview of the major findings are described as below:

### 6.1 Species performance (Chapter II):

Based on an evaluation of over ten FTS at four sites, *F. semicordata*, *L. leucocephala* and *B. variegata* were found to be the three best performing species in that order. *L. leucocephala* was not considered for modeling due to its susceptibility to *Psyllid* infestation as well as the availability of much information on its growth and yield. In spite of its high popularity among the farmers, *L. leucocephala* is being discouraged for large scale planting in Nepal as elsewhere in the tropics.

The species were evaluated based on their height, diameter at 50 cm. *(d50)* growth as well as on their biomass (foliage and wood) yield. No significant (p=.05) difference was found in their growth rates across the sites. However, height, *d50* and biomass weight significantly (0.05) differed among the species. There was also variation among species in the foliage and woody biomass dry matter contents. Major nutritive values such as crude protein and cell soluble contents also varied significantly. Results from the on-farm trials indicated that the best performing species at the resea

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research trials were also among the most popular species on farms.

**6.2 Biomass tables (Chapter III):**

Allometric regression techniques were used to develop fodder and woody biomass models. These models indicated that a single predictor variable *(d50)* in the case of *B.variegata*, and two variables (height and crown diameter) in *F. semicordata,* explained most of the variation in foliage and woody biomass yield at all sites. It was also observed that the four site specific regression equations had similar slopes and intercepts. This was determined by plotting the relationships between the x and y by individual site. The fitted lines were closely related in height and slope. 3enferroni confidence bounds of the slopes and intercepts vere calculated at 95% confidence interval and were found to e of similar range. Therefore, it was concluded that the ite-specific biomass functions did not differ significantly p=0.05) and data from the four sites were pooled to derive ne common model. The common model was found to be adequate based on the % variation explained) to estimate foliage and oody biomass for the region.

The models did however, vary among species. In the case *B. variegata*, diameter at 50 cm (*d50*) gave adequate fit. r *F. semicordata* crown diameter and height were the most fluential variables in predicting oven dry foliage and od weights (Chapter III). The data collected from the farm

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farmer's field for *F. semicordata* were used to validate and expand the biomass model for this species. The same two predictors, height and crown weight again, gave the best fit. However, the model form was changed as the on-farm data came from older trees. Therefore, two models were used to derive fodder and wood biomass tables for the central and western region of Nepal. Model A was adequate to estimate biomass for trees up to eight years of age and Model B for trees above eight years of age.

**6.3 Development of a new agroforestry system (Chapter IV):**

The design of an improved agroforestry system incorporating the yield and production information generated by this study was the subject of the third and final chapter. This study used the socio-economic information gathered in a village adjoining the Hetauda (Inner Tarai) trial site. The Nawalpur village was also a site for the on-farm fodder tree management activities of the fodder tree research project. Linear programming (LP) was applied to obtain an optimum allocation of the scarce land resources in the village characterized by rapidly declining fodder and fuelwood supply from nearby forests. The constraints imposed on the system were: a) supply of adequate food calories for the ext five years; b) supply of required fodder TDN (total igestive nutrients); c) supply of 50% of the fuelwood emand of the village; d) reduction of soil loss from the ropland; and e) minimum use of peak season labor and

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organic fertilizers. It was assumed that there was the potential to increase the current cropping intensity. The analysis indicated that for high-yielding FTS (composed of a minimum of the three best performing species such as *F. semicordata, L. leucocephala* and *B. variegata*) closely planted and regularly coppiced in a rice, maize and livestock based agroforestry system, the economic returns would be 63% higher than the existing level. Specifically the results indicated that by the end of the five-year period of the proposed scheme, 2700 million kilo calories of food, 1068 tons of TDN, and 550 tons of fuelwood could be produced by using about 18,000 person days of peak season labor, 7000 tons of organic fertilizer, 429 ha. of lowland (*khet*), and 260 ha. of upland (*bari*).

However, the success of the models would depend on how effectively the farmers were able to mobilize the peak season labor to meet the increase in labor demands. This study suggested a traditional labor pooling system (*parma*) commonly practiced in Nepal to solve the labor and bullock ( for meeting animal traction needs) bottlenecks. Increased compost production was also needed and was expected to occur automatically if more trees were planted. More than 80 ha. were proposed to be planted under multipurpose tree species (MPTS) including the FTS under the new land allocation scheme.

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**7.0 DISCUSSION AND CONCLUSION:**

Out of the ten species tested at four sites located in three ecological zones, three FTS - *F. semicordata, L.leucocephala*, and *B. variegata* - have consistently shown better performance in all aspects of growth and yield. A few species including *F.hispida* and *F.lacor* that did show good height and diameter growth at Pokhara could not be compared with other FTS due to their very early stage of growth, as well as being grown only at the Pokhara site. Nevertheless, the results indicated that the common practice of growing a large number of FTS as opposed to a few high yielding FTS may not be an ideal decision from the fodder production point of view. It is argued that farmers plant many species to stagger the fodder yield throughout the four month long dry season. However, the study found that farmer's decision was made more on the basis of what was growing on the farm before they started farming and which species were most easy to propagate than on a long-term planning of regular fodder supply scheme. In other words, in the study areas, the farmers either retained the naturally generated FTS or grew only those which were easily propagated. At most of the sites the farmers reported that they did not plant the FTS growing on their farms. They were all natural regeneration protected and managed by the farmers to use as FTS.

Biomass modeling has been shown to be a promising new area in fodder tree research. The study has developed sepa

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separate allometric equations for foliage, total wood, and total biomass for *F. semicordata*, and *B. variegata*. These equations have been used to prepare fodder and wood biomass tables. These tables were validated separately for each of the four sites and therefore, are recommended for regional use. These tables should be particularly useful to the extension agents, development agencies, and farmers for quick estimates of the fodder yield. Site validation is strongly recommended, although these tables have been found to predict biomass within a reasonable limit.

Improving the management of FTS in Nepal will require a sustained research effort generating information on the growth potentials and climatic suitability of over 100 species of shrubs and tree fodder known to be grown in Nepal. In this study only species that were readily available and commonly known to the farmers were tested. Some of the common hill species such as *Ficus lacor, Bridelia retusa*, and *G. pinnata* could not be tested in the Tarai and Inner Tarai plots due to the lack of adequate seedlings. However, their performance at one site did indicate their potential for further investigations. Nevertheless, this study has, for the first time in Nepal tested a large number of species in a multi-location trial. Preparation of fodder and woody biomass models for these species had not previously been attempted on as large a scale. The next objective will be to prepare comprehensive biom

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biomass tables applicable to the whole region. The presentation of fodder and fuelwood yield tables encompassing a large height and diameter range is expected to be a useful resource in the fodder tree data-base. The demonstration of agroforestry design and analysis provides the ways the research information can be used to improve the management of these valuable trees in improving the supply of fodder and fuelwood. The sequential combinations of species selection, biomass modeling, and agroforestry design demonstrate an appropriate approach to improve the agroforestry management in the central and western regions of Nepal. Finally, the report opens a whole new area of research and study opportunity in the areas of FTS in particular and agroforestry systems of Nepal in general.

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## CHAPTER II

## EVALUATING THE GROWTH PERFORMANCE OF COMMONLY GROWN FODDER TREE SPECIES IN CENTRAL AND WESTERN NEPAL


### Abstract

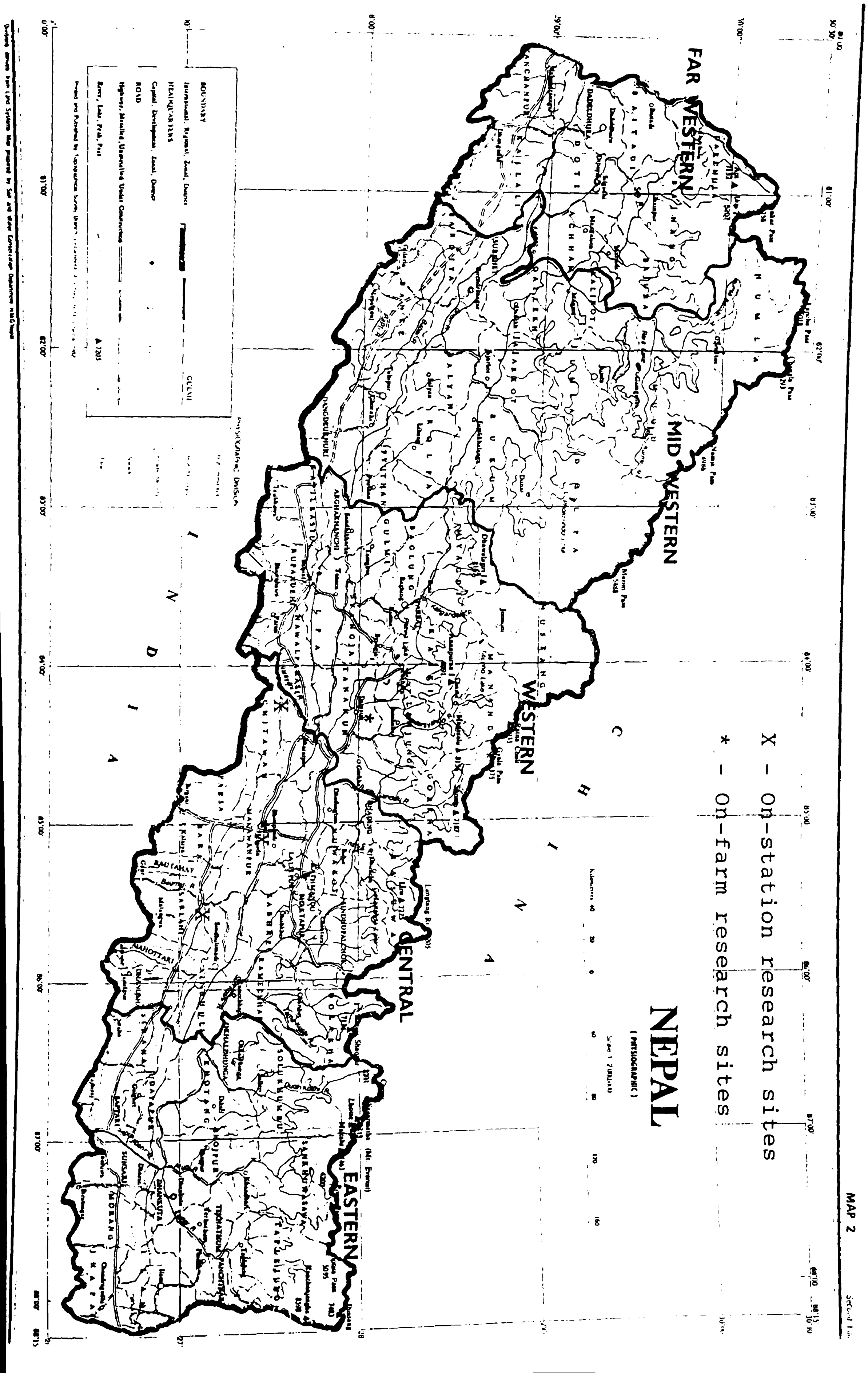
Ten commonly grown fodder tree species of central and western Nepal were evaluated at four sites over a five year period. *Ficus semicordata* (Buchattam. ex Sm.), *Bauhinia variegata* Linn., and *Leucaena leucocephala* (Lam.) de Wit were found to perform best. *F. semicordata* was found to be significantly higher (p=.05) in diameter and foliage growth than the rest. The three top performing species did well in all the sites. Height, diameter, foliage and wood growth were significantly (p=.05) different among species. The four sites were significantly different in diameter, foliage, and wood weight but not in height growth. A concurrent study conducted on the farmers' fields indicated that the best performing (on-station) trial species were among the best growing ones on farms. The crude protein (CP) and lignin contents of fodder trees were significantly different among species but not among sites. Dry matter content was highest in *B. variegata* and lowest in *Morus alba*. Four different lopping intensities applied to four species did not significantly affect the final foliage weight. In general, the highly preferred fodder trees growing on the farmers' fields as well as those found in the forests were found to have high crude protein (CP) and organic matter (OM) contents. The results indicated that native FTS of Nepal, if carefully selected and planted on the farmer's fields, had the potential to improve the poor fodder stands commonly found throughout the Midhills.


### 1.0 INTRODUCTION:

### 1.1 Background:

As a part of the Fodder Tree Management Project (FTMP), Species Evaluation and Selection Program of the Tribhuvan University, Nepal, fodder tree species (FTS) trials were established at four sites in three ecological zones of Nepal i.e., the Tarai, the Inner Tarai, and the Middle Hills (Fig 2.1).

**Figure 2.1 Map of Nepal showing the locations of the research sites**



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Four sites and sixteen species were (Fig. 2.1 and Appendix 2, Table 2.1) established in on-station experimental plots. The sites selected were representative of the upland farm (*bari*) land found in the Middle Hills, the Inner Tarai and the Tarai regions of Nepal. Marginal lands in these regions include non-cultivated inclusions (NCIs) in which growing fodder tree species (FTS) in the Midhills of Nepal are commonly found.

Two trials in the Tarai and the Inner Tarai were set up in 1985, and the remaining two in the Inner Tarai and the Midhills were established in 1986. The fifth trial, at a second site in Pokhara area, was established in 1988 to supplement the poor performance of the first trial plot at another site in Pokhara. The species included in the trial were native fodder species with the exception of *Leucaena leucocephala*, the sole exotic (Appendix 2, Table 2.1).

Lopping management trials were carried out on six native species located on farmers' fields. The on-farm trees were selected from locations near the research-station trials at Hetauda, Tanahu and Pokhara. Karmaiya site did not have suitable on-farm fodder trees and therefore was not included. Most of the farms in Nepal are less than one hectare in size. Within and between the individual farms, site variability is high due to the interaction of factors including altitude, aspect, soil type, soil depth and management practices adopted by the respective farmers. The othe

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other equally important factor is the type of species grown in order to fulfill the specific needs of the farmers concerned. It has been shown (Rusten 1989) that a farmer requires a range of species in order to meet a variety of needs derived from tree products for a large part of the year at a minimum amount of risk. Thus, the Middle Hill farmers grow a large number of species of fodder trees. On-farm trials on fodder tree species (FTS) must take these factors into considerations. The diversity of tree species extant on private farms are a valuable resource for yield, production, and management oriented studies, provided an appropriate research design and inventory can be established.

Under this research project, on-farm trees of known age, species, owner, and site were leased from farmers, and joint research by the farmers and the researchers was initiated with the aim of long- term improvement of fodder management. Major variables measured were: height, diameter at breast height (dbh), tree age, regeneration method, age of first lopping, lopping intensity, average yield per tree, preferred fodder species, and foliar nutrient contents. These data were used to complement the results obtained from the on-station trials in evaluating the fodder tree species.

Nutrient analysis was carried out on fodder samples collected from the four trial sites. The purpose was to incl

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**2.0 LITERATURE REVIEW**

Hudson (1987) surveyed all forestry related research in Nepal and reported that with one or two exceptions, all the research recorded up to the end of 1986 could be described as 'applied', i.e directed towards finding solutions to predefined practical problems. Silviculture research accounted for 88% and species selection research accounted for 44% of the silviculture research. Hudson (1987) also found that research on the use of trees as fodder and on the growing of agricultural crops along with trees was new. Little research had been done on the management of established forests and very little on natural forests. A recently concluded 25-year Master Plan for the forestry sector in Nepal recommended that species trials of fodder trees, research on their management, yields, and propagation needed top priority in forestry research sector (MFSC 1988). an der Dool (1987) examined the survival and growth of nine odder tree species at Pokhara. Considerable differences re found between species particularly in height growth of *semicordata*, *M. alba*, *Premna integrifolia*, and *F. riculata*. Among these FTS, *F. semicordata* had the highest erage increase in height at the age of three. *M. alba* had highest percent survival one year after planting. Napier

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and Parajuli (1987) conducted early growth trials of fourteen fodder tree species at Hetauda and Chalnakhel and found that after 18 months of growth, *F. semicordata*, *B. variegata*, *Bauhinia purpurea*, *Grewia* spp., and *Litsea* spp. outperformed the rest of the species at both the sites.

Howel (1987) reported that climatic and soil factors had the most important influences on the survival and growth of the FTS in Nepal, and that it was necessary to choose from those that were adapted to the climate and would grow well on the given soils. Farm forestry research carried out by the Institute of Forestry, Nepal has reported that *Bauhinia* spp., *F. semicordata*, *Ficus lacor*, *Garuga pinnata*, *Litsea monopetala*, and *Artocarpus lakoocha* were the commonly sought after fodder species by the farmers (Dixit 1987). Harrison (1989) conducted a fodder species elimination trial at the Lumle Agricultural Center (altitude 2000 m). He reported that *F. auriculata, L. monopetala*, and *Prunus cerasoides* were the hardiest and most productive species. Growth differences among species were highly significant (p=0.01). Upadhyay (1991), did a country-wide survey of farmers knowledge and perception about fodder trees. He reported that, in each of the districts in the Middle Hills and the Tarai, the most commonly grown FTS were: *L. monopetala, Bauhinia spp., F. semicordata*, and *L. leucocephala*. According to Hawkins and Malla (1983), the

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most preferred FTS[1] by farmers were those which self-regenerated or which could be easily and reliably propagated. The criteria for species selection were suggested to be silvicultural requirements, nutritional values, and fodder yield.

Stewart (1990) has developed a manual for conducting hardwood species trials in the tropics and sub-tropics. He recommended that the layout for multi-purpose tree species (MPTS) trials could be a conventional pure plot of the type generally used for testing industrial forestry species. However, pure plot trials would be inappropriate for species such as FTS which are grown in the farming systems along with other crops. The objectives in testing multipurpose species initially should be to assess their adaptability to new sites in terms of survival and vigor. Response to management interventions is the most important variable to ensure a sustained supply of products. But in species selection trials, it is necessary first to determine whether the trees could be successfully established before investigating the best management techniques for maximum sustainable production (Stewart 1990).

Species choice also depends upon the nutritive values of fodder tree species (FTS). The chemical composition of fodder foliage is known to vary widely not only by species,

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[1]The definition of the 'most preferred fodder tree species' is generally associated with: a) ease of propagation, b) good for milk production, and c) fast growth.

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but also by their location, age, methods of cultivation, climatic conditions, and soils (Ivory 1989). This is specially true of protein and mineral contents, which reflect the qualities of fodder.

Information on nutritive values of fodder trees from Nepal is limited. Stebler (1970) determined the chemical composition of leaves of 13 fodder species found in the Jiri region of eastern Nepal. Field and Pandey (1969) carried out chemical analysis of leaves of two tree species from Trishuli area in central Nepal. Pandey (1975, 1982) reported chemical composition of 46 fodder plants found in eastern parts of the country. Dutt (1978) estimated the nutritive values of 17 tree fodder found in Annapurna region in western Nepal. Bajracharya *et al* (1985) reported feed values for 195 fodder plants (trees, shrubs, and vines) found in the Kathmandu valley.

However, none of these studies have done any comparative analysis among the species and sites. They also fail to relate the nutritional values to site characteristics so as to establish some management oriented conclusions. Under the current study, 23 commonly used fodder trees, from three separate locations, were evaluated and analyzed on the basis of multiple site and species comparisons.

Nutrient content analysis can indicate the gross feeding potential of tree fodder. The chemical composition of the fodder plants provides important information about the nutrit

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nutritional values of fodder products (Joshi and Singh 1989). Crude protein (CP) gives indirect information on feed digestibility. Highly digestible fodder will give more energy (Ranjhan 1977). Lignin is resistant to the microbial actions in the rumen and is considered responsible for poor digestion of feed stuffs (Ranjhan 1977). Organic matter (OM) and total ash (TA) contents are inversely related; higher content of OM is a desirable quality of a fodder plant. Higher percentage of cellulose and hemicellulose in fodder leaves indicate poor quality of feed and low digestibility (Pathak and Jakhmola 1983).

## 3.0 STUDY OBJECTIVES

The overall objective of the trial was to evaluate a large number of species under similar silvicultural conditions to compare and contrast growth performance in terms of survival, height and diameter growth, fodder and wood weights, nutrient contents, and foliage to wood ratio. The trial objectives are listed below:

### 3.1 Main objective:

i) to screen a potentially high yielding group of fodder tree species out of the commonly grown native and exotic species;

### 3.2 Specific objectives:

i) to measure the variation in growth by sites and by species;

ii) to compare and contrast the species performance in terms of height, diameter, green to dry matter ratio, foliage yield, wood yield, and total dry matter yield across the four sites;

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3) to assess species adaptability over sites in terms of survival and vigor;

4) to compare and contrast the on-station and on-farm results especially those related to growth performance of common fodder species, nutritional values, and lopping treatments.

## 4.0 HYPOTHESES

In evaluating FTS, most frequently asked questions are: what variables should be measured ?, which ones are related ?, and can the variables evaluated be used to make inferences regarding the nature of the population ?. For instance, if only diameter is measured, tree size of multi-stemmed trees will be underestimated (Stewart 1990). If trees growing at different locations have similar growth rates, then separate analysis may not be warranted for each location. Knowledge about a widely distributed tree population has practical as well scientific implications; the data from several sites with similar growth can be pooled to construct regional biomass tables. This following null hypotheses were tested:

**HO:1.** There are no differences among species in terms of height, diameter, oven dry foliage, and wood weight of individual fodder trees;

**HO:2.** There are no differences among sites in height, diameter, and oven dry biomass weight of individual fodder trees;

**HO:3.** For on-farm FTS, all species have equal height and diameter; and

**HO:4.** Different lopping intensities do not result in different foliage yield.

## 5.0 METHODOLOGY

### 5.1 On-station research design:

The selection of an appropriate research design was governed by many factors, including the total number of variables needed to evaluate the species, adequate number of sample

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trees for conducting significant tests, and site characteristics such as the amount of space available and within-site variability. Major factors included in the study were: 1) species, 8-12 at each site; and 2) sites (location), one to two in each ecological zones; 3) site specific factors i.e., soils, aspects, and $p^H$. The major variables examined were: 1) total tree height; 2) basal and girth diameter; 3) crown diameter; 4) crown height; 5) crown length; 6) dry foliage weight; 7) dry wood weight; 8) green weight to dry weight ratio; and 9) plant survival rates. Two experimental designs were selected: a) forty-tree plot with three blocks in a randomized block design (RBD); and b) sixteen-tree plot with three replication for a completely randomized design (CRD), (Appendix 2, Figures 2.1 and 2.2). One of the objectives of the research was to prepare biomass tables (Chapter III), which necessitated a large number of trees in the trials wherever space permitted. The project also investigated the effects of four harvesting variables related to lopping intensity on selected fodder trees. As a result, at one site in the Tarai (Karmaiya) and in the Inner Tarai (Hetauda) region, RBD trials were established in June 1985 (Appendix 2, Figure 2.1 and Figure 2.2). Under this design, an area of one hectare was divided into three blocks. In each block, ten experimental sub-plots of four fodder trees for each FTS were planted (Appendix 2, Figure 2.1). The idea was to make the design as flexible as

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possible so as to accommodate a large number of treatments. For the remaining two sites at Rampur and Pokhara, the CRD design (Appendix 2, Figure 2.2) was adopted due to lack of adequate space. At these sites, three replicates each comprising a 16-tree plot were established in June 1986. Since the first trial plot at Pokhara did not do well, an additional trial comprising of 14 species and three replications (12 tree-plot each) was established in 1988 based on a CRD design.

**5.2 On-farm research design:** To improve the applicability of research results to the conditions encountered in the farmers' field, simultaneous species evaluation and management trials were carried out on adjoining farm land. A single tree or a group of three trees was treated as an experimental unit (EU) and three to nine such trees as three replicated EUs depending on the availability of suitable number of trees. Limited number of trees were selected due to two reasons: 1) undisturbed trees were difficult to find; and 2) farmers were unwilling to lease more than few trees for a three year period. These three trees formed a replicated block at each site for a particular species. This design was thought appropriate since trees were found growing far apart in a condition similar to a randomized situation. Trees of approximately uniform age and size were selected. The FTS were tested at three sites are shown in Table 2.1.

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**Table 2.1 On-farm sites and fodder tree species included in the trials**

| Spp. | SITE Hetauda | Tanahu | Pokhara |
|---|---|---|---|
| *F.semicordata* | X | X | X |
| *B.variegata* | X | X | X |
| *F.auriculata* | X | X | - |
| *A.lakoocha* | X | - | - |
| *L.monopetala* | X | - | - |
| *G.pinnata* | - | X | - |

**5.3 Assessment methodology:** Most conventional techniques of species screening rely on height and diameter measurements. Measuring only one diameter for a multi-stemmed tree such as a fodder tree will underestimate its size and weight as compared to a single-stemmed tree (Stewart 1990). As there are many methods by which these variables can be measured, it is difficult to duplicate these values in comparing species within the trials and across sites. Based on prior experience, diameters were measured at the base of the seedlings at 3 to 6 months of age; at 30 cm at age two; and at 50 cm when 3 to 5 years old. Total height was measured vertically when the tree was standing and along the stem after it was felled. The latter was called tree length. The diameter was measured for each stem with a diameter of equal to or greater than 3 cm, as most of the trees were multi-stemmed. The foliage and wood weights were measured through destructive sampling. The procedures adopted for the non-destructive and destructive methods are detailed below.

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**5.3.1 Non-destructive measurements:** All the measurements described here were recorded on Form A1 (Appendix 2, Tables 2.2 and 2.3). The forms were modified if the trial design was different than CRBD. Specific measurement techniques are as follows:

Height: Total height was measured as the vertical distance from the average ground line (on relatively level ground) to the apical bud of the main stem. The uppermost portion of the main stem was referred as top of the tree. For leaning trees such as *F. semicordata*, the height also was measured vertically, not along the slope of the stem.

Crown height: This is the vertical height from ground to base of live crown. Since the primary concern was crown productivity, base of live crown was considered as the lowest portion of the continuous green foliage.

Crown length: This is the distance from the base of the crown to the uppermost point of the stem. Crown height plus crown length equalled tree height.

Diameter: In this study, diameter was measured as diameter outside bark (dob) at 50 cm (*d50*) from the base of the stem. For consistency, diameter was determined by diameter tape.

Crown diameter: Crown diameter was measured using a non-elastic tape, stretched along an axis from one edge of the crown to its opposite edge, passing through the geographical center. To maintain consistency, the research crew used the procedures suggested by Briscoe (1990). Diameter me

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measurements were taken at 90 degree angle from both the sides such that $d_{av} = (d1+d2)/2$.

Multiple stems: Each stem was treated individually when vertically separated at 50 cm. height or below. For analysis purposes, each stem separated at this point was considered a single tree.

Phenology: An assessment of tree phenology, particularly the seasonality of its flowering and seed production, is essential for evaluating the production potential of any FTS. It is also important to know the time of leaf and pod/fruit production in order to assess the species' likely value in local farming systems (Rusten and Gold 1991; Rusten 1990; Pandey 1982). The usefulness of a FTS is maximized if it produces fodder at times of acute shortage, as in the middle of dry season. Form A1 (Appendix 2. Table 2.2) indicates the methods of phenology assessment.

Since the aim of this research was to measure foliage weight when the nutrient contents were maximum and also when the farmers needed the foliage most, each FTS was evaluated using a phenology description. Under this system, each tree was coded numerically, on a scale of 1 to 6, for leaf, flower and pod/fruit status (Stewart 1990). For example, a leafless tree was coded 1, leaves flushing 2, tree in full leaf (young) was coded 3, tree with matured leaf 4, tree with leaves falling was coded 5, and matured and flushing leaves on same tree was coded 6. Flower phenology was coded as fo

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as follows: 1 - no flowers; 2 - flower buds; 3 - open flowers; 4 - dead flowers; and 5 - flowers of mixed ages. Finally the pods were classified as following: 1 - no pods; 2 - immature pods; and 3 - mature pods.

The time table followed for the measurements described above were:

a) three months after planting to assess survival, height, and basal diameter;

b) at the end of second growing season (usually 11-12 months after planting) to assess survival, height, and diameter;

c) at the end of third or fourth growing season (usually 36-48 months) to assess height, diameter, crown dimensions, and biomass;

d) at the end of fifth growing season (after 60 months after planting) at which stage sample trees of selected FTS were felled and the biomass measured.

**5.3.2 Destructive sampling**: Sample trees were marked prior to destructive sampling. Heights, diameters, and crown dimensions were remeasured. Each sample tree was cut down and the following measurements were recorded:

Tree length: Tree length was measured as the distance from the groundline to the top of the measured stem along the actual alignment of the stem, equivalent to the height of the tree if it were erect.

Foliage weight: Foliage included leaves, succulent branches, flowers, fruits, and twigs. All succulent branches less than or equal to 1 cm diameter were separated along with leaves, twigs, succulent limb tops and fruits and weighed both fresh and dry. Trees were felled and all branches were cut flush with the bole and separated by individual stem. The weight

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of each biomass component was measured within 100 gm of accuracy using spring scales and a sling to hold the crown material.

Dry weight: To measure dry weight, crowns were divided into two horizontal and two vertical live sections. From each live section, a sample branch was randomly selected. The four sample sections were mixed and divided into foliage and branchwood biomass. Different sections of main stemwood were also included in the sample green wood biomass. Over 300 samples of green foliage and wood materials were examined for percent dry matter content. Samples were collected from all the species and sites. For each composite sample, weights were recorded (Appendix 2, Table 2.3) and moisture contents determined by oven drying at 100°C for 24 hours or until constant weight was reached.

**5.3.3 Soil sampling:** Each trial plot was subdivided based on vegetation and landscape characteristics, such as apparent fertility and moisture gradients. This defined the number of soil sampling units in each plot. On each sampling unit, starting near an edge a 'core sample' was taken at the five points of a 'W' shaped walking route. Samples were extracted from the top 15 cm of the soil surface following standard procedures (Jackson 1987). The five core samples were properly mixed, dried, and freed of stones bigger than two cm in diameter (Jackson 1987) before drawing a one kg. composite sample. The composite samples were taken to the

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Soil and Plant Analytical Laboratory in Kathmandu. Samples were properly packed and labelled before submitting for analysis (Table 2.2). Sampling was done during January-March of 1991.

**5.3.4 Climatic data collection:** Climatic information was obtained from the Nepal Meteorological Service's Climatic Records of Nepal publications (DIHM 1986). It included rainfall data from 1971 to 1989 for the four nearest climatological stations in or near each trial site. These records were considered to be useful, as all of the study sites had adjoining Meteorological Stations. Annual precipitation, mean monthly temperature, and mean monthly relative humidity were the major variables collected. Additional information such as annual radiation and soil temperatures were of interest but were found to be irregularly recorded and therefore discarded. A summary of soil and climatic data is given in Table 2.2.

**Table 2.2 Summary of climatic and soil information of the four sites**

| Site | Av.temp. (°C) | Av. ppt. (mm) | Av. RH (%) | Soil PH | Organic Carbon (%) | Tot. N (%) |
|---|---|---|---|---|---|---|
| armaiya | 23.68 | 1869.2 | 76.4 | 7.13 | 0.78 | .07 |
| etauda | 22.68 | 2248.7 | 77.6 | 8.26 | 0.77 | .06 |
| ampur | 23.67 | 1990.9 | 81.8 | 6.44 | 1.61 | .06 |
| okhara* | 20.46 | 3558.7 | 80.8 | 7.16 | 1.91 | .14 |
| verage | 22.62 | 2416.9 | 79.1 | 7.25 | 1.27 | .08 |

the soil data are average of two sites.

**.3.5 Sample foliage collection for nutrient analysis:** rees were selected based on their unlopped stage and verage size and phenology acceptable for fodder harvest.

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Sample foliage was collected by lopping the branches located at the middle of the crown. Samples were collected during the month of February to coincide with the onset of the fodder harvesting season. The collected samples were immediately weighed for green weight. The weighed samples were packed and sealed in plastic bags and labelled.

**5.3.6 Nutrient analysis techniques:** The samples were oven-dried at 80°C to obtain constant weight. After drying, the samples were ground and were submitted for nutritional analysis in the laboratories of the Central Livestock Development Center (CLDC), Kathmandu. The samples were analyzed for total nitrogen (N) using the Macro-kjeldahl procedure. Crude protein (CP) was obtained by multiplying total N by a constant factor (6.25). The total ash was determined by combusting samples overnight at 600°C, and the loss in weight during ashing was regarded as the organic matter (OM) content. Cellulose, hemicellulose, and lignin contents were determined using the procedure of Goering and Van Soest (1970). Each value determined was the average of three determinations.

**5.4 Data analysis:** The species data were tested through linear parameters. Analysis of variance (ANOVA) using species, blocks, and interactions as levels were carried out for each site and F statistics were computed to test hypotheses. Pairwise mean comparison was used to compare the specific means. Multiple comparison procedures were used to

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compare the means of the ten species at all sites. While selecting the method, the criterion used was the protection against a type I error as well as the power to detect the real differences when they existed. Cramer and Swanson (1973) as reported by Petersen (1985) after studying 88,000 differences in a computer simulation concluded that there was little difference between the Fisher's Protected Least Significance Differences (FPLSD) and the Waller-Duncan Bayes LSD (BLSD) procedures. Peterson (1985) recommended the use of BLSD for two reasons: a) it gives a single value which is large when the sample F indicates that the means are homogeneous, and small when the means appear to be heterogeneous; and b) its power to detect real differences does not depend on the number of means being compared. The Student-Newman-Keuls test (SNK) has been reported to be inconclusive in demonstrating to maintain overall protection levels for all possible distributions of means (Wilkinson 1990). BLSD was used to compare different combinations of means. Multiway Factorial ANOVA was used to partition the growth variations among sites, blocks, and species (Zar 1984).

## 6.0 RESULTS

This section is divided into two parts: 6.1) reports the results of on-station research trials, and 6.2) reports the results of on-farm research trials.

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**6.1 On-station research trial results:**

One of the major objectives for conducting these trials was to comprehensively evaluate commonly grown FTS to find out if (and how) the fodder trees varied among different species and sites in growth performance. Although a total of sixteen species were included in the trials, only seven species were grown at all sites due to unavailability of planting materials and space. Analysis of variance (ANOVA) was the major statistical tool used to investigate the effects in block, species and site levels. The major results of these trials are summarized below:

**6.1.1 Survival:** Seedling survival was measured at all sites when the plantations were six months old. Table 2.3 presents the mean survival percentage by site and species. *L. monopetala* and *F.semicordata* had the best survival among the species tested.

**Table 2.3 Survival percentage of the fodder tree species by site and species in central and western Nepal**

| Fodder tree species | % Survival two years after planting by site | | | | | | |
|---|---|---|---|---|---|---|---|
| | Karmaiya | Hetauda | Rampur | Pokhara1 | Pokhara2[2] | Mean | SD |
| *M.alba* | 76 | 54 | 95 | 40 | 96 | 72.2 | 24.8 |
| *L.monopetala* | 95 | 75 | 88 | 62 | 93 | 82.6 | 13.9 |
| *B.variegata* | 88 | 67 | 94 | 32 | 98 | 75.8 | 27.4 |
| *F.semicordata* | 92 | 73 | 95 | 54 | 98 | 82.4 | 18.6 |
| *B.purpurea* | 78 | 62 | 76 | 72 | 86 | 74.8 | 8.8 |
| *F.auriculata* | 55 | 48 | 42 | 54 | 70 | 53.8 | 10.5 |
| *L.leucocephala* | 85 | 77 | 71 | 56 | 65 | 70.8 | 11.1 |
| All Species | 81.3 | 65.1 | 80.3 | 52.9 | 86.6 | 73.2 | 13.9 |

[2] This is the second site at Pokhara which was established to supplement the poorly performing trial of the first site at the Institute of Forestry Campus, Pokhara.

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**Table 2.3.1 ANALYSIS OF VARIANCE - SURVIVAL PERCENTAGE**

| SOURCE | SUM-OF-SQUARES | DF | MEAN-SQUARE | F-RATIO |
|---|---|---|---|---|
| Site | 5552.18 | 3 | 1850.73 | 88.33**[1] |
| Spp. | 10480.40 | 6 | 1746.73 | 83.37** |
| Block | 0.65 | 2 | 0.32 | 0.02NS |
| Site Spp. | 4170.78 | 18 | 231.71 | 11.06** |
| Spp. *Block | 66.57 | 12 | 5.55 | 0.26NS[2] |
| Site *Block | 132.68 | 6 | 22.11 | 1.06NS |
| Error | 754.29 | 36 | 20.95 | |

[1] ** - highly significant (p=0.05); [2] NS - nonsignificant (p=0.05)

The ANOVA indicated that there were significant differences in survival percentage among species as well as sites at p=.01 level (Table 2.3.1). The survival percentage difference among the blocks however was not significant at p =.05 level.

Explanations for the results could be the different soil nutrient status, different inherent site quality such as past land use history at each site, and varying quality of seedlings. Other silvicultural factors such as weeding and plant protection may also have contributed to the difference.

**6.1.2 Growth performance:**

**6.1.2.1 Growth at individual-site** - First of all FTS were compared within each of the four sites based on the height, diameter at 50 cm *(d50)*, foliage weight, and wood weight values. Analysis of variance (ANOVA) was carried out to study the variation at block, species, and interaction levels. Table 2.4 presents the ANOVA for Karmaiya site.

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**Table 2.4. Analysis of variance for height,*d50*,foliage and wood growth at Karmaiya site in central Nepal**

| SOURCE | SUM-OF-SQUARES | DF | MEAN-SQUARE | F-RATIO |
|---|---|---|---|---|
| A. Height: | | | | |
| Block | 6.15 | 2 | 3.08 | 5.80** |
| Spp. | 87.23 | 9 | 9.70 | 18.26** |
| Block*Spp. | 9.15 | 18 | 0.51 | .96NS |
| Error | 63.71 | 120 | 0.53 | |
| B. Diameter: | | | | |
| Block | 3.38 | 2 | 1.69 | 0.98NS |
| Spp. | 123.29 | 9 | 13.70 | 7.94** |
| Block*Spp. | 32.63 | 18 | 1.81 | 1.05NS |
| Error | 207.09 | 120 | | |
| C. Foliage weight: | | | | |
| Block | 134.34 | 2 | 67.17 | 5.59** |
| Spp. | 5284.54 | 9 | 587.17 | 48.84** |
| Block*Spp. | 155.67 | 18 | 8.65 | 0.72NS |
| Error | 1442.59 | 120 | 12.02 | |
| D. Wood weight: | | | | |
| Block | 441.92 | 2 | 220.96 | 7.40** |
| Spp. | 12435.29 | 9 | 1381.70 | 46.30** |
| Block*Spp. | 370.28 | 18 | 20.57 | 0.69NS |
| Error | 3581.42 | 120 | 29.85 | |

** - highly significant; NS - nonsignificant at p=0.05.

The blocks and species were significantly different but the interactions were not significant for all the four growth attributes (Table 2.4). Block difference was not significant in diameter growth. Since the ANOVA results were consistent across sites, site factor was added as a factor to carry out multiway factorial ANOVA (Zar 1984) to compare variation in FTS growth due to site as well. Height, diameter, foliage, and wood growth were individually tested using species, block, and site as factors.

**Total height:** FTS growth patterns were not uniform across sites. Roughly half of the trees were erect and the remaining half were leaning and spreading at Karmaiya, Het

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| Fodder specie |
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| M. alb |
| L. mon |
| B. var |
| F. sem |
| P. int |
| B. pur |
| F. aur |
| F. glab |
| A. lak |
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Hetauda, and Rampur. At Pokhara, the trees were less spreading. Although height measurement is suitable only for erect trees, due to its popularity and usefulness, FTS were regularly measured for their growth using this attribute. For leaning and spreading trees, height was generally measured along the vertical distance from base to the tip to maintain uniformity across species. Since the trial plots were of variable age (3 to 6 years), three year data were used to compare performance across sites (Tables 2.5 - 2.8).

**Table 2.5. Mean heights (m) and standard errors for three year old fodder trees at four sites in central and western, Nepal**

| Fodder tree species | TRIAL SITE Karmaiya mean | Karmaiya std.error | Hetauda mean | Hetauda std.error | Rampur mean | Rampur std.error | Pokhara mean | Pokhara std.error | All sites |
|---|---|---|---|---|---|---|---|---|---|
| M. alba | 2.4 | .50 | 2.2 | .17 | 4.2 | .66 | 3.0 | .36 | 3.0 |
| L. monopetala | 1.8 | .38 | 2.1 | .40 | 2.6 | .06 | 2.9 | .42 | 2.3 |
| B. variegata | 3.2 | .15 | 3.3 | .06 | 5.6 | .61 | 2.4 | .07 | 3.6 |
| F. semicordata | 4.3 | .45 | 4.5 | .44 | 4.4 | .52 | 5.9 | .10 | 4.8 |
| P. integrifolia | 3.0 | .23 | 1.2 | .30 | . | . | 1.3 | .28 | 1.8 |
| B. purpurea | 3.1 | .25 | 2.9 | .57 | 2.7 | .21 | . | . | 2.9 |
| F. auriculata | 2.0 | .30 | 2.2 | .39 | 2.3 | .11 | 2.8 | .75 | 2.3 |
| F. glaberrima | 1.4 | .29 | 1.2 | .13 | . | . | 2.8 | .21 | 1.8 |
| A. lakoocha | 2.2 | .72 | 1.3 | .11 | 1.3 | .10 | 2.4 | .15 | 1.8 |
| L. leucocephala | 4.3 | .37 | 4.4 | .32 | 6.2 | .99 | 3.0 | .32 | 4.5 |
| All Spp. Mean | 2.8 | | 2.5 | | 3.5 | | 2.9 | | 2.9 |
| Std.error | .94 | | 1.15 | | 1.58 | | 1.15 | | 1.03 |

The highest growth was recorded by *F. semicordata*, followed by *L. leucocephala* and *B. variegata* (Table 2.5). The Analysis of Variance (ANOVA) for the mean height distribution is given in Table 2.5.1. There were significant differences among species in height growth, but height was not significantly different among the sites and blocks (Table 2.5.1).

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**Table 2.5.1 ANALYSIS OF VARIANCE - MEAN HEIGHT (m.)**

| SOURCE | SUM-OF-SQUARES | DF | MEAN-SQUARE | F-RATIO |
|---|---|---|---|---|
| Site | 2.74 | 3 | 0.91 | 2.05NS |
| Block | 0.49 | 2 | 0.24 | 0.54NS |
| Spp. | 132.92 | 9 | 14.77 | 33.11** |
| Site *Block | 5.57 | 6 | 0.93 | 2.08NS |
| Block *Spp. | 7.87 | 18 | 0.44 | 0.98NS |
| Spp. *Site | 38.03 | 27 | 1.41 | 3.16** |
| Error | 20.07 | (54-9[1])=45 | 0.45 | |

** - highly significant; NS - non-significant; [1] - 9 dof lost due to missing values.

The species differences can be explained by the fact that the species included in the trials belonged to different habitats and one species was exotic. The sites were selected to be as uniform as possible to detect the species differences which may explain non-significant differences among sites (Table 2.5.1).

**Diameter:** Different measures of diameter growth were used to assess tree growth performance. Diameter was recorded at the base of the bole when the tree were under a year old, at 30 cm above the ground *(d30)* when under three year old, and at 50 cm height *(d50)* after three years. The reason was due to the multiple stem characteristic of many of the species under study. A summary of mean values are given in Table 2.6.

Table 2.6.1 presents the ANOVA for the diameter distribution. Both sites and species show significant differences. The null hypothesis was rejected for both the species and site factors at p=0.01 level. Unlike height gr

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growth, diameter was significantly different among sites. The reason for the site difference may be due to varying nature of diameter growth among species. The spreading type multi-stemmed FTS such as *F.semicordata* and straight growing single-stemmed *A.lakoocha* had large diameter differences (Table 2.6).

**Table 2.6. Mean diameter at 50 cm (*d50*) and standard error of the fodder trees at four sites in central and western Nepal.**

| Fodder Tree Species | TRIAL SITE Karmaiya mean | Karmaiya std.error | Hetauda mean | Hetauda std.error | Rampur mean | Rampur std.error | Pokhara mean | Pokhara std.error | All site mean |
|---|---|---|---|---|---|---|---|---|---|
| M. alba | 3.2 | .35 | 3.4 | .39 | 7.9 | .66 | 3.3 | .70 | 4.4 |
| L. monopetala | 3.0 | .53 | 4.7 | .95 | 7.7 | .18 | 5.7 | .66 | 5.3 |
| B. variegata | 5.4 | .51 | 6.9 | .33 | 10.0 | 1.31 | 3.0 | .27 | 6.3 |
| F. semicordata | 11.1 | .91 | 9.7 | 1.48 | 10.2 | .62 | 10.3 | 1.49 | 10.3 |
| P. integrifolia | 4.5 | .37 | 2.7 | 1.32 | - | - | 1.8 | .19 | 3.0 |
| B. purpurea | 3.6 | .52 | 5.2 | 1.38 | 5.6 | .55 | - | - | 4.8 |
| F. auriculata | 4.3 | .62 | 5.4 | .76 | 5.0 | .83 | 3.9 | 1.16 | 4.6 |
| F. glaberrima | 2.7 | .61 | 2.2 | .11 | - | - | 3.7 | .51 | 2.9 |
| A. lakoocha | 4.0 | .95 | 2.9 | .11 | 2.6 | .18 | 5.3 | .71 | 3.9 |
| L. leucocephala | 5.2 | .57 | 7.7 | .98 | 9.2 | 1.56 | 4.0 | .09 | 6.5 |
| All Spp. Mean | 4.7 | | 5.1 | | 7.4 | | 4.53 | | 5.2 |
| Std. error | 2.44 | | 2.43 | | 2.51 | | 2.45 | | 2.06 |

Trees at Karmaiya and Pokhara sites were unusually slender and tall compared to trees of similar age at Hetauda and Rampur probably due to shading by old tree boundaries around the trial plots.

**Table 2.6.1 ANALYSIS OF VARIANCE - MEAN DIAMETER AT 50 CM HEIGHT**

| SOURCE | SUM-OF-SQUARES | DF | MEAN-SQUARE | F-RATIO |
|---|---|---|---|---|
| Site | 41.40 | 3 | 13.81 | 7.54** |
| Block | 7.43 | 2 | 3.72 | 2.03NS |
| Spp. | 503.01 | 9 | 55.90 | 30.20** |
| Site *Block | 21.78 | 6 | 3.63 | 1.98NS |
| Block *Spp. | 35.13 | 18 | 1.95 | 1.07NS |
| Spp. *Site | 167.63 | 27 | 6.21 | 3.39** |
| Error | 82.43 | (54-9[1])= 45 | 1.83 | |

** - highly significant; NS - non-significant; [1] - 9 DF lost due to missing values.

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**Fodder and wood weight:** Since height and diameter alone are not the best index of fodder tree performance, individual tree fodder weight was also evaluated. Oven dry weights of the foliage and total wood weight (Table 2.7) were obtained for all sites by destructive sampling of three year old fodder trees.

**Table 2.7. Mean fodder and wood dry weight (dry matter kg/tree) of ten FTS at four sites in central and western Nepal**

| Species | TRIAL SITE | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Karmaiya | | Hetauda | | Rampur | | Pokhara | | All Sites | |
| | F* | W* | F | W | F | W | F | W | F | W |
| M. alba | 1.5 | 3.2 | 1.6 | 3.4 | 2.2 | 4.5 | 1.6 | 2.4 | 1.7 | 3.4 |
| L. monopetala | 0.5 | 0.8 | 0.8 | 1.1 | 0.3 | 0.7 | 0.7 | 0.9 | 0.6 | 0.9 |
| B. variegata | 2.7 | 5.6 | 1.3 | 4.0 | 1.9 | 4.1 | 1.6 | 2.2 | 1.9 | 4.0 |
| F. semicordata | 7.7 | 17.2 | 5.4 | 8.8 | 4.0 | 8.8 | 2.5 | 4.7 | 4.9 | 9.9 |
| P. integrifolia | 0.7 | 4.0 | 0.3 | 1.7 | . | . | 0.5 | 2.3 | 0.8 | 2.3 |
| B. purpurea | 1.1 | 3.4 | 1.2 | 2.3 | 1.8 | 2.9 | . | . | 1.3 | 2.9 |
| F. auriculata | 0.8 | 2.9 | 0.8 | 2.0 | 0.7 | 1.3 | 0.8 | 1.7 | 0.8 | 2.0 |
| F. glaberrima | 0.6 | 0.8 | 0.4 | 0.6 | . | . | 0.5 | 0.7 | 0.5 | 0.7 |
| A. lakoocha | 0.9 | 1.9 | 0.2 | 0.4 | 0.4 | 0.5 | 0.6 | 1.1 | 0.5 | 1.0 |
| L. leucocephala | 3.3 | 16.6 | 5.6 | 15.0 | 2.4 | 2.8 | 1.2 | 2.0 | 3.2 | 9.1 |
| All Spp. Mean | 2.0 | 5.0 | 1.8 | 3.9 | 1.7 | 3.2 | 1.1 | 2.0 | 1.6 | 3.5 |
| Std. error | 2.21 | 5.05 | 2.03 | 4.59 | 1.23 | 2.73 | 0.68 | 1.18 | 1.42 | 2.99 |

* F = forage; W = wood

The ANOVA results (Tables 2.7.1 and 2.7.2) indicate that, on the basis of the dry foliage and wood weight of the species tested, there were significant differences among the species and sites at p=0.01 level. The blocks were not significantly different at p=0.05 level).

**Table 2.7.1 ANALYSIS OF VARIANCE - DRY FORAGE WEIGHT**

| SOURCE | SUM-OF-SQUARES | DF | MEAN-SQUARE | F-RATIO |
|---|---|---|---|---|
| Site | 14.00 | 3 | 4.67 | 25.21** |
| Block | 0.59 | 2 | 0.30 | 1.60NS |
| Spp. | 231.93 | 9 | 25.77 | 139.21** |
| Site*Block | 1.46 | 6 | 0.24 | 1.31NS |
| Block*Spp | 3.67 | 18 | 0.20 | 1.10NS |
| Spp.*Site | 66.12 | 27 | 2.45 | 13.24** |
| Error | 8.33 | (54-9[1]) = 45 | 0.19 | |

** - highly significant; NS - non-significant; [1] - 9 DF lost due to missing values.

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Only one interaction component, species versus site was found to be significant at p=0.01 level in both the foliage weight and wood weight comparison (Tables 2.7.1 and 2.7.2).

**TABLE 2.7.2 ANALYSIS OF VARIANCE - DRY WOOD WEIGHT**

| SOURCE | SUM-OF-SQUARES | DF | MEAN-SQUARE | F-RATIO |
|---|---|---|---|---|
| Site | 202.06 | 3 | 67.35 | 76.54** |
| Block | 0.75 | 2 | 12.090 | 0.43NS |
| Spp. | 1202.15 | 9 | 31.400 | 151.79** |
| Site *Block | 5.25 | 6 | 14.897 | .99NS |
| Block *Spp | 5.07 | 18 | 29.884 | .32NS |
| Spp. *Site | 662.48 | 27 | 15.272 | 27.88** |
| Error | 39.58 | (54-9[1]) 45 | 0.88 | |

** - highly significant; NS - non-significant;[1] - 9 DF lost due to missing values.

An illustration of the growth patterns of all the species is provided in Figure 2.2.

**Percent dry matter content:** Although most tree fodder is harvested and utilized in green form, dry weight is an important criteria of evaluating FTS for two reasons. First the actual quality of the fodder is judged based on its total digestive nutrients (TDN) content, and TDN is calculated based upon the dry matter content of the fodder.Second, dry matter content is known to vary among the species (Joshi and Singh 1989) and it may vary among the sites. For these reasons, percent dry matter was also used as a criteria to evaluate the FTS. *F. semicordata* and *M. alba* had the highest foliage percent dry matter and *P. integrifolia* and *F. semicordata* the lowest wood percent dry matter respectively (Table 2.8).

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gure 2.2 **Three year growth pattern of fodder tree species in central and western Nepal**

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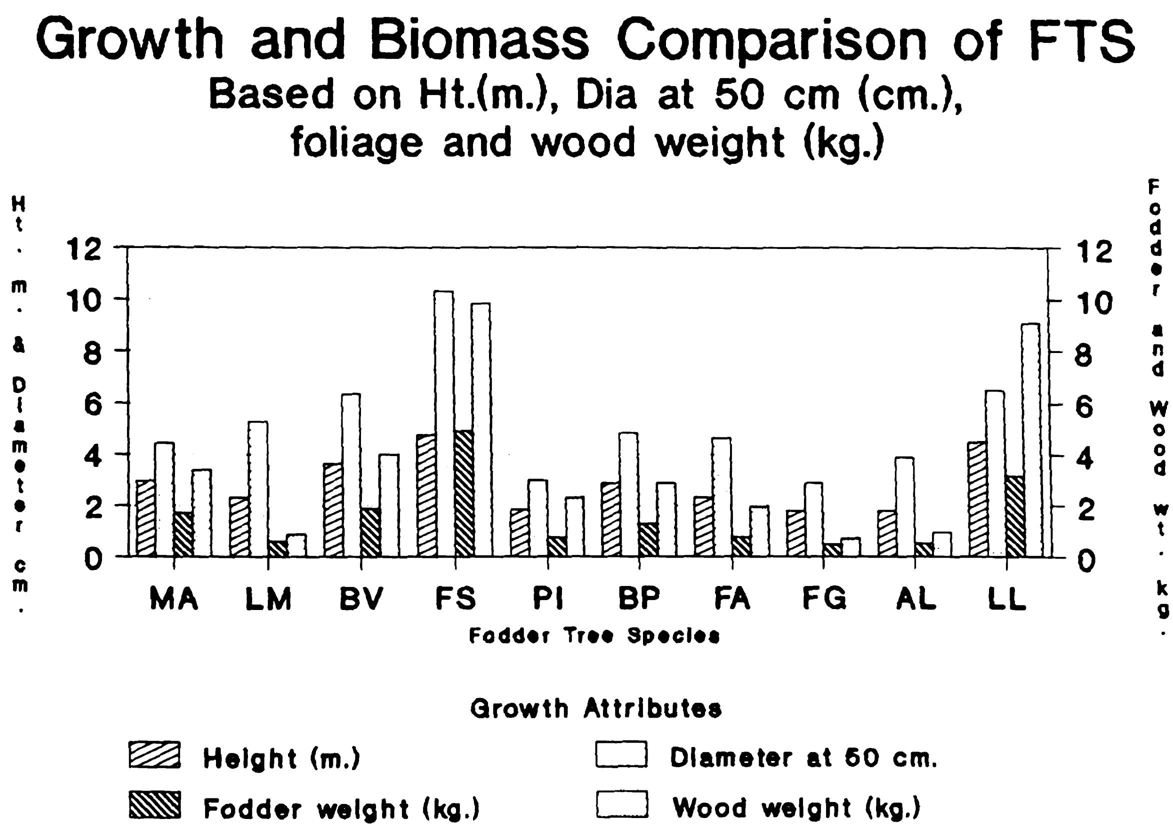


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ANOVA (Table 2.8.1) based on the RBD arrangements indicated that, for both the foliage and wood matter, percent dry matter significantly varied (p=0.01) among species but not among sites.

**Table 2.8 Mean and SD values of percent dry matter (DM) content in foliage and wood weight of ten FTS in central and western Nepal**

| Fodder Species | % DM (Foliage) | | % DM (Total wood) | |
|---|---|---|---|---|
| | Mean | Std.Dev. | Mean | Std. Dev. |
| *M. alba* | 26.6 | 2.29 | 53.9 | 4.01 |
| *L. monopetala* | 33.1 | 4.62 | 42.9 | 4.23 |
| *B. variegata* | 35.7 | 8.80 | 41.1 | 3.08 |
| *F. semicordata* | 45.0 | 6.25 | 36.4 | 5.79 |
| *P. integrifolia* | 25.8 | 1.16 | 37.4 | 1.62 |
| *B. purpurea* | 40.5 | 4.33 | 50.3 | 3.07 |
| *F. auriculata* | 30.7 | 3.77 | 36.5 | 2.97 |
| *F. glaberrima* | 30.0 | 2.41 | 46.1 | 9.19 |
| *A. lakoocha* | 32.2 | 2.53 | 44.7 | 1.17 |
| *L. leucocephala* | 30.0 | 1.59 | 50.6 | 5.19 |
| All Species | 33.0 | 6.80 | 44.0 | 7.15 |

**Table 2.8.1 ANALYSIS OF VARIANCE - % DRY MATTER, FOLIAGE**

| SOURCE | SUM-OF-SQUARES | DF | MEAN-SQUARE | F-RATIO |
|---|---|---|---|---|
| Site | 80.482 | 2 | 40.241 | 2.471NS |
| Spp. | 974.515 | 9 | 108.279 | 6.650** |
| Error | 293.081 | 18 | 16.282 | |

NS = non-significant; ** - highly significant

**Table 2.8.2 ANALYSIS OF VARIANCE - % DRY MATTER, TOTAL WOOD**

| SOURCE | SUM-OF-SQUARES | DF | MEAN-SQUARE | F-RATIO |
|---|---|---|---|---|
| Site | 22.922 | 2 | 11.461 | 0.518NS |
| Spp. | 1060.818 | 9 | 117.869 | 5.326** |
| Error | 398.348 | 18 | 22.130 | |

NS - non-significant; ** - highly significant

In general, trees with higher percent foliage dry weight and lower percent branch wood dry weight are preferred species by rural farmers. Based on this criteria, *F. glaberrima, F. semicordata, L. monopetala* and *B. variegata* were

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were found to be better fodder tree species. These FTS were found to have higher fodder:wood ratios (Appendix 2, Table 2.4).

**6.1.3 Multiple comparisons:**

In order to compare and contrast the ten species included in the trial, multiple comparison of the means was carried out using the Waller-Duncan Bayes LSD (BLSD) method (Petersen 1985). In this method, the standard error of a difference between means is computed and the outcome is multiplied by an appropriate minimum average risk $(t - t_B)$ to obtain the BLSD value. Then a risk ratio comparable to the significance levels of other procedures is selected. Duncan (1955) showed that a *k* ratio of 100 is equivalent to an $\alpha$ of 0.05, while a *k* ratio of 500 is equivalent to an $\alpha$ of 0.01. The following analysis has been obtained using BLSD method at *k*=100.

**Table 2.9 Pairwise mean differences of foliage dry weight using Waller and Duncan's Bayes LSD (BLSD) method of multiple comparison.**

| FTS code | FS | LL | BV | MA | BP | FA | LM | AL | PI | FG |
|---|---|---|---|---|---|---|---|---|---|---|
| Mean | 4.89 | 3.15 | 1.87 | 1.73 | 1.3 | .78 | .75 | .59 | .51 | .48 |
| Grouping | I | | II | | | | | III | | |

Means underlined by the same line are not significantly (k = 100) different.

Only *F. semicordata* was significantly (p=0.05) different from all the remaining nine species, when compared on the basis of dry fodder weight (Table 2.9). *L. leucocephala, B. variegata*, and *M. alba* fell in the second group and the remaining six fell in the third group (Table 2.10). *L.*

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*leucocephala* was significantly different from six species except *B. variegata* and *M. alba* which were the third and fourth best performing species in the trial plots. Table 2.10 presents all possible comparisions of mean foliage weight values. In this matrix-style presentation, each species was compared with the remaining nine FTS. The value at the intersection of any two FTS indicate the magnitude of difference between the two. It is then compared with the BLSD value and significance is determined.

Once again, significant differences in the dry foliage weights were found in *F.semicordata,* and *L.leucocephala*. All possible pairwise mean comparisons (Table 2.10) indicated that the foliage weight of the two species were significantly higher than the remaining eight.

**Table 2.10 Difference between means of oven dry foliage weights of various FTS in central and western Nepal compared with BLSD method of multiple mean comparison.**

| FTS Spp.code | Mean Fol. Wt. (kg.) | | .48 FG | .51 PI | .59 AL | .75 LM | .78 FA | 1.30 BP | 1.73 MA | 1.87 BV | 3.15 LL |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Rank | 10 | 9 | 8 | 7 | 6 | 5 | 4 | 3 | 2 |
| FS | 4.89 | 1 | 4.41* | 4.39* | 4.38* | 4.30* | 4.11* | 3.59* | 3.16* | 3.02* | 1.74* |
| LL | 3.15 | 2 | 2.67* | 2.65* | 2.64* | 2.56* | 2.37* | 1.85* | 1.42 | 1.28 | |
| BV | 1.87 | 3 | 1.39 | 1.37 | 1.36 | 1.28 | 1.09 | 0.57 | 0.14 | | |
| MA | 1.73 | 4 | 1.25 | 1.23 | 1.22 | 1.14 | 0.95 | 0.43 | | | |
| BP | 1.30 | 5 | 0.82 | 0.80 | 0.79 | 0.71 | 0.52 | | | | |
| FA | 0.78 | 6 | 0.30 | 0.28 | 0.27 | 0.19 | | | | | |
| LM | 0.59 | 7 | 0.11 | 0.09 | 0.08 | | | | | | |
| AL | 0.51 | 8 | 0.03 | 0.01 | | | | | | | |
| PI | 0.50 | 9 | 0.02 | | | | | | | | |

* significant at <u>k</u> = 100 or $\alpha = 0.05$

Notations: MA: <u>Morus alba</u>; FS: <u>Ficus semicordata</u>; BV: <u>Bauhinia variegata</u>; FA: <u>Ficus auriculata</u>; BP: <u>Bauhinia purpurea</u>; LL: <u>Leucaena leucocephala</u>; PI: <u>Premna integrifolia</u>; LM: <u>Litsea monopetala</u>; FG: <u>Ficus glaberrima</u>; AL: <u>Artocarpus lakoocha</u>.

Table 2.11 presents the rankings of the ten FTS based on the four growth attributes discussed above. The ranking shows the dominance of *F. semicordata* and *L. leucocephala* over

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over all the remaining species in all the attributes of growth and yield. It must be noted that *L. leucocephala* has recently been affected by psyllid (*Heteropsylla cubana*) infestation and is no longer recommended for planting. Rankings based on the four attributes of height, diameter at 50 cm., foliage dry weight, and wood dry weight and their multiple comparison tests are shown in Table 2.11.

Mean growth values were also used to rank the sites (Table 2.12). Karmaiya was ranked first both in foliage and wood weight values. Hetauda was ranked first in diameter growth and Pokhara in height growth. The comparisons shown here are only for common age of three years (Table 2.12).

**Table 2.11. Species ranking and their significance based on different measurement criteria.**

| Rank | Mean ht.(m.) | Rank | Mean d50(cm) | Rank | fol.wt(kg.) | Rank | wood wt(kg.) |
|---|---|---|---|---|---|---|---|
| FS | 4.8 a | FS | 10.3 a | FS | 4.9 a | FS | 9.9 a |
| LL | 4.5 ab | LL | 6.5 b | LL | 3.2 b | LL | 9.1 a |
| BV | 3.6 abc | BV | 6.3 b | BV | 1.9 bc | BV | 4.0 b |
| MA | 3.1 cd | LM | 5.3 bc | MA | 1.7 bcd | MA | 3.4 b |
| BP | 2.9 cd | BP | 4.8 bcd | BP | 1.3 cd | BP | 2.9 b |
| LM | 2.3 d | FA | 4.6 bcd | FA | 0.9 cd | PI | 2.3 b |
| FA | 2.3 d | MA | 4.4 bcd | LM | 0.8 cd | FA | 2.0 b |
| PI | 1.8 d | AL | 3.7 cd | AL | 0.6 cd | AL | 1.0 b |
| AL | 1.8 d | PI | 3.0 d | PI | 0.5 d | LM | 0.9 b |
| FG | 1.8 d | FG | 2.9 d | FG | 0.5 d | FG | 0.7 b |
| LSD[1] | 1.2 | | 2.2 | | 1.4 | | 4.4 |

eans followed by the same letter are not significantly (k=100 or $\alpha$=0.05) ifferent. [1] stands for Waller and Duncan's Bays Least Significant ifference.

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**Table 2.12 Ranking of site performance based on height, *d50*, fodder dry weight, wood dry weight of the 3-year old trial FTS.**

| Ranking order | Mean Values Height(m.) | D50cm(cm.) | Fol wt.(kg) | Wood wt.(kg) |
|---|---|---|---|---|
| 1 | 3.5 (R)a[1] | 7.0 (R)a | 2.0 (K)a | 5.0 (K)a |
| 2 | 3.0 (P)a | 5.1 (H)ab | 1.8 (H)ab | 4.0 (H)ab |
| 3 | 2.8 (K)a | 4.7 (K)ab | 1.7 (R)ab | 3.2 (R)ab |
| 4 | 2.6 (H)a | 4.4 (P)b | 1.2 (P)b | 2.1 (P)b |
| BLSD | 1.6 | 2.5 | 0.7 | 2.6 |

K: Karmaiya; H: Hetauda; R: Rampur: P: Pokhara
[1] same letter in a column indicate non-significant difference between two means ($p < 0.05$).

The above comparisons were for trees at age three. Fodder trees generally mature at age ten. Trees often change growth behavior as they age. The lower foliage and wood weight at Rampur site may be due to poaching of the trial plots by villagers for fodder.

**6.2 On-farm research results:**

The objective of the on-farm trials was to collect information so that the data from research plots could be compared and contrasted with actual field conditions. It was hoped that inferences could be made either supporting or rejecting the results obtained from the experimental data. The major findings are described below:

**.2.1 Growth performance of on-farm trees:**

In order to establish relationships between the trees rown under the on-station and on-farm conditions, three to 4 trees belonging to six FTS of known age and growth .story were monitored for three years. The trees were lected randomly and each tree was treated as a replicate.

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Height, dbh, crown diameter, and crown height growth of 24 *F.semicordata* trees were measured for three years. The average age of these trees was 10 years. The evaluation criteria was to compare the net increment in height and dbh growth during the three year period. Table 2.13 summarizes the results.

**Table 2.13 Mean height, dbh, crown diam. and crown length of ten year old on-farm *F. semicordata* trees at three sites**

| Site | Height (m.) | | Dbh (cm.) | | Crown diam. (m.) | | Crown length (m.) | |
|---|---|---|---|---|---|---|---|---|
| | Mean | SD | Mean | SD | Mean | SD | Mean | SD |
| Hetauda | 7.3 | 1.3 | 23.0 | 4.9 | 2.80 | 1.4 | 5.3 | 2.0 |
| Tanahu | 9.8 | 1.3 | 26.9 | 4.8 | 3.50 | 1.3 | 6.7 | 1.8 |
| Pokhara | 6.5 | 1.1 | 21.9 | 2.2 | 2.35 | 1.2 | 4.3 | 0.9 |

SD = standard deviation

**Height and diameter growth of other FTS:**

The mean height and dbh growth differences among common on-farm FTS are given in Table 2.14. To compare growth rates, ANOVA on mean height and diameter increments was carried out (Tables 2.14.1 and 2.14.2). Since the species were significantly different both in height and diameter growth, multiple comparisons of the mean values were carried out using the BLSD method (Appendix 2, Table 2.5). In terms of height growth, *A.lakoocha* was significantly different from others. *F.semicordata*, *B.variegata* and *L.monopetala* were not significantly different from each other. Based on the diameter increment values, *A.lakoocha* was significantly different from *F.semicordata*. *F.auriculata* was also significantly different from three other FTS (Appendix 2,

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Table 2.6). One note of explanation regarding the large height growth of *A.lakoocha* is that the trees were located at very good sites as compared to others.

**Table 2.14 Height, dbh and their mean differences of on-farm trial FTS at three sites in central and western Nepal.**

| Species | Ht87 (m.) | Ht90 (m.) | Mean Diff. (m.) | Dbh87 (cm.) | Dbh90 (cm.) | Mean Diff. (cm.) | Sample No. |
|---|---|---|---|---|---|---|---|
| *A.lakoocha* | 10.07 | 12.70 | 2.63a | 25.67 | 34.83 | 9.16a | 3 |
| *F.semicordata* | 8.06 | 9.99 | 1.93b | 23.06 | 27.57 | 4.51b | 24 |
| *L.monopetala* | 10.02 | 11.71 | 1.69bc | 27.33 | 29.20 | 1.81cd | 3 |
| *B.variegata* | 7.71 | 9.37 | 1.66bc | 19.30 | 21.23 | 1.91cd | 12 |
| *G. pinnata* | 8.24 | 9.83 | 1.59c | 19.00 | 21.48 | 2.53c | 6 |
| *F.auriculata* | 7.90 | 9.27 | 1.37c | 23.07 | 26.88 | 3.82b | 6 |

**Table 2.14.1 ANALYSIS OF VARIANCE - MEAN HEIGHT INCREMENT (m.)**

| SOURCE | SUM-OF-SQUARES | DF | MEAN-SQUARE | F-RATIO |
|---|---|---|---|---|
| Spp. | 2.894 | 5 | 0.579 | 15.011** |
| Error | 0.463 | 12 | 0.039 | |

**Table 2.14.2 ANALYSIS OF VARIANCE - MEAN Dbh INCREMENTS (cm.)**

| SOURCE | SUM-OF-SQUARES | DF | MEAN-SQUARE | F-RATIO |
|---|---|---|---|---|
| Spp. | 113.880 | 5 | 22.776 | 143.080** |
| Error | 1.910 | 12 | 0.159 | |

NS = non-significant; ** - highly significant

### 6.2.3 Lopping intensity trials

In order to evaluate the effect of different lopping regimes practiced by the villagers, 24, 12, 6, and 3 randomly selected on-farm trees belonging to *F. semicordata, B. variegata, F.auriculata,* and *A. lakoocha* respectively were given four treatments: 25% lopping, 50% lopping, 75% lopping and 100% lopping based on the crown length. At the end of the third year, all the trees were fully lopped and dry foliage and branch weight were compared. Table 2.5 in

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Appendix 2 provides the data and Table 2.15 provides the result of the ANOVA of total dry weight values for *F.semicordata*.

**Table 2.15 Analysis of variance for mean fodder weight of lopping intensity trial trees of *F.semicordata* on-farm trees**

| SOURCE | SUM-OF-SQUARES | DF | MEAN-SQUARE | F-RATIO |
|---|---|---|---|---|
| Site | 81.70 | 2 | 40.85 | 1.17NS |
| Lopping regime | 34.24 | 3 | 11.41 | 0.33NS |
| Site *Lopping | 95.43 | 6 | 15.91 | 0.46NS |
| Error | 418.33 | 12 | 34.86 | |

NS - Nonsignificant at $p = 0.05$

The results indicated that the four lopping intensities did not produce significant differences in the dry foliage weight of the four treatments (Table 2.15). Three sites - Hetauda, Tanahu and Pokhara were also not found significant in total foliage weight (Table 2.15). The other FTS were not analyzed due to small number of observations.

**6.2.4: Nutrient contents:** Collection of foliage samples from all the study sites and their chemical analysis indicated that the highest percent organic matter (OM), and crude protein (CP), were found in *L. monopetala* and *A. lakoocha* respectively. *L. leucocephala* and *Ficus spp.* also had high CP and OM (Table 2.16 and Appendix 2, Figures 2.3 and 2.4). These FTS were reported by the farmers as highly preferred trees.

The farmers' preference was based on the milk yielding capacity of the fodder leaves when fed to the lactating buffalos. In general, the farmers' choice was found to be

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related to higher CP and lower cellulose contents. The preferred species also had high DM, another indicator of good quality feed. Except for the *L.monopetala*, the preferred species also had lower lignin content (Table 2.16, Appendix 2, Table 2.7).

**Table 2.16 Nutrient contents (mean values) of common on-farm fodder tree species from three sites in central and western Nepal**

| Species | DM | OM | CP | Lignin | Cellulose |
|---|---|---|---|---|---|
| *F. hispida* | 27.7 | 87.5 | 21.2 | 15.0 | 23.3 |
| *A. lakoocha* | 29.0 | 91.4 | 20.3 | 21.6 | 28.3 |
| *L. monopetala* | 29.0 | 93.0 | 19.2 | 35.6 | 20.3 |
| *F. lacor* | 29.9 | 90.8 | 17.8 | 25.3 | 26.8 |
| *F. semicordata* | 30.4 | 92.2 | 14.0 | 26.3 | 25.3 |
| *Bridelia retusa* | 36.8 | 91.4 | 10.3 | 17.2 | 26.8 |
| *B. variegata* | 30.9 | 92.1 | 20.2 | 14.1 | 22.3 |

Nutritive values are known to vary according to the stage of leaf maturity of a particular FTS. They may also vary by species and sites. In this study, the samples were all collected during the same season. However, due to altitudinal differences of the three sites, the growth stages were not similar. None of the nutrient variables was significantly different among sites (Table 2.16.1).

*Ficus hispida* had the highest percentage of CP content at all three sites followed by *A.Lakoocha*. Dry matter (DM) and organic matter (OM) were not significantly ($p=0.05$) different among species. Crude protein (CP), lignin and cellulose contents were significantly different among species.

Table 2

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**Table 2.16.1. Analysis of variance of nutrient contents of FTS**

VARIABLE - CRUDE PROTEIN

| SOURCE | SUM-OF-SQUARES | DF | MEAN-SQUARE | F-RATIO |
|---|---|---|---|---|
| Site | 1.66 | 2 | 0.83 | 0.64NS |
| Spp. | 105.16 | 6 | 17.53 | 13.66** |
| Error | 15.51 | 12 | 1.29 | |

VARIABLE - LIGNIN

| SOURCE | SUM-OF-SQUARES | DF | MEAN-SQUARE | F-RATIO |
|---|---|---|---|---|
| Site | 42.54 | 2 | 21.27 | 0.82NS |
| Spp. | 1082.79 | 6 | 180.46 | 6.92** |
| Error | 313.012 | 12 | 26.08 | |

VARIABLE - DRY MATTER

| SOURCE | SUM-OF-SQUARES | DF | MEAN-SQUARE | F-RATIO |
|---|---|---|---|---|
| Site | 138.32 | 2 | 69.160 | 2.571NS |
| Spp. | 21.67 | 6 | 3.611 | 0.134NS |
| Error | 322.747 | 12 | 26.896 | |

VARIABLE - ORGANIC MATTER

| SOURCE | SUM-OF-SQUARES | DF | MEAN-SQUARE | F-RATIO |
|---|---|---|---|---|
| Site | 2.19 | 2 | 1.10 | 0.217NS |
| Spp. | 66.93 | 6 | 11.15 | 2.210NS |
| Error | 60.57 | 12 | 5.05 | |

VARIABLE - CELLULOSE

| SOURCE | SUM-OF-SQUARES | DF | MEAN-SQUARE | F-RATIO |
|---|---|---|---|---|
| Site | 105.32 | 2 | 52.66 | 3.36NS |
| Spp. | 352.43 | 6 | 58.74 | 3.75* |
| Error | 188.05 | 12 | 15.67 | |

S - nonsignificant; * - significant; and ** - highly significant at p = 0.05

**.0 HYPOTHESIS TESTING:**

0.1. There are no species differences in terms of height, diameter, oven dry foliage, and wood weight of individual trees.

This hypothesis tested whether or not there was ignificant difference among the species in their height, iameter at 50 cm, and dry weight values. The ANOVA tables shown

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shown in Tables 2.5.1, 2.6.1, and 2.7.1-2 indicated that the species were significantly (p=0.05) different in all of these characteristics.

**HO.2.** There are no differences among sites in terms of height, diameter, and biomass weight of individual FTS.

This hypothesis tested whether or not site had a significant effect on growth performance of FTS, including biomass yield. The ANOVA tables presented in Tables 2.5.1, 2.6.1, and 2.7.1-2 indicated that the null hypothesis could be rejected (P=0.05) while comparing the site performance based on diameter, foliage weight and total wood weight values for four sites involved. Height variable was however, found to be nonsignificant (Table 2.5.1). It was thus concluded that sites showed differences as well similarities in FTS growth values.

**HO:3.** For on-farm FTS, all species have equal height and diameter.

This hypothesis tested whether or not the height and dbh growth of on-farm trees measured for three years significantly differed among themselves. Table 2.14.1 shows the ANOVA results. The null hypothesis was rejected and it was concluded that the on-farm species significantly (p=0.01) differed in their mean height and diameter growth measured over a period of three years.

**HO:4.** Different lopping intensities do not result in different foliage yield.

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This hypothesis tested whether or not four foliage lopping intensities (25%, 50%, 75%, and 100% lopping of crown length) applied to randomly selected trees of four FTS significantly affected the third year total foliage yield. Table 2.14 provided the ANOVA of the data obtained. The null hypothesis could not be rejected at P=0.05. It was therefore concluded that the treatments did not affect the final foliage yield of the four FTS tested after two cycles of lopping treatments.

**8.0 DISCUSSIONS AND IMPLICATIONS**

The research trial results have presented standardized FTS evaluation methods. Although sixteen species were included in the trials, not all of them could be tested at all four sites for logistical reasons. Thus popular Midhill species such as *F. hispida*, and *G. pinnata* were not compared with other species in the Inner Tarai and the Tarai. However, several studies (Harrison 1989; and Gajurel *et al* 1987) have indicated their superiority under the Midhills conditions. This study emphasizes the following points:

a) the conventional practice of selecting FTS based solely on their geographic location and native habitat is not necessary;

b) widely adaptive high yielding species should be identified and tested outside their area of local origin;

c) FTS selection should be based on both nutritional and silvicultural considerations. For example, *A. lakoocha* is ve

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very difficult to propagate, and while this species is highly regarded as a fodder tree, there are equivalent or better species available which are much more easier to propagate and more widely adapted to a range of locations;

d) the conventional wisdom recommending only the "top of the line" preferred FTS to farmers is not practical since as yet, we do not know have a meaningful basis to delineate the truly 'best' FTS;

e) farmers should be made aware of trade-offs between nutritional values and total biomass. A particular FTS rich in crude protein (CP) may yield so little foliage that the ultimate nutrition gained will be quite small whereas nutritively poor species may be able, in total, to provide higher fodder protein yield. A case in point is the comparison between *F.semicordata*, and *A.lakoocha*. Although the former has higher CP%, the total digestive nutrient (TDN) derived from a single tree of latter species is quite high;

f) traditional methods of screening FTS based on height and dbh are not suitable; and

g) propagation research for good quality FTS such as *A.lakoocha* should also be carried out.

Traditional methods should be replaced by an assessment method that is based on: 1) fodder (green or dry) weight, 2) crown diameter, 3) fodder to wood ratio, and 4) percent CP

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content. If a single criterion is to be used, crown volume or dry fodder weight is recommended. The use of edaphic and climatic variables in establishing site index appears to have good potential. Establishment of site index values for fodder trees will help improve the management of FTS.

Nepal's demand for forestry products and services has been steadily increasing with the increase in human and livestock population. The effort over the past 20 years regarding afforestation activities and related research has been small, diffused, disorganized, and largely unsuccessful. Ongoing government and private forestry programs are not expected to solve Nepal's current fodder and fuelwood crisis. The major problem is that there is not enough land to plant trees even if there were resources to carry out massive afforestation programs. Under such tremendous pressures, it is evident that the research activities must be carried out within the constraints of the present situation. Selection of high yielding multipurpose tree species (MPTS) of which the FTS are an important part, should be a high research priority. An ideally selected tree should be one which can grow well on poor sites available to the farmers and yield high fodder/fuel production. The current Master Plan of the Government of Nepal states that "improved management of important fodder trees and shrubs in the Tarai, the Midhills, and the Mountains ..remains a most important major program in respect of improved land use, hi

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higher productivity, and meeting the rural population needs" (Wyatt-smith 1987). The plan stresses the need to restrict the species selection to a few key proven species. However, this decision should be based on research results and farmers' choice. The selected species should have both high yield and adequate nutrient contents.

This study has the following implications with regards to influencing future trends and directions in FTS research and development:

a. *F. semicordata, B. variegata*, *Morus* spp., *Litsea monopetala* are potential FTS for the Tarai and Inner Tarai regions of Nepal where the fodder situation is critical and fodder trees are not cultivated as widely as in the Middle Hills. Psyllid-resistant *L. leucocephala* hybrids are still promising MPTS among the farmers of Nepal and should be grown. psyllid resistant lines of *Leucaena* spp. are now available from the Nitrogen Fixing Tree Association, Hawaii (Wheeler and Brewbaker 1990).

b. Variation in individual growth performance by the FTS due to site factors is not significant. Nitrogen is the most commonly found limiting element followed by low $p^H$. Application of organic manure and lime, both of which are easily available in Nepal, can remedy these limitations.

c. There is a need to develop a local FTS or MPTS trial manual stressing the need for different methodology and analytical techniques. Specifically, the manual should pr

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provide guidelines for carrying out research on multiple stemmed spreading trees and shrubs. The data analysis techniques should be simple to follow but powerful enough to detect real differences among the means being compared. It should also not require a large number of observations or mean values.

d. Many of the FTS currently growing in farmers' field are not the ideal trees suitable to the farmers or to their animals. Farmers prefer medium trees with dense crown. Animals prefer trees which produce succulent and protein-rich foliage. Many species currently found on farms are the residual regeneration of the natural vegetation which have been allowed to grow as fodder trees by farmers. There apparently was no selection based on fodder values of the trees. Therefore, there is a need for Fodder Stand Improvement in the private fodder orchards. With the new trend of planting nursery grown saplings, this task can be accomplished provided that the high yielding species are identified and tested before being produced in the nurseries.

e. Finally, as with all field research (especially in developing countries) this study has been carried out within numerous limitations. They include: 1) difficulty in finding ideal trial sites with uniform soil conditions; 2) difficulty in establishing stringent site control on exogenous factors; 3) lack of standard on-farm research me

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methodology; 4) lack of trained research staff; and 5) insufficient time and funds. Therefore wide application of the reported results should be done with caution. Further verification of results should be carried out. However, for general extension and planning purposes the results are expected to be useful.

**9.0 CONCLUSION**

This paper has presented a comparative performance of a large number of fodder tree species in a multi-location trial over a five year period. This is beginning of one of the first such long-term systematic studies carried out in Nepal. Results indicate that conventional thinking, i.e., FTS growing in the Midhills may not do well in the plains (Tarai), needs reexamination. This has a very important practical implication in that the government agencies, driven by this belief, are trying to plant exotic fodder trees in the Tarai. However, the vast number of FTS found in the Midhills, more than 195 in Kathmandu valley alone (Bajracharya *et al* 1985), can provide the necessary fodder germplasm for the Tarai. What is needed is more thorough testing and development of better nursery stock.

There is also a need to utilize the traditional knowledge of the farmers in carrying out species selection. For example, this study indicated that the farmers in the village of Karmaiya (Tarai) have already started planting fodder trees which they used to grow in their previous dwelling

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dwellings in the Hills. The management systems applied are also similar to the ones practiced by the farmers in the Hills and thus there is a spontaneous transfer of technology in progress in some parts of Nepal.

Finally, improving the productivity of the FTS in Nepal will require a comprehensive research and development effort. Fodder stand improvement should include identification of an "ideotype" tree along with the development of its appropriate silviculture and management regimes. There is also a need to develop a better method of incorporating these "ideotype" trees into the complex farming systems of Nepal.

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# APPENDIX 2

Table

| S.no. |
| --- |
| 1 |
| 2 |
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| 16 |

Site C

# APPENDIX 2

**Table 2.1. List of fodder tree species included in the species evaluation trial in central and western Nepal**

| S.no. | Common name | Scientific name | Site code |
|---|---|---|---|
| 1 | Khanayo | *Ficus semicordata* | K, H, R, P |
| 2 | Pakhuri | *Ficus glaberrima* | K, H, P |
| 3 | Nemaro | *Ficus auriculata* | K, H, R, P |
| 4 | Kabhro | *Ficus lacor* | P |
| 5 | Faledo | *Erythrina arborescence* | P |
| 6 | Badahar | *Artocarpus lakoocha* | K, H, R, P |
| 7 | Koiralo | *Bauhinia variegata* | K, H, R, P |
| 8 | Tanki | *Bauhinia purpurea* | K, H, R |
| 9 | Ginderi | *Premna integrifolia* | K, H, P |
| 10 | Ipil-Ipil | *Leucaena leucocephala* | K, H, R, P |
| 11 | Kimbu | *Morus alba/indica* | K, H, R, P |
| 12 | Thotne | *Ficus hispida* | P |
| 13 | Kutmiro | *Litsea monopetala* | K, H, R, P |
| 14 | Phosro | *Grewia oppositifolia* | P |
| 15 | Gayo | *Bridelia retusa* | P |
| 16 | Bedilo | *Ficus clavata* | P |

Site Code: K - Karmaiya; H - Hetauda; R - Rampur; P - Pokhara

District:
Trial Sit

| Tree No. |
|---|
| 1.1 |
| 1.2 |
| 3.1 |
| 1.1 |
| 3.1 |

Notations:

Appendix 2, Table 2.2. Sample data collection form

FODDER TREE MANAGEMENT PROJECT

**FORM A1: GENERAL TREE INVENTORY FORM**

District: MAKWANPUR Block No. ONE Plot No.: 1
Trial Site: NAWALPUR, HETAUDA Date of Recording: 10/01/91 Spp. Name: B.variegata

| Tree No. | Rep. No. | Block No. | Height (m) | D50 (cm) | Aspect | Topography | pH value | Soil Texture | Phenology | Remarks |
|---|---|---|---|---|---|---|---|---|---|---|
| 1.1 | 1 | 1 | 4.6 | 10.9 | s/w | f | 6.4 | LS | 3 tree w/matured leaves | |
| 1.2 | 1 | 1 | 2.4 | 4.5 | s/w | f | 6.6 | LS | 4 tree w/leaves falling | |
| 3.1 | 1 | 1 | 5.2 | 12.1 | s/w | f | 6.4 | LS | 3 | |
| 1.1 | 1 | 1 | 4.5 | 7.4 | s/w | f | 6.7 | SL | 4 | |
| 3.1 | 1 | 1 | 3.8 | 9.8 | s/w | f | 6.0 | SL | 4 | |

otations: s/w - south-west; f- flat; LS - Loamy sand; SL - Sandy loam

Distric
Trial S

| Tree No. |
|---|
| 1.1 |
| 2.1 |
| 3.1 |
| 3.2 |
| 4.1 |
| 5.1 |
| 6.1 |
| 6.2 |
| 1.1 |
| 2.1 |
| 3.1 |
| 4.1 |
| 6.1 |
| 1.1 |
| 2.1 |
| 3.1 |
| 4.1 |
| 5.1 |
| 6.1 |
| 6.2 |

Appendix 2, Table 2.3. Sample data collection form

FODDER TREE MANAGEMENT PROJECT

**FORM A2: FRESH WEIGHT RECORDING FORM**

District: KASKI
Trial Site: LIVESTOCK FARM, POKHARA

Block No. ONE
Date of Recording: 15/1/91

Plot No.: 2
Spp. Name:F.semicordata

| Tree No. | Rep. No. | Block No. | Height (m) | D50 (cm) | Crown Height(m) | Crown Diam(m) | Crown Le'th(m) | Tree Le'th(m) | FW(F) (kg.) | FW(W) (kg.) | FW(T) (kg.) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1.1 | 1 | 1 | 5.4 | 6.0 | 1.0 | 1.2 | 4.4 | 5.5 | 2.1 | 3.6 | 5.7 |
| 2.1 | 1 | 1 | 5.6 | 5.5 | 0.6 | 1.2 | 5.0 | 5.6 | 3.1 | 5.3 | 8.4 |
| 3.1 | 1 | 1 | 5.8 | 8.0 | 0.7 | 1.2 | 5.1 | 5.9 | 2.4 | 4.4 | 6.8 |
| 3.2 | 1 | 1 | 4.1 | 6.0 | 1.0 | 0.7 | 3.6 | 4.2 | 2.2 | 3.0 | 5.2 |
| 4.1 | 1 | 1 | 5.3 | 5.0 | 0.9 | 0.9 | 4.4 | 5.3 | 2.9 | 4.4 | 7.3 |
| 5.1 | 1 | 1 | 5.6 | 8.5 | 0.7 | 1.6 | 4.9 | 5.7 | 4.7 | 6.8 | 11.5 |
| 6.1 | 1 | 1 | 3.4 | 4.0 | 0.6 | 1.5 | 2.8 | 3.5 | 2.9 | 3.5 | 6.4 |
| 6.2 | 1 | 1 | 4.3 | 4.5 | 0.7 | 1.3 | 3.6 | 4.4 | 2.4 | 3.1 | 5.5 |
| 1.1 | 2 | 1 | 5.6 | 9.0 | 0.9 | 1.6 | 4.7 | 5.6 | 4.3 | 12.8 | 17.1 |
| 2.1 | 2 | 1 | 5.7 | 9.0 | 1.3 | 1.7 | 4.4 | 5.7 | 4.1 | 11.3 | 15.4 |
| 3.1 | 2 | 1 | 5.3 | 8.0 | 1.1 | 1.3 | 4.3 | 5.4 | 4.0 | 15.2 | 19.2 |
| 4.1 | 2 | 1 | 4.7 | 8.0 | 1.1 | 0.8 | 3.7 | 4.8 | 2.9 | 4.8 | 7.7 |
| 6.1 | 2 | 1 | 5.2 | 8.0 | 2.1 | 0.5 | 3.1 | 5.3 | 2.6 | 10.6 | 13.2 |
| 1.1 | 3 | 1 | 5.2 | 7.0 | 1.0 | 1.6 | 4.2 | 5.2 | 4.6 | 14.2 | 18.8 |
| 2.1 | 3 | 1 | 3.6 | 4.0 | 1.2 | 1.0 | 2.4 | 3.8 | 2.4 | 5.3 | 7.7 |
| 3.1 | 3 | 1 | 5.5 | 7.0 | 1.8 | 1.7 | 3.7 | 5.6 | 3.7 | 9.4 | 13.1 |
| 4.1 | 3 | 1 | 5.4 | 8.0 | 0.6 | 1.2 | 4.8 | 5.5 | 4.3 | 11.8 | 16.1 |
| 5.1 | 3 | 1 | 5.5 | 7.0 | 0.9 | 2.1 | 4.6 | 6.0 | 6.0 | 12.9 | 18.1 |
| 6.1 | 3 | 1 | 6.0 | 8.0 | 0.6 | 2.0 | 5.4 | 6.0 | 6.3 | 14.7 | 21.0 |
| 6.2 | 3 | 1 | 6.2 | 5.5 | 2.4 | 2.1 | 3.8 | 6.2 | 3.0 | 9.0 | 12.0 |

Table 2

| Species |
| --- |
| L.leuco |
| F.semic |
| B.varie |
| B.purpu |
| F.auric |
| M.alba |
| L.monop |
| P.integ |
| A.lakoo |
| F.glabe |
| All Spe |

**Table**

**A. He**

| Spp. |
| --- |
| AL |
| FS |
| LM |
| BV |
| GP |

**B. Db**

| Spp. |
| --- |
| AL |
| FS |
| LM |
| BV |
| GP |
| BLSD |

## Appendix 2

**Table 2.4. Five year green and dry biomass comparison of pooled data for Karmaiya and Hetauda**

| Species | Green and oven dry biomass (Kg/tree) | | | |
|---|---|---|---|---|
| | green foliage Weight | green wood Weight | dry total Weight | green foliage to to Wd.wt.Ratio |
| L.leucocephala | 11.88 | 35.96 | 22.68 | 1:3.0 |
| F.semicordata | 11.23 | 35.47 | 18.45 | 1:2.4 |
| B.variegata | 4.75 | 11.57 | 6.48 | 1:3.2 |
| B.purpurea | 3.01 | 4.67 | 4.00 | 1:1.6 |
| F.auriculata | 2.59 | 6.94 | 3.17 | 1:2.7 |
| M.alba | 1.98 | 6.41 | 3.90 | 1:3.2 |
| L.monopetala | 1.75 | 2.34 | 1.53 | 1:1.3 |
| P.integrifolia | 1.71 | 5.79 | 2.85 | 1:3.4 |
| A.lakoocha | 1.62 | 2.48 | 1.67 | 1:1.5 |
| F.glaberrima | 1.51 | 1.99 | 1.17 | 1:1.3 |
| All Species | 4.20 | 11.51 | 6.59 | 1:2.7 |

**Table 2.5 Multiple comparison of differences between means of height and dbh increments of on-farm FTS in central and western Nepal**

**A. Height:**

| Spp. ------> | | FA | GP | BV | LM | FS |
|---|---|---|---|---|---|---|
| | Mean ht. | 1.37 | 1.59 | 1.66 | 1.69 | 1.93 |
| AL | 2.63 | 1.26* | 1.04* | .97* | .94* | .70* |
| FS | 1.93 | .56* | .43* | .27 | .24 | |
| LM | 1.69 | .32 | .10 | .03 | | |
| BV | 1.66 | .29 | .07 | | | |
| GP | 1.59 | .22 | | | | |

**B. Dbh:**

| Spp. ------> | | LM | BV | GP | FA | FS |
|---|---|---|---|---|---|---|
| | Mean dbh | 1.81 | 1.91 | 2.53 | 3.82 | 4.51 |
| AL | 9.16 | 7.35* | 7.25* | 6.63* | 5.34* | 4.65* |
| FS | 4.51 | 2.70* | 2.60* | 1.98* | 0.69 | |
| LM | 3.82 | 2.01* | 1.91* | 1.29* | | |
| BV | 2.53 | 0.72* | 0.62 | | | |
| GP | 1.91 | 0.10 | | | | |

BLSD values: Height - 0.34; Dbh - 0.70

Appendi

| Sample |
|---|
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| 20 |
| 21 |
| 22 |
| 23 |
| 24 |

| Sample N |
|---|
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| 6 |
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| 8 |
| 9 |
| 10 |
| 11 |
| 12 |
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| 18 |
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| 20 |
| 21 |
| 22 |
| 23 |
| 24 |

Treatmen

Appendix 2, Table 2.6 Growth and biomass data of on-farm F.semicordata trees selected for lopping intensity trials in central and western Nepal

| Sample No. | Site | Treatment | Height(m) | Dbh(m) | Crown diam(m.) |
|---|---|---|---|---|---|
| 1 | HETAUDA | 1 | 9.6 | 31.3 | 5.5 |
| 2 | HETUADA | 1 | 6.3 | 16.0 | 3.5 |
| 3 | HETAUDA | 2 | 6.2 | 22.6 | 2.8 |
| 4 | HETAUDA | 2 | 11.3 | 33.6 | 5.5 |
| 5 | HETAUDA | 3 | 7.5 | 28.5 | 2.7 |
| 6 | HETAUDA | 3 | 7.0 | 22.6 | 3.2 |
| 7 | HETAUDA | 4 | 11.7 | 23.8 | 3.8 |
| 8 | HETAUDA | 4 | 5.2 | 23.8 | 2.7 |
| 9 | TANAHU | 1 | 6.8 | 21.5 | 2.3 |
| 10 | TANAHU | 1 | 11.6 | 26.5 | 4.0 |
| 11 | TANAHU | 2 | 6.8 | 20.0 | 2.6 |
| 12 | TANAHU | 2 | 6.2 | 20.5 | 2.4 |
| 13 | TANAHU | 3 | 10.2 | 21.0 | 3.6 |
| 14 | TANAHU | 3 | 7.8 | 20.0 | 1.8 |
| 15 | TANAHU | 4 | 5.9 | 19.0 | 2.2 |
| 16 | TANAHU | 4 | 11.7 | 27.0 | 3.4 |
| 17 | POKHARA | 1 | 5.9 | 18.5 | 2.8 |
| 18 | POKHARA | 1 | 6.4 | 24.8 | 2.0 |
| 19 | POKHARA | 2 | 9.7 | 33.5 | 3.7 |
| 20 | POKHARA | 2 | 6.3 | 23.5 | 2.5 |
| 21 | POKHARA | 3 | 5.4 | 20.5 | 2.1 |
| 22 | POKHARA | 3 | 11.2 | 26.0 | 3.8 |
| 23 | POKHARA | 4 | 8.2 | 23.3 | 1.9 |
| 24 | POKHARA | 4 | 5.7 | 21.9 | 2.2 |

contd...

| Sample No. | Site | Tot.dry fol. fol. wt.(kg.) | Tot.dry bra. wt. (kg.) | Tot.dry wt. wt. (kg.) | Tot.green wt. wt. (kg.) |
|---|---|---|---|---|---|
| 1 | HETAUDA | 17.3 | 23.5 | 40.8 | 103.7 |
| 2 | HETUADA | 9.4 | 12.0 | 21.4 | 54.2 |
| 3 | HETAUDA | 7.8 | 8.2 | 16.0 | 40.4 |
| 4 | HETAUDA | 23.0 | 28.2 | 51.2 | 129.4 |
| 5 | HETAUDA | 9.5 | 12.3 | 21.8 | 55.4 |
| 6 | HETAUDA | 10.3 | 12.9 | 23.2 | 58.8 |
| 7 | HETAUDA | 11.8 | 19.9 | 31.7 | 81.7 |
| 8 | HETAUDA | 8.3 | 7.5 | 15.8 | 39.3 |
| 9 | TANAHU | 5.1 | 6.2 | 11.3 | 28.4 |
| 10 | TANAHU | 21.8 | 19.6 | 41.4 | 102.8 |
| 11 | TANAHU | 7.4 | 9.1 | 16.5 | 41.8 |
| 12 | TANAHU | 4.1 | 6.4 | 10.5 | 26.8 |
| 13 | TANAHU | 12.6 | 13.9 | 26.5 | 66.7 |
| 14 | TANAHU | 6.0 | 8.4 | 14.4 | 36.6 |
| 15 | TANAHU | 4.5 | 5.1 | 9.6 | 24.2 |
| 16 | TANAHU | 12.7 | 14.6 | 27.3 | 68.6 |
| 17 | POKHARA | 9.4 | 12.0 | 21.4 | 54.2 |
| 18 | POKHARA | 3.8 | 4.8 | 8.6 | 21.9 |
| 19 | POKHARA | 13.0 | 11.7 | 24.7 | 61.2 |
| 20 | POKHARA | 8.6 | 6.3 | 14.9 | 36.5 |
| 21 | POKHARA | 3.7 | 3.0 | 6.7 | 16.4 |
| 22 | POKHARA | 11.4 | 15.0 | 26.4 | 67.2 |
| 23 | POKHARA | 8.1 | 6.0 | 14.1 | 34.7 |
| 24 | POKHARA | 4.0 | 4.5 | 8.5 | 21.3 |

Treatment codes: 1 - 100% lopping; 2 - 75% lopping; 3 - 50% lopping; and 4 - 25% lopping based on the crown length measurements.

Table 2

| Site & item |
|---|
| NETUADA |
| DM |
| OM |
| TA |
| CP |
| Cell so |
| Cellulo |
| Hemicel |
| Lignin |
| TAMAHU |
| DM |
| OM |
| TA |
| CP |
| Cell so |
| Cellulo |
| Hemicel |
| Lignin |
| POKHARA |
| DM |
| OM |
| TA |
| CP |
| Cell so |
| Cellulo |
| Hemicel |
| Lignin |

DM - dr

Appendix 2

Table 2.7. Nutrient contents of important fodder leaves from three different sites in central and western Nepal

| Site & item | A.lakoocha | B. variegata | F.semicordata | F.hispida | F.lacor | G.pinnata | L.monopetala |
|---|---|---|---|---|---|---|---|
| | Percent nutrient content in fodder dry matter by species | | | | | | |
| **HETUADA** | | | | | | | |
| DM[1] | 26.60 | 35.00 | 35.60 | 33.20 | 29.80 | 29.00 | 38.40 |
| OM | 89.69 | 94.31 | 91.44 | 84.42 | 90.90 | 94.04 | 93.76 |
| TA | 10.13 | 5.69 | 8.56 | 15.58 | 9.10 | 5.96 | 6.24 |
| CP | 19.82 | 19.70 | 13.02 | 20.85 | 16.81 | 21.09 | 17.84 |
| Cell sol.content | 37.61 | 60.43 | 39.73 | 54.44 | 38.99 | 62.87 | 38.52 |
| Cellulose | 28.23 | 17.20 | 27.41 | 21.57 | 25.26 | 16.41 | 20.31 |
| Hemicellulose | 6.85 | 4.17 | 9.54 | 10.31 | 4.50 | 3.90 | 5.52 |
| Lignin | 27.31 | 18.20 | 23.32 | 13.68 | 31.25 | 16.82 | 35.65 |
| **TANAHU** | | | | | | | |
| DM | 31.20 | 28.60 | 25.60 | 28.60 | 32.40 | 25.00 | 26.60 |
| OM | 93.80 | 93.80 | 91.82 | 89.72 | 91.02 | 92.85 | 90.30 |
| TA | 9.37 | 6.20 | 8.18 | 10.28 | 8.98 | 7.15 | 9.70 |
| CP | 18.73 | 19.32 | 14.80 | 20.94 | 19.28 | 19.27 | 20.96 |
| Cell sol.content | 39.50 | 35.61 | 48.57 | 50.43 | 38.01 | 50.99 | 38.33 |
| Cellulose | 29.25 | 25.07 | 22.96 | 23.91 | 41.71 | 28.23 | 22.62 |
| Hemicellulose | 5.75 | 6.74 | 3.58 | 10.57 | 6.01 | 8.91 | 7.12 |
| Lignin | 25.50 | 15.50 | 30.93 | 15.18 | 21.27 | 11.87 | 31.93 |
| **POKHARA** | | | | | | | |
| DM | 29.20 | 19.0 | 30.00 | 21.20 | 27.60 | 35.0 | 22.60 |
| OM | 90.63 | 88.15 | 93.33 | 88.44 | 90.46 | 92.50 | 94.96 |
| TA | 9.37 | 11.85 | 6.67 | 11.56 | 9.54 | 7.50 | 5.04 |
| CP | 18.73 | 21.74 | 14.05 | 21.65 | 17.18 | 20.94 | 19.20 |
| Cell sol.content | 53.38 | 55.86 | 42.71 | 49.25 | 33.57 | 55.47 | 37.10 |
| Cellulose | 27.43 | 24.72 | 25.58 | 24.52 | 30.47 | 17.32 | 18.00 |
| Hemicellulose | 8.11 | 10.59 | 7.19 | 10.24 | 10.65 | 7.67 | 5.83 |
| Lignin | 11.08 | 8.47 | 24.52 | 15.99 | 23.31 | 19.54 | 39.07 |

DM - dry matter; OM - organic matter; TA - total ash; CP - crude protein;

*Appendix 2. Figure 2.1* **Experimental layout of fodder tree species evaluation trial at Karmaiya and Hetauda based on randomized block design**

Appendix 2. Figure 2.1 Experimental layout of fodder tree species evaluation trial at Karmaiya and Hetauda based on randomized block design

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# FODDER TREE SPECIES EVALUATION TRIAL (1985-1991)

LAYOUT PLAN FOR RANDOMIZED BLOCK DESIGN

SITES: KARMAIYA AND HETAUDA

TREATMENT LEVELS: TEN (10)

TRIAL AREA : 0.5 Ha.

NUMBER OF BLOCKS: THREE (3)

NUMBER OF REPLICATIONS: TEN (10)

NO. OF PLANTS/REP.: FOUR (4)

ANOVA TABLE

| SOURCE | DF | SS | MS | F |
|---|---|---|---|---|
| SPECIES | 9 | | | |
| BLOCK | 2 | | | |
| ERROR | 18 | | | |
| TOTAL | 30 | | | |

SPP. CODES: 1-MA; 2-LM; 3-BV; 4-FS; 5-PI
6-BP; 7-FA; 8-FG; 9-AL; 10-LL

* EACH NUMBER REPRESENTS A PLOT OF FOUR TREES

LAYOUT PLAN

↑N

| | | |
|---|---|---|
| * 6 9 1 8 3 2 10 7 5 4 | 5 6 9 1 2 10 4 7 8 3 | 4 8 2 9 6 5 3 10 1 7 |
| 7 4 5 3 8 10 6 1 4 2 | 9 10 4 6 1 3 2 5 7 8 | 10 1 7 6 9 8 2 4 3 5 |
| 2 5 6 10 9 7 4 3 9 1 | 4 8 2 9 6 5 3 10 1 7 | 7 4 5 3 8 10 6 1 4 2 |
| 8 2 3 7 4 1 9 6 5 10 | 1 3 7 5 10 4 8 9 2 6 | 8 2 3 7 4 1 9 6 5 10 |
| 3 7 10 5 4 8 1 2 6 9 | 6 9 1 8 3 2 10 7 5 4 | 5 6 9 1 2 10 4 7 8 3 |
| 5 6 9 1 2 10 4 7 8 3 | 2 5 6 10 9 7 4 3 9 1 | 9 10 4 6 1 3 2 5 7 8 |
| 9 10 4 6 1 3 2 5 7 8 | 10 1 7 6 9 8 2 4 3 5 | 2 5 6 10 9 7 4 3 9 1 |
| 4 8 2 9 6 5 3 10 1 7 | 3 7 10 5 4 8 1 2 6 9 | 6 9 1 8 3 2 10 7 5 4 |
| 1 3 7 5 10 4 8 9 2 6 | 8 2 3 7 4 1 9 6 5 10 | 1 3 7 5 10 4 8 9 2 6 |
| 10 1 7 6 9 8 2 4 3 5 | 7 4 5 3 8 10 6 1 4 2 | 3 7 10 5 4 8 1 6 2 9 |

Appendix 2. Figure 2.2 Experimental layout of fodder tree species evaluation trial at Rampur and Pokhara based on completely randomized design

**Appendix 2. Figure 2.2 Experimental layout of fodder tree species evaluation trial at Rampur and Pokhara based on completely randomized design**

# FODDER TREE SPECIES EVALUATION TRIAL (1985-1991)

## LAYOUT PLAN FOR COMPLETELY RANDOMIZED DESIGN

Date of plantation: June, 1986

Sites: Rampur, Pokhara

Number of Species - 8 & 12

Spacing (plant to plant) - 2.5 meter

Number of Replication: three

Number of lopping treatments: three

Number of plants per replication: 128 & 72

ANOVA OUTLINE

| SOURCE | DF | SS | MS | F |
|---|---|---|---|---|
| TOTAL | 31 | | | |
| SPECIES | 7 | | | |
| ERROR | 24 | | | |

EXPERIMENTAL LAYOUT: Rampur

Spp. Notations:

- * 1: Morus alba
- 2: Litsea monopetala
- 3: Bauhinia variegata
- 4: Ficus semicordta
- 5: Bauhinia purpurea
- 6: Ficus auriculata
- 7: Artocarpus lakoocha
- 8: Leucaena leucocephala

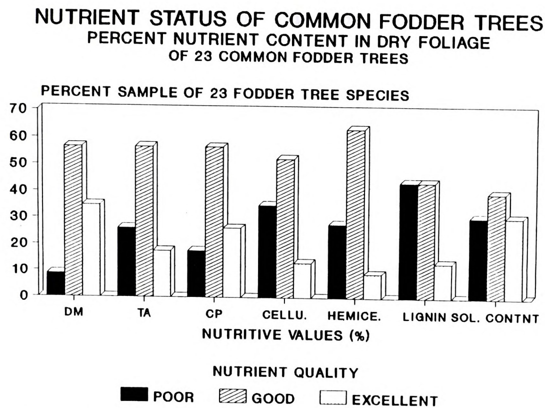
↑N

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 4 | 1 | 7 | 3 | 8 | 5 | 2 | 6 |
| 2 | 4 | 6 | 7 | 8 | 3 | 1 | 5 |
| 5 | 4 | 1 | 3 | 2 | 8 | 6 | 7 |

* Indicates a plot of 16 plants

Appendix 2. Figure 2.3 Percent nutrient contents of 23 common fodder tree species foliage in sample trees of central and western Nepal

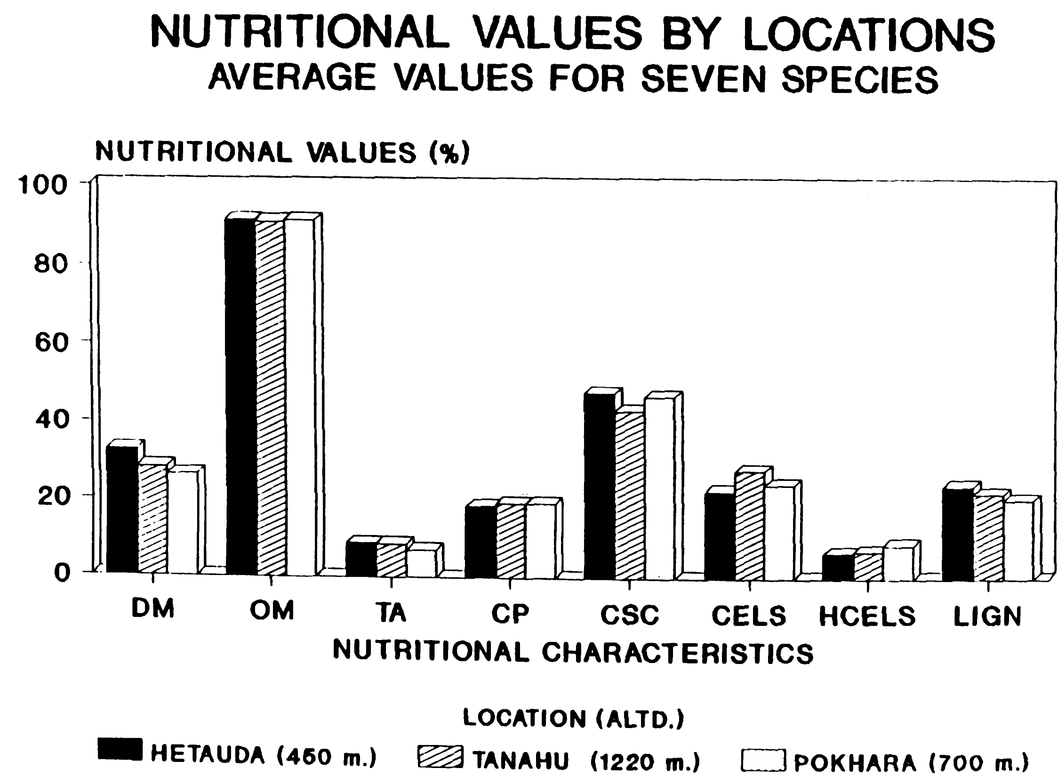
**Appendix 2. Figure 2.3 Percent nutrient contents of 23 common fodder tree species foliage in sample trees of central and western Nepal**




Notations: DM - dry matter; TA - Total ash; CP - crude protein CELLLU - Cellulose; HEMICE - Hemicellulose; SOL.CONTNT - Cell soluble content

*Appendix 2. Figure 2.4* **Percent nutrient contents of common fodder tree species in three locations in central and western Nepal**

**Appendix 2. Figure 2.4 Percent nutrient contents of common fodder tree species in three locations in central and western Nepal**




Notations: DM-dry matter; OM-organic matter; TA-Total ash;CP-crude protein; CSE-Cell soluble content; CELS-Cellulose; HCELS-Hemicellulose; LIGN-lignin

**PR**
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## CHAPTER III

## PREDICTING BIOMASS IN FODDER TREES USING INDIVIDUAL-TREE MODELS: CASE STUDIES OF *Ficus semicordata* and *Bauhinia variegata* TREES FROM NEPAL

### Abstract

Allometric regression equations were developed to predict fodder, total wood, and total biomass yield of two high yielding fodder tree species (FTS) - *Ficus semicordata, and Bauhinia variegata* - of central and western Nepal. Individual-tree models were selected as most fodder tree species are managed on an individual-tree basis. Data were gathered from experimental plots and farmer's fields. Logarithmic transformations of both dependent and independent variables gave the best estimates of dry foliage, total wood, and total biomass. Two different sets of regressor variables comprised the best fitting equations for the two species. For *F.semicordata*, crown diameter and total height best predicted the component and total biomass ($R^2$>.80). For *B. variegata*, however, diameter at 50 cm. *(d50)* for trees less than five years of age and dbh for mature trees explained most of the variation in component and total biomass ($R^2$>.81). To develop regional biomass models, site specific equations were developed for four sites. Three of the site models were found to have similar slopes and intercepts. Therefore, data from all four sites were pooled together and a single model was developed for each of the two species. Two types of models were developed to meet the needs of widely varying structure of tree populations in the region. The models developed from the experimental data were recommended for younger trees, and models based on on-farm trees were suggested for older trees. Based on these models, regional fodder and fuelwood biomass tables were prepared. The information generated by these models and tables are expected to help fill information gap for improving the management of fodder trees in Nepal. Further studies are needed to validate and refine these preliminary models.

### 1.0 INTRODUCTION

The importance of understanding of trees on a whole tree basis for better utilization of their products can not be overstressed. Whole tree harvesting has been reported to increase yields by as much as 33% over conventional

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roundwood harvests (Baumgras 1980). However, realizing this potential in fulfilling the increasing needs of fuelwood, fodder, and timber products will require better estimation of whole tree biomass. This paper discusses the use of regression analysis for biomass estimation in community forest and private farm lands. Biomass refers to the amount of foliage and wood matter accumulation at a specified point in time. Biomass is increasingly being used as a unit of measurement in the evaluation of multi-purpose tree species (MPTS) including fodder tree species (FTS). Conventional forestry measures of stem diameter and volume are inadequate or inappropriate for assessing the potential of species that produce both fodder and fuelwood. In many new community and private plantations, the main emphasis is on fodder and fuelwood production. Assessment of total biomass provides important management information.

Simple techniques are required to overcome the difficulty of estimating production of many multi-stemmed, highly branched species. Regression analysis is the most common procedure for estimating tree biomass composed of fresh foliage (leaves, twigs, and succulent branches) and branch and stem wood matter (Kozak 1970; Mohns *et al* 1988; Harrison 1989; Stewart 1990). Oven dry foliage and wood weights may be estimated from measurements of fodder tree (both native and exotic species) growth parameters. Most of the emphasis in estimating biomass has been directed at individual trees,

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because such trees are often managed on an individual tree basis. Besides, majority of yield models are for trees and not stands.

Volume and biomass models consist of equations or tables that describe how tree volume or biomass varies based on easily measurable tree variables such as stem diameter, tree height, and crown dimension. Biomass tables differ from volume tables in that they use units of weight instead of volume. This paper discusses the use of logarithmic regression to estimate fodder and woody biomass weights of individual tree. Individual stems of sample trees were destructively sampled and weight of foliage and wood components were determined. Least square linear allometric models were used because predictions from the allometric equations can be extrapolated more readily than simple linear or weighted linear equations (Crow and Schlaegel 1988).

The analysis was based on information gathered from four different experimental sites which are: Karmaiya, Hetauda, Rampur and Pokhara (Figure 3.1). The data were used to develop both individual-tree (local) and combined (regional) biomass models. Fodder and wood dry weight tables were prepared based on the developed models. Validation of the models were done by splitting the data as well as by using independently collected information from farmers' field.

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## 2.0 OBJECTIVES AND HYPOTHESES

### 2.1 General objectives:

- to develop a fodder biomass prediction model using experimental and historical (on-farm) data.

- to demonstrate an application of these methods for two high yielding fodder tree species (i.e. *Ficus semicordata* (Buchattam. ex Sm.) and *Bauhinia variegata*, Linn.) in central and western Nepal.

- to suggest modeling techniques for predicting growth and yield for other commonly grown fodder tree species in Nepal.

### 2.2 Specific objectives:

- to develop and test a set of regression equations to estimate total foliage biomass (kg.) of individual trees as a function of physiological, climatological, and management variables.

- to use regression equations to estimate fodder, wood, and total biomass per tree by individual ecological zone (e.g.Tarai, Inner Tarai, and the Middle Hills).

- to apply the final regression equations to independently collected on-farm data in order to validate the models.

- to develop regional fodder and fuelwood weight tables using the final regression models.

**2.3 Hypotheses:** Major issues confronted in improving fodder tree management include: a) non-availability of local and general volume or weight tables of major fodder tree species; b) lack of knowledge about the suitable predictor variables; and c) lack of a standard methodology for growth and yield modeling. Addressing these issues was the goal of the modeling study. Hypotheses were set up to establish relationships between variables, identify key variables, and answer management related questions. The major hypotheses were:

**HO.1:** fodder, total wood, and total aboveground biomass are independent of total height and tree diameter;

**HO.2:** crown diameter, crown length and crown height are not good predictors of the fodder weight and wood weight;

**HO.3:** biomass models do not vary among species but do vary among the sites;

**HO.4:** precipitation, temperature, relative humidity and percent soil organic matter are not related to fodder and wood biomass;

**HO.5:** lopping intensity does not influence fodder biomass;

**HO.6:** a single allometric model is adequate to estimate component and total biomass of *Ficus semicordata* and *Bauhinia variegata* trees.

## 3.0 LITERATURE REVIEW

### 3.1 Theory of growth and yield modeling:

**3.1.1 Definitions:** Growth is the increase in diameter, basal area, height, volume, quantity (or weight) or value of individual trees or stands during a given period (SAF 1958). Yield is total amount available for harvest at a given time (Avery and Burkhart 1983). A growth model is a mathematical function, or system of functions, used to relate actual growth rates to measured tree stand and site variables. Estimation is the statistical process of deriving regression coefficients for models which define the growth rates as a function of tree, stand, and site variables.

**3.1.2 Concepts:** The concept of growth and yield modeling originated with yield tables used in Germany during the 18th century (Munro 1974). The first forest growth models, developed late in the 19th century, were based primarily on graphical descriptions and interpretations (Munro 1974). Advances in the theory of mathematical analysis and devel

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development in computing technology have changed the concept of growth models by reducing the time taken to solve sophisticated equations. Currently, models are developed to meet specific needs of forest managers in their daily work.

**3.2 Model Classification:** In general, growth models attempt to produce, at some point or points in simulated time, summaries (tables, graphs etc.) which indicate the state of a tree or stand on a per unit tree or area basis in much the same manner as do conventional inventory statistics (Munro 1974). Growth models can be distinguished on the basis of two features: inter-tree dependency status and primary unit parameter requirement (such as single tree or stand). Munro (1974) suggested the following broad classification of growth models:

1. Whole stand models
2. Single tree models
    a. distance-dependent
    b. distance-independent

**3.2.1 Whole stand models:** The conventional normal yield table is an example of a stand model. However, it bears little resemblance to modern models of the same type. Most of the current stand models provide necessary stand information for economic analysis. These models simulate different forest management practices, often involving economic criteria to determine present net worth of the proposed practices. The advantages of these models are their ab

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ability to utilize conventional inventory information, their fast computation, and their simplicity (Munro 1974). However, lack of individual tree information is one of their disadvantages. Their applicability in FTS is limited, as fodder trees are generally managed on an individual tree basis.

**3.2.2 Single tree/distance-dependent models:** Most of these models assume that the amount of competition to which a tree is subjected to is proportional to the amount that the competition circle of the subject tree is overlapped by competition circles or polygon of neighboring trees (Munro 1974). The competition circle is defined as some function of dbh. Newnham (1964) initiated this approach in constructing a stand model. He tested the effects of various spatial distributions of mortality. Lin (1970) used this concept to demonstrate that the competition a tree has undergone in the past five years is a useful variable in assessing the growth of that tree for a subsequent five years.

Bella (1971) demonstrated a workable, iterative algorithm for defining the limits of competition effects. Mitchel (1969) suggested that branch growth could be used as a governing variable of biomass. Arney (1972) demonstrated the use of bole and crown growth to estimate aboveground biomass. Although these models are capable of producing very detailed information about a tree or stand structure calculation of a meaningful biological measure of

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competition are difficult, and these models need detailed stand information. Distance-independent models have shown that much of the information thought possible only from distance dependent models can be obtained without inter-tree distance measurements. As such, the application of distance-dependent models in FTS is considered limited due to lack of knowledge of interplant competition. Since MPTS (including FTS) are rarely managed in stands, the applicability of distance-dependent models is not justifiable in managing these trees. Therefore, these models were not considered.

**3.2.3 Single tree/distance-independent models:** Since one of the major objectives of yield prediction models in FTS is to create biomass tables for individual trees, the individual tree/distance independent allometric modeling approach was selected for this research. The basic difference between these models and distance-dependent models is the absence of the requirements for inter-tree distance measures. Under this approach, trees are grown (height and diameter) individually, or in groupings of similar diameters and species, according to a mathematical function. Techniques of assigning and assessing growth and mortality differ from model to model and also from modeler to modeler (Munro 1974). The models vary from a simple regression type (Lemon and Schumacher 1962) where periodic dbh growth is expressed as a function of stand competition, site and existing tree size, to complicated stochastic models (Dress 1970). These model

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models are generally more economical in terms of computer resources than the other two model type, although stand level models are sometimes equally or less expensive. Single tree models, however, may provide a less realistic and detailed representation of the inter-tree competitive processes (Clutter *et al* 1983). For gross yield projections, there is no specific advantage in using more complex distance-dependent models. The analytical modeling approach is not suited for FTS, as all the biological estimators have not yet been developed to the stage where biomass and biomass growth can be identified as individual cells and cell wall thickening and aggregated into trees with detailed dimensions of interest to resource managers (Ford 1987). In FTS management, single tree biomass tables will be useful if allometric relationships can be established between fodder weight and an easily measured variable such as diameter or crown diameter.

Distance-independent models may be further divided into conceptual and empirical models. The former are based on the development of quantitative theory and mathematical compatibility in growth and yield functions. The empirical model searches for a "best" growth expression function, commonly through a regression approach, and models are developed without rigorous attention to mathematical sophistication (Munro 1974). Empirical models are however, data driven (Ramm 1992).

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Most mathematical models are used to produce detailed tree and stand information. Each tree is measured for its species, height, diameter, and crown class. Other variables including crown diameter, volume, or biomass may be derived by allometric relationships with tree diameter and height. Dynamic tree variables such as diameter are predicted from an equation based on diameter at the last (t-1) time period, and some measure of stand density, such as basal area.

**3.3 Data requirements:** In order to construct individual-tree models, data are collected from permanent or temporary plots as well as from experimental plantations. Proper inventory of the tree population is important because the fit of an equation relating diameters or heights of a multi-stemmed tree to biomass improves as more stems are included. Large trees or stems may contribute most to the biomass, therefore data collected must cover all the height or diameter class in proportion to population distribution. In FTS, since majority of trees are multi-stemmed, data are needed for individual stems for modeling.

The sample size should be determined based on the variation of tree growth parameters in the population. The following points are considered important while fitting the model: a) selecting a function that produces an appropriately shaped curve; b) fitting the data using a suitable and adequate statistical and/or graphical technique together with an examination of residuals for detecting bias;

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bias; and c) applying the model to extrapolate relationships at a wider scale with greater accuracy. A major advantage of distance-independent models lies in the elimination of the necessity for stem charts[1]. They are highly flexible but they require considerable skill in data analysis on the part of the researcher. The literature reviewed below will describe the various approaches upon which the present research was based.

**3.4 Literature relevant to biomass modeling:**

**3.4.1 Assessment of fodder tree productivity:** There is a general trend in fodder biomass literature to report fodder productivity through individual plant height and diameter measurements (Applegate et al 1985; Thapa et al 1989; Sapkota 1987; Dixit 1987; Harrison 1989). During the last ten years, attempts have been made to explore the importance of other variables such as crown length, crown diameter, and diameter at 30 cm (d30) (Wormald et al 1983; Mohns et al 1988; Karki and Tuladhar 1988). However, few studies have yet developed a standard set of indicators to be used to objectively assess fodder productivity both on an individual tree or on an orchard basis on a scale befitting the needs of a diverse group of users.

Regression models or yield tables are potential tools to estimate productivity on a regional scale (MFSC 1988). Based

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on the needs of researchers, extension personnel and farmers, the construction of standard fodder weight tables (both local and general) of important FTS is possible through direct measurement techniques. The theoretical foundation for such modeling can be drawn from the established procedures followed in traditional forestry disciplines to carry out growth and yield modeling.

**3.4.2 Attempts at fodder yield standardization:** Unlike traditional forestry, obtaining data on the long-term growth of individual fodder trees is not yet possible due to lack of adequate data. Until now, only a limited number of trees of a few species have been used to develop standardized fodder yield predictions (Wormald et al 1983; Thapa et al 1989; Harrison 1989). Such studies have also lacked proper experimental design, particularly in meeting statistical requirements such as replication and randomization. Harrison (1989) noted that height alone was not a good index of the performance of fodder trees. In recent years, Wormald *et al* (1983); and Karki and Tuladhar (1988) have suggested the use of dbh, collar diameter, crown height and crown diameter based weight tables to predict yield. These approaches are based on the hypothesis that larger crowns produce larger yield. But this approach still ignores growth rates (Heuch 1986).

Human influence, particularly seasonal lopping, is another major constraint in assessing the standard

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productivity rates of fodder trees (Mohns *et al* 1988). Malla (1977) reported that yield estimates based on crown dimensions varied from 10-50 tons/ha/yr (fresh weight) for individual trees, primarily due to variation in tree shape. With a large variation in the silvicultural characteristics of the fodder tree species, it is very difficult to devise one standard method to measure productivity. Yet there is so much discrepancy in reported yield of different trees by different authors that a search for a standard method has become imperative.

A study aimed at establishing a relationship between direct measurements (dbh, collar diameter, crown height, crown diameter, tree height, etc) and indirect measurements (fresh and dry weight) should yield usable information for fodder tree management. Karki and Tuladhar (1988) proposed preliminary regression models to estimate the fodder productivity of *F. semicordata* and *B. variegata* based on the sampling of 2.5 year old trees grown on trial plots. The models predicted fodder weight as a function of stem height, stem volume and basal diameter. For trees growing on farmer's fields, the authors suggested basal diameter, dbh and crown diameter be used as predictor variables. These variables independently were found to explain more than 70% variation in fodder yield in on-farm *Garuga pinnata* trees.

Ideally a growth model for an individual multipurpose tree, such as a fodder tree, should consist of a relatively

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simple set of relationships between environmental and physiological responses (Harrington 1988). As long as the environment can be measured and plant parameters estimated, growth can be modeled as a function of the environment (Reed 1980) and plant parameters. Among tree models, volume and biomass models are the most common. They describe relationships between tree volume or biomass and easily measurable dimensions such as stem diameter and height (Pukkala *et al* 1990). The quantity of branches and foliage are usually stated as biomass, since it is a more useful measure than volume (Hawkins 1987).

**3.4.3 Key variables:** Biomass equations contain two classes of variables - a single dependent variable and one or more independent or predictor variable. The biomass components selected should allow for yield estimation of multiple products such as fodder and fuelwood. The biomass of a tree is generally measured in weight, both green and dry, since it is difficult to measure the volume of a multitude of limbs, twigs, and foliage. The green and dry weights among trees with identical dbh and total height can vary significantly, between and within species, due to difference in moisture content, specific gravity, stem form, and crown size. Oven dry weight is the most replicable and exacting biomass characteristic (Pukkala *et al* 1990) and should be used when evaluating productivity for fodder yield. The

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standard method is to make assessment on an oven dry weight basis (Young and Carpenter 1967).

Most distance-independent individual tree models are a function of age, height, diameter and site index. Estimates can be made of changes over time of tree diameter, height, form, volume, and or changes in the number of trees per unit area. These system "driver" variables (input data which affects the rate at which state variables change over time) are based on tree species, age, land quality, climate, area history, and vegetation present. The decision variables (such as volume or biomass) are predicted as functions of the driver variables. If the estimate of biomass yield is for a single species in a limited geographic area, other species are excluded and the specific information on climate, soils, and species characteristics are used (Bruce and Wensel 1984).

Beck (1973) used multiple regression techniques to relate diameter growth to initial diameter, age, site index, and several indices of competition for individual Yellow-Poplar (*Liriodendron tulipifera* L.) trees growing in pure stands of natural origin in North Carolina over a 5-year period. A wide variety of regression techniques (Draper and Smith 1981; Myers 1990) have been used to screen variables and analyze interactions of their relationships. Jacobs and Monteith (1981) compared regression equations for total above stump dry weights of a number of tree species, inclu

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including spruce (*Picea spp.*), white pine (*Pinus strobus*), and maples (*Acer spp.*). Comparisons were made for trees from Maine, New York, and West Virginia, and the authors concluded that weight was significantly related to dbh and total height.

Baskerville (1972) used logarithmic regression to estimate plant biomass. He destructively sampled 102 balsam fir (*Abies balsamea*) tree stems and predicted the weight of each tree component by regressing it against various dimensions of the standing tree. The author recommended the use of logarithmic variable transformation techniques when necessary assumptions of regression analysis were not met. He also provided a method of converting logarithmic estimates to arithmetic units. Sprugal (1983) described a method of correcting bias in log-transformed allometric equations. Brown (1976) determined regression relationships between live and dead crown weight and dbh, crown length, tree height, and crown ratio. Strong correlations resulted for functions having dbh as the only independent variable. However, for most species, the addition of height, crown length, and especially crown ratio improved precision. Site index and stand density also improved precision for some species.

**3.4.4 Estimating biomass by tree components:** In recent years, biomass estimates have been reported by components, e.g., roots, branches, foliage. Chiyenda and Kozak (1984), Moh

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Mohns *et al* 1988 and Corbyn *et al* (1988) have described procedures to estimate both component and total biomass of individual trees. However, since the amount of root material is of little practical significance to the farmer, biomass studies generally deal with aboveground biomass (Mohns *et al* 1988). Linear regression equations are used to model biomass of the individual components (tree product) of interest and total biomass is predicted by summing the individual estimates (Chiyenda and Kozak 1984). General methods for biomass estimation have been extensively described (Parde 1980; Satoo and Madgwick 1982). Regression analysis is a common method because of its simplicity in determining estimates and the ease with which results can be applied. It relates easily measurable variables such as diameter and height to the component biomass of the tree or stands (Baskerville 1972; Madgwick and Satoo 1975).

**3.5 Yield prediction models:** The simplest individual tree yield prediction model expresses yield per tree as a function of age, site index, basal area, and other characteristics of the tree and surrounding environment. Clutter *et al* (1983) subdivided yield prediction models into current yield prediction and future yield prediction. Current volume, for example, is obtained from the current values of age, site index, and basal area. Future projections can be estimated by solving the equation with appropriate values for site index, future age, and the pred

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predicted basal area, height, or diameter at the projected age.

**3.6 Biomass estimation techniques:** Tree weight or biomass equations are developed in the same way as volume equations. Trees are destructively sampled and the weight of each component is determined and related by regression to standing tree dimensions. This method is also known as the mean-tree method and is based on the identification of the mean tree of the population by some easily measured parameter, usually basal area, and its subsequent felling and weighing (Thompson 1990). Tree weight is more difficult to predict because its weight per unit volume can vary with geographic location, age, size, growth rate, moisture content, specific gravity, and species type (Clark 1983). For estimating total-tree and tree component biomass, researchers have used diameter at breast height, total height, height to a 4-inch top, diameter at base of live crown, height to base of crown, crown length, crown ratio, form class, and other easily measured tree dimensions. According to Applegate *et al*. (1985), diameter at breast height is the best predictor variable for species that do not develop multiple stems or branches at or near ground level. Nevertheless, the dimensions traditionally used to predict volume, namely dbh and some measure of height, are still the best predictors of above-stump total tree, stem and crown weight (Clark 1983; Applegate *et al* 1985; Hawkins

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1987; Mohns *et al* 1988; Thapa *et al* 1989; Pukkala *et al* 1990). Studies in the Southeast United States have shown that total height, height to a 4-inch top, and sawlog merchantable height are all highly correlated with total tree, stem, and crown weight when used with dbh as independent variables (Clark 1981). Equations developed for a wide geographic application require both dbh and height as independent variables to predict tree weight accurately (Crow 1978; Honer 1971).

Most of the above studies have shown that foliage and crown weight, the major focus of this study, are more variable and difficult to estimate than total tree and stem weight. Researchers who have examined the relationship of crown weight with other tree variables have found stem diameter at the base of the live crown to be the best single predictor of crown weight in both conifers (Storey *et al* 1955; Brown 1971; Ralston 1973) and hardwoods (Storey and Pong 1957; Phillips and Cost 1979). Research results from the southeastern U.S. agree with these findings (Clark 1981). However, diameter at base of a live crown has limited application because it is not easily measured on standing trees (Crow 1978; Loomis *et al* 1966). Mohns *et al* (1988) found that the overbark diameter at 30 cm above ground *(d30)* was a superior predictor variable than dbh for small tree biomass. Stewart (1990) reported that height gave a poorer fit than diameter. Diameters measured at 0.3m and 0.5m were better predict

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better predictors ($R^2$ >.9) than diameter at 0.1m. **3.7 Analytical techniques:** In most cases, the predicted variable, dry foliage or wood weight, is expressed as a function of dimensional variables, such as diameter and tree height, in the power (allometric) equation: $Y=aX^be$ or $Y=aX_1^bX_2^ce$. The most common procedure for estimating biomass in individual trees is through the use of least square regression equations (Cunia 1981; Cunia and Briggs 1984; Kozak 1970). Whittaker and Woodwell (1968) refer to this technique as dimensional analysis and Kira and Shidei (1967) use the term allometry[2]; both refer to the process where dry weight is determined from destructive sampling and related by least square regression analysis to easily measured tree dimensions such as dbh or a combinations of dbh and tree height. Freedman (1984) demonstrated the ability of the allometric model to predict aboveground biomass accurately for a variety of woody plants. Clutter *et al* (1983) have summarized recommended techniques for fitting volume and weight prediction models to individual trees or plots.

**3.8 The model:**

The general linear model can be written as:

$$Y_j = \beta_0 + \beta_1 X_{1j} + \beta_2 X_{2j} + \ldots + \beta_m X_{mj} + \epsilon_j$$

where,

[2] Allometry explains the relative growth of a part of a tree in relation to the growth of another part of the whole tree.

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$X_{1j}, X_{2j}, \ldots\ldots\ldots$

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$\beta_0, \beta_1, \ldots\ldots\ldots, \beta_m$ = parameters of the model
$X_{1j}, X_{2j}, \ldots\ldots\ldots, X_{mj}$ = values of the predictor (independent) variable for the *j*th population element.
$Y_j$ = value of the dependent variable for the $_j$th population element.

The quantity $\epsilon_j$ represents a random error term that expresses the difference between $Y_j$ and the predicted Y values. The random variable $\epsilon$ is assumed to be additive to the model and randomly distributed with mean 0 and constant variance $\sigma^2$. From an analysis standpoint, $\beta_0, \beta_1, \ldots, \beta_m$ and $\sigma 2$ are the population model parameters to be estimated from the data. The known constants are the value of the predictor variables. The random variable Y has a distribution with a mean of $\beta_0 + \beta_1 X_1 + \ldots + \beta_m X_m$ and a variance of $\sigma^2$.

**3.9 Criteria for model selection:** According to Clutter *et al* (1983), there are no exact rules for making the "best" model selection. The final decision rests with the analyst and should reflect his/her subject matter knowledge as well as their interpretation of the criterion statistic values. Some of the common rules recommended by Clutter *et al* (1983) and Myers (1990) are:

1. select as the final model the candidate regression with the smallest values of $RMS^p$ (residual mean square values for p parameters). The selected model should represent the best compromise between (a) minimizing the size of the model, and (b) having a $RMS^p$ value that is reasonably close to the $\sigma^2$ value.

2. the model selected as the best should (a) contain as few variables as possible, and (b) have an $R^2$ value that is not substantially less than $R^{2max}$ (the maximum of $R^{2p}$ values). Clutter et al (1983) suggest using $RMS^p$ in preference to $R^{2ap}$ (adjusted squared multiple correlation coefficient).

3. the model selected should have smallest value of $s^2$ where $s^2$ is the mean square error.

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## 4.0 STUDY AREA

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4. select the model with the smallest natural dispersion around the line as measured by coefficient of variation (CV), the residual estimate of error standard deviation, measured as the percent of the average response value.

According to Hawkins (1987), the major criteria followed in selecting the biomass equation of best fit are:

1. the adjusted correlation coefficient squared ($R^2adj$);
2. the variance ratio from the ANOVA;
3. Furnival's Index, a normal distribution of the residuals when plotted against the predictor variable (Furnival 1961) and %precision (95% confidence interval (CI) as % of Y);
4. the difference between $Y_i$ and standardized residuals.

### 3.10 Single versus composite models

Burton *et al* (1991) found that the allometric equations for leaf area of sugar maple (*Acer saccharum*) in the Northern hardwood forests did not differ significantly among sites. Crow (1983) found that allometric equations for estimating red maple biomass in the Lake States did not differ by stand age and site index, and that a single model was valid for a wide range of conditions. Exploration of the development of a single model in FTS is important because of the need to construct regional models.

## 4.0 STUDY AREA

**4.1 Trial location description:** For biomass modeling, the study area was comprised of four FTS trial plots and three farmer's field sites. The fodder tree species evaluation trial plots, set up by the author between 1985-1988, were located at Karmaiya (Tarai), Hetauda (Inner Tarai), Rampur (Inner Tarai), and Pokhara (Midhills) in central and western

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**5.0 MATERIALS**

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Nepal (Figure 3.1). Two plots (Karmaiya and Hetauda) were planted in June, 1985; one plot each at Rampur and Pokhara were planted in June, 1986; and the last plot - a replacement - was planted at Pokhara in 1988. All plots were measured once per year, biomass measurements were carried out in the spring of 1990. The trial plot at Pokhara was inventoried both during Spring and Summer of 1991.

The farmers' fields were located at Nawalpur, near Hetauda in the Makwanpur district, at Ghansi Kuwa and Chhang near Damauli in the Tanahu district and at Madanpokhara near Pokhara in Kaski district (Figure 3.1). The Nawalpur site represented the Inner Tarai ecological zone and sites in Tanahu and Kaski were from the Midhills. All of these village sites had extensively cultivated fodder trees. Trees were first inventoried for their approximate age, propagation and management history. Then a minimum of three trees were selected in three different locations to provide a layout of a replicated and randomly distributed plot design. The selected trees were leased from the farmers for the duration of the research, and only researchers were involved in the destructive as well as nondestructive measurements.

**5.0 MATERIALS AND METHODS**

Current yield was predicted based on the current values of diameter at 50 cm (*d50*), total height, tree length and crown dimensions. For the prediction of future yield, future height, *d50*, a

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**Figure 3.1 Map**
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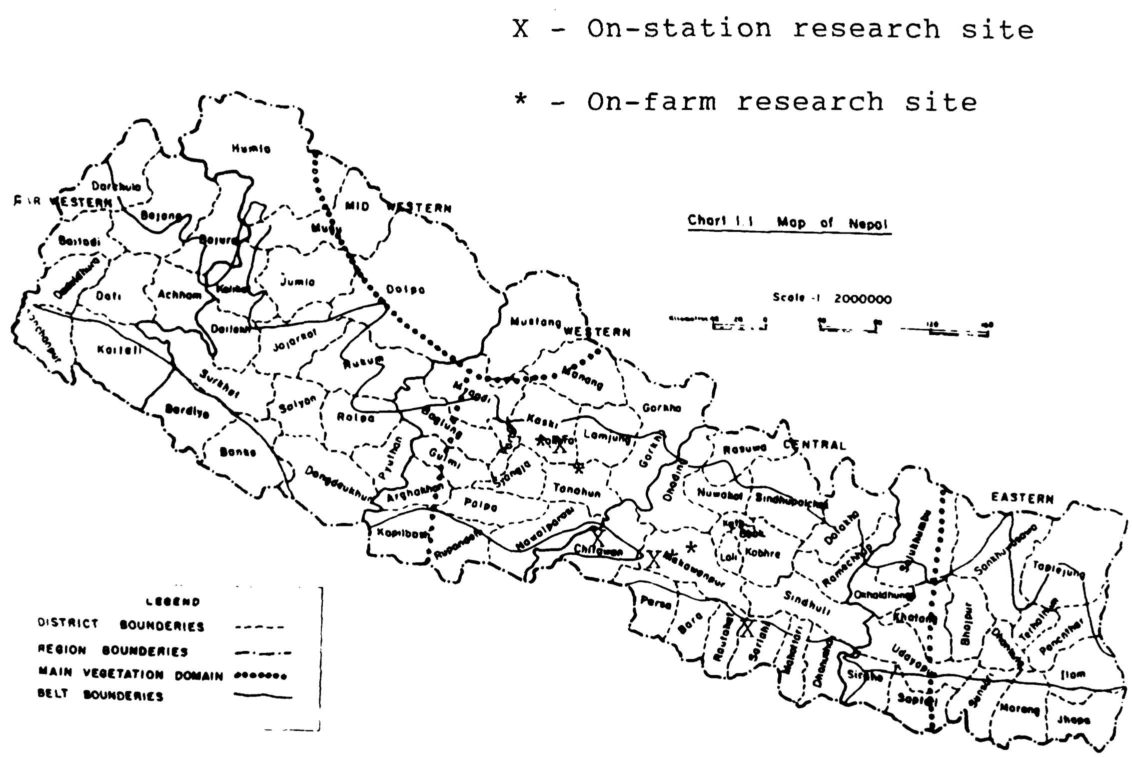
height, *d50*, and crown dimensions were predicted based on current growth or climatic variables. These generated variables were then used as independent variables to predict future yield for a projected age, a process similar to Schlaegel (1983). Two types of models are being constructed for FTS modeling: local models based on site-specific data and general models based on the pooled data from the farmers fields and experimental plots located in three different ecological zones.

**Figure 3.1 Map of Nepal showing the location of the study areas in central and western regions of Nepal**



**5.1 Sampling** 

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**Table 3.1 Sampli**

| Dia50cm class cm | Fi Pop. distrib No. of tree |
|---|---|
| < 6.0 | 63 |
| 6.1-8.0 | 54 |
| 8.1-10.0 | 41 |
| 10.1-14.0 | 50 |
| > 14.0 | 33 |
| Total | 241 |

**5.2 Research**

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(Chapter II).

**5.3 Variables**

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**5.1 Sampling strategies:** The sampling strategy was aimed at selecting those trees which would adequately represent the population in both the experimental plot and nearby farmer's field. The population in turn was assumed to represent the fodder tree population growing both in the forests and farms in the central and western parts of Nepal. Table 3.1 shows the stratified sampling distribution in relation to the population classes. The sample allocation was slightly heavier on upper diameter class to reflect the actual population structure in the region.

**Table 3.1 Sampling distribution by diameter class and species**

| *Ficus semicordata* | | | | | *Bauhinia variegata* | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Dia50cm class cm | Pop. distribution No. of trees | % | Sample distribution No. of trees | % | diam 50 cm. class cm | Pop. distribution No. of trees | % | Sample distribution No. of trees | % |
| < 6.0 | 63 | 26.1 | 17 | 17.4 | < 4.0 | 130 | 34.8 | 16 | 24.3 |
| 6.1-8.0 | 54 | 22.4 | 22 | 22.7 | 4.1 - 6.0 | 85 | 22.8 | 17 | 25.8 |
| 8.1-10.0 | 41 | 17.0 | 17 | 17.5 | 6.1 - 8.0 | 64 | 17.2 | 16 | 24.2 |
| 10.1-14.0 | 50 | 20.8 | 24 | 25.0 | 8.1 - 10.0 | 45 | 12.1 | 9 | 13.6 |
| > 14.0 | 33 | 13.7 | 17 | 17.4 | > 10.0 | 49 | 13.1 | 8 | 12.1 |
| Total | 241 | 100.0 | 97 | 100.0 | | 373 | 100.0 | 66 | 100.0 |

**5.2 Research design:** The sampling plan followed the experimental designs used to conduct the species evaluation trials (Chapter II). The data were collected from plots established under randomized block design at Karmaiya and Hetauda and completely randomized design at Rampur and Pokhara sites. The data for on-farm trees were collected from fodder trees selected for lopping management trials (Chapter II).

**5.3 Variables measured:** In developing growth and yield models for FTS, it was difficult to predetermine key variables whic

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**5.4 Sampling**

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**5.4.1 Tree sa**

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variables which would accurately predict biomass. Due to the need to establish relationships for different biomass components for each of the tree species, a fair number of variables were measured. In this study, the total number of biological, physical, and environmental variables measured were 12, 13, and five respectively.

**5.4 Sampling methods:** The total tree population at each site was divided into five height and diameter classes. In each height and diameter class, between 30 and 50% of the trees were sampled for lopping and weighing. All the measurements were carried out during the winter and early spring months of 1990/91. Individual trees were selected randomly from the experimental plots and farmer's field based on stratified random sampling techniques. Five diameter classes were the sampling strata. Selected trees were measured for tree height, diameter at 50 cm (*d50*), crown height, tree length, crown diameter, and crown length prior to felling. After the felling, the trees were separated into live foliage (leaves, twigs, and succulent branches) and total wood (stemwood and branchwood).

**5.4.1 Tree sampling:** For the two species selected for this study - *Ficus semicordata*, and *Bauhinia variegata*, a 100 % inventory was done for initial height (m), diameter (cm), crown height (m), and crown diameter (m). For biomass measurements, 15 to 30 trees per species were randomly selected in each of the five diameter strata for destructive sampling. For

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sampling. For *F. semicordata* and *B.variegata*, the sampling plan implemented is described below.

Sampling operations were carried out in the dormant season. All selected trees were measured for diameter over bark at 50 cm. using a diameter tape and total height using a graduated pole. A sample of inventory forms used are given in Tables 2.2 and 2.3 in Appendix 2)

A stratified random sampling technique was also used to select representative samples of leaves by age, light position (sun versus shade), and location in the crown. The strata was the different vertical sections of the crown. Total wood (branch and stem wood) was also sampled by cutting chips and pieces both from the main stem and branches. Dry weight percentage was calculated by oven drying at 100°C the sample leaves to a constant moisture percentage. Fresh weight (FW) was converted to dry weight (DW) using the present moisture content (MC) in the formula:

$$DW = FW\ (1 - MC/100)$$

Twenty one composite soil samples covering five sites and all the blocks were collected to carry out physical and chemical soil analysis (see Chapter II, Table 1.1). One composite soil sample was the aggregation of five samples.

**5.5 Impact of lopping on biomass production:** In order to incorporate the widely prevalent practice of lopping (fodder harvesting by chopping off succulent branches, leaves, and twigs) in the biomass model, a study was designed to test

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the effect of different intensities of lopping. Four lopping levels were selected: complete lopping; 75% lopping; 66% lopping; 50% lopping (based on the proportion of the crown length). A single tree for each species was used as an experimental unit replicated at three locations within a site. The trees were regularly measured for their basic geometry prior to lopping. The lopping was done during the common season of lopping, using the farmers themselves as the loppers, once a year for three consecutive years. Lopped biomass was separated into foliage and branchwood and weighed for green weight (Appendix 2, Table 2.6). Oven dry matter content of foliage and wood samples were obtained to estimate dry weight/tree. At the end of three cycles of lopping all trees were fully lopped and the total dry matter yield was compared. Yield did not differ significantly among the replicates or among the treatments (see Chapter II, Table 2.15). This result confirms that the farmer's overwhelming practice of 100 % lopping (over 70% of the farmers were reported to practiced this in the study villages) may not reduce annual fodder yield in the deciduous FTS grown in Nepal. The use of existing on-farm trees to undertake a preliminary lopping intensity investigation was deemed to be a practical approach even if this approach did not allow for standard statistical rigors. The test compared the total biomass under varying lopping intensities o

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**5.6 Model bui**

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intensities of matured trees. Lopping frequency and tree age were kept constant.

Based on the ANOVA results shown in Table 2.15 (Chapter II), this study assumes that there are no significant differences in annual fodder biomass yield of *F.semicordata* and *B. variegata* trees due to varying lopping intensity. Human interventions in the form of 100% lopping intensity may not affect the annual foliage yield per tree.

**5.6 Model building methods:**

**Variable screening:** Although this study primarily focused on allometric modeling of foliage and woody biomass, a large number of biological, physical, and environmental variables were screened to gain a better understanding of variable relationships. Foliage and wood weight estimates were determined by screening logical combinations of all variables i.e.; total height, diameter, crown length, crown diameter, crown height, tree length, and crown ratio using multiple regression techniques. The basic model was:

$$w = f(d_1, d_2, h, dh, d_2h, c, dc, d_2c, R, dR, d_2R)$$

or,

$$lnw = f(lnd, lnh, lndh, lnc, lndc, lndR)$$

where

$d_1$ = diameter at 50 cm.
$d_2$ = diameter at 1.3m. or dbh
h = tree height, m
c = crown length/crown diameter/crown height (m),
R = crown ratio, (live crown length/tree height) * 10
w = biomass weight in kg.

The variable selection procedures as described by Draper and Smith (1981), Myers (1990), and Wilkinson (1990) were used in choosing a suitable model.

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**5.7 Biomass estimation**: Least square regression techniques were used to estimate biomass of individual fodder trees. Separate regression equations were developed to estimate biomass of individual components (fodder, total wood). The model had three assumptions: 1) it was assumed that foliage, total wood and total biomass weight were normally distributed for each value of total height and diameter; 2) the true mean of all the sampled tree populations fit the linear model $\mu = a + bX$, or the power equation $Y = aX^{b}e$ for a single variable model and $\mu = a + bX_1 + cX_2$ or $Y = aX_1^{b}X_{2c}e$ for a two variable model; and 3) the variance, $\sigma^2$, was constant for all tree populations.

On checking whether or not the data in this study satisfied these assumptions, it was found that the variance of Y's (foliage, total wood, and total biomass weight) were not uniform across the domain of X's. The Chi-Square value (using Bartlett test for homogeneity of group variance) for Y was 0.784 and for two Xs were 0.164 and 0.292 in the *F. semicordata* model. This indicated that the variance in fodder and total wood weight was higher than that in either height or crown diameter. The same was true in *B. variegata* model as well. The variables were then log transformed to yield the following models:

$$LN(Y_i) = a + \beta LN(X_i) + LN(\epsilon_i) \quad (1)$$

$$Ln(Y_i) = a + \beta Ln(X_{1i}) + \beta_2 Ln(X_{2i}) + Ln(\epsilon_i) \quad (2)$$

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The sample variance was then assumed to be an unbiased estimate of $\sigma^2$ at $LN(X_i;$ and the estimate $LN(Y_i)$ an unbiased estimate of $\mu$ at $LN(X_i;$ and the deviation (noise) around LN(Y) was calculated using $\sigma^2$.

**5.8 Transformation of the data:** Data transformation was carried out to stabilize the variance and make the assumptions more reasonable to justify the use of the least squares method. The underlying need to transform the data was also due to the use of different measurement units by the regressor variables (e.g., meter and centimeter), heterogeneous variance, outlier observations, and possible measurement errors in the regressor variables. *Natural log* transformation on both x and y variables was carried out to change the model forms and satisfy the assumptions.

**5.9 Conversion of logarithmic estimates:** Logarithmic transformation changes the distribution of residuals causing a slight underestimation in biomass prediction (Baskerville 1972; Sprugel 1983; and Pukkala *et al* 1990). A correction factor given by $(s.e.)^2/2$ was added to the equations (1) and (2), where s.e. was the standard error of the estimate. The base-10 s.e. was first converted into base e by multiplying by 2.303 before using the value in the formula above (Sprugel 1983). The actual models that were used in the biomass prediction given are below:

$$Ln\ (Y) = [a + (s.e.)^2/2] + b\ Ln\ (X) \qquad (3)$$

$$Ln\ (Y) = [a + (s.e.)^2/2] + b\ Ln\ (X_1) + c\ Ln\ (X_2) \qquad (4)$$

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The estimated variance was given by the following equation:

$$\sigma_{A^2} = e^{(2\sigma^2+2\mu)} - e^{(\sigma^2+2\mu)} \quad (5)$$

Cunia and Briggs (1984) discussed the disadvantage of log transformed model related to nonadditivity of the predicted component weights to the values estimated by the whole tree regression model. In this study however, since the focus was on the individual estimates, no adjustments were made to ensure the additivity of the components.

**5.10 Residual analysis:** Residual analysis was performed: 1) to determine whether the residuals from the regression conformed to the assumptions of the model, (i.e., were uncorrelated, normally distributed and had uniform variance); 2) to assess the 'lack of fit' or misspecifcation in the model from systematic trends in the residuals; and 3) to examine visually the shape of relationships between residuals and predicted values as well as possible predictor variables not yet introduced into the regression model.

**5.11 Yield prediction:** A general linear model (GLM) was used to predict future yield of individual fodder trees. Current tree biomass was predicted for two tree species as a function of current tree growth. Both the tree component yield and the total biomass yield were predicted for the research plot and the farmer's field. The difference between the current and future model was due to the inclusion of projected height and diameter values as independent variables in the latter as opposed to the current values in the former. T

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## 6.0 RESULTS

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**Table 3.2** **Summ**
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| Site code | Site name | S |
|---|---|---|
| 1 | Karmaiya | <u>Ficus</u> |
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| | Karmaiya | <u>Bauhir</u> |
| 2 | | ( |
| | Hetauda | |
| | Hetauda | |
| 3 | Rampur | |
| | Rampur | |
| 4 | Pokhara | |
| | Pokhara | |
| Total All Sites | | |
| All Sites | | |

Table 3.3

species. Dia

the former. The objective was oriented towards exploring a large number of variables to develop preliminary fodder and wood biomass models. The fodder and wood biomass tables presented are also considered preliminary in nature due to the use of data from relatively young trees from experimental plots.

## 6.0 RESULTS

**6.1 Species growth patterns:** *Ficus semicordata*, and *B. variegata* (FS and BV respectively), the two fodder species selected for biomass modeling, demonstrated dissimilar growth patterns (Chapter II). FS growth was significantly (p=0.05) different from that of BV in diameter and dry foliage weight. On average each BV tree had two stems and FS had three. Five year growth patterns of the tree population sampled are given in Table 3.2.

**Table 3.2 Summary information on the two fodder tree species selected for biomass modeling in central and western Nepal**

| Site code | Site name | Species | # of Trees measured | # of Stems measured | Stem/ species | No.of Trees felled & weighed | Remarks |
|---|---|---|---|---|---|---|---|
| 1 | Karmaiya | Ficus semicordata (FS) | 111 | 240 | 2.2 | 30 | single stems were felled and weighed |
| | Karmaiya | Bauhinia variegata (BV) | 46 | 100 | 2.2 | 22 | -----ditto---- |
| 2 | Hetauda | FS | 105 | 373 | 3.6 | 27 | -----ditto---- |
| | Hetauda | BV | 48 | 105 | 2.2 | 15 | -----ditto---- |
| 3 | Rampur | FS | 44 | 147 | 3.3 | 20 | |
| | Rampur | BV | 46 | 110 | 2.4 | 15 | -----ditto---- |
| 4 | Pokhara | FS | 18 | 20 | 1.1 | 20 | -----ditto---- |
| | Pokhara | BV | 52 | 58 | 1.1 | 14 | -----ditto---- |
| Total All Sites | | FS | 278 | 780 | 2.8 | 97 | |
| All Sites | | BV | 192 | 342 | 1.8 | 66 | |

Table 3.3 presents the annual growth rates of the two species. Diameter measurements were made at the basal point

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**Table 3.3: Annu**
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| Site | Species code | Ye pl |
|---|---|---|
| Karmaiya | FS | 1 |
| | BV | 1 |
| Hetauda | FS | 1 |
| | BV | 1 |
| Rampur | FS | 1 |
| | BV | 1 |
| Pokhara | FS | 1 |
| | BV | 1 |
| All Sites | FS | |
| | BV | |

Figure 3.2

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in year one, at 30 cm above the base of the tree (*d30*) in year two and after year three at 50 cm stem height (*d50*). Figure 3.2 shows the typical characteristics of their growth and development (see Appendix 3, Tables 3.1 and 3.2 for complete information on the sampled trees). On-farm tree data are given in Appendix 3, Tables 3.3 and 3.4).

**Table 3.3: Annual height, and diameter growth increments of *F.semicordata* and *B.variegata* trees at four research sites**

| Site | Species code | Year planted | Year 1 ht. (m.) | Year 2 ht. (m.) | Year 2 d30 (cm.) | Year 3 ht. (m.) | Year 3 d50 (cm.) | Year 5 ht. (m.) | Year 5 d50 (cm.) |
|---|---|---|---|---|---|---|---|---|---|
| Karmaiya | FS | 1985 | .655 | 3.28 | 4.32 | 4.46 | 9.72 | 5.783 | 11.442 |
| | BV | 1985 | .620 | 2.42 | 4.18 | 3.30 | 5.43 | 4.132 | 6.330 |
| Hetauda | FS | 1985 | .482 | 2.65 | 4.18 | 4.77 | 10.76 | 5.922 | 10.474 |
| | BV | 1985 | .530 | 2.30 | 5.40 | 3.20 | 6.82 | 4.823 | 7.030 |
| Rampur | FS | 1986 | .457 | 2.02 | 6.55 | 4.15 | 10.20 | 4.850 | 10.990 |
| | BV | 1986 | .450 | 2.98 | 4.10 | 4.67 | 7.14 | 5.557 | 10.043 |
| Pokhara | FS | 1988 | .614 | 3.56 | 3.01 | 5.88 | 6.825 | NA | NA |
| | BV | 1986 | .490 | 2.43 | 2.98 | 3.78 | 4.450 | NA | NA |
| All Sites | FS | | .552 | 2.88 | 4.52 | 4.82 | 9.38 | 5.02 | 10.970 |
| | BV | | .523 | 2.53 | 4.17 | 3.74 | 5.96 | 4.84 | 7.800 |

Figure 3.2 shows the growth curves for height and diameter. FS consistently showed higher growth rates than BV. The mean annual increment (MAI) in terms of dry weight per tree for the two species were (respectively) 3.7 and 1.3 kg/year during the five year period of their growth at Karmaiya and Hetauda. FS growth rate was higher than that of BV (Figure 3.2). Average height, diameter at 50 cm (*d50*), and oven dry above ground biomass weight of a three year old FS tree were 4.52 m., 9.38 cm., and 14.75 kg. respectively. The corresponding growth figures for an average BV trees were 3.74 m., 5.96 cm., and 5.87 kg, respectively (for details see Chapter II).

Figure 3.2 Five
trees

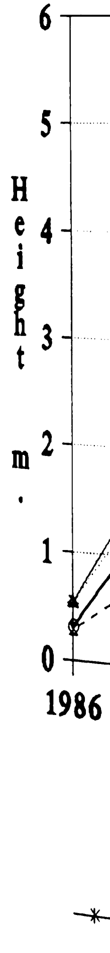


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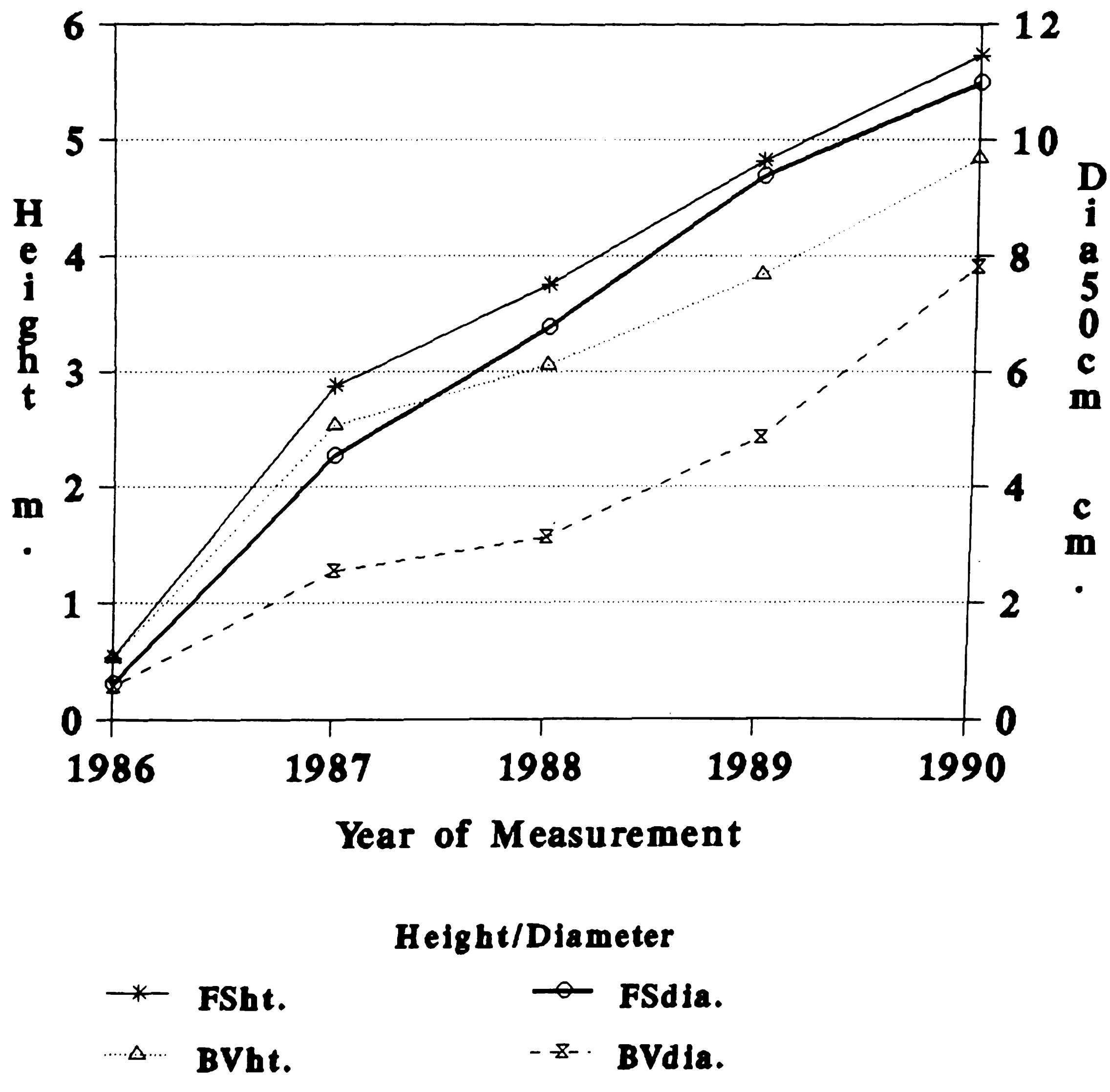
**Figure 3.2 Five year growth curves of *F. semicordata*, and *B. variegata* trees at four research sites in central and western Nepal**




**Data came from four trial sites at Karmaiya, Hetauda, Rampur, and Pokhara in central and western Nepal**

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**6.2. Exploratory data analysis (EDA):** A large number of variables were collected to establish prediction relationships between biomass (fodder and wood weight) and predictor variables such as height, diameter at 50 cm (*d50*), crown diameter, soil nutrients and climatic variables. On-farm tree growth variables included total height, dbh, and crown dimensions. Foliage weight, total wood weight, and total above ground biomass weight were the dependent or predicted variables. All the candidate predictors were examined first for linearity, homogeneity in variance, and lack of multicollinearity. To test these conditions histograms, probability plots, density plots, and other graphical displays were examined (Appendix 3, Figures 3.1 and 3.2). Means, standard deviations, and skewness values were also examined. Most of the predictors were negatively skewed due to the presence of a large number of small trees. The response variables such as fodder and wood weights had higher kurtosis values. The data were therefore log transformed. Figures 3.1 and 3.2 in Appendix 3 illustrate the normal distribution of *d50* and total dry weight in BV and crown diameter and total dry weight in case of FS - the predictor and response variables in each species.

**6.2.1 Nonstandard conditions:** Nonstandard conditions were noticed as a result of the exploratory data analysis described above. These conditions led to several actions. For measurement errors - variables selected for candidate models were e

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models were examined for violations of assumptions and abnormal data points. For model misspecification, the scatter plots provided a preliminary information as to which *metric* was most important for the response or the regressor variables. This analysis pointed out transformation requirements. Multicollinearity diagnostics- the correlation matrix of the regressor variables allowed examinations of associations among multiple regressor variables and pointed out the problem variables which needed further investigations in subsequent model building process.

**6.2.2 Climatic and soil variables:** A number of climatic and soil variables were tested for their predictive relationship to FTS components and total biomass. Average annual precipitation, average annual temperature, and average percent silt content were found to be significantly correlated with the height, diameter, and weights of BV (dominant and codominant trees only). The Pearson correlation was about 0.80 and $R^2$ >0.70. For FS, average annual precipitation and % organic matter were found to explain fair amount of variations in height, weight, and diameter (again for dominant and codominant trees only). The Pearson correlation was about 0.70 and $R^2$ value was about 0.60. However, the relationships were not uniform across the sites.

**6.2.3 Detection of outliers:** Outliers were detected while carrying out data exploration. They were also manifest in

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residuals with large studentized residual and leverage values. In order to examine their actual influences, the outliers were removed from the models and two residual plots (with outliers and without outliers) were examined. The $R^2$ and $s^2$ values for the two models differed by only a small amount. Removal of the outliers decreased $R^2$ without reducing the $s^2$ proportionately. For example, in the total biomass model for FS, the $R^2$ was reduced from .824 to .805 and the $s^2$ changed slightly from .078 to .077. However, for BV, the outlier removal improved the prediction ($R^2$ improved from 0.829 to .852) and therefore, the model presented excludes the outlier.

Regarding the outlier in FS, the premise was that since the objective of this study was to build preliminary empirical models, outliers were a very integral part of the modeling process. The removal of such values may remove important information from the models prescribed (Myers 1990). Therefore, the FS models presented do include a outlier which has shown large leverage. However, in the case of BV, the removal of a single case of an outlier did improve the prediction power ($R^2$) of the model and therefore was excluded from the total model.

**6.3 Regression Models:** One of the original features of this study was that the aboveground biomass had been separated into two components: fodder and total wood (branchwood and stemwood). The conventional practice in biomass studies

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(Mohns *et al* 1988; Applegate *et al* 1985, Hawkins 1987; Crow 1983) has been to separate the total biomass into leaf, branchwood, and stemwood. The rationale for departing from this convention is based on the prevailing practice among FTS users (farmers) who manage these trees for fodder and fuelwood only.

Several regression models were tested using different combinations of tree variables in order to estimate dry weight of these two components. Table 3.4 summarizes the results of 30 allometric models fitted for FS and BV for four sites and three products (total biomass is the third product estimated). Composite models for the entire study area were estimated for each component of the two FTS species. For Karmaiya site, models for BV were better fitted with $R^2$ values ranging from 0.91 to 0.95. Models for FS showed poor fit ($R^2$ <0.80). For Hetauda site, BV models indicated better fit than those of FS. Models for Rampur and Pokhara indicated similar fit with $R^2$ values of more than 0.80. Foliage models had better fit in FS than in BV and vice versa was true for total wood model. For total biomass model, BV model had higher $R^2$ (0.85) value than FS model ($R^2$=0.82).

In general, the prediction models gave similar fits for BV and FS. The $R^2$ values were, respectively, 0.852 and 0.824 (Table 3.4) for their total biomass models. The highest $R^2$ value (0.948) was obtained for wood component model of BV at

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the Karmaiya site. The lowest $R^2$ value (0.751) was also obtained at Karmaiya site, for the wood component model of FS. The standard error values were higher for BV because more variation was encountered in the total biomass yield per tree as compared to that found in FS. The predictor, *d50*, explained most of the variation in BV. Crown height was also a good predictor in BV but the $R^2$ produced was lower than that of the model with *d50* as the predictor. A combination of crown height and *d50* slightly improved the $R^2$, but due to a multicollinearity problem, this model was rejected. For FS, three variables {total height (TH), crown diameter (CD), and tree length (TL)} were found to explain most of the variation in biomass yield. Although CD and TL combined produced slightly higher $R^2$ than CD and TH, combined, CD and TH were included due to the ease in measuring total height rather than tree length. Since these two variables were correlated, both should not be included in the model.

The possible reasons for variation in the model fitting are: a) FS had more spreading crown growth as well as more number of stems per tree than BV; b) The trees at Rampur site were damaged due to human poaching; and c) The trees had variable age composition.

*Table 3.4. Prediction equations[1] for the estimation[2] of fodder, total wood and total biomass for Ficus semicordata and Bauhinia variegata*

| | MODEL STRUCTURE | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Fodder | | | | | Total wood | | | | | Total biomass | | | | | Sample characteristics | |
| *SITE/ Species* | a | $\beta_1$ | $\beta_2$ | $R^2$ | SE | a | $\beta_1$ | $\beta_2$ | $R^2$ | SE | a | $\beta_1$ | $\beta_2$ | $R^2$ | SE | size n | range(d50 for BV, & height(m) for FS) |

Table 3.4. Prediction equations[1] for the estimation[2] of fodder, total wood and total biomass for *Ficus semicordata* and *Bauhinia variegata*

| SITE/ Species | Fodder a | Fodder $\beta_1$ | Fodder $\beta_2$ | Fodder $R^2$ | Fodder SE | Total wood a | Total wood $\beta_1$ | Total wood $\beta_2$ | Total wood $R^2$ | Total wood SE | Total biomass a | Total biomass $\beta_1$ | Total biomass $\beta_2$ | Total biomass $R^2$ | Total biomass SE | Sample size n | range(d50 for BV, & height(m) for FS) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **KARMAIYA** | | | | | | | | | | | | | | | | | |
| F.semicordata | 0.899 | 0.853 | 0.321 | .784 | .191 | .802 | .851 | .557 | .751 | .240 | 1.527 | .846 | .462 | .786 | .204 | 30 | 2.7-10.5 |
| B.variegata | -1.247 | 1.114 | | .909 | .185 | -1.516 | 1.660 | | .948 | .204 | -.760 | 1.467 | | .946 | .184 | 22 | 2.1-11.5 |
| **HETAUDA** | | | | | | | | | | | | | | | | | |
| F.semicordata | 0.152 | 0.495 | 1.018 | .800 | .209 | .389 | .664 | .927 | .774 | .254 | .972 | .590 | .969 | .809 | .217 | 27 | 3.5-7.55 |
| B.variegata | -0.864 | 1.119 | | .923 | .134 | -.479 | 1.355 | | .889 | .197 | .014 | 1.287 | | .910 | .167 | 14* | 3.5-13.1 |
| **RAMPUR** | | | | | | | | | | | | | | | | | |
| F.semicordata | 0.247 | 0.617 | 0.916 | .813 | .143 | -.388 | .867 | 1.352 | .760 | .242 | .571 | .765 | 1.164 | .839 | .164 | 20 | 3.05-6.1 |
| B.variegata | -1.045 | 1.004 | | .765 | .304 | -.489 | 1.300 | | .798 | .359 | -.044 | 1.220 | | .812 | .322 | 15 | 2.1-16.1 |
| **POKHARA** | | | | | | | | | | | | | | | | | |
| F.semicordata | -0.039 | 0.702 | 0.690 | .816 | .163 | .345 | .578 | .472 | .762 | .152 | .844 | .641 | .584 | .836 | .137 | 20 | 3.40-6.2 |
| B.variegata | -0.993 | 0.968 | | .833 | .215 | -.628 | 1.089 | | .811 | .261 | -.106 | 1.047 | | .831 | .234 | 14 | 1.85-7.8 |
| **ALL SITES** | | | | | | | | | | | | | | | | | |
| F.semicordata | 0.489 | 0.977 | 0.461 | .826 | .250 | .472 | 1.174 | .491 | .795 | .277 | 1.165 | 1.086 | .483 | .824 | .277 | 97 | 2.7-10.5 |
| B.variegata | -1.141 | 1.104 | | .819 | .265 | -1.122 | 1.538 | | .839 | .344 | -.489 | 1.399 | | .852 | .298 | 65* | 1.85-16.1 |

1 Models: $\ln Y = a + \beta \ln X_1$ for *Bauhinia variegata* and $\ln Y = a + \beta_1 \ln X_1 + \beta_2 \ln X_2$ for *Ficus semicordata* )
Notations: $R^2$ = squared multiple correlation coefficient; SE = standard error of estimate; $X_1$ = diameter at 50 cm in centimeter (for *Bauhinia*) and crown diameter in meter (for *Ficus*); $X_2$ = height in meter; a = intercept; $\beta_i$ = coefficients.

2 The correction factor for all the equation is given by $\exp[(SE*2.303)^2/2]$.

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Differences were noted in the distribution of biomass between trees of different ages. In general, as the trees grew older the proportion of wood component increased. This factor was however, not expected to affect the models adversely as only one (Pokhara) out of four sites was relatively young. The regression functions for the Pokhara site had dissimilar slopes and elevations and therefore were not included in the regional models.

To test whether the slopes and intercepts of the regression lines were significantly different or not, regression equations were compared using methods described by Zar (1984). The lines representing Karmaiya, Hetauda, and Rampur in the experimental models were not significantly different among the three sites (Appendix 3, Table 3.5). However, the slopes and intercepts of equations with the inclusion of Pokhara site were significantly ($p=0.05$) different (Appendix 3, Table 3.6).

**6.4 Individual site versus composite models:** A major objective of this study was to develop regional fodder and wood biomass models. As a first step, individual site models for individual tree components were developed. The idea was to include as few predictor variables as possible in each model, and if possible, to use the same predictor variable/s throughout so as to justify pooling the data to construct a composite model. It was determined that total height, *d50*, fodder and wood weight of the subject trees did not

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significantly ($p=.05$) vary by sites (see Chapter II). It was also determined (from the tree population data analysis) that the mean total height used in the prediction models did not vary significantly by site. The between site variation was not significant at $p = 0.05$ (Appendix 3, Table 3.5). The regression slopes and intercepts for predicting total biomass for both the FTS were found to be similar for three of the four sites (Figures 3.3 and 3.4). Confidence intervals for most of the equations were narrow (Table 3.5 and Appendix 3, Figures 3.3 and 3.4). The probable reason for significantly different slopes and intercepts for the Pokhara site is the abnormal (the old trees on the plot borders provided shading effect) site conditions which contributed to dissimilar growth patterns of trial species. The regression slopes for on-farm models however were not significantly different. Thus it was concluded that no important differences existed among the regression equations of the four sites, and a composite equation was applied to all four sites. The Pokhara site data to improve the robustness of the model even though the regression slopes for this site was significantly different than those of other sites. The confidence limits of all the four regression lines are given in Table 3.5.

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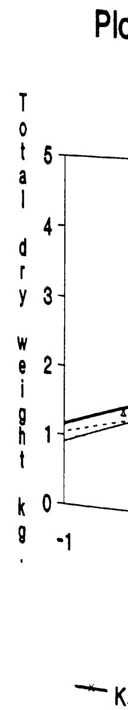


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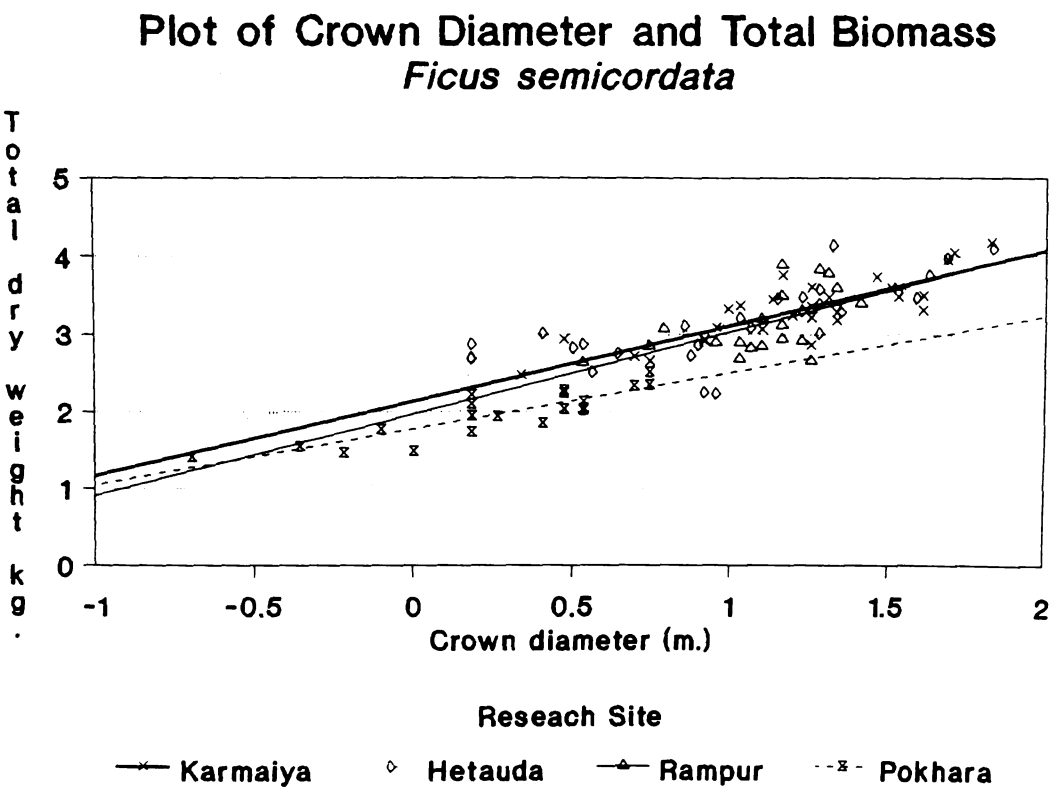
**Figure 3.3. Regression of crown diameter (X) on total tree dry biomass weight (Y) in *F.semicordata* sample trees at four sites.**




Data came from sample trees at four sites in central and western Nepal.

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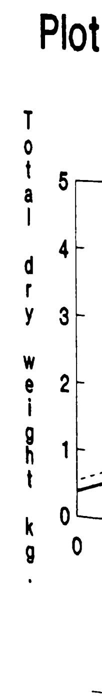


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**Figure 3.4 Regression plots of *d50* (X) on total tree dry biomass weight (Y) in *B.variegata* sample trees at four sites in Nepal.**

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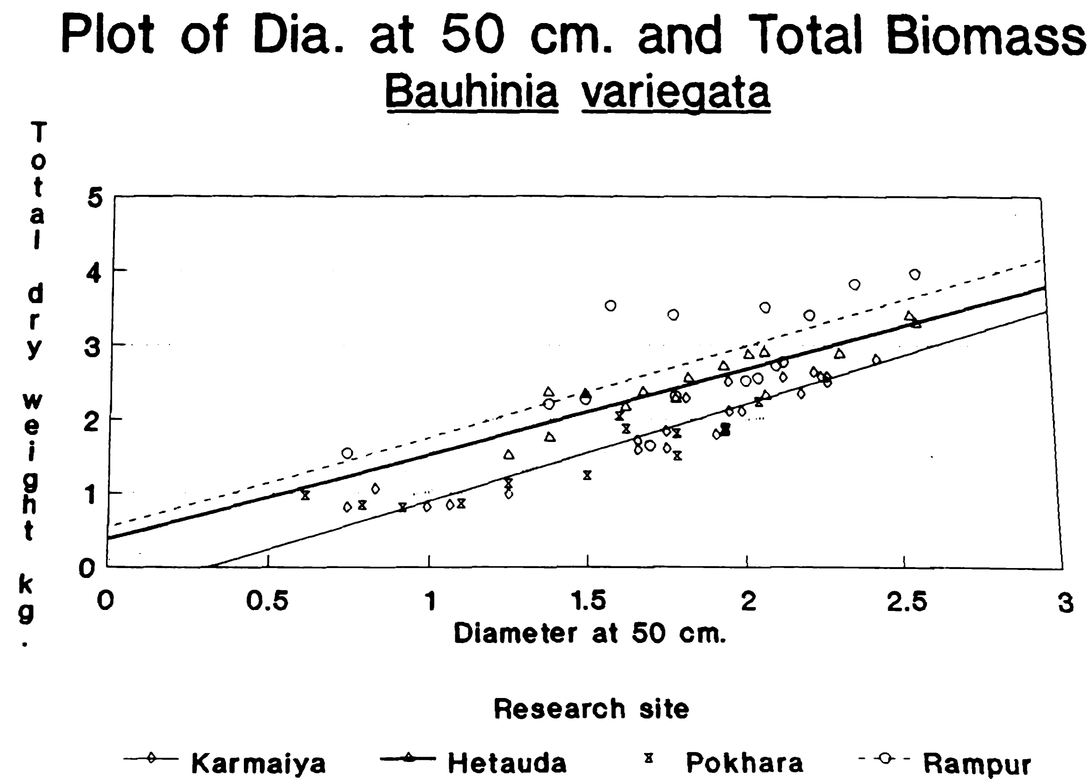


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**Table 3.5. 95% Co**
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| Site | |
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| | *F.* |
| | Interc |
| Karmaiya | 1.035 to 2.0 |
| Hetauda | 0.279 to 1.6 |
| Rampur | -0.073 to 1.2 |
| Pokhara | 0.094 to 1.5 |

[1] Bonferroni

**6.5 Criteria**

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**Table 3.5. 95% Confidence limits[1] for intercepts and slopes of regression equations for total biomass estimations for *F.semicordata* and *B.variegata* in central and western Nepal**

| Site | Confidence bounds | | | |
|---|---|---|---|---|
| | *F.semicordata* | | *B.variegata* | |
| | Intercepts | Slopes | Intercepts | Slopes |
| Karmaiya | 1.035 to 2.019; | $\beta_1$: 0.555 to 1.137 | -1.090 to -0.430; | 1.225 to 1.589 |
| | | $\beta_2$: 0.117 to 0.808 | | |
| Hetauda | 0.279 to 1.665; | $\beta_1$: 0.356 to 1.137 | -0.456 to -0.670; | 0.962 to 1.534 |
| | | $\beta_2$: 0.514 to 1.424 | | |
| Rampur | -0.073 to 1.215; | $\beta_1$: 0.388 to 1.173 | -0.840 to 0.752; | 0.828 to 1.612 |
| | | $\beta_2$: 0.736 to 1.592 | | |
| Pokhara | 0.094 to 1.594; | $\beta_1$: 0.440 to 0.843 | -0.624 to 0.412; | 0.717 to 1.378 |
| | | $\beta_2$: 0.116 to 1.052 | | |

[1] Bonferroni method was used (Myers 1990).

**6.5 Criteria for model selection:**

As stated previously, the models with the smallest residual mean square (RMS) values, the smallest number of predictor variables, an acceptable $R^2$ (>.80), smallest dispersions around the fitted line as predicted by the CV, and largest percentage of variation accounted for (VAF) were selected.

Apart from $R^2$, %VAF[3] was also used to measure goodness of fit. In a situation, where all the candidate models had $R^2 > 0.80$, it was difficult to conclude the best fitting equation.

Therefore, %VAF was calculated (Stewart 1990) since it has the advantage of taking degrees of freedom into account by comparing mean squares rather than sum of squares:

$$\%\ VAF = [MS_T - MS_E]/MS_T$$

[3] $R^2$ = regression sum of square/total sum of square whereas %VAF = regression mean square/total mean square values; %VAF takes degree of freedom into account, $R^2$ does not (Stewart 1990).

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For example, in the model for estimating total dry biomass of FS, both the height and tree length gave good fit with identical $R^2$ values. However, %VAF was slightly higher in the model with height as the second predictor (the other model used tree length). Therefore, height was selected as the second predictor. In most of the models, however, %VAF followed closely with the corresponding $R^2$ values.

**6.6 Tests of the models:**

The criteria for accepting or rejecting a model was based on maximizing $R^2$ ( i.e., $R^2 = 1.0$) and having all $\beta_i$ significantly different from zero. The procedure for carrying out the significance test was based on Cramer (1972). The full model was first tested using an ANOVA. In all the models the two tail probability values were less than .001. Thus the null hypothesis was rejected at well above the a priori ($p = 0.05$) level. This led to the conclusion that the multiple correlation was indeed significantly ($p=0.05$) different from zero. Second, the individual regression coefficients were tested and only significant ones were retained. The model building or variable selection procedure followed was based on the MAXR (maximum $R^2$) procedure described by Myers (1990). Under this procedure the variable initially selected to enter the model had to produce the largest $R^2$ as a single regressor. The subsequent variables allowed to enter were also based on this criterion. At each stage a replacement of the entered variable was a

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variable was allowed if the replacement produced a larger $R^2$. The decision was also based on the inclusion of only those variables that had absolute student *t* values well above 2.0 and tolerance values greater than 0.1 (Wilkinson 1990). Finally, the researcher's own knowledge of FTS management problems and practical factors involved in data collection were also considered. For example, in the total biomass model for FS, total height and tree length independently produced $R^2$ values of .124 and .144 respectively. However, since total height is more easily understood and measured than tree length, it was included in the final models.

**6.7 Residual Analysis:** For the selected models, standardized residuals were plotted against the estimated responses. A fan shaped or heteroscedastic distribution was undesirable. The errors were distributed in random patterns around zero with one or two detectable outliers (Appendix 3, Figures 3.5 and 3.6). However, the lack of pattern in the distribution indicated that the model was properly specified (Myers 1990; Wilkinson 1990). No patterns were detected in plots of standardized residuals against the predictors, which led to the conclusion that the models met all the underlying conditions. Bartlett's test for homogeneity of variance were carried out on the residuals, gave a Chi-Square value of 6.494 (p=.09) for BV and 14.425 (p=0.00) for FS. This also indicated homogeneity of variance.

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Residual analysis was also used to improve the model selection. For example, the importance of including height as a predictor variable for BV was tested. The addition of height improved the $R^2$ value from 0.832 to 0.855. Residual analysis, however, indicated a pattern in error distribution. The single variable model was selected because of the possibility of increasing efficiency in field work.

**6.8 Cross validation:** To test model robustness and validity, tests were conducted to examine whether or not the models developed above would predict the biomass of a new population with similar range of allometric variables as was collected in the study data. One of the techniques of cross validation was *data splitting*, i.e. the partitioning of the data into subsamples. This was done by randomly taking a portion of the pooled data and running the same regression models. Twenty nine observations in FS and 19 in BV were included in the validation models. Once again, *d50* in case of the BV and two predictors, *total height* and *crown diameter,* in case of the FS, to adequately predict fodder, total wood, and total biomass. However, in order to test the validity of the model in an independent situation (i.e., in farmers' field), data was collected in the farmers' field around the experimental plots for both species. This data was used to test the validity of the fodder, total wood, and total biomass models for each of the two species. In all the three biomass models, the "best" predictor variables were height and crc

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height and crown diameter for FS and dbh for BV. All models were significant (F value >45.0 for FS and >57.0 for BV) and the $R^2$ values were acceptable (0.812 and 0.852, respectively, for the fodder model). Table 3.6 summarizes the parameters of the validation models based on data splitting for both FS and BV. Log transformation was done to change the form of the models tested.

The models described in Table 3.4 can be designated as on-station models and Table 3.6 as their validation models. These allometric regression models are assumed to represent *Ficus* and *Bauhinia* tree population of central and western Nepal. The models were found to be robust upon validation (Table 3.6). The regression slopes and intercepts for predicting total biomass were not significantly different among three sites in on-station data models. The validated models (Table 3.7) were then used to predict the biomass for trees with the range of height above that recorded in the experimental plots. For the on-farm data, models were developed based on the data obtained from the lopping trial data. Total height and crown diameter in FS and Dbh in BV gave the best fitting equations (Table 3.7). The regression lines were not significantly different among the three sites involved in on-farm trial. Therefore, common prediction equations applicable for the two species (FS and BV) are listed in Tables 3.7.

**Table 3.6 Paramet**
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| Response variable | Predi varia |
|---|---|
| *Ficus semicordata* | |
| Total | crndia |
| Wood wt. | |
| Fodder wt. | |
| *Bauhinia variegat* | |
| Total | Dbh |
| Wood wt. | " |
| Fodder wt. | " |

[a] Correction fact

**Table 3.7 Regiona**
**two FTS**

| Component | |
|---|---|
| *F.semicc* | |
| **A: For trees up t** | |
| Fodder | LnFw= |
| Total wood | LnWw= |
| Total Biomass | LnTw= |
| **B: For trees beyc** | |
| Fodder | LnFw= |
| Branchwood | LnWw= |
| Total | LnTw= |

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**Table 3.6 Parameter estimates of allometric equations for validation of regression models of fodder tree species in Nepal**

| Response variable | Predictor variable | Lna | $b_1$ | $b_2$ | se | $r^2$ | CF[a] | F |
|---|---|---|---|---|---|---|---|---|
| *Ficus semicordata* | | | | | | | | |
| Total | crndiam/htm. | 1.124 | 1.262 | .406 | .317 | .766 | 1.305 | 42.67 |
| Wood wt. | " | 0.344 | 1.445 | .410 | .397 | .729 | 1.519 | 34.96 |
| Fodder wt. | " | 0.573 | 1.042 | .367 | .252 | .783 | 1.183 | 46.84 |
| *Bauhinia variegata* | | | | | | | | |
| Total | Dbh | -0.187 | 1.328 | | .337 | .831 | 1.352 | 83.30 |
| Wood wt. | " | -0.771 | 1.459 | | .382 | .821 | 1.473 | 78.21 |
| Fodder wt. | " | -0.885 | 1.008 | | .322 | .755 | 1.317 | 52.48 |

[a] Correction factor was given by $\exp[(se*2.303)^2/2]$ for all the equations

**Table 3.7 Regional models for individual and total biomass estimation for two FTS in central and western regions of Nepal**

| Component | Models[1] *F.semicordata* | *B.variegata* |
|---|---|---|
| **A: For trees up to 5 years of age (On-station models)** | | |
| Fodder | LnFw= 0.489+0.977*LnCd+.461*LnHt. | LnFw= -1.126+1.100*LnDo5 |
| Total wood | LnWw= 0.472+1.174*LnCd+.491*LnHt. | LnWw= -1.099+1.531*LnDo5 |
| Total Biomass | LnTw= 1.165+1.086*LnCd+.483*LnHt. | LnTw= -0.469+1.393*LnDo5 |
| **B: For trees beyond 5 years of age ( On-farm models)** | | |
| Fodder | LnFw= 0.565+1.102*LnCd+.599*LnHt. | LnFw= -1.583+1.684*Lndbh |
| Branchwood | LnWw= 0.690+1.227*LnCd+.649*LnHt. | LnWw= -0.962+1.627*Lndbh |
| Total | LnTw= 1.316+1.165*Lncd+.634*LnHt. | LnTw= -0.540+1.651*Lndbh |

[1] The correction factor for conversion to arithmetic form is given by $\exp[(SE*2.303)^2/2]$; For SE values see Tables 3.4 and 3.6.

**6.9 Yield predictions:** The future yield of the two fodder tree species was predicted using two types of models. For trees whose growth parameters such as *d50*, height and crown diameter range were within the data gathered from the experimental plots, on-station models were used. For trees not covered by the on-station models with an age range of five to fifteen years, on-farm models were suggested. In general, the diameter and height ranges included in the on-station models covered trees of up to five years of age.

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Future growth was estimated based on the regressions carried out on the predicted tree parameters such as height and diameter. For example, the data gathered from the farmer's field were used for predicting the future height and diameter growth of the currently growing fodder trees on the experimental plots. This was justified on the grounds that the data were independently collected from the farmer's field within the two geographical regions of the country under reference. The trees were selected randomly and were part of the regularly monitored management research trials. The regression equations provided in Tables 3.4 and 3.6 were used to prepare the fodder, and fuelwood biomass tables for both FS (Appendix 3, Tables 3.7 and 3.8) and BV (Appendix 3, Tables 3.9 and 3.10). Figures 3.7 and 3.8 in Appendix 3 illustrates the projected foliage, total wood, total biomass growth curves based on the above yield tables.

**6.10 Hypothesis testing**: Based on the results, the hypotheses formulated for this study were tested and the following results were obtained. The tests were valid only for *F. semicordata* since the hypotheses were tested for this species only.

**HO #1:** Fodder, total wood, and total aboveground biomass are independent of total height and tree diameter.

This hypothesis tested the conventional notion that biomass weight will be strongly related to total tree height and dbh (i.e., diameter breast height). To test this hypothesis, tr

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hypothesis, trees growing in the farmers field were randomly selected. Their height and dbh were regressed with total biomass and both of these variables were found to be significant (p=.001). The null hypothesis was therefore rejected. Dbh and height are related to fodder and wood biomass.

**HO #2:** Crown diameter, crown length, and crown height are not associated/related to the fodder and wood biomass of FS.

Here the null hypothesis tested whether or not the crown dimensions were significant predictors of biomass. Tests carried out on crown height, crown diameter, crown length, and crown ratio (crown length/height*10) indicated significant relation (p <.005) by all but crown ratio (p=.247) with total biomass. Therefore, the null hypothesis was rejected.

**HO #3:** Biomass does not vary among species but does vary among sites.

This hypothesis tested the premise that sites had significant effect on the biomass models but that species did not. The tests involved inclusion of both the sites and species as dummy variables and comparison of regression lines. It was found that the regression lines were significantly (p=0.05) different for individual species but not for individual sites (except for Pokhara which was concluded to be abnormal site). Therefore the null hypothesis was rejected.

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**HO #4:** Precipitation, temperature, relative humidity, and % organic matter are not good predictors of individual tree biomass.

This hypothesis tested the relationship of climatic and soil variables with biomass variables. Regression of height and *d50* of dominant and codominant trees on climatic aand soil varibales indicated that only average annual relative humidity gave significant (p=.008) relationship with the total biomass. Temperature, precipitation, and % organic matter were found to have weaker relationship ($r^2$<0.6). Therefore, the null hypothesis was not rejected.

**HO #5:** Lopping intensity does not significantly affect fodder biomass.

This hypothesis tested whether different lopping intensity of foliage branches by the farmers significantly affected the annual fodder yield of an individual tree or not. Four lopping intensities were tested on randomly selected fodder trees (Appendix 2, Table 2.6). The ANOVA (Table 2.15.1) showed that the final foliage dry weight did not vary significantly (p=.004) amongst the four treatments. Therefore, the null hypothesis was not rejected.

**HO #6:** A single allometric model is adequate to estimate component and total biomass of *Ficus* and *Bauhinia* species.

The hypothesis tested whether or not a single model was adequate ($R^2$>.8) to predict fodder, totalwood, and total biomass. To test this hypothesis, foliage and wood biomass were first separately estimated using the identical model

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**7.0 DISCUSSIO**

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and their slopes and intercepts were compared. The tests for comparing regression lines and slopes did not vary significantly (p=0.05). Therefore, the null hypothesis was not rejected. A single allometric model did explain adequate variation in both the component and total biomass of *Ficus* and *Bauhinia* species.

**7.0 DISCUSSIONS AND IMPLICATIONS**

The results of the FTS modeling indicate that foliage and woody biomass can be estimated within an acceptable margin of error through allometric regression. A large number of variables were screened and various candidate models were examined. Biomass was found to be related to physical, biological, and environmental variables such as % organic matter content, % sand and % silt content, total height, d50, crown diameter, tree length, average annual temperature and precipitation. However, allometric variables were found to be superior predictors over climatic and physical variables. This is in line with other findings (Wormald *et al* 1983; Karki and Tuladhar 1988) reported from eastern and central Nepal. The results obtained were similar to biomass models developed for exotic species in Zimbabwe (Gwaze and Stewart 1990). The authors used eight hardwood exotic species of 16-30 months age for log linear allometric regression modeling. They found that diameter and crown diameter were the best predictors. In the current study, the

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regression analysis carried out on the potential predictors indicated that the "best" prediction equation for the two species (*F.semicordata*, and *B.variegata*) were found to relate biological variables *d50*, height, and crown diameter with the tree components such as fodder and total wood, as well as total biomass. This was true in sample trees drawn from both the experimental plots and farmers field. The final models selected contained only two variables - height and crown diameter in the case of FS and only one variable - diameter at 50 cm - *d50* in the case of BV. The inclusion of two variables in the model for FS is due to spreading nature of growth of this species. Tree length was a slightly better predictor. However, the popularity of total height measurement and its wide popularity among the practioners led to its rejection in the model. In contrast, BV generally had straight stems and "normal" crown structure and therefore its biomass could be predicted using only one predictor - *d50* or height.

The slopes and intercepts of the regression equations for both species were found to be similar. Only the models based on the experimental data at Pokhara had significantly different slopes and elevations. This was due, it is believed, to the early age of the sampled trees as well as the highly shaded and gravel mixed site characteristics. The data from the farmers' field did not show such variations. The inventory data from the four individual sites were therefore poo

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therefore pooled together and one single model for each species was developed. This can be explained by the fact that the species did not vary significantly ($p=0.05$) in their growth attributes among sites. This manifests the homogeneity of the site quality in most of the locations in Nepal -degraded and abandoned marginal farm and waste land. In the short run this will mean that a single model may be used to predict the fodder and wood biomass for one or more ecological zones. In the long run, based on the anticipated practice of pre-planting soil amelioration, site-specific growth may vary. The regional models still have tremendous scope and should continue to be refined.

The biomass models need to be divided into two types (Pukkala *et al* 1990): local and general models. Local models should be used to carry out management plans for a specific village or a district and should have higher predictive power. Only one variable may be considered adequate for such models. The site specific models which included d50 for BV and crown diameter (CD) for FS are possible examples of such models. However, at the regional level, the general models (such as the one recommended for the FS with height and crown diameter as predictors), may prove to be more robust. The categorization of the allometric models into two groups will generate more information for the benefit of diverse groups of clients who use biomass tables. For example, extension personnel and resource managers will find local

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biomass tables useful in designing projects and making resource assessments. Researchers will find general biomass tables useful to derive more specific localized models and/or for further refining the existing models.

Annual precipitation and temperature were also found to be useful to predict height, diameter, and biomass. This is important information for future research aimed at deriving site indices for MPTS. Site index values can be derived to represent the complex mix of climatic and soil variables. In conventional forest modeling, site indices have been used to predict present or future yield (Clutter *et al* 1983). In this study climatic and soil variables indicated strong relationships with biomass variables both in FS and BV. The relationship was stronger in BV than in FS, which again indicated that the relationship may be weaker in trees with spreading growth habits. Further research is needed on this topic. The derivation of site index, however, holds promise as potential biomass predictor.

There is an advantage to expressing the biomass as continuous functions of diameter and height. Few extension agents and resource mangers working in Nepal are trained in complicated model building techniques. They are, however, well versed with the tree inventory system of measuring height and diameter. This study, therefore, recommends that height and crown diameter should be used to predict the biomass of trees with spreading crowns. In case of "normal"

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(erect stem or nonspreading growth) trees, *d50* at early growth stages and dbh after maturity may be suitable for modeling growth and yield. Since the range of heights and diameters of the experimental trees did not represent the entire tree population of the regions, separate models were developed for the older and larger trees. The fodder and wood tables derived from these models (Appendix 3, Tables 3.7- 3.10) indicated relatively large variations between the two predictions. However, in the experience of this author, the trees in the trial plots have indeed shown accelerated growth after year four. Trees reach a 'take off' stage in their growth and development at varying ages. The biomass tables developed in this study may be the manifestation of such 'take off' growth after year five for both species of trees modeled. The models developed from the experimental data may underestimate the biomass of older trees and the on-farm models may overestimate the biomass of younger trees. In the validation models, however, the predictions were within 80% of the actual figures. In the case of BV, the dry foliage weight, wood weight, and total biomass were found to be strongly related to dbh. Therefore future biomass was predicted through regressing these response variables on dbh. The model derived in this study for predicting fodder weight based on diameter at breast height (dbh) was as follows:

$$Ln*FWt.=-1.78+1.684*Ln(dbh) \text{ with } R^2=0.852 \text{ and } s^2=.186$$

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This equation predicted about 87% of the actual fodder biomass.

The general predictors presented above for the two important FTS can be applied at regional levels within the limits of height and diameter defined. A single model has been found to be valid for estimating biomass over a range of sites for each species. It is hoped that these two models will provide acceptable estimates of fodder and fuelwood weights for FS and BV trees of central and western Nepal. The models are not, however, recommended for general application without considering specific site conditions and tree characteristics. Users should apply common sense in applying these models.

The following steps are suggested to the potential users: first, apply the equations in trees similar to the ones described; second, apply only within the range of tree sizes used to develop the equations; third, use more than one equation, if available, to understand the estimates of the range of values; and finally for accurate estimates develop your own site specific equations.

The results of this study have also indicated that geographically generalized fodder and wood biomass estimation equations are feasible. They may partially solve the current problem of poor extrapolation of values from the localized equations. Schmit and Grigal (1981) suggested that data collected from many regions serves to make models more applicable an

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**8.0 CONCLUSION**

Increasing scarcity of the valuable forest products has forced the people of the world, particularly those from the Third World countries, to utilize the trees as completely as possible. However, in order to realize this possibility, managers have to acquire solid information on complete tree products in quantitative form. Models have the potential to provide this information. Good models depend upon accurate forest inventory. This study has attempted to develop models by carrying out fodder tree inventory for a period of five years. It may appear that the biomass information thus obtained is more costly than conventional volume information. However, since the method shown here requires sampling of only a few trees, in the long run this method may not prove to be costlier than other methods in use. This study did have limitation in terms of the growth period of the trees studied. It also may have failed to fully address the impact of human factor in the management. The author is aware of these shortcomings and recommends further investigations to refine the suggested models.

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APPENDIX 3

**Appendix 3. Tal**
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| Sample No. | Site |
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| 1 | HETAUD |
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| 57 | KARMAIY |
| 58 | POKHAR |
| 59 | POKHAR |
| 60 | POKHAR |
| 61 | POKHAR |

**Appendix 3. Table 3.1. Summary of the sample *Ficus semicordata* trees data from four research sites in central and western Nepal**

| Sample No. | Site | Height(m) (m) | Dia50(cm) (cm) | Crowndia (m) | Fol.dry wt. (kg.) | Wd. dry wt. (kg.) |
|---|---|---|---|---|---|---|
| 1 | HETAUDA | 3.4 | 8.4 | 3.6 | 9.030 | 11.223 |
| 2 | HETAUDA | 5.1 | 12.6 | 3.6 | 12.797 | 16.549 |
| 3 | HETAUDA | 5.8 | 11.2 | 3.9 | 12.797 | 14.070 |
| 4 | HETAUDA | 3.7 | 4.8 | 1.8 | 6.244 | 5.930 |
| 5 | HETAUDA | 4.4 | 5.9 | 2.5 | 8.127 | 9.213 |
| 6 | HETAUDA | 5.1 | 9.4 | 3.4 | 11.481 | 20.938 |
| 7 | HETAUDA | 6.9 | 19.9 | 3.8 | 21.414 | 40.870 |
| 8 | HETAUDA | 6.8 | 11.0 | 3.6 | 14.242 | 21.273 |
| 9 | HETAUDA | 5.7 | 14.7 | 3.4 | 11.610 | 15.578 |
| 10 | HETAUDA | 6.0 | 10.6 | 2.9 | 10.630 | 11.156 |
| 11 | HETAUDA | 3.5 | 4.4 | 2.5 | 3.870 | 5.561 |
| 12 | HETAUDA | 4.7 | 11.3 | 2.8 | 9.985 | 14.673 |
| 13 | HETAUDA | 5.6 | 13.6 | 4.9 | 11.920 | 20.000 |
| 14 | HETAUDA | 5.3 | 8.8 | 1.9 | 8.050 | 7.538 |
| 15 | HETAUDA | 4.6 | 6.5 | 1.7 | 7.121 | 10.519 |
| 16 | HETAUDA | 7.5 | 19.2 | 6.3 | 23.994 | 36.013 |
| 17 | HETAUDA | 7.5 | 13.5 | 3.2 | 15.067 | 16.583 |
| 18 | HETAUDA | 3.9 | 9.1 | 2.4 | 9.649 | 12.596 |
| 19 | HETAUDA | 3.6 | 5.3 | 1.7 | 7.585 | 9.146 |
| 20 | HETAUDA | 7.1 | 15.8 | 5.1 | 18.834 | 24.288 |
| 21 | HETAUDA | 4.8 | 9.5 | 2.4 | 5.470 | 9.581 |
| 22 | HETAUDA | 7.6 | 18.8 | 5.4 | 24.974 | 28.107 |
| 23 | HETAUDA | 6.0 | 10.1 | 2.6 | 12.281 | 13.166 |
| 24 | HETAUDA | 5.1 | 8.9 | 1.5 | 9.494 | 0.653 |
| 25 | HETAUDA | 5.4 | 6.0 | 1.2 | 6.760 | 7.906 |
| 26 | HETAUDA | 5.6 | 5.5 | 1.3 | 7.792 | 9.849 |
| 27 | HETAUDA | 5.8 | 8.0 | 1.2 | 6.914 | 7.772 |
| 28 | KARMAIYA | 5.7 | 15.0 | 3.3 | 9.494 | 15.678 |
| 29 | KARMAIYA | 5.2 | 10.0 | 5.0 | 12.436 | 14.640 |
| 30 | KARMAIYA | 3.9 | 5.8 | 2.0 | 6.244 | 8.677 |
| 31 | KARMAIYA | 4.8 | 14.0 | 3.5 | 11.610 | 16.717 |
| 32 | KARMAIYA | 5.0 | 11.0 | 3.8 | 9.494 | 14.472 |
| 33 | KARMAIYA | 5.3 | 7.8 | 2.5 | 7.688 | 10.519 |
| 34 | KARMAIYA | 4.2 | 8.5 | 2.1 | 6.914 | 7.203 |
| 35 | KARMAIYA | 4.3 | 10.4 | 2.6 | 9.082 | 9.615 |
| 36 | KARMAIYA | 3.7 | 13.0 | 3.0 | 9.546 | 11.725 |
| 37 | KARMAIYA | 2.7 | 7.0 | 1.4 | 6.605 | 7.203 |
| 38 | KARMAIYA | 5.5 | 5.8 | 2.5 | 8.308 | 10.850 |
| 39 | KARMAIYA | 4.3 | 6.3 | 2.1 | 7.224 | 6.868 |
| 40 | KARMAIYA | 4.3 | 8.5 | 3.8 | 11.094 | 15.477 |
| 41 | KARMAIYA | 4.5 | 8.2 | 2.7 | 10.578 | 16.750 |
| 42 | KARMAIYA | 4.2 | 4.0 | 2.6 | 8.772 | 13.032 |
| 43 | KARMAIYA | 4.2 | 7.8 | 4.5 | 16.667 | 19.564 |
| 44 | KARMAIYA | 3.6 | 15.0 | 5.4 | 22.962 | 28.877 |
| 45 | KARMAIYA | 10.5 | 27.0 | 6.2 | 34.882 | 43.048 |
| 46 | KARMAIYA | 5.8 | 12.0 | 4.6 | 14.654 | 17.856 |
| 47 | KARMAIYA | 6.6 | 15.0 | 3.2 | 13.674 | 28.576 |
| 48 | KARMAIYA | 7.5 | 16.5 | 4.3 | 17.699 | 23.852 |
| 49 | KARMAIYA | 4.7 | 8.0 | 4.6 | 14.500 | 21.809 |
| 50 | KARMAIYA | 6.5 | 14.9 | 2.8 | 11.146 | 17.588 |
| 51 | KARMAIYA | 5.1 | 7.5 | 3.1 | 14.706 | 16.583 |
| 52 | KARMAIYA | 5.4 | 16.1 | 5.0 | 15.428 | 17.454 |
| 53 | KARMAIYA | 3.1 | 7.0 | 3.5 | 7.740 | 9.548 |
| 54 | KARMAIYA | 7.6 | 19.5 | 5.5 | 20.434 | 36.281 |
| 55 | KARMAIYA | 7.0 | 14.2 | 3.5 | 13.106 | 23.517 |
| 56 | KARMAIYA | 6.9 | 13.0 | 3.7 | 14.293 | 17.588 |
| 57 | KARMAIYA | 6.5 | 10.5 | 3.5 | 11.042 | 13.735 |
| 58 | POKHARA | 5.4 | 6.0 | 1.2 | 4.180 | 3.920 |
| 59 | POKHARA | 5.6 | 5.5 | 1.2 | 4.696 | 4.456 |
| 60 | POKHARA | 5.8 | 8.0 | 1.2 | 3.818 | 3.149 |
| 61 | POKHARA | 4.1 | 6.0 | 0.7 | 2.167 | 2.513 |

Table 3.1 contd....

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| 62 | POKHARA | 5.3 | 5.0 | 0.9 | 3.04 | 2.814 |
| 63 | POKHARA | 5.6 | 9.0 | 1.6 | 5.005 | 4.288 |
| 64 | POKHARA | 3.4 | 4.0 | 1.5 | 3.044 | 3.283 |
| 65 | POKHARA | 4.3 | 4.5 | 1.7 | 3.818 | 4.623 |
| 66 | POKHARA | 5.6 | 9.0 | 1.6 | 3.251 | 4.288 |
| 67 | POKHARA | 5.7 | 9.0 | 1.7 | 3.664 | 3.786 |
| 68 | POKHARA | 5.3 | 8.0 | 1.3 | 3.096 | 3.752 |
| 69 | POKHARA | 4.7 | 8.0 | 0.8 | 2.012 | 2.278 |
| 70 | POKHARA | 5.2 | 8.0 | 0.5 | 1.858 | 2.211 |
| 71 | POKHARA | 5.2 | 7.0 | 1.6 | 4.954 | 4.757 |
| 72 | POKHARA | 3.6 | 4.0 | 1.0 | 2.270 | 2.111 |
| 73 | POKHARA | 5.5 | 7.0 | 1.7 | 4.489 | 3.149 |
| 74 | POKHARA | 5.4 | 8.0 | 1.2 | 2.735 | 2.915 |
| 75 | POKHARA | 5.5 | 7.0 | 2.1 | 5.676 | 4.657 |
| 76 | POKHARA | 6.0 | 8.0 | 2.0 | 5.315 | 4.925 |
| 77 | POKHARA | 6.2 | 5.5 | 2.1 | 6.398 | 5.796 |
| 78 | RAMPUR | 5.9 | 15.5 | 3.2 | 12.229 | 20.670 |
| 79 | RAMPUR | 4.2 | 15.8 | 3.5 | 10.268 | 17.320 |
| 80 | RAMPUR | 3.9 | 11.3 | 2.8 | 7.018 | 10.988 |
| 81 | RAMPUR | 5.3 | 14.5 | 3.0 | 10.578 | 13.752 |
| 82 | RAMPUR | 4.7 | 13.8 | 3.2 | 11.455 | 11.122 |
| 83 | RAMPUR | 3.6 | 9.6 | 3.0 | 8.875 | 8.308 |
| 84 | RAMPUR | 6.1 | 12.3 | 3.2 | 16.770 | 25.192 |
| 85 | RAMPUR | 3.6 | 9.5 | 2.9 | 8.617 | 8.208 |
| 86 | RAMPUR | 3.7 | 8.2 | 3.2 | 9.340 | 9.514 |
| 87 | RAMPUR | 3.4 | 7.1 | 2.1 | 7.688 | 9.481 |
| 88 | RAMPUR | 5.6 | 11.8 | 4.1 | 14.396 | 15.444 |
| 89 | RAMPUR | 5.3 | 14.8 | 3.8 | 13.313 | 23.216 |
| 90 | RAMPUR | 4.4 | 13.1 | 4.5 | 15.738 | 28.274 |
| 91 | RAMPUR | 4.7 | 7.9 | 1.7 | 6.863 | 7.002 |
| 92 | RAMPUR | 6.1 | 11.2 | 4.5 | 15.428 | 30.552 |
| 93 | RAMPUR | 3.7 | 10.3 | 3.4 | 6.450 | 12.027 |
| 94 | RAMPUR | 3.1 | 7.9 | 3.5 | 7.172 | 7.772 |
| 95 | RAMPUR | 3.5 | 8.4 | 2.8 | 7.018 | 7.504 |
| 96 | RAMPUR | 3.8 | 6.5 | 2.6 | 8.462 | 9.615 |
| 97 | RAMPUR | 4.4 | 10.3 | 2.2 | 7.430 | 14.104 |

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Appendix 3. Table 2. Summary of the sample *Bauhinia varigata* trees data from four sites in central and western Nepal

| Sample No. | Site | Height(m) | Dia50(cm) | Fol.dry wt(kg) | Wd.dry wt(kg) |
|---|---|---|---|---|---|
| 1 | HETAUDA | 4.2 | 6.0 | 3.148 | 6.499 |
| 2 | HETAUDA | 6.9 | 10.2 | 5.045 | 12.821 |
| 3 | HETAUDA | 5.9 | 8.0 | 3.479 | 6.696 |
| 4 | HETAUDA | 4.3 | 6.3 | 3.549 | 9.257 |
| 5 | HETAUDA | 6.7 | 12.9 | 7.567 | 22.058 |
| 6 | HETAUDA | 4.0 | 5.4 | 2.888 | 7.681 |
| 7 | HETAUDA | 3.7 | 5.1 | 2.540 | 6.105 |
| 8 | HETAUDA | 3.4 | 4.0 | 1.826 | 3.900 |
| 9 | HETAUDA | 3.2 | 3.5 | 1.600 | 2.915 |
| 10 | HETAUDA | 3.7 | 5.0 | 2.957 | 7.563 |
| 11 | HETAUDA | 3.6 | 6.5 | 3.305 | 7.011 |
| 12 | HETAUDA | 5.3 | 8.0 | 5.045 | 13.077 |
| 13 | HETAUDA | 5.4 | 9.6 | 6.088 | 11.620 |
| 14 | HETAUDA | 5.5 | 7.0 | 4.801 | 10.202 |
| 15 | HETAUDA | 6.6 | 13.1 | 6.436 | 20.581 |
| 16 | KARMAIYA | 4.6 | 5.8 | 1.774 | 3.781 |
| 17 | KARMAIYA | 4.0 | 5.8 | 1.600 | 3.348 |
| 18 | KARMAIYA | 4.2 | 5.3 | 1.913 | 2.915 |
| 19 | KARMAIYA | 2.3 | 2.9 | 1.044 | 1.260 |
| 20 | KARMAIYA | 2.1 | 2.1 | 0.661 | 0.827 |
| 21 | KARMAIYA | 4.1 | 7.4 | 2.470 | 5.712 |
| 22 | KARMAIYA | 4.0 | 7.1 | 2.992 | 5.199 |
| 23 | KARMAIYA | 3.3 | 3.5 | 0.939 | 1.576 |
| 24 | KARMAIYA | 2.9 | 5.3 | 2.018 | 3.427 |
| 25 | KARMAIYA | 7.3 | 11.5 | 4.905 | 11.620 |
| 26 | KARMAIYA | 4.6 | 9.8 | 2.957 | 9.296 |
| 27 | KARMAIYA | 3.2 | 6.8 | 1.774 | 4.136 |
| 28 | KARMAIYA | 4.6 | 7.1 | 3.688 | 8.548 |
| 29 | KARMAIYA | 5.6 | 9.4 | 3.966 | 10.044 |
| 30 | KARMAIYA | 2.4 | 2.3 | 0.870 | 1.260 |
| 31 | KARMAIYA | 2.6 | 3.5 | 1.044 | 1.615 |
| 32 | KARMAIYA | 6.0 | 8.5 | 3.305 | 9.690 |
| 33 | KARMAIYA | 5.3 | 9.0 | 2.818 | 7.642 |
| 34 | KARMAIYA | 5.4 | 9.8 | 3.235 | 9.926 |
| 35 | KARMAIYA | 3.4 | 6.2 | 2.957 | 6.854 |
| 36 | KARMAIYA | 6.0 | 9.6 | 4.001 | 9.217 |
| 37 | KARMAIYA | 3.0 | 2.7 | 0.800 | 0.827 |
| 38 | POKHARA | 5.6 | 7.8 | 3.409 | 5.987 |
| 39 | POKHARA | 4.8 | 7.0 | 2.157 | 4.254 |
| 40 | POKHARA | 5.2 | 6.0 | 2.574 | 3.506 |
| 41 | POKHARA | 4.2 | 4.5 | 1.322 | 2.127 |
| 42 | POKHARA | 3.2 | 3.0 | 0.905 | 1.339 |
| 43 | POKHARA | 2.1 | 2.5 | 0.696 | 1.182 |
| 44 | POKHARA | 2.3 | 2.2 | 0.835 | 1.260 |
| 45 | POKHARA | 2.5 | 1.9 | 0.870 | 1.418 |
| 46 | POKHARA | 4.9 | 5.1 | 2.192 | 4.254 |
| 47 | POKHARA | 4.3 | 6.0 | 1.879 | 2.639 |
| 48 | POKHARA | 3.6 | 5.0 | 2.505 | 5.199 |
| 49 | POKHARA | 3.1 | 3.5 | 1.113 | 1.970 |
| 50 | POKHARA | 3.3 | 7.0 | 2.157 | 4.097 |
| 51 | POKHARA | 3.8 | 7.0 | 1.983 | 4.569 |
| 52 | RAMPUR | 3.2 | 6.0 | 1.913 | 5.515 |
| 53 | RAMPUR | 4.8 | 7.5 | 2.053 | 6.854 |
| 54 | RAMPUR | 2.0 | 5.5 | 1.287 | 2.521 |
| 55 | RAMPUR | 5.2 | 7.8 | 2.227 | 7.011 |
| 56 | RAMPUR | 5.6 | 8.3 | 3.549 | 7.130 |
| 57 | RAMPUR | 6.2 | 10.8 | 7.793 | 19.931 |
| 58 | RAMPUR | 3.6 | 4.5 | 1.461 | 5.672 |
| 59 | RAMPUR | 2.2 | 2.1 | 1.078 | 1.812 |
| 60 | RAMPUR | 4.0 | 9.3 | 2.714 | 16.662 |

Table 3.2

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Table 3.2 contd....

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|---|---|---|---|---|---|
| 61 | RAMPUR | 4.4 | 8.5 | 2.244 | 8.863 |
| 62 | RAMPUR | 7.4 | 12.0 | 4.801 | 16.347 |
| 63 | RAMPUR | 8.2 | 13.2 | 6.053 | 27.731 |
| 64 | RAMPUR | 8.1 | 16.1 | 5.149 | 17.174 |
| 65 | RAMPUR | 2.4 | 4.9 | 1.670 | 4.983 |
| 66 | RAMPUR | 2.8 | 4.0 | 1.513 | 5.278 |

Appendix 3. Ta

| Sample No. | Si |
|---|---|
| 1 | HF |
| 2 | HF |
| 3 | HF |
| 4 | HF |
| 5 | HF |
| 6 | HI |
| 7 | HI |
| 8 | HI |
| 9 | TA |
| 10 | TA |
| 11 | TA |
| 12 | TA |
| 13 | T |
| 14 | T |
| 15 | T |
| 16 | T |
| 17 | PO |
| 18 | PO |
| 19 | PO |
| 20 | PO |
| 21 | PO |
| 22 | PO |
| 23 | PO |
| 24 | PO |

**Table 3.4 Sum**
**sites in c**

| Sample No. |
|---|
| 1 |
| 2 |
| 3 |
| 4 |
| 5 |
| 6 |
| 7 |
| 8 |
| 9 |
| 10 |
| 11 |
| 12 |

**Appendix 3. Table 3.3. Summary of on-farm *F.semicordata* sample tree data from three sites in central and western Nepal**

| Sample No. | Site | Height (m) | Crown dia. (m) | Fol.dry wt. (kg.) | Bra.wd.wt. (kg.) |
|---|---|---|---|---|---|
| 1 | HETAUDA | 9.6 | 5.5 | 38.494 | 65.191 |
| 2 | HETAUDA | 6.3 | 3.1 | 20.795 | 33.355 |
| 3 | HETAUDA | 6.2 | 2.8 | 17.441 | 22.923 |
| 4 | HETAUDA | 11.3 | 5.5 | 51.187 | 78.241 |
| 5 | HETAUDA | 7.5 | 2.7 | 21.130 | 34.234 |
| 6 | HETAUDA | 7.0 | 3.2 | 22.833 | 35.933 |
| 7 | HETAUDA | 11.7 | 3.8 | 26.264 | 55.398 |
| 8 | HETAUDA | 5.2 | 2.7 | 18.473 | 20.864 |
| 9 | TANAHU | 6.8 | 2.3 | 11.249 | 17.127 |
| 10 | TANAHU | 11.6 | 4.0 | 48.478 | 54.359 |
| 11 | TANAHU | 6.8 | 2.6 | 16.538 | 25.221 |
| 12 | TANAHU | 6.2 | 2.4 | 9.133 | 17.687 |
| 13 | TANAHU | 10.2 | 3.6 | 28.070 | 38.651 |
| 14 | TANAHU | 7.8 | 1.8 | 13.235 | 23.362 |
| 15 | TANAHU | 5.9 | 2.2 | 9.933 | 14.289 |
| 16 | TANAHU | 11.7 | 3.4 | 28.122 | 40.450 |
| 17 | POKHARA | 5.9 | 2.8 | 20.795 | 33.355 |
| 18 | POKHARA | 6.4 | 2.0 | 8.540 | 13.410 |
| 19 | POKHARA | 9.7 | 3.7 | 28.664 | 32.556 |
| 20 | POKHARA | 6.3 | 2.5 | 19.015 | 17.467 |
| 21 | POKHARA | 5.4 | 2.1 | 8.153 | 8.254 |
| 22 | POKHARA | 11.2 | 3.8 | 25.413 | 41.769 |
| 23 | POKHARA | 8.2 | 1.9 | 18.034 | 16.628 |
| 24 | POKHARA | 5.7 | 2.2 | 8.927 | 12.371 |

**Table 3.4 Summary of on-farm *B.variegata* sample tree data at two sites in central and western Nepal**

| Sample No. | Height(m) (m) | DBH(m) (m) | Fol.dry wt. (kg.) | Bra.wd.dry wt. (kg) |
|---|---|---|---|---|
| 1 | 5.7 | 10.1 | 5.753 | 9.488 |
| 2 | 6.5 | 14.2 | 12.161 | 20.050 |
| 3 | 8.7 | 15.0 | 14.547 | 23.967 |
| 4 | 8.3 | 19.1 | 16.803 | 26.549 |
| 5 | 8.4 | 19.1 | 16.803 | 26.549 |
| 6 | 9.3 | 20.6 | 18.143 | 27.419 |
| 7 | 8.7 | 21.3 | 17.162 | 28.290 |
| 8 | 6.8 | 22.0 | 27.787 | 40.244 |
| 9 | 6.8 | 22.0 | 25.596 | 42.188 |
| 10 | 7.6 | 22.1 | 20.497 | 30.988 |
| 11 | 7.1 | 22.6 | 19.974 | 39.432 |
| 12 | 9.0 | 23.5 | 35.992 | 52.111 |

**Appendix 3. Table 3.5 Testing differences between regression functions of *F.semicordata* at Karmaiya, Hetauda, and Rampur**

$H_0$: $\beta_1 = \beta_2 = \beta_3 = \beta_4$; $H_A$: All four $\beta$'s are not equal

| Regression lines | TSS | Reg.SS | RSS | $\beta_1$ | $\beta_2$ | DF |
|---|---|---|---|---|---|---|
| Karmaiya | 5.10 | 3.99 | 1.11 | .82 | .42 | 27 |
| Hetauda | 5.92 | 4.78 | 1.14 | .58 | .98 | 24 |
| Rampur | 3.08 | 2.67 | 0.42 | .59 | 1.35 | 17 |
| $SS_t$ | 14.48 | 11.20 | 3.28 | .66 | .79 | 74 |
| $SS_p$ | 14.10 | 11.44 | 2.67 | - | - | 68 |

Test:

$$F = \frac{SS_t - SS_p \,/\, (m+1)\,(k-1)}{SS_p/DF_p} = \frac{14.48 - 14.10/6}{14.10/68} = .305$$

Here m = 2; K = 3

Since $F_{0.05(1),3,68} = 2.74$, do not reject $H_0$.

Conclusion: The slopes of the three regression lines are not significantly different.

**Appendix 3. Table 3.6 Comparing regression equations among four sites for *B.variegata* allometric model.**

Information summary:

| Regression | $\Sigma x^2$ | $\Sigma xy$ | $\Sigma y^2$ | n | b | Res. SS | Res. DF |
|---|---|---|---|---|---|---|---|
| Karmaiya | 5.49 | 8.05 | 13.96 | 22 | 1.47 | 0.68 | 20 |
| Hetauda | 2.37 | 2.95 | 6.00 | 15 | 1.29 | 0.40 | 13 |
| Pokhara | 2.96 | 3.10 | 4.14 | 14 | 1.05 | 0.66 | 12 |
| Rampur | 3.90 | 5.73 | 11.34 | 15 | 1.22 | 1.34 | 13 |
| "Pooled" | | | | | | 3.08 | 58 |
| "Common" | 14.72 | 19.83 | 35.44 | 66 | 1.26 | 8.73 | 61 |
| "Total" | 16.65 | 22.91 | 36.67 | 66 | 1.38 | 5.15 | 64 |

$H_0$: $\beta_1 = \beta_2 = \beta_3 = \beta_4$; $H_A$: All four $\beta$'s are not equal

$$F = \frac{8.73 - 3.08/4 - 1}{3.08/58} = \frac{1.88}{.053} = 35.53$$

Since $F_{0.05(1),3,58} = 2.76$, reject the $H_0$.

To test for differences between elevations:

$H_0$: The four regression lines have the same elevation.
$H_A$: The three lines do not have the same elevation.

$$F = \frac{5.15 - 3.08/4 - 1}{8.73/61} = 4.82$$

Since $F_{0.05(1),3,61} = 2.76$, reject $H_0$.

Conclusion: Slopes and elevations of all four regression lines are significantly different.

# Appendix 3

**Table 3.7. Fodder biomass table[b] for *Ficus semicordata* for central and western regions of Nepal[a] (individual-tree, oven dry weight in (kg.)**

| Crown Diameter (m) | Tree Height (m) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
| .50 | 1.35 | 1.62 | 1.85 | 2.05 | | | | | | | | | |
| .75 | 2.00 | 2.41 | 2.75 | 3.05 | 3.32 | | | | | | | | |
| 1.0 | 2.65 | 3.19 | 3.65 | 4.04 | 4.40 | 4.72 | | | | | | | |
| 1.25 | 3.29 | 3.97 | 4.53 | 5.04 | 5.47 | 5.87 | 6.24 | | | | | | |
| 1.50 | 3.94 | 4.75 | 5.42 | 6.01 | 6.53 | 7.01 | 7.46 | 10.46 | | | | | |
| 1.75 | 4.58 | 5.52 | 6.30 | 6.98 | 7.59 | 8.15 | 11.55 | 12.40 | 13.20 | | | | |
| 2.00 | 5.21 | 6.29 | 7.18 | 7.96 | 8.65 | 9.30 | 13.37 | 14.35 | 15.29 | 16.18 | | | |
| 2.25 | 5.85 | 7.05 | 8.05 | 8.93 | 9.71 | 10.42 | 15.22 | 16.34 | 17.42 | 18.43 | 19.42 | | |
| 2.50 | 6.48 | 8.58 | 8.93 | 9.89 | 10.76 | 11.55 | 17.10 | 18.35 | 19.55 | 20.70 | 21.80 | 22.88 | |
| 2.75 | 7.12 | 9.34 | 9.80 | 10.86 | 11.81 | 12.68 | 19.05 | 20.40 | 21.73 | 23.00 | 24.24 | 25.43 | |
| 3.00 | 9.12 | 11.13 | 13.81 | 15.79 | 17.61 | 19.32 | 20.92 | 22.45 | 23.92 | 25.27 | 26.68 | 27.99 | |
| 3.25 | 9.96 | 12.70 | 15.09 | 17.24 | 19.24 | 21.09 | 22.85 | 24.52 | 26.13 | 27.66 | 29.14 | 30.57 | |
| 3.50 | 10.81 | 13.78 | 16.37 | 18.71 | 20.87 | 22.89 | 24.79 | 26.60 | 28.35 | 30.01 | 31.61 | 33.15 | |
| 3.75 | 11.66 | 14.87 | 17.66 | 20.18 | 22.54 | 24.70 | 26.75 | 28.70 | 30.58 | 32.38 | 34.11 | 35.78 | |
| 4.00 | 12.51 | 15.96 | 18.95 | 21.56 | 24.17 | 26.50 | 28.70 | 30.80 | 32.82 | 34.74 | 36.60 | 38.39 | |
| 4.25 | 13.38 | 17.07 | 20.26 | 23.16 | 25.85 | 28.34 | 30.69 | 32.94 | 34.83 | 35.10 | 39.14 | 40.06 | |
| 4.50 | 14.24 | 18.17 | 21.58 | 24.67 | 27.52 | 30.18 | 32.68 | 35.08 | 37.38 | 39.56 | 41.68 | 43.72 | |
| 4.75 | 15.12 | 19.29 | 22.90 | 26.18 | 29.21 | 32.03 | 34.69 | 37.23 | 39.67 | 41.99 | 44.23 | 46.51 | |
| 5.00 | 16.00 | 20.40 | 24.23 | 27.69 | 30.90 | 33.88 | 36.69 | 39.38 | 41.96 | 44.42 | 46.79 | 49.09 | |
| 5.25 | 16.89 | 21.53 | 25.57 | 29.23 | 32.61 | 35.76 | 38.73 | 41.56 | 44.29 | 46.88 | 49.39 | 51.82 | |
| 5.50 | 17.78 | 22.68 | 26.93 | 30.78 | 34.35 | 37.66 | 40.79 | 43.77 | 46.64 | 49.37 | 52.01 | 54.57 | |
| 5.75 | 18.67 | 23.81 | 28.27 | 32.31 | 36.05 | 39.54 | 42.81 | 49.95 | 48.96 | 51.83 | 54.60 | 57.28 | |
| 6.00 | 19.57 | 24.96 | 29.64 | 33.88 | 37.80 | 41.45 | 44.89 | 48.18 | 51.34 | 54.34 | 57.25 | 60.06 | |

[a] This table has been prepared based on the sampling of two population data - within the height (ht.) range of 2-7.9 m and crown diameter (cd) range of 0.5-2.9 m. range the data were collected from the five year old experimental plots and model used was LnFw=.489+.977Ln*cd+.461Ln*ht with a correction factor of 0.1657; and beyond these ranges the data came from the farmer's filed and the model used was LnF=.565+1.102Ln*cd+.599Ln*ht with a correction factor of 0.1528

[b] Users are advised to validate the tables before using.

Appendix 3

Table 3.8. Total wood biomass table for __Ficus__ __semicordata__ **for the central and western Nepal**[a] **(individual-tree, oven dry weight in kg.)**

| Crown Diameter (m) | Tree Height (m) 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.50 | 1.15 | 1.40 | 1.61 | 1.96 | | | | | | | | |
| 0.75 | 1.84 | 2.25 | 2.59 | 3.16 | 3.41 | | | | | | | |
| 1.00 | 2.58 | 3.15 | 3.63 | 4.43 | 4.78 | 5.41 | | | | | | |
| 1.25 | 3.36 | 4.10 | 4.72 | 5.76 | 6.21 | 7.03 | 10.21 | | | | | |
| 1.50 | 4.16 | 5.07 | 6.52 | 7.13 | 7.69 | 8.70 | 12.78 | 13.79 | | | | |
| 1.75 | 4.98 | 6.08 | 7.81 | 8.55 | 9.22 | 10.43 | 15.44 | 16.65 | 17.84 | | | |
| 2.00 | 5.83 | 7.11 | 9.14 | 10.00 | 10.78 | 11.51 | 18.17 | 19.61 | 21.00 | 22.32 | | |
| 2.25 | 6.69 | 8.17 | 10.50 | 11.48 | 12.38 | 14.96 | 21.00 | 22.67 | 24.25 | 25.80 | 27.29 | |
| 2.50 | 7.57 | 9.24 | 11.87 | 12.99 | 14.01 | 16.73 | 23.89 | 25.78 | 27.61 | 29.35 | 31.05 | 32.69 |
| 2.75 | 8.47 | 10.34 | 13.28 | 14.53 | 15.67 | 18.53 | 26.88 | 29.01 | 31.05 | 33.02 | 34.92 | 36.77 |
| 3.00 | 12.23 | 15.89 | 19.13 | 22.09 | 24.85 | 27.45 | 29.91 | 32.27 | 34.56 | 36.74 | 38.86 | 40.92 |
| 3.25 | 13.49 | 17.54 | 21.10 | 24.36 | 27.42 | 30.28 | 33.00 | 35.60 | 38.12 | 40.53 | 42.87 | 45.14 |
| 3.50 | 14.78 | 19.20 | 23.11 | 26.68 | 30.02 | 33.16 | 36.13 | 38.99 | 41.74 | 44.38 | 46.94 | 49.43 |
| 3.75 | 16.08 | 20.90 | 25.15 | 29.04 | 32.67 | 36.09 | 39.32 | 42.43 | 45.43 | 48.30 | 51.10 | 53.80 |
| 4.00 | 17.40 | 22.61 | 27.20 | 31.41 | 35.34 | 39.04 | 42.53 | 45.90 | 49.14 | 52.25 | 55.26 | 58.34 |
| 4.25 | 18.75 | 24.32 | 29.32 | 33.85 | 38.09 | 42.07 | 45.84 | 49.47 | 52.96 | 56.31 | 59.56 | 62.72 |
| 4.50 | 20.11 | 26.13 | 31.44 | 36.30 | 40.85 | 45.12 | 49.16 | 53.05 | 56.80 | 60.39 | 63.87 | 67.26 |
| 4.75 | 21.49 | 27.92 | 33.60 | 38.79 | 43.65 | 48.21 | 52.53 | 56.68 | 60.69 | 64.53 | 68.25 | 71.87 |
| 5.00 | 22.87 | 29.72 | 35.76 | 41.29 | 46.47 | 51.32 | 55.86 | 60.34 | 64.61 | 68.69 | 72.65 | 76.50 |
| 5.25 | 24.29 | 31.56 | 37.98 | 43.86 | 49.35 | 54.51 | 59.39 | 64.08 | 68.61 | 72.95 | 77.16 | 81.25 |
| 5.50 | 25.73 | 33.43 | 40.23 | 46.46 | 52.27 | 57.74 | 62.91 | 67.88 | 72.68 | 77.28 | 81.74 | 86.06 |
| 5.75 | 27.16 | 35.29 | 42.46 | 49.03 | 55.17 | 60.94 | 66.40 | 71.65 | 76.72 | 81.57 | 86.27 | 90.84 |
| 6.00 | 28.63 | 37.20 | 44.77 | 51.69 | 58.17 | 64.24 | 70.00 | 75.54 | 80.87 | 85.99 | 90.95 | 95.77 |

[a] This table has been prepared based on the sampling of two population data - within the height (ht.) range of 2-7.9 m and crown diameter (cd) range of 0.5-2.9 m. range the data were from the experimental plots and the model used was LnF=.472+1.174Ln*cd+.491Ln*ht with a correction factor of 0.2035 and beyond these ranges the data came from trees selected from the farmer's field and model used was LnW=.690+1.227Lncd+.645Lnht with a correction factor of 0.1490.

[b] Users are advised to validate the tables before using.

Appendix 3

**Table 3.9. Estimated oven dry weight fodder and wood biomass table for *B.variegata* (< 5 years of age) based on the diameter at 50 cm as the predictor variable[a].**

| Ht[b](m) | Do5 (cm.) | Fodder Wt.(kg) | Wood Wt.(kg) | Total wt (Kg.) |
|---|---|---|---|---|
| 1.6 | 2.0 | 0.000 | 1.255 | 1.958 |
| 1.9 | 2.5 | 1.024 | 1.800 | 2.721 |
| 2.2 | 3.0 | 1.262 | 2.416 | 3.557 |
| 2.5 | 3.5 | 1.507 | 3.099 | 4.464 |
| 2.8 | 4.0 | 1.756 | 3.846 | 5.436 |
| 3.1 | 4.5 | 2.008 | 4.651 | 6.462 |
| 3.4 | 5.0 | 2.266 | 5.512 | 7.546 |
| 3.7 | 5.5 | 2.527 | 6.430 | 8.680 |
| 4.0 | 6.0 | 2.793 | 7.396 | 9.865 |
| 4.3 | 6.5 | 3.059 | 8.423 | 11.101 |
| 4.6 | 7.0 | 3.330 | 9.488 | 12.379 |
| 5.0 | 7.5 | 3.604 | 10.612 | 13.708 |
| 5.3 | 8.0 | 3.881 | 11.775 | 15.074 |
| 5.6 | 8.5 | 4.162 | 12.988 | 16.478 |
| 5.9 | 9.0 | 4.442 | 14.239 | 17.922 |
| 6.2 | 9.5 | 4.726 | 15.549 | 19.414 |
| 6.5 | 10.0 | 5.013 | 16.878 | 20.926 |
| 6.8 | 10.5 | 5.298 | 18.274 | 24.095 |
| 7.1 | 11.0 | 5.590 | 19.688 | 25.713 |
| 7.4 | 11.5 | 5.877 | 21.158 | 27.385 |
| 7.7 | 12.0 | 6.178 | 22.669 | 29.079 |
| 8.0 | 12.5 | 6.469 | 24.215 | 30.815 |
| 8.3 | 13.0 | 6.767 | 25.790 | 32.590 |
| 8.7 | 13.5 | 7.071 | 27.440 | 34.364 |
| 9.0 | 14.0 | 7.367 | 29.079 | 36.162 |
| 9.3 | 14.5 | 7.668 | 30.753 | 38.016 |
| 9.6 | 15.0 | 7.973 | 32.492 | 39.925 |
| 9.9 | 15.5 | 8.281 | 34.261 | 41.846 |
| 10.2 | 16.0 | 8.585 | 36.089 | 43.293 |

The equations used for these estimates are as following:

[a] Fodder: LnFWt.=-1.226+1.100*LnDo5; $R^2$=.812; $s^2$=.269; CF=0.192
Wood: LnWWt.=-1.099+1.531*LnDo5; $R^2$=.830; $s^2$=.352; CF=0.329

[b] Height was predicted as:LnHt.=.311+.618*Do5; $R^2$=.762; $s^2$=.031

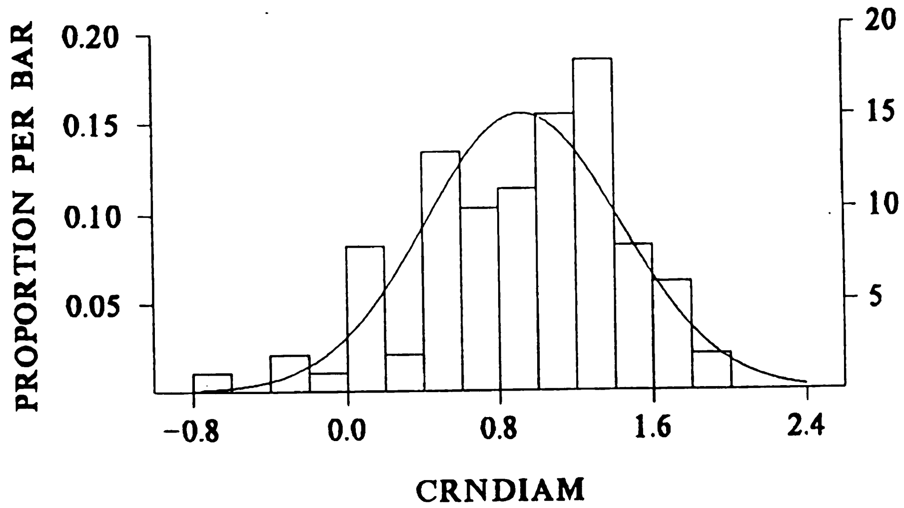
## Appendix 3

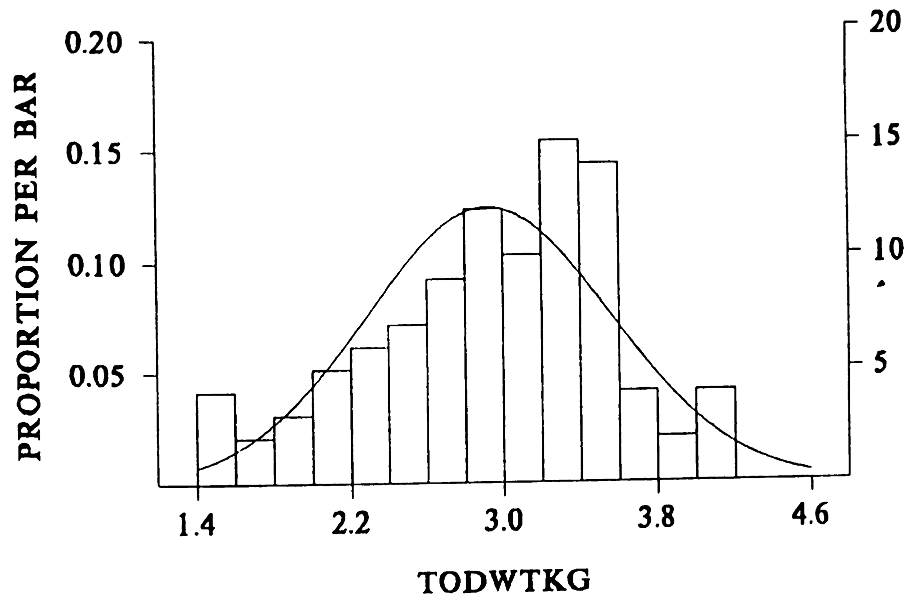
**Table 3.10. Estimated oven dry weight fodder and wood biomass table for *B. variegata* (> 5 year) based on the diameter at breast height (Dbh) as predictor variable[c].**

| Dbh[d] (cm) | Fodder wt.(kg.) | Wood wt.(kg) | Total biomass (kg.) |
|---|---|---|---|
| 7.50 | 6.699 | 10.903 | 17.497 |
| 8.00 | 7.463 | 12.098 | 19.453 |
| 9.00 | 9.107 | 14.658 | 23.618 |
| 10.0 | 10.870 | 17.409 | 28.107 |
| 11.0 | 12.769 | 20.328 | 32.917 |
| 12.0 | 14.776 | 23.406 | 37.978 |
| 13.0 | 16.912 | 26.656 | 43.337 |
| 14.0 | 19.163 | 30.084 | 49.009 |
| 15.0 | 21.520 | 33.650 | 54.927 |
| 16.0 | 23.999 | 37.375 | 61.069 |
| 17.0 | 26.576 | 41.264 | 67.491 |
| 18.0 | 29.253 | 45.286 | 74.218 |
| 19.0 | 32.040 | 49.452 | 81.126 |
| 20.0 | 34.918 | 53.732 | 88.323 |
| 21.0 | 37.940 | 58.207 | 95.679 |
| 22.0 | 41.017 | 62.740 | 103.337 |

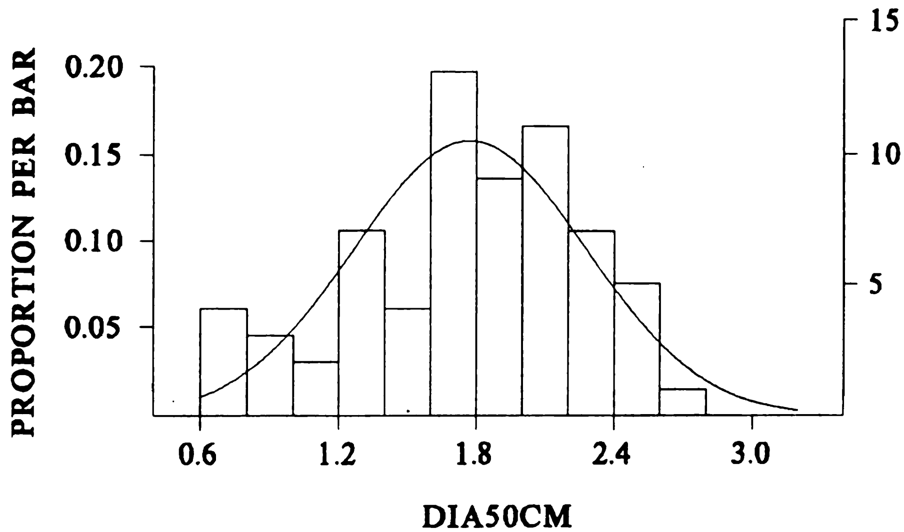
[c] Fodder: LnFwt.=-1.583+1.684*LnDbh; $R^2$=.852; $s^2$=.186
Wood: LnWWt.=-0.962+1.627*LnDbh; $R^2$=.872; $s^2$=.165
Total biomass =-0.540+1.651*LnDbh; $R^2$=.871; $s^2$=.168

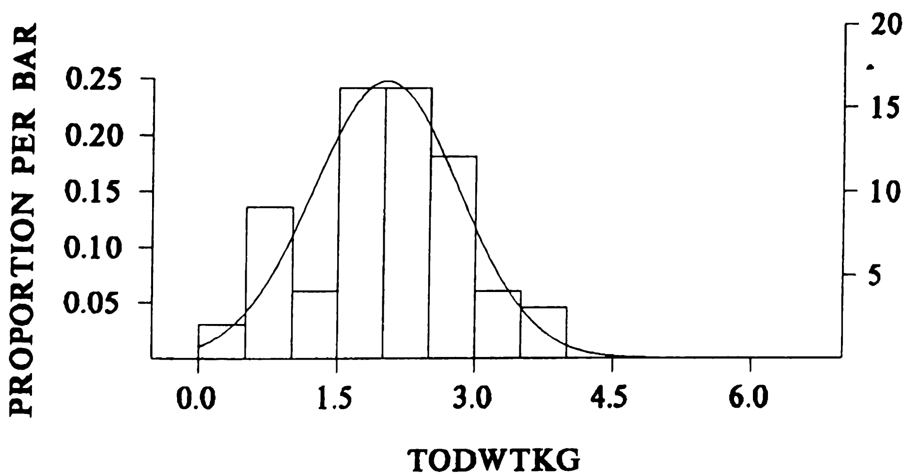
**Appendix 3. Figure 3.1 Distribution of log transformed dependent(total dry weight) and independent (crown diameter) variables of *Ficus semicordata* individual-tree model**



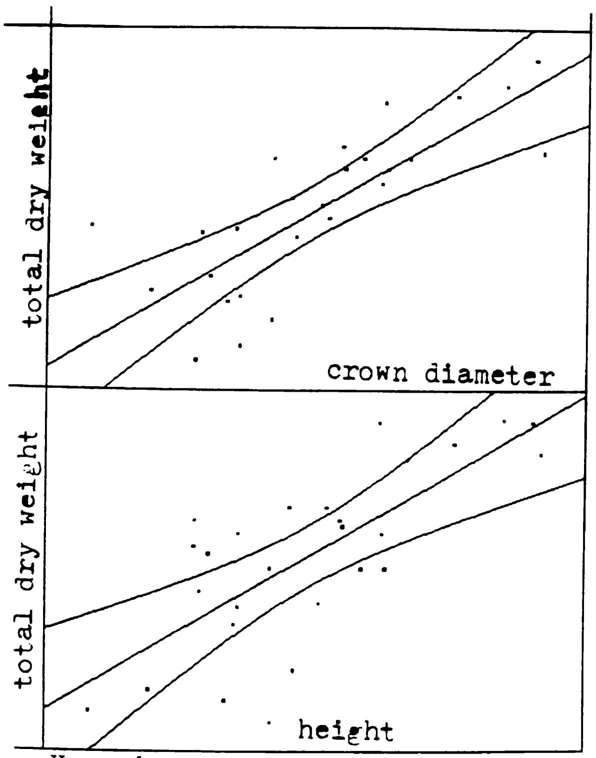



**Appendix 3. Figure 3.2 Distribution of log transformed dependent(total dry weight) and independent (diameter at 50 cm) variables of *Bauhinia variegata* individual-tree model**

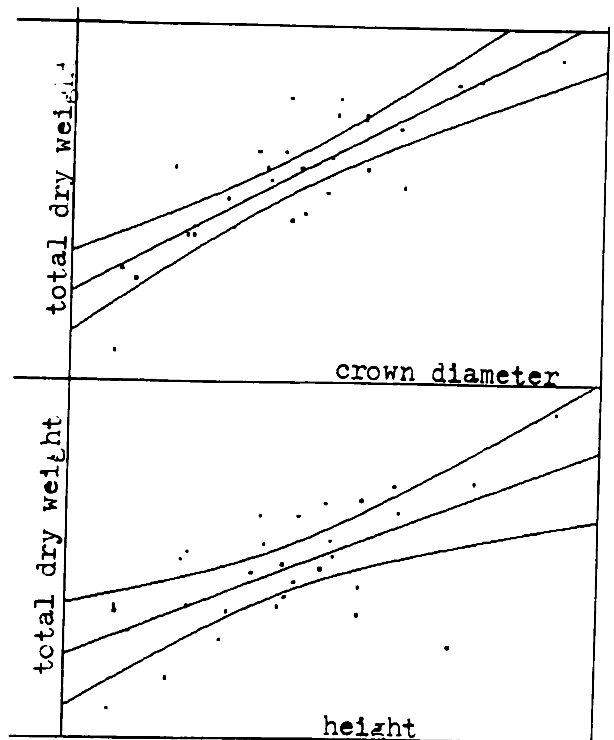


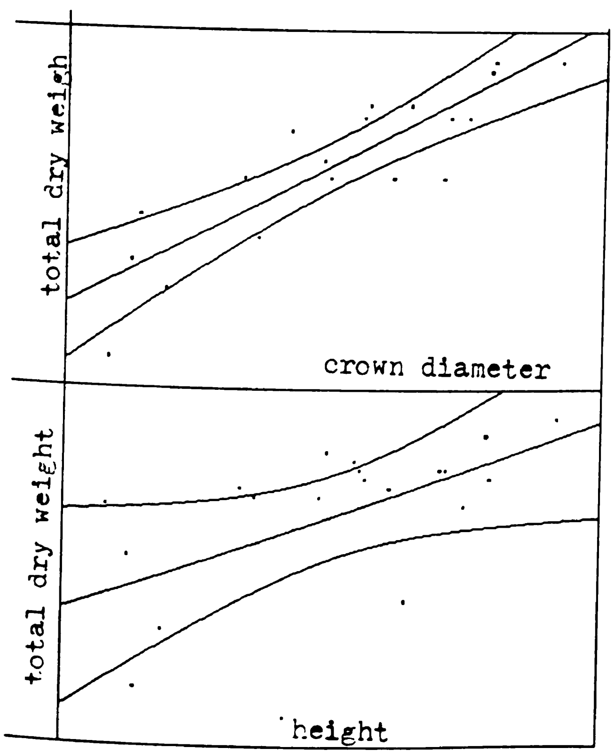
**Appendix 3. Figure 3.3 Scatter plots of crown diameter against total dry biomass weight with linear fits and their 95% confidence band in *F.semicordata* individual-tree models**



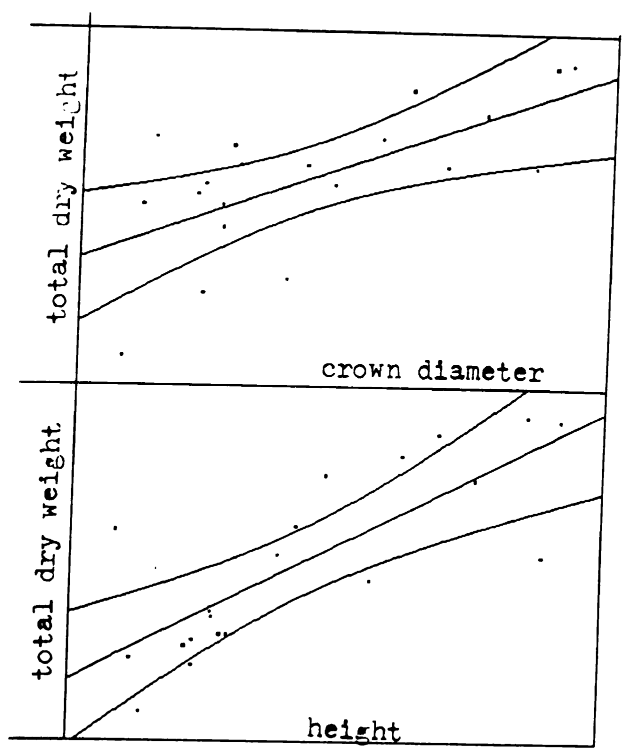

Karmaiya




Hetauda

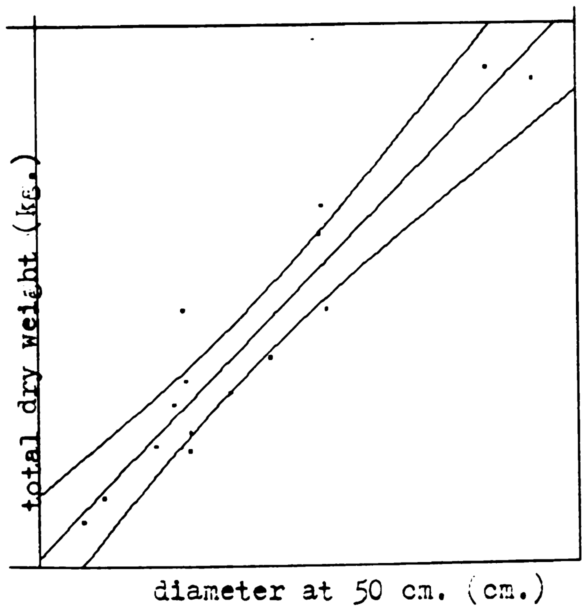



Rampur

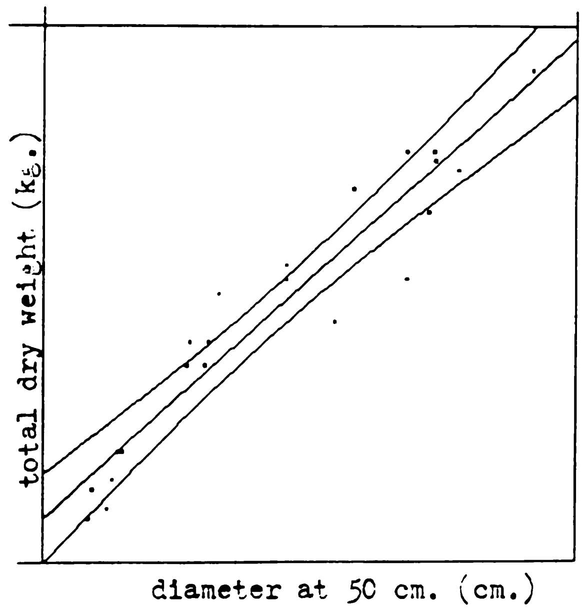



Pokhara

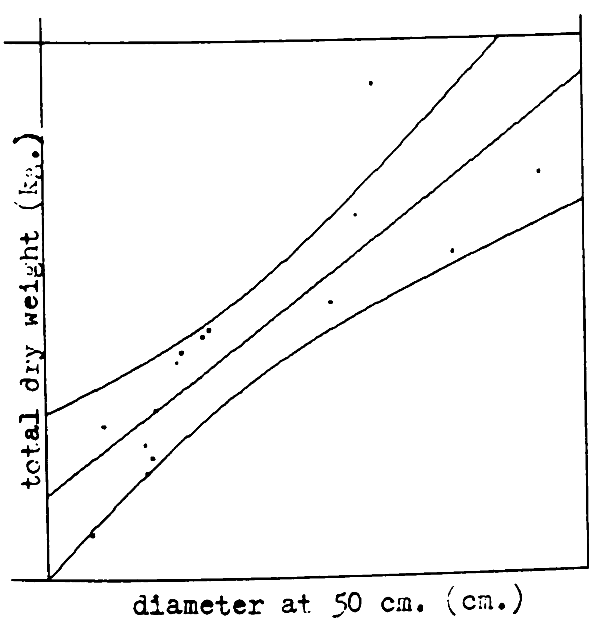
**Appendix 3. Figure 3.4 Scatter plots of diameter at 50 cm (*d50*) against total dry biomass weight with linear fits and their 95% confidence band in *B.variegata* individual-tree models**



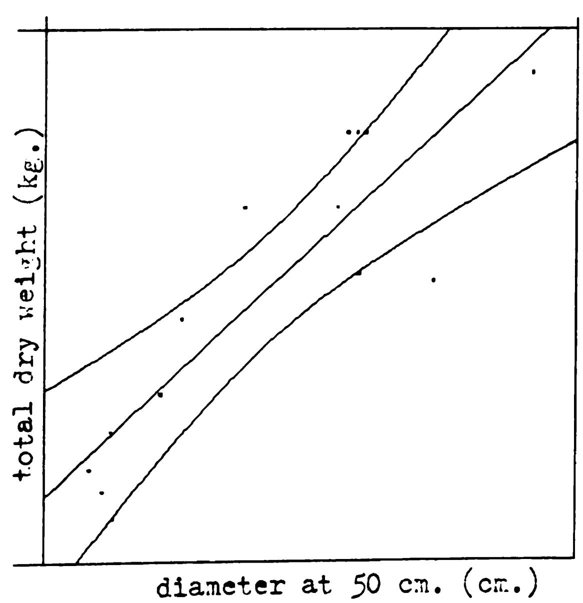

Karmaiya




Hetauda

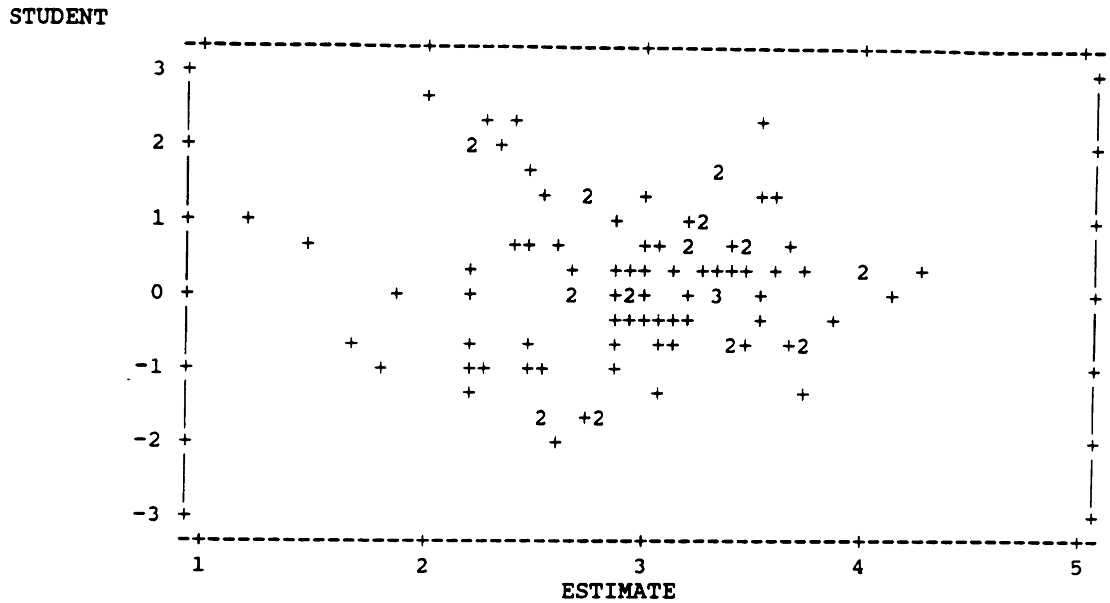



Rampur

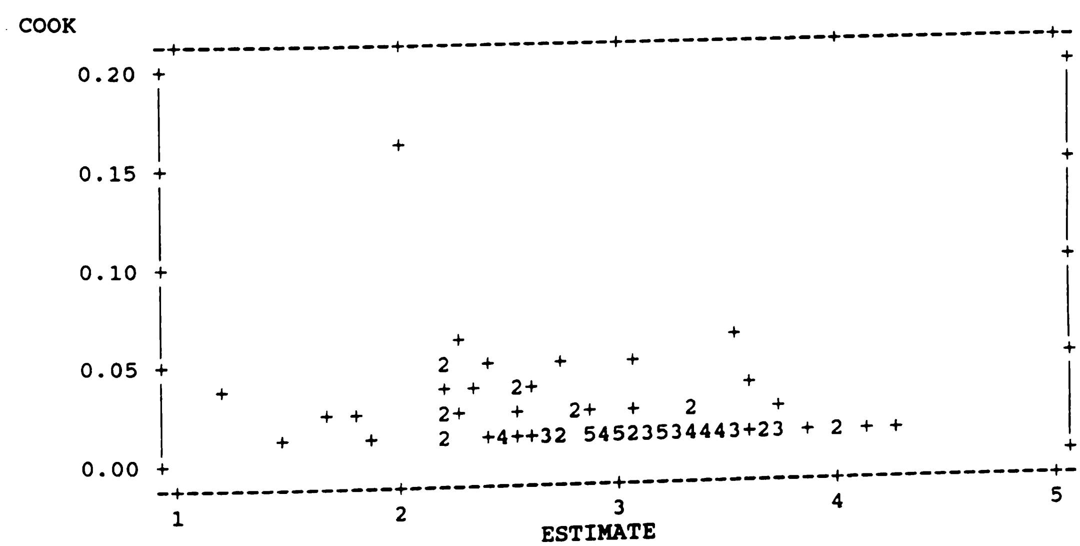



Pokhara

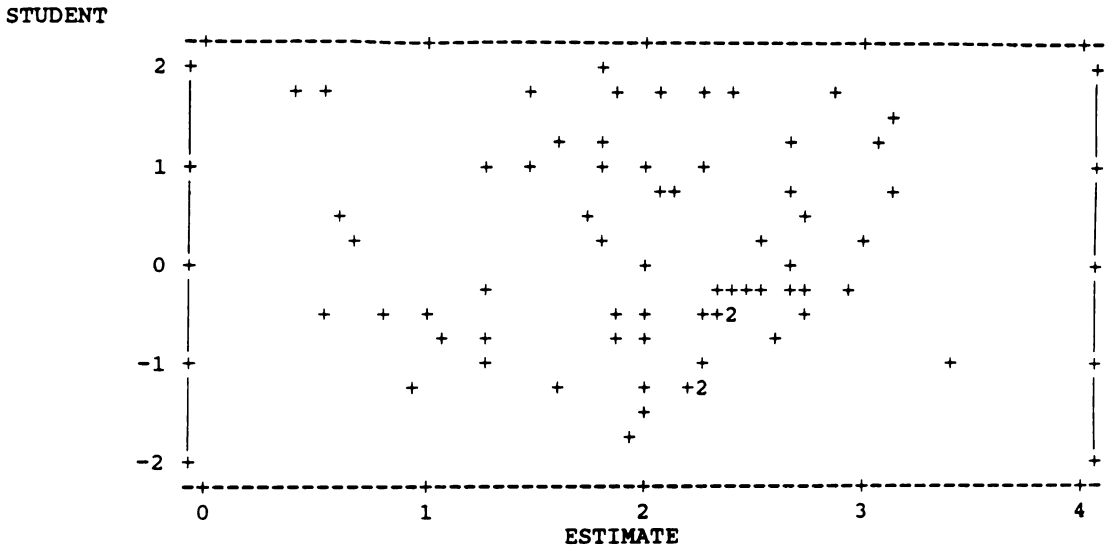
**Appendix 3. Figure 3.5a Plot of studentized residuals against estimated values of total dry biomass weight in *F.semicordata* individual-tree model**



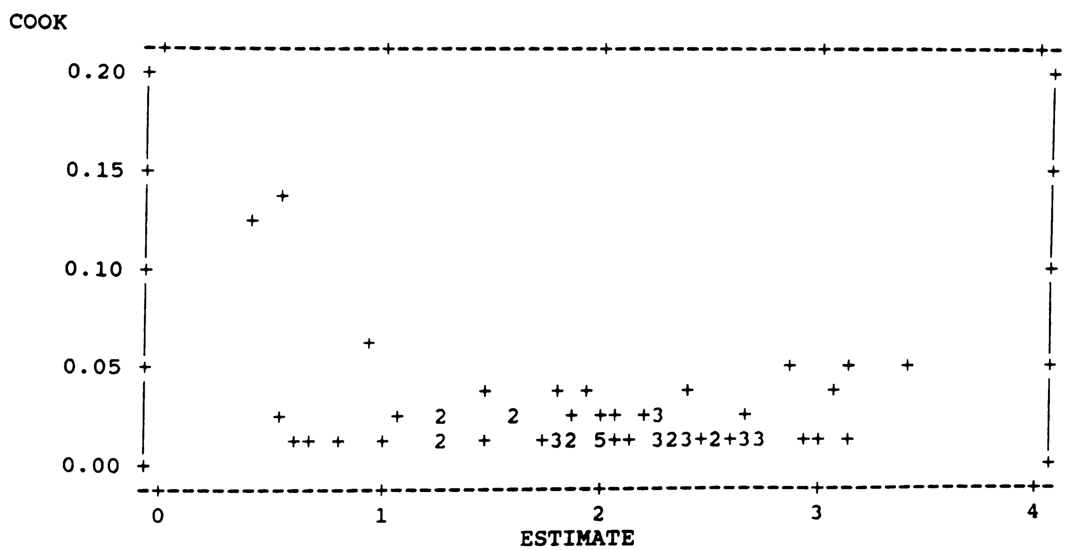

**Appendix 3. Figure 3.5b Plot of Cook's distance against the estimated total dry biomass weight in *F.semicordata* individual-tree models**



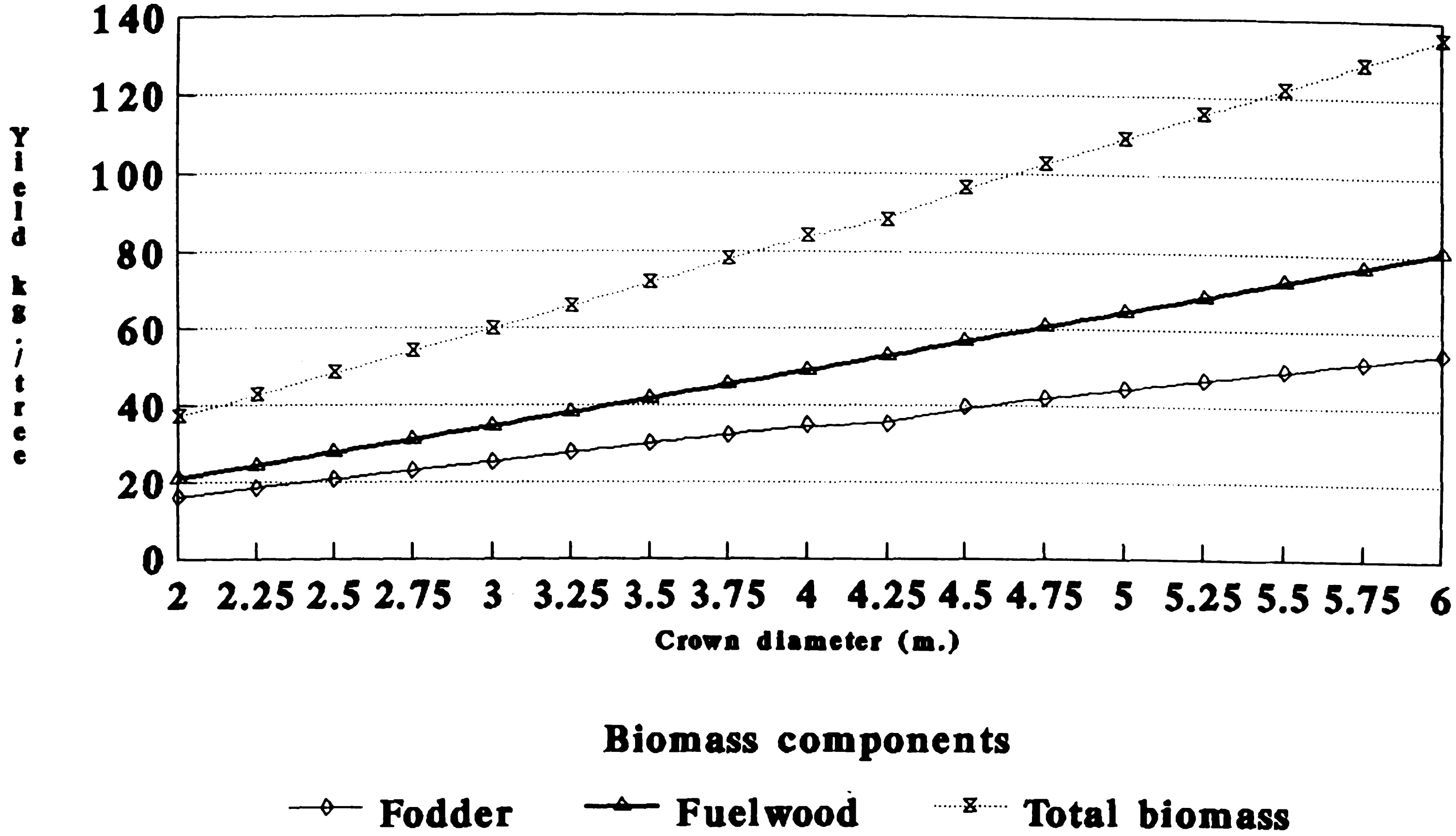
**Appendix 3. Figure 3.6a Plot of studentized residuals against estimated values of total dry biomass weight in *B.variegata* individual-tree model**




**Appendix 3. Figure 3.6b Plot of Cook's distance against the estimated total dry biomass weight in *B.variegata* individual-tree models**

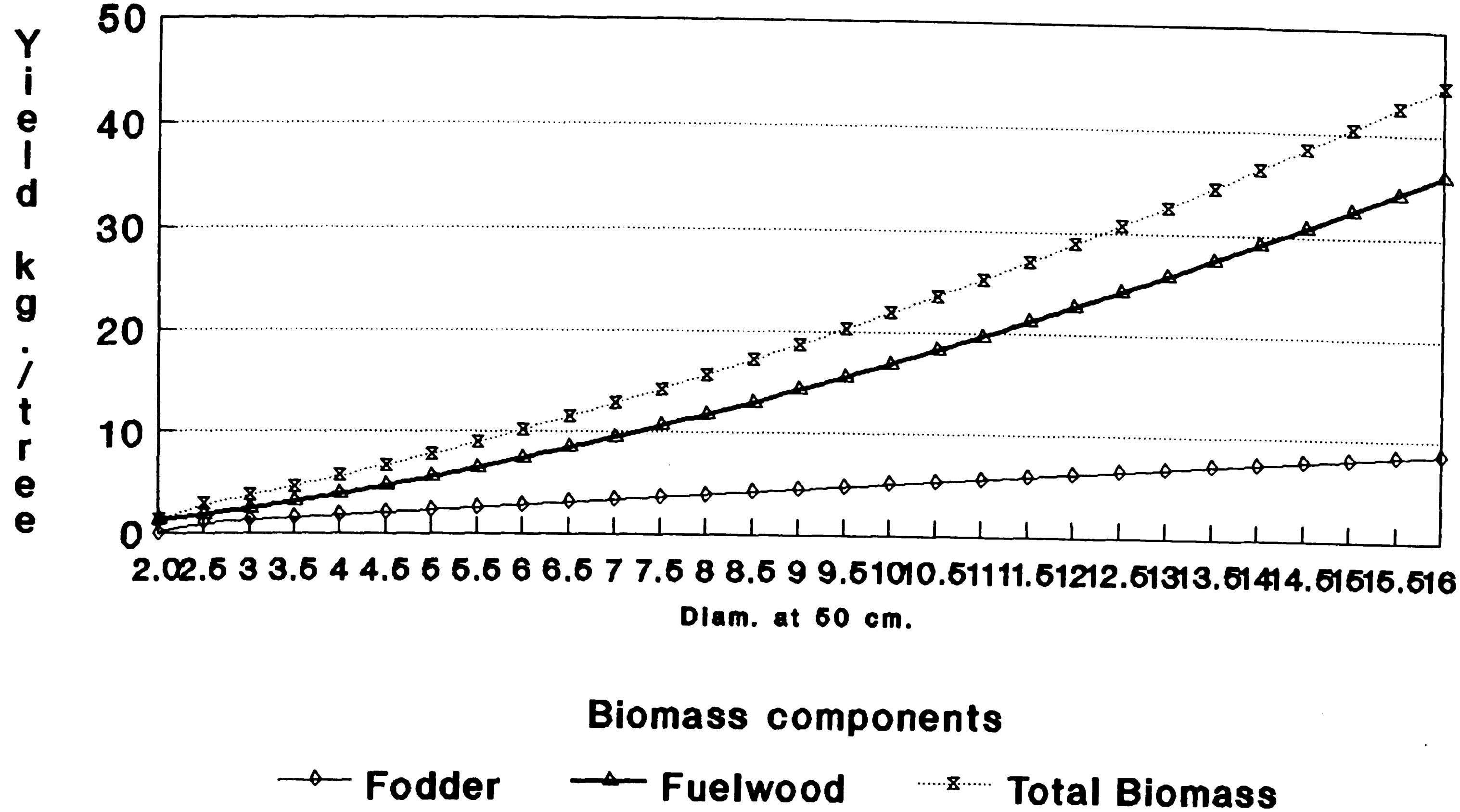


**Appendix 3. Figure 3.7 Predicted biomass yield functions in *F.semicordata* individual-tree models in central and western Nepal**




**Fodder, fuelwood, and total biomass in dry weight based on allometric regression models.**

**Appendix 3. Figure 3.8 Predicted biomass yield functions in *B.variegata* individual-tree models in central and western Nepal.**




Fodder, fuelwood, and total biomass yield in dry weight based on allometric regression models

# CHAPTER IV

# DESIGN AND ANALYSIS OF AN IMPROVED CROP-LIVESTOCK-FODDER AGROFORESTRY SYSTEM


## Abstract

A village in central Nepal was surveyed in 1986 and 1991 to investigate the socio-economic and biological factors which impact management of agroforestry systems. Seventy-two households (HH), 20% of the total, were surveyed with structured questionnaires. In terms of food production, the village was found barely self-sufficient (95%). Fodder and fuelwood was in short supply. To meet the needs of a growing population (2.5% per annum), the village needed to increase food production by an annual rate of about three percent, fodder by ten percent, and fuelwood by twenty percent in the next five years. A new fodder tree based agroforestry system is proposed to meet these goals. The paper describes this scheme and demonstrates the value of linear programming (LP) as a tool to analyze proposed land use alternatives. programming. Based on field research trials, three high yielding fodder tree species were suggested for inclusion in the proposed agroforestry scheme. These trees were found to have high financial rate of return ranging from 18 to 46%.

Based on the assumptions of labor surplus, adequate credit availability, and increased use of chemical fertilizer, the LP output indicated that at the end of a five year period, 2540 million kilo calories of food, 738 tons of TDN, and 1080 tons of fuelwood could be produced by using 20,000 peak season labor person days, 429 ha. of *khet* and 260 *bari* land, and 6574 metric tons of compost. Soil erosion loss would be reduced from the current level of 5.5 tons/ha. to an estimated 3.7 tons/ha. Net returns would also increase from the current estimate of NRs. 2.72 m. to an estimated 4.3 million at the end of the five year period. There were no surplus resources of land, labor and compost. It was concluded that the current resource allocation system in the study village was inefficient. In order to meet the immediate needs of basic necessities such as food, fodder and fuelwood, the village needed to produce more compost and provide higher peak season labor. This was possible by growing more trees and staggering crop schedules.


## 1.0 INTRODUCTION

Agroforestry has now become a well-established field of applied science, drawing concepts and practices from crop, fruit, vegetable, pasture, animal, and forest sciences. Research in this discipline has transcended sectoral and professional barriers. Today, planners and managers are in a position to obtain research information to design and recommend agroforestry systems for a diverse group of farmers.

Redesigned and more productive agroforestry systems are needed in Nepal. The per capita arable land of 0.14 ha. has to meet not only the increasing demands for food, fodder, fuelwood but also remain productive to sustain the flow of essential goods and environmental services to the human, animal and natural systems (Karki 1988; Nield 1985).

Current fodder and fuelwood supply falls far short of demand. Deforestation is continuing due to expanded food and fodder production. The situation is serious throughout the country but is most serious in central Tarai and Hill regions. In these areas there are over 1000 people per sq. km. of arable land (DFMAS 1986). Each household in the Middlehills requires 2.8 ha. of unmanaged forest to provide fodder (Wyatt-smith 1982) whereas at the present time each household has access to less than one hectare of degraded forest. The situation in central Nepal is more serious due to higher population density. This region requires more intensive efforts to increase the supply of basic forest products. Agroforestry projects are the preferred interventions being funded and implemented by the government as well as private agencies. However, in rushing projects to the villages, development agencies have failed to understand the concepts of traditional agroforestry systems upon which the new systems are supposed to expand and improve. The result has been a waste of scarce resources. A case in point is the World Bank funded Tarai Community Forestry Project. The agroforestry programs under this project are highly capital intensive and poorly adopted by the farmers (Dixit, 1989).

This paper illustrates a method of designing and analyzing an agroforestry scheme in a fodder and fuelwood deficit village located in the Inner Tarai region of Nepal. The validation of this study comes from actual village level research and species inventories. Based on the previously reported results (Chapters II and III), improvement of fodder tree stands is recommended. This study analyzes land allocation problems between food crops and three high yielding fodder tree species and derives a more optimal land allocation solution through an improved agroforestry design. Any change in land reallocation should not only be acceptable to farmers, but also should address the input supply and output demands expected to prevail in the study area.

## 2.0 OBJECTIVES

### 2.1 General objectives:

1. Demonstrate an application of a mathematical tool in designing and analyzing an improved crop-livestock-fodder based agroforestry system in a typical village in Nepal.

2. Define the cost and benefit parameters of this system along with the inputs and outputs of both the proposed and traditional system.

3. Carry out an optimal allocation of village land resources using linear programming techniques.

4. Interpret the research results in the context of the practical problems faced by the villagers.

### 2.2 Research objective:

1. To demonstrate the feasibility of improving food, fodder, and fuelwood production through an improved agroforestry system.

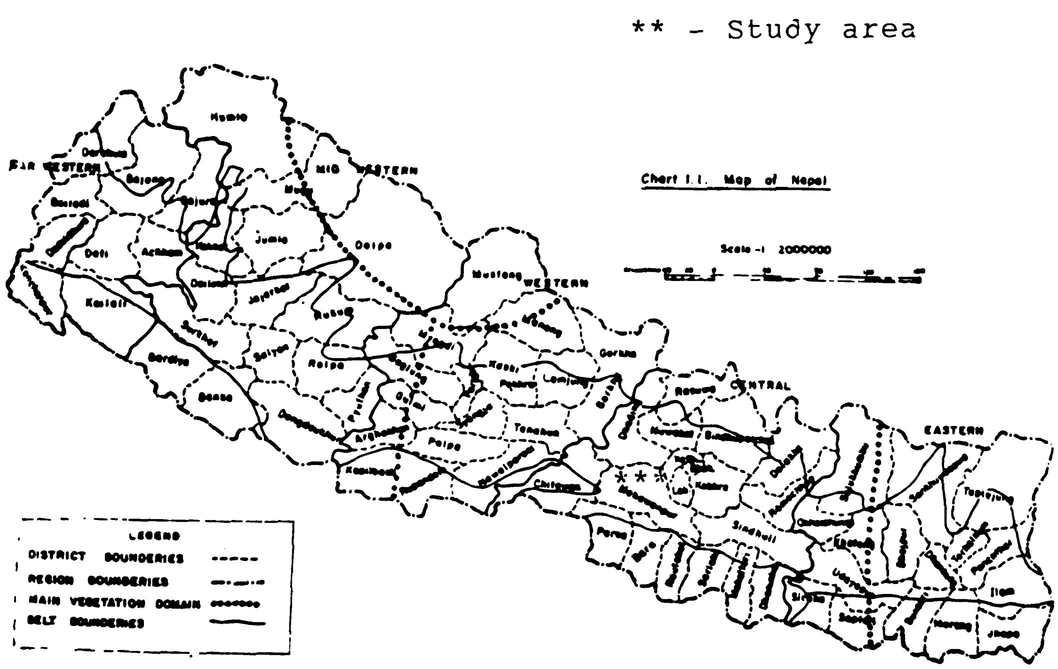
## 3.0 STUDY AREA

**3.1 Location:** Nawalpur village is situated on the bank of the Rapti river adjacent to the town of Hetauda in Makwanpur district (Fig. 4.1). The East West Highway of Nepal passes through this village. It is situated at 27° 25′ N latitude at an average elevation of 450 meters above mean sea level. The climate is monsoonal and humid sub-tropical. Maximum temperatures vary between 24° C and 38° C and minimum temperature vary between 8° C and 18° C. Relative humidity ranges from 73 to 85 percent. The average annual precipitation is about 1972 mm, over 80% of which falls between June and September.

**3.2 Topography and Geology:** The terrain is flat to undulating, forming a gentle sloping stair like topography.

Soil texture is sandy loam to loam and slightly acidic. The village was established by clearing natural deciduous forests during the early nineteen sixties. The main natural vegetation type is classified as a *Shorea robusta/ Terminalia spp.* forest type. Farming is characterized by rice-wheat cropping on the lowland and maize-millet/mustard on the upland. A large number of fodder trees are included as part of the traditional agricultural production system. Fertility in these areas is declining rapidly and the system can not be considered sustainable in its present form. A new, more balanced type of farming system will have to be designed for this and similar villages, if sustainable production is to be obtained.

<u>Figure 4.1 Location of the study area in central Inner Tarai, Nepal</u>



**3.3 Demography:** The village has diverse ethnic, religious, and socio-economic groups. Upper caste *Brahmins* dominate the population (73%) while tribal caste *Lamas* are in minority (3%). The upper caste *Chhetry* comprises of 14% and the middle castes - *Newar* and *Magar* - makes up 5%. There were about 363 households in the village with a population of about 2474 in 1989. About 55% of the population was adult; 41% of the men and 33% of the women were literate; and 63% of the children attended schools (Mahato and Karki 1986).

**3.4 Problem identification:** Based on the findings of the baseline survey (Mahato and Karki 1986), villagers in the study area were found to be interested in improving both fodder and fuelwood production. They also wanted to increase farm yard manure (FYM) based compost production. However, they did not want food production to be affected nor did they want to employ more hired labor than they could afford. The increasing rate of soil erosion due to rain water run-off also needed to be minimized. The main problem faced by the villagers is how much of the upland *(Pakho)* area is to be allocated to the fodder and fuelwood plantation to sustain the supply of fodder and fuelwood.

Major problems identified by the Project (Mahato and Karki 1986) in the livestock sector of the village economy were: 1) a large number of unproductive animals in the farms; 2) inadequate and constantly decreasing fodder and feed availability due to deterioration of natural pasture and forests; 3) inefficient animal breeds; 4) lack of animal health service and disease control measures; and 5) shortage of proper marketing facilities for live animals and livestock products. Livestock farming is properly understood in the context of a predominantly subsistence mixed crop-livestock economy. There are a minimum number of animals which must be raised to maintain the subsistence farming. In the study area, this equates to two oxen, one adult female buffalo, two cows, and four goats per family. The average farm size in the study area was 1.1 ha. and 6.8 members comprised a family.

## 4.0 LITERATURE REVIEW

**4.1 General Review:** Agroforestry spans the content of many academic specialties as well as the two major forms of land use: forestry and agriculture (Gordon and Bentley 1990). The concepts and practices of agroforestry are complex. Agroforestry programs succeed only if they address and solve a multitude of problems faced by the farmers in developing countries. Agroforestry practices involve complex arrangements and combinations of plants, animals, and microbial elements. Thus, there are conflicting resource allocation decisions a farmer or a manager must face in designing agroforestry systems.

Different tools have been used to analyze these decisions and allocation questions. Raintree (1981, 1982) discussed factors that made agroforestry systems complex and argued that basic bioeconomic techniques were required for agroforestry applications.

Dykstra (1984) demonstrated the use of linear programming (LP) to solve a diet problem in a village in Tanzania where fuelwood production was of equal importance. The problem dealt with land allocation among maize, beans, green vegetables, and *Eucalyptus melliodora* trees. Wojtkowski *et al* (1991) used a bordered matrix approach to bioeconomic modeling in analyzing a rubber-cacao agroforestry system in Brazil. The challenge was to test a number of planting densities and management strategies to achieve the best production and profit levels for each situation. Ball *et al* (1991) used multi-period linear programming to determine resource allocation for tobacco farmers in Ontario, Canada. The study examined the feasibility of intercropping tobacco with walnuts and hardwoods such as red oak (*Quercus rubra*). Scherr (1991) reviewed seventy-two papers dealing with the economic analysis of temperate zone agroforestry. The author concluded that little work had been done using optimization models or production functions. Harwell and Dangerfield (1989) used the net present value (NPV) technique to compare agroforestry and traditional forestry activities. The results indicated the superiority of beef cattle based agroforestry over loblolly pine forestry on marginal lands. Thurman *et al* (1989) used soil expectation value criterion to examine the interplanting of trees and agricultural crops as an alternative to conventional soil conservation practices in Northwest Missouri. The authors found that the agroforestry enterprises were more profitable over the long run than conventional cropping systems. Wojtkowski and Cubbage (1991) used a bordered matrix approach to the bioeconomic modeling of agroforestry system in Bahia, Brazil. This method was used to model multi-canopied agricultural or forestry production systems to find the optimal planting pattern and density based on pre-specified economic criteria. Etherington and Matthews (1983) developed an iterative computer program called MULBUD (Multi-enterprise, multi-period budgeting) and demonstrated its use for intercropping coconut plantings with banana. While limited in flexibility, it provided quick assistance in carrying out economic appraisal of perennial crops and other enterprises common in agroforestry land-use systems in the tropics. Sterk and Ginneken (1987) used MULBUD to carry out the cost-benefit analysis of forest plantations in a watershed in northeastern Thailand. MULBUD however, does not have the capacity to carry out optimization procedures such as minimizing the costs and maximizing the benefits.

**4.2 Specific Review:** Linear programming (LP) has been used by many authors to model agroforestry systems. Betters (1988) demonstrated the use of LP to select economically optimal tree/crop combinations involving Eucalyptus, maize and bean crops. The author cited a hypothetical scenario in African farming system. Burgess (1981) used multi-stage LP to model and optimize a coconut-based intercropping system for small farmers in Western Samoa. Davis (1989) developed a workbook to demonstrate the practical utility of LP in agroforestry systems. Etherington and Nainggolan (1987) have combined static linear programming and dynamic budgeting (MULBUD) to analyze farm plans involving both long term perennial and annual crops in Indonesia. Lubega (1987) examined hedgerow profitability through LP drawing examples from semi-arid area of Kenya. Mendoza *et al* (1987) used a multi-objective programming (MOP) to identify optimal allocation of land to alternative agroforestry systems in Nigeria. The authors used the example of black walnut intercropped with various crops to demonstrate its applicability. Mendoza (1987) argued that land use allocation for any agroforestry system should address economic, biological/physical and silvicultural concerns. He illustrated a MOP method using a case study of hedgerow intercropping from Nigeria. According to the author, MOP models generated a number of satisfactory - rather than optimal - allocation alternatives. Wojtkowski *et al* (1988) also used MOP to evaluate agroforestry systems and optimize the species mix and density of the two participant maize/cassava/leucaena/teak agroforestry system. They used the yield, labor and spacing data from published African sources. Their analysis offered a set of optimal compromise solutions for different users.

According to several of the above authors (Scherr 1991; Wojtkowski and Cubbage 1991), however, the biggest bottleneck is the severe lack of empirical data to develop statistically-based models and biological data to formulate deterministic models. There are continuing efforts in the area of optimization and bioeconomic simulation modeling. These efforts may broaden the choice of alternatives in agroforestry modeling.

**5.0 METHODOLOGY:**

**5.1 Sample Survey:**

**5.1.1 Baseline survey:** As a part of on-farm fodder tree management research program of the Fodder Tree Management Project, the Nawalpur village was first surveyed in 1986. Seventy two households (20% of the total) were interviewed with structured (open and close ended) questionnaires. The households (HH) were selected randomly. Multiple visit methodology was adopted to collect fodder and fuelwood collection and consumption data. The enumerators were students from the Institute of Forestry at Hetauda. The survey was completed during the winter months of 1986. The survey aimed at collecting as much information as possible on the socio-economic profile of the village in the context of fodder tree cultivation and management practices. Information was gathered specifically on household size, age distribution of the family members, labor supply and demand, land holding patterns and their size, food production, and fodder and fuelwood supply and demand. Information on fodder trees, age of first lopping, intensity of lopping, costs of planting, tending, amount of foliage production, and average age of rotation was also gathered. The survey focus was the whole farm agroforestry model.

Based on the survey findings, the villagers' main concern was to ensure the sustained flow of fodder and fuelwood. Fodder production was more important than fuelwood since the village had electricity available to supplement the fuelwood requirement. The nearby forests are expected to be inaccessible in few years time as the forests around the village are rapidly declining or becoming inaccessible. The farmland is also experiencing increasing flooding and soil erosion problems.

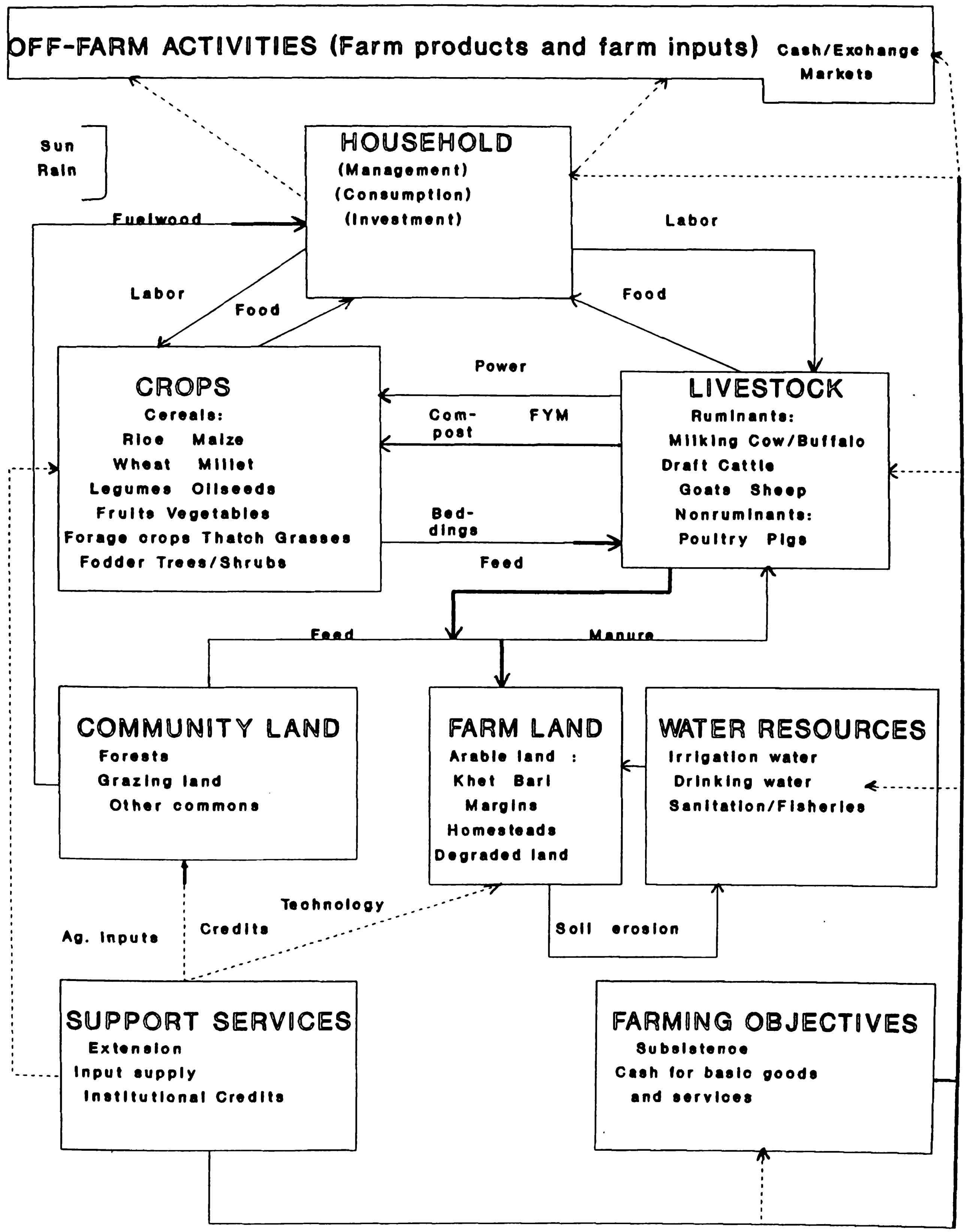
**5.1.2 Key-informant survey:** Twenty households out of the 72 selected above were retained as the key-informants and were surveyed in 1991 to update the baseline information. These farmers were also the cooperators in the on-farm fodder tree management research conducted by the author. Structured questionnaires were once again used to gather information on cropping systems, animal husbandry, and fodder cultivation.

**5.2 Conceptual whole system agroforestry model**

**5.2.1 Conceptual Basis:** A conceptual model of the Nawalpur village crop-livestock-fodder tree based agroforestry system is illustrated in Fig 4.2. This model is different from the linear programming (LP) model.

The conceptual resource interaction model is a means of identifying the objectives and constraints upon which the LP model will be based. The model presents the overall picture of a typical farm along with the basic constraints in the form of the linear programming model. Land, labor, food, fodder and fuelwood production; erosion control; compost production and other important components were studied in a holistic framework. Interactions of the components within and outside the system is also depicted. The unit of analysis is the entire village, since the resource interactions can be studied more conveniently at this level. However, it is recognized that in the process of decision-making, the farm household (a recognized socio-economic sub-system) rather than a whole village is an appropriate unit of analysis. Therefore, the model proposes that the whole farm unit be a focus of any agroforestry decision. The conceptual model has two major objectives: a) maximizing net returns by improving management, and b) adequate subsistence food, fodder, and fuelwood production. This formulation of farming objective is a great abstraction from reality, as a subsistence farmer practices a dynamic cropping system with multiple objectives. The dominance of the two objectives varies from place to place as well as from activity type to activity type.

**Figure 4.2 Resource interactions of a model crop-livestock-tree based agroforestry system in the Inner Tarai region of Nepal**




Legend:___ Permanent relationship; --- Intermittent relatioship

**5.2.2 Resource allocation patterns:**

**Labor:** Based on an average daily availability of 3.8 adult labor units at each HH (DFAMS 1986) the annual labor supply is estimated to be 1057 person days per HH. Cereal cultivation was estimated to take up 116, minor crops 24, other crops 10, fodder and livestock 589, and off-farm activities 170 for a total labor input of 909 person days per year. A typical family hired about 51 person days (p.days) of labor during the peak season. Therefore, surplus labor was estimated at 282 person days per year (Appendix 4, Table 4.1). Activities such as domestic work, child care, care for sick and elderly, market visits and food preparation were not included due to the poor quality of data. Labor availability has been calculated by multiplying per family resources (adult male and female work force) in person days based on six day work weeks for 52 weeks, standard in Nepal. No account of child labor has been made although livestock related work, mainly herding, are commonly done by children during off-school hours.

Much off-farm work is related to working as agricultural labor in large farms, government offices, shop keeping and tending jobs. About 5% of the annual total labor was hired and was used for crops. The hired labor proportion increased as farm size increased. Overall, there was about 24% labor surplus in the study area (Appendix 4, Table 4.1).

**Animal traction:** Animal traction is another important constraint in the model described above. Draft power bottlenecks occur because of limited oxen availability on small farms (less than the two required for ploughing) and because of oxen density on larger farms. Rice planting operations involved hiring draft animals. However, in the LP model described later, this constraint was not included. It was assumed that available oxen in the village would be exchanged for family labor to remove this constraint. This practice is common in other parts of Nepal (APROSC 1980)

**Manure and Fertilizer:** Farm yard manure (FYM) or compost is a critical constraint as it directly affects production levels of all agroforestry products. In the study area the estimated compost application per year is 10.8 metric (m.) tons/ha. on the upland. Maize received the highest dose, about 14.0 tons/ha., followed by rice. Per hectare application rates decreased as farm size increased. Some chemical fertilizers were also applied but they were not considered as constraints as their usage is relatively minor. On average the animals produced 3.2 tons/year of dung and when mixed with bedding material and litter, compost production was estimated at 10.3 tons/HH/year.

**Land:** Land was determined to be one of the scarcest resources in the model. In analyzing agroforestry systems, the operated (owned and rented cultivated land) area was considered more relevant than the total area owned. Farmers invariably indicated the actual resources they managed rather than the total legally owned resources. Therefore, farm size indicated the land managed for the purpose of growing crops, trees, and raising livestock. Grazing areas and public forest land were excluded from the model as they were communally owned and managed. However, marginal lands (lands classified as arable land but not regularly cultivated due to physical limitations) were included in the total land budget. Land quality is generally an important determinant of technical productivity. For instance, the *khet* lands (lowlands) are usually more fertile than *bari* plots (uplands).

**Irrigation:** Irrigation is invariably a critical determinant of *khet* productivity. It can be a constraint to increasing productivity in lowland farming, but since the agroforestry interventions will be limited to upland and noncultivated enclosures, irrigation was not treated as constraint in the model.

**Farm capital:** Farm capital is also a scarce resource. The largest part of farm capital is tied up in land, for which only approximate valuations were available. Due to its proximity to urban settlement, the size of the intrinsic (fixed) capital in the study area was larger than the national average of Nepalese Rupees (NRs.) 224,148. The 1990 average for the village was NRs. 255,909.00, 90% of which was tied up in land. Livestock generated 6% of the capital and the remaining 4% was related to structures like house and animal sheds. Even though most of the farmers did consider fixed capital such as land, bullocks, and farm equipment as important constraints they were not included in the LP model as constraints since these were out of the scope of this study.

**Short term credit:** Both institutional and non-institutional credit sources are used to meet operating capital needs. On average, each HH in the study area required NRs.15,354 as short term credit. Although it is considered to be a constraint, especially by farmers planning to change their cropping patterns, the government of Nepal does have low-interest credit program in place for the village. It was therefore assumed that enough credit will be available to the needy farmers through this program.

**Land capability:** Since the majority of the farms in the study area are oriented towards subsistence production, cereals dominated the arable land use occupying over 80% of the farm land. The cropping intensity (percent cropping of the farmland in a year) was estimated to be 158%, higher than the national average of 153% (DFAMS 1986). However, due to favorable physical and climatic conditions, the cropping system has potential for further intensification. All of the lowland farms are suitable for three croppings in a year. Two seasons of rice cropping is practiced by about one third of the farmers. The uplands are also gently sloping (1 to 5 degrees slopes) and soils are deep and moderately well drained (LRMP 1983).

The integrated crop-livestock-forest farming system that has evolved, based on traditional knowledge base of the farmers, meets subsistence requirements with less risk to the environment. However, due to population growth (2.5%) and people's growing needs, major components such as paddy, maize, wheat and tree crops need further enhancement. Because of deforestation on the hilly slopes above the village, the farmers need to initiate protection measures to minimize soil erosion. The cropping patterns are also affected by other agroforestry system components, notably livestock. One way to increase farm production is through increased cropping intensity by double cropping on the uplands and triple cropping on the lowlands. On a national level, cropping intensity has been increasing at a rate of about 1.5% per annum and is directly related to the family size (DFMAS 1986). The upper limit of the cropping intensity in the village is estimated at 225% in the *khet* and 200% in the *bari* plots.

**Animal husbandry:** The livestock sector is an integral part of the area's agroforestry system. Cattle (oxen) provide draft power and manure, buffalo yield milk and manure, and goats are kept for meat and cash. Cattle also have cultural significance. Livestock herd size increases with farm size, largely as a function of farmer's wealth and desirability of balancing the crop and livestock components of the system. This is important in relation to draft power, manure requirements and feed resources. Number of oxen are also related to farm size.

In the crop-livestock-fodder tree based agroforestry systems widely prevalent in the Midhills of Nepal, livestock have an indispensable role to play. Compost mainly from cattle and buffalo manure is a major source of replenishing soil nutrients and organic matter. Animals are instrumental in the transfer of nutrients from the forests and pasture areas to arable land. Mathema and Van der veen (1980) reported that compost was the chief reason for keeping cows and goats and second most important reason for keeping bullocks and buffalo (the primary reasons being draft power and milk production respectively). Buffalo and goats are also kept to generate cash income through sales of milk, milk products, and live animals in the nearby markets. *Ghee* or raw butter, hide, and skins are exported.

Animals utilize a variety of resources and by-products which have low or zero opportunity costs. Roughage, both forest litter and crop residues, have little value except as an input to livestock. Likewise, animal husbandry absorbs a large amount of slack season and child labor which would otherwise be unproductive (DFAMS 1986).

**Farm forestry:** The study village had more than 20 different species of fodder and other multipurpose trees growing on its farms (Table 4.2). The estimated number of trees exceeded 8,500 on 400 ha. of farmlands. The estimated TDN production in the village was estimated at 178 m.tons/year.

**Whole farm model:** The components described above form a complex system of farming. It can be simplified by looking at the major components first. We assumed that the food production was going to increase at the rate of the population growth (2.5% per annum) as a result of the on-going government programs. The livestock population was expected to grow by one percent, and it was assumed that farmers were willing to plant new trees in place of the old and unproductive ones. Many farmers were also committed to undertake new practices for improved fodder tree management. The incentive to planting and managing more productive trees was that the nearby forests were rapidly declining. These assumptions are based on the findings of the above described surveys.

Finally, it was also assumed that the planning horizon was five years. This is a short term plan. The lowlands, especially land with irrigation facilities, were assumed not to compete with fodder trees. This ensured that rice production was not affected by increases in upland fodder tree cultivation. In order to meet the estimated demands of food, fodder, and fuelwood within the constraints of land, labor, and compost (organic fertilizer), the resource allocation problem was analyzed in a holistic framework. The optimum solution was determined using linear programming with an objective of maximizing net returns.

**5.3 Analytical tools**: Linear programming (LP) was used in the evaluation of several alternative land use options. The objective was to maximize net returns. The major constraints were: fulfillment of minimum food needs expressed in calories, animal fodder (TDN), fuelwood, and organic manures or compost. The model was also required to minimize the use of hired labor and soil erosion as these were important limiting factors to increased production. The entire cultivated area was to be utilized for cropping. More than two cropping per year was assumed for *khet* land. For *bari* land, only maize acreage or actual cultivated land cultivated in a year was used since millet, the other major crop, was relay-cropped and was represented by maize itself. Legumes and oilseeds were not included as they were minor crops.

The resource allocation decision involved selection of land management alternatives which gave maximum net returns while meeting all the major resource constraints. Thus the decision variables were defined as follows:

$X_{ij}$ = cropped area allotted to alternative i in year j, where i=1 for lowland paddy, i=2 for lowland maize, i=3 for lowland wheat, i=4 for upland maize, and i=5 for *Ficus semicordata*, i= 6 for *Bauhinia variegata*, and i=7 for *Leucaena leucocephala*. All fodder trees are assumed to grow only in uplands. The planning horizon is five years with year zero for before project initiation. Therefore, $j=0,1,\ldots, 5$.

**5.3.1 Model formulation:**

The objective was to maximize net returns. Mathematically, we can generalize the function as follows:

$$\text{Maximize} \quad Z = \Sigma\, \Sigma\, C_{ij}X_{ij}$$

subject to,

1. $\Sigma FiX_{ij}$ >= Nt (million kilo calories (t= 0,1,...,5)/year)
2. $\Sigma TiX_{ij}$ >= Tt (tons of total digestive nutrients/year)
3. $\Sigma EiX_{ij}$ <= St (tons of soil loss/year)
4. $\Sigma LiX_{ij}$ <= Mt (person days/year)
5. $\Sigma WiX_{ij}$ >= Wt (fuelwood in m. tons/year)
6. $\Sigma KiX_{ij}$ <= Kt (acreage of <u>khet</u> cropped area/year)
7. $\Sigma BiX_{ij}$ <= Bt (acreage of <u>bari</u> arable land/year)
8. $\Sigma MiX_{ij}$ <= Ct (amount of compost produced/year)
9. $\Sigma PiX_{ij}$ >= Ht (acreage under a particular crop/year)
10. $A_{ij}$ >= 0 (i=1,...7; j=0,1,...5: nonnegativity constraint).

where,

$Z$ = total net returns after variable costs

$C_{ij}$ = Net returns (1990 Rupees) per hectare from activity i in year j.

$X_{ij}$ = hectares planted under each crop/tree in a particular year.

**5.3.2 LP model development:**

**Objective function:** Maximization of the net returns was determined to be the objective of the LP model. The model will determine what activities will yield maximum net returns given the magnitude of resources available and constraints to satisfy. Based on the individual activity's estimated net returns the objective function equation was determined to be:

Maximize PNV = $7.1X_{11}+3.4X_{21}+2.6X_{31}+3.5X_{41}+.......+8.8X_{75}$

**Total food requirement:** An adult requires 2750 kilocalories (kcal) of food each day (APROSC 1986). Assuming that 88% of the calories are obtained from cereals, the current food requirement is estimated at 2178 million kcal. Based on annual population growth of 2.5%, the food requirement at the end of the five year planning period will be 2612 million kcal or 2478 calories (from cereals) for each adult unit. Therefore the first set of constraint is written as:

$\Sigma F_i X_{ij}$[1] >= 2.2 to 2.5 x $10^9$ kcal

**Fodder TDN requirement:** Each livestock unit (LU) is estimated to require 1052 kg. of TDN per year (DFMAS 1986; APROSC 1986). For an estimated 1104 LUs in the village, the annual TDN requirement is 1160 M.tons/year. This is expected to increase to 1260 M.tons at the end of year five. It is projected that fodder trees and food crops included in the model will supply 50% of the total requirement. This constraint is written as:

$\Sigma T_i X_{ij}$ >= 580 to 630 M.tons of TDN.

**Fuelwood requirement:** The per capita requirement of fuelwood in the study area was estimated at 600 kg./year. At present, fuelwood requirement for the village was 1484 M.tons which was expected to reach to 1668 tons after year five. It is projected that 15% of the total requirement will be supplied

[1] For all the constraints, the subscript i = 1,...,5; and j = 1,...,7.

from on-farm sources. The fuelwood constraint is written as:

$\Sigma W_i X_{ij}$ >= 220 to 270 M.tons.

**Peak season labor requirement:** Each HH was estimated to have a labor availability of 3.8 person days per day for 312 days. The peak annual peak season labor availability was estimated at 45 person days/HH or 16,335 per year for the village. The supply was projected to grow at an annual rate of three percent. At the end of the five year period the peak season labor requirement is expected to be 51 person days/HH or 20,247 person days per year for the village. The supply is estimated at 18,937. The labor constraint is written as:

$\Sigma L_i X_{ij}$ <= 16335 to 18937 person days.

**Compost (organic manure) requirement:** It was estimated that each HH produced 10.3 M.tons of compost per year. The total production in the village was 3739 M.tons per year. Based on the prospect of more tree planting by the farmers and more litter collections, the manure production was assumed to increase at the rate of 10% per annum. As a result, by the end of year five the compost production was expected to reach 5475 tons per year. Fifteen percent of the nutrient needs is assumed to be met through chemical fertilizers. Therefore converting chemical fertilizer into compost equivalent units the total compost requirement was raised at 5260 in year 0 and 6580 in year five. The original constraint is written in the following form:

$\Sigma M_i X_{ij}$ <= 3740 to 5475 M.tons

**Minimum top soil loss:** Due to shallow soil characteristics, monsoon type of rainfall, and less than optimal land use practices, the village has been increasingly losing top soil through soil erosion. It is estimated that currently 3.0 to 6.8 M. tons/ha. of soils are lost annually (LRMP 1983). In order to sustain crop productivity, soil loss must be reduced particularly from the upland. Tree planting is expected to reduce soil loss from 6.8 tons/ha to 3.0 tons/ha. Current soil loss from the village is estimated at 2900 M.tons which is expected to decrease to 2700 tons by year five. The constraint is written as:

$\Sigma E_i X_{ij}$ <= 2900 to 2700 M.tons/ha.

**Acreage constraints:** The village has 400 ha. of arable land. *Khet* (lowland) occupied 160 ha. and *bari* (upland) remaining 240 ha. Currently 2.2 crops per year are grown in *khet* and 1.6 crops in *bari*. By year five, the cropping intensity is expected to reach 268% in *khet* and remain unchanged in *bari*. Fodder and other purpose trees are currently grown on the estimated 80 ha. of marginal lands. At the end of five year period, the tree acreage is expected to reach 110 ha. Since the farmers were interested in growing at least three fodder tree species (FTS), a minimum acreage was to be allotted to selected FTS. Three constraints were included to satisfy these requirements:

A. *Khet* area constraint - $\Sigma K_i X_{ij}$ <= 352 to 430 ha.

B. *Bari* area constraint - $\Sigma B_i X_{ij}$ <= 260 ha.

C. FTS acreage constraint - $\Sigma D_i X_{ij}$ <= 10 ha.

**Nonnegativity conditions:** In order to ensure that none of the activities contained negative values, the nonnegativity constraint is written as follows:

$X_{ij} >= 0$ where i = 1,...., 5; j = 1,...,7

Table 4.2 in Appendix 4 gives the coefficient of matrix for the LP model along with the original constraint levels.

## 6.0 RESULTS

### 6.1 Sample survey results

As mentioned above, the basic socio-economic data were collected from the sample household and key-informant surveys conducted in the village in 1986 and 1991. Production cost information was gathered from a key-informant survey in 1991. Secondary information was gathered from the reports published by DFMS (1986) and APROSC (1986).

**6.1.1 Land use:** The village contains 400 hectares (ha). of arable land. In addition, there were an estimated 80 ha. of marginal land under homesteads containing various fodder and multi-purpose trees. The average size of holding was about 1.3 ha. About 50% of the land was *khet*, one third of which was fully irrigated (18%). The cropped area and production for the year 1989/90 is shown in Table 4.1.

Table 4.1: Estimated cropped area and production in Nawalpur village, Hetauda (1989/90), Nepal.

| Item | Cropped area (Ha.) | % of the total Cropped Area | Gross Prod. (M.Ton) | Yield Kgs/ha. | National Av. Yield M.Ton/ha | Net prod. (M.Ton) |
|---|---|---|---|---|---|---|
| Paddy | 250 | 35.0 | 456.2 | 2225 | 2140 | 246.4 |
| Maize | 177 | 24.8 | 342.2 | 1541 | 1520 | 289.2 |
| Wheat | 35 | 4.9 | 38 | 1086 | 1270 | 32.1 |
| Millet | 111 | 15.6 | 60 | 540 | 930 | 48.7 |
| Legumes | 28 | 3.9 | 11.2 | 400 | 555 | 9.5 |
| Oilseeds | 33 | 4.6 | 16 | 485 | 555 | 13.5 |
| Trees/Grasses/ Fruits/Veg. | 80 | 11.2 | - | - | - | - |
| Total | 714 | 100 | 923.6 | - | - | 639.4 |

**6.1.2 Fodder Trees:** The total number of fodder trees currently grown by the villagers was estimated at 8,568 averaging 23 trees per household (HH). An estimated (Table 4.2) 725.2 metric tons of green tree fodder was produced from farm trees annually. On average each tree produced 84 kg. of fresh or 31 kg. of dry foliage per year. Based on an average total digestive nutrient (TDN) content of 70% of the estimated dry fodder production of 268 tons, the total TDN produced from village fodder trees was estimated at 187 tons per year. This constituted 22% of the total TDN supply in the village. The most common and preferred species were: *Artocarpus lakoocha, Litsea monopetala, Bauhinia variegata, Ficus auriculata, Ficus lacor, Ficus semicordata, Celtis australis*, and *Terminalia belerica* in descending order. Table 4.2 lists the FTS species enumerated in the study area with number of trees and estimated fodder production.

**Table 4.2 Number and estimated fodder production from Fodder Trees in Nawalpur village in central Nepal.**

| Species Name | Average age (yr.) | Estimated No. of trees | Yield kg./tree | Total Prod. M.ton/yr. |
|---|---|---|---|---|
| *Litsea monopetala* | 10.5 | 2356 | 75.0 | 177.0 |
| *Ficus semicordata* | 12.0 | 1106 | 112.5 | 124.4 |
| *Terminalia belerica* | 25.0 | 1063 | 104.2 | 110.8 |
| *Ficus lacor* | 16.5 | 633 | 105.0 | 66.5 |
| *Ficus auriculata* | 14.5 | 453 | 85.0 | 38.5 |
| *Celtis australis* | 16.0 | 398 | 77.5 | 30.8 |
| *Artocarpus lakoocha* | 9.0 | 383 | 75.0 | 28.7 |
| *Albizia spp.* | 10.0 | 339 | 52.0 | 17.6 |
| *Bauhinia variegata* | 8.5 | 333 | 88.0 | 29.3 |
| *Ficus hispida* | 11.5 | 332 | 65.7 | 21.8 |
| *Garuga pinnata* | 12.0 | 298 | 112.4 | 33.5 |
| Others | - | 874 | 53.0 | 46.3 |
| Total/average | 13.2 | 8568 | 83.8 | 725.2 |

**6.1.3 Livestock:** There were 2876 head of livestock with an average herd size of eight per family. Herd composition is described in Table 4.3. Two thirds of the livestock units (LSU) belonged to cattle and about a quarter belonged to water buffalo.

**Table 4.3 Herd composition of the livestock population in the Nawalpur Village**

| Animal Type | Av. Animal No./HH | LSU | % of LSU | Adult Male | Adult Female | Young |
|---|---|---|---|---|---|---|
| Buffalo | 1.05 | 0.84 | 27.7 | .15 | .60 | .34 |
| Cow | 1.80 | 0.90 | 29.7 | - | 1.2 | 0.6 |
| Bullock | 1.95 | 1.09 | 36.0 | 1.5 | | .45 |
| Goat | 3.45 | 0.20 | 6.6 | 1.0 | 1.45 | 1.0 |
| Total | 8.25 | 3.03 | 100 | 2.55 | 4.25 | 1.85 |

**6.1.4 Demand and supply of feed and fodder:**

Based on the standard assumptions[2] (APROSC 1986) regarding

[2] a. crop residues and fodder trees will eventually supply 50 and 25 percent respectively of the total fodder requirement in the study areas;

b. the average dry matter content of the fodder leaves is assumed to be the annual feed requirements by different types of animal in terms of TDN kg./year, the total annual feed requirement was calculated.

The estimated annual TDN requirement of 1160 M. tons was based on the standard feed requirement of each animal (Table 4.4). For future years, the estimate was increased at the rate of one percent per year, expected to be the animal population growth rate. Based on the animal husbandry practices prevalent in the study area, each livestock unit (equivalent to an adult male buffalo) is estimated to require 1052 kg. TDN per year. Only 750 kg. of TDN per animal were estimated to be currently available in the village.

**Table 4.4 TDN requirements for the livestock population in Nawalpur village**

| Item | TDN Reqd. kg./yr./animal | No. of Animal per HH | Liv.Unit per HH | TDN Reqd. M.ton/yr/HH | TDN Reqd. M.ton/yr.(village) |
|---|---|---|---|---|---|
| Adult male cattle | 683 | 1.50 | 0.98 | 1.03 | 372.0 |
| Ad.female cattle | 663 | 1.20 | 0.76 | .80 | 289.0 |
| Young cattle | 257 | 1.05 | 0.25 | .27 | 98.0 |
| Ad. male buffalo | 1052 | 0.15 | 0.15 | .16 | 57.4 |
| Ad. female buff. | 1033 | 0.60 | 0.59 | .62 | 225.1 |
| Young buffalo | 364 | 0.30 | 0.11 | .11 | 39.6 |
| Adult goat | 76 | 2.45 | 0.17 | .19 | 67.5 |
| Young goat | 30 | 1.00 | 0.03 | .03 | 10.9 |
| Total | - | 8.25 | 3.04 | 3.20 | 1159.5 |

**6.1.5 Yield Data:** Yields of agricultural crops were estimated based on the survey findings. Tree yields were based on the growth and yield models developed from experimental trials (Chapter III). Table 4.5 indicates the

0.33% and the TDN content 70 percent.

projected five year yield for three FTS recommended for planting in the study area.

**Table 4.5 Yield table (dry weight basis) for five year old fodder tree species in central and western Nepal**

| Year after | Foliage yield kg./tree | | | Fuelwood yield kg./tree | | |
|---|---|---|---|---|---|---|
| Planting | FS | BV | LL | FS | BV | LL |
| 1 | 2.7 | 1.1 | 2.4 | 3.9 | 1.8 | 3.8 |
| 2 | 3.9 | 1.9 | 3.6 | 4.7 | 3.0 | 4.6 |
| 3 | 5.3 | 2.8 | 5.1 | 6.4 | 4.2 | 6.5 |
| 4 | 6.8 | 4.3 | 6.3 | 8.3 | 5.6 | 8.5 |
| 5 | 8.4 | 5.3 | 7.9 | 10.3 | 7.2 | 10.8 |
| 6 | 10.0 | 6.4 | 9.6 | 12.4 | 8.9 | 13.2 |

Notations: FS - *F.semicordata;* BV - *B.variegata;* LL - *L.leucocephala*

Based on the yield per tree, yield estimates of harvest per hectare of FTS stand were estimated (Table 4.6).

**Table 4.6 Estimated yields of coppice and final harvests from three fodder tree species in Nawalpur village (tons/ha.)**

| Species/ Products | year | fodder | fuelwood |
|---|---|---|---|
| *F.semicordata* | | | |
| First coppice | 3 | 6.6 | 8.0 |
| Second coppice | 4 | 8.5 | 10.4 |
| Final Harvest | 5 | 15.8 | 19.3 |
| *B.variegata* | | | |
| First coppice | 3 | 3.5 | 5.3 |
| Second coppice | 4 | 5.4 | 7.0 |
| Final harvest | 5 | 8.1 | 13.5 |
| *L.leucocephala* | | | |
| First coppice | 3 | 6.4 | 8.1 |
| Second coppice | 4 | 7.9 | 10.6 |
| Final harvest | 5 | 14.8 | 20.2 |

Based on the value of production and variable costs, input/output tables were prepared for individual crop enterprises (Tables 4.7 and 4.8). The amount of straw is shown as the byproducts used both as fodder and fuelwood. TDN contributions from each hectare of Paddy, Wheat, Maize were estimated to be 0.659, 0.283, and 0.280 M.tons/year respectively (APROSC 1986). The fuelwood contribution was

0.2, 0.2, and 0.4 M.tons/ha/year of fuelwood equivalent (MPFS 1988).

**Table 4.7 Input output tables for the major food crops in Nawalpur village**

| Crop | Grain kg/ha. | Straw kg/ha. | Seed kg/ha. | Compost kg/ha. | Chem. kg/ha. | Human labor p. days | Animal traction pairdays |
|---|---|---|---|---|---|---|---|
| Local Paddy | 2443 | 2277 | 52 | 1354 | 36 | 123 | 55 |
| Impd. Paddy | 2846 | 2173 | 50 | 1500 | 45 | 125 | 57 |
| Local Maize | 1208 | 1772 | 26 | 6080 | 8 | 87 | 32 |
| Impd. Maize | 2656 | 1654 | 25 | 7345 | 10 | 93 | 36 |
| Local Wheat | 957 | 1436 | 71 | 3138 | 36 | 70 | 34 |
| Impd. Wheat | 1325 | 1264 | 65 | 3500 | 40 | 72 | 36 |

Net returns were calculated (Table 4.8) by subtracting the variable costs and the value of the family as well as hired labor at prevailing wage rates. Only peak season labor was valued at the prevailing wage rates. The peak season labor has the same financial value as hired labor (DFMAS 1986). Since the villagers are unable to afford more hired labor, it was assumed that they were willing to rearrange their cropping schedules and labor usage in such a way that more of the family labor was switched to peak season labor. The justification for this assumption is based on the prevailing practices in other parts of Nepal (APROSC 1980)

**Table 4.8 Net returns from different crop and tree enterprises in Nawalpur village in central Nepal (Nepalese Rupees)**

| Item | Input costs | Gross income | Gross margins | Labor cost | Net returns |
|---|---|---|---|---|---|
| Paddy | 1255 | 8337 | 7082 | 1785 | 5297 |
| Maize | 959 | 3087 | 2128 | 962 | 1166 |
| Wheat | 1123 | 2757 | 1636 | 690 | 946 |
| FS | 13660 | 63200 | 49540 | 42410 | 7400 |
| BV | 10250 | 21760 | 11510 | 8810 | 2700 |
| LL | 15020 | 64815 | 49795 | 42995 | 6800 |

**6.1.6 Assumptions:** In carrying out the financial analysis to define the coefficients of objective function variables in the LP model, following assumptions have been made:

1. The discount rate used is 12%. This is the real interest rate. This was based on the average borrowing rate of both institutional and noninstitutional credit and average inflation rate from 1985-1990. The discount rate was used in converting the future net returns to the present net values (PNV) in defining the coefficients for LP objective function.
2. Labor wage was NRs.35/person/day which was the actual wage paid by the project to the nursery labors.
3. As the prices of inputs and outputs were expected to increase at the same rate i.e., at the rate of general inflation, existing prices were used to value future goods.

In order to find an optimal solution which maximized net returns by satisfying all the built-in constraints, coefficients for individual activities were separately derived. One of the important steps of the analysis was to determine the returns of individual activities. For crop activities, the net return values shown in Table 4.8 were used to project future net returns. The input/output information related to crop farming was gathered both from the sample survey and secondary sources (DFAMS 1986). For individual tree activity, net present value (NPV), benefit cost ratio (B/C) and internal rate of return (IRR) methods of cost-benefit calculations were used to arrive at the financial viability including net returns. The idea was first to find out whether individual tree planting on a hectare basis was profitable. The management plan for the recommended fodder trees is given in Appendix 4, Table 4.3. Each of the three fodder tree species (FTS) was evaluated to determine its financial performance before deciding to include them in the resource allocation routines through LP. Market prices were used to value the inputs and outputs. Only peak season labor was included in the variable cost calculations since family labor did not participate in the labor market and there was a large amount of surplus labor available in the village. The following table (Table 4.9) provides a summary of the financial analysis for the tree components (also see Appendix 4, Tables 4.4 and 4.5):

**Table 4.9 Financial analysis of three fodder tree species in Nawalpur village in central Nepal**

| Species | No. of trees/ha. | Mgmt. type | PNV (NRs.'000) | B/C Ratio | FIRR % |
|---|---|---|---|---|---|
| F.semicordata | 2500 | Coppice growth | 317.21 | 3.52 | 45.70 |
| B.variegata | 2500 | Coppice growth | 37.20 | 1.43 | 17.97 |
| L.leucocephala | 2500 | Coppice growth | 270.55 | 2.72 | 39.16 |

## 6.2 Results of the LP modeling

### 6.2.1 Appropriate agroforestry schemes

Linear programming models[3] were generated for seven land

[3] The computer package AELP developed by Dr. Stephen Harsh of the MSU Dept. of Agric Economics was used to solve the LP problem. The package had a limitation of accepting only 40 rows and 40 columns which played a part in restricting the size and complexity of this LP model.

use alternatives. The activities included four crop and three tree enterprises (Appendix 4, Table 4.2). Only cereal crops were included to minimize the size of the model. The analysis provided insights into the interactions among different resources and production potentials. Since LP models were analyzed for five years, the analysis also indicated the amount of resources required to meet the projected demands for food, fodder, and fuelwood in the village. For example, the village was estimated to have produced 3739 metric tons of compost in 1990. However, the minimum amount of compost needed to meet the food calories in year 1 of the proposed scheme was 5260 metric tons. There was no feasible solution at the current level of compost and peak season labor use. The solution was obtained by assuming that the deficit will be made up by applying chemical fertilizer which is the prevailing practice. Two types of models were run - one type for maximizing net returns assuming that the implementation of the land allocation scheme as suggested by the optimal model was possible. In this model, no constraint was enforced to satisfy the minimum acreage under *Bauhinia* and *Leucaena* fodder trees. The second model ensured that the area planted under trees did not decrease in subsequent years. Tables 4.10 and 4.11 provide summary of the results.

**Table 4.10 Summary results of linear programming solution for an optimal land allocation scheme with maximum net returns as the maximizing criterion.**

| Item | Yr 0 | Yr 1 | Yr 2 | Yr 3 | Yr 4 | Yr 5 |
|---|---|---|---|---|---|---|
| **Objective function value (NRs.'000)** | 2718.77 | 3243.58 | 3505.33 | 4149.35 | 4379.47 | 4402.20 |
| **Cropped Area (ha.)** | | | | | | |
| -LL Paddy | 249.99 | 338.57 | 340.33 | 343.11 | 366.16 | 374.53 |
| -LL Maize | 0.03 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| -LL Wheat | 35.00 | 13.43 | 33.61 | 52.89 | 51.84 | 54.45 |
| -UL Maize | 239.00 | 181.87 | 176.42 | 148.76 | 145.03 | 164.76 |
| -UL FTS/1 | 20.99 | 78.13 | 83.58 | 111.24 | 114.97 | 95.24[1] |
| -UL FTS/2 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |
| -UL FTS/3 | - | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 |

[1] The acreage under FTS are cumulative i.e., the acreage in following year includes plantation area from preceding year.

Total objective function value for the five year period was NRs. 19,679,930. Net returns by the end of year five at present value increased by 62% over existing returns. The above model has achieved the goal of maximizing net returns by allocating the most profitable activities in each year of the five year period while meeting resource constraints. The solution has also generated a gradual increase in profit levels over the five year period due to allocating acreages to the most profitable activities such as rice and *Ficus* trees. The cropped area allocated for rice is shown to increase rather drastically from year zero to year one. The acreage under other crops varies over the years.

Under this optimal land allocation model, the land allocation schemes suggested by the solution may not be acceptable to the farmers of the Nawalpur village. Only one FTS is included in the optimal solution and they have to make large cropping readjustments, including clear felling of fodder trees. There is also a large jump in resource

requirements in year one from year zero reflecting a need to acquire variable inputs such as compost and labor within one year. This will not be possible as the farmers practice a subsistence agriculture. Besides, a more practical solution requires growing more than one species of fodder tree in the agroforestry system in order to meet green fodder demand for a period of four to six months. The cropped area also needs to increase in proportion to the demand for outputs and supply of inputs over subsequent years in the subsistence farm economy.

An ideal optimal solution will maximize net returns with a more acceptable and practical acreage allocation of the land resources to each of the desired activities. Therefore, in order to achieve such an allocation, a second model was formulated wherein multiple FTS were forced to enter the solution. The difference between the two models is not large in the magnitude of resource use and production levels as well as in terms of the objective function. However, the concept behind it is relevant in the context of agroforestry system. It stresses the need for crop diversification and slower transition from the existing cropping technology to a new technology. Table 4.11 provides the summary of the solutions.

The total objective function of this model was NRs. 19,086,220, three percent less than that of the preceding model. The average yearly net return is about NRs. 3.8

million. Although this model has a lower objective function, it provides more realistic land allocation figures.

**Table 4.11 Linear programming solution for an optimal land allocation model for an improved agroforestry scheme with minimum tree acreage as resource constraints**

| Item | year 1 | year 2 | year 3 | year 4 | year 5 |
|---|---|---|---|---|---|
| **Objective function value** (NRs. '000) | 3147.96 | 3449.42 | 3992.43 | 4191.46 | 4304.95 |
| **Cropped area allocation** (ha.) | | | | | |
| -LL Paddy | 319.14 | 332.32 | 335.62 | 346.85 | 355.63 |
| -LL Maize | 0.00 | 20.14 | 19.44 | 6.67 | 0.01 |
| -LL Wheat | 32.86 | 21.54 | 40.93 | 64.47 | 73.37 |
| -UL Maize | 190.37 | 173.72 | 160.50 | 150.97 | 153.40 |
| -UL FTS/FS | 49.63 | 66.28 | 79.49 | 89.04 | 86.60[1] |
| -UL FTS/BV | 10.00 | 10.00 | 10.00 | 10.00 | 10.00 |
| -UL FTS/LL | 10.00 | 10.00 | 10.00 | 10.00 | 10.00 |
| Total cropped area | 612.00 | 634.00 | 656.00 | 678.00 | 689.00 |

*1* The acreage under FTS are cumulative.

Spring maize has been included as an alternative crop to rice or wheat in the lowlands. Land area currently occupied by maize is gradually planned to be put under fodder trees explaining the decrease in the maize acreage. This is somewhat a realistic situation in the village since in order to meet the increasing demand for fodder and fuelwood, a modest change in the crop and tree species composition is necessary. However, since millet and maize are cultivated under a relay-cropping system, the total land use change is minimal. Since most of legume and oilseed crops are cultivated during winter season their inclusion is implied under maize and tree acreages. These crops were not included in the LP model as their contribution to cereal calories budget is negligible. The major resource use levels are presented in Table 4.12.

**Table 4.12 Production levels and resource requirements for the optimum LP solutions for an improved agroforestry scheme in Nawalpur village**

| Item | year 0 | year 1 | year 2 | year 3 | year 4 | year 5 |
|---|---|---|---|---|---|---|
| Food ( m.k.cal) | 2177.6 | 2286.72 | 2324.34 | 2394.00 | 2465.82 | 2540.00 |
| TDN, m.ton | 320.0 | 301.85 | 352.80 | 454.73 | 536.46 | 736.99 |
| Soil loss, m.t. | 3005.5 | 2888.55 | 2895.15 | 2800.00 | 2705.00 | 2581.32 |
| Labor, m.days | 8405.0 | 13150.00 | 16000.00 | 17768.55 | 19225.64 | 19970.00 |
| Fuelwood, m.ton | 129.0 | 169.49 | 294.65 | 461.76 | 625.58 | 1080.23 |
| Compost, m.ton | 4144.5 | 5257.39 | 5400.00 | 5670.00 | 6100.00 | 6573.51 |
| Lowland (ha.) | 285.0 | 352.00 | 374.00 | 396.00 | 418.00 | 429.00[4] |
| Upland (ha.) | 260.0 | 260.00 | 260.00 | 260.00 | 260.00 | 260.00 |

Some of the major features of the above described optimal solution were as follows (see Appendix 3, Figure 4.1)

- Food, fodder, and fuelwood production has been shown to increase by 17%, 130%, and 537% respectively over the existing levels respectively.
- The labor and compost requirements are shown to increase by 138% and 59% respectively over the five year period.
- The soil loss through run-off is estimated to decrease by about 15% over the same period.

**6.2.2 Levels of production and consumption:**

At the present time, the village produces 2178 million kilo calories of cereals, 320 metric tons of fodder TDN, and 129 tons of fuelwood by using 8,405 person days of peak season labor, 285 ha. of *khet* land, 260 ha. of *bari* land, and 4144 m. tons of compost. At this level the per capita availability of these goods are respectively: 2412 kilo calories, 290 kg. of TDN/LSU, and 51 kg. of fuelwood/year. However, the standard requirements are: 2750 kilo calories of nutrient, 1052 kg. of TDN/LSU, and 600 kg. of fuelwood/person/year. By the end of the five year period of

4 The lowland area is shown to increase as the cropping intensity is assumed to increase from 220% to 268% as a result of three croppings.

the proposed agroforestry scheme, the availability of these goods is estimated to reach 2540 k.cal. of food calories/individual/year; 880 kg/LSU/year. of TDN; and 393 kg./person/year of fuelwood. Nutrient availability shows only a slight increase because only cereal calories have been included in the solutions. It is estimated that the actual calories available will be about the minimum requirement of 2750 k.cal/day for each adult if the calorie contribution from the other crops are accounted for (Appendix 4, Table 4.2).

**6.2.3 Critical resources:** Land, peak season labor, and compost were the most critical resources influencing the optimum solution as well as in reorganizing land use patterns. This is reflected in the shadow prices of these resources provided by the LP solution:

**Table 4.13 Shadow prices of critical resources in the linear programming model for agroforestry scheme, Nawalpur**

| S.No. | Type of Constraint | Shadow prices (NRs. '000) | Slack level |
|---|---|---|---|
| 1. | Food calories | -15.50 | 0.00 |
| 2. | Peak season labor | 0.12 | 0.00 |
| 3. | Lowland | 68.32 | 0.00 |
| 4. | Upland | 69.45 | 0.00 |
| 5. | Compost | 0.45 | 0.00 |

Table 4.13 indicates the shadow prices and slack resources from dual solutions. The shadow prices are the optimal values of the dual variables for the respective resource constraints. The positive shadow prices indicate that the constraint is binding upon the optimal solution. The zero shadow price means that there are still resources

left unused. The negative shadow price indicate the amount by which the objective function value would be increased if an additional unit of the food calories was produced. This reflects the practical problems faced by the farmers of the study area. The goal of maximizing net returns conflicts with the need to meet non-market or low market products such as fodder production and soil erosion control.

**7.0 DISCUSSION AND IMPLICATIONS**

The results presented above indicate the complexity of agroforestry systems in general and rural resource interactions in particular. The importance of undertaking a holistic view of the farming system has been shown to lead to a better understanding of the agroforestry system. The application of decision-making tools such as LP have great potential in agroforestry design and analysis because, by definition, agroforestry has more components and variables than either agriculture or forestry systems. In this study only seven components were considered due to the limitation of the computer package which accepted only 40 rows and 40 columns.

The results have provided useful insights into the functioning of the traditional farming system in Nepal's Inner Tarai region. Two of the points highlighted by the model are: a) peak season labor is a critical resources which need to be supplied through better scheduling of the farming operations; b) manures and fertilizers can seriously limit farm production; and d) despite planting high yielding FTS, supply of animal feed (TDN) is far below the requirement.

Under the existing system, only traditional crops such as paddy, wheat, maize, millet, oilseeds, and legumes are being cultivated along with over 10 different species of multipurpose trees. The system is not optimal from the maximum net returns point of view because of low investment in terms of labor, fertilizer, and technical know-how. It is also not meeting the growing demand for food, fodder, and fuelwood.

The improved agroforestry scheme designed here has indicated the potential to increase net returns while meeting the basic needs of the villagers. However, major constraints to implement the plan appear to be the lack of organic manures and hired labor. Therefore, if growing demands for food, fodder, and fuelwood are to be met, villagers need to overcome these two constraints. This will require investments in terms of more tree planting with improved tree species as well as improving labor use patterns. Peak season labor is shown to be a constraint because under the current cropping system most of the farming is patterned after the monsoon rains. However, with a slight rescheduling of cropping, such as planting early maize in the lowland, family labor use can be used in place of hired labor. A very common solution in other parts of Nepal is labor pooling or the *Parma* system. Under this system all the available labor person days of the village are mobilized to accomplish major farming operations by one household or locality at a time as per the weather suitability and timing necessity of a particular crop. The work force is rotated till the major cropping operations are completed for all participating farmers. The compost bottleneck can be solved by producing more tree litter as well as applying chemical fertilizers. This is already occurring in the village.

These proposed solutions to alleviate the labor and compost constraints are believed to be technically feasible, socially acceptable, and financially sound. The recommendation to the farmers of the study area emphasizes the land reallocation factor. Increasing cropping intensity and productivity are among the few remaining alternatives to meet the food and fiber needs of the people of the Nawalpur village.

In order to overcome the increasing deficits of food, fodder, and fuelwood, better species selection and application of a combined performance approach i.e., evaluating the performance of all the major species together, taking resource sharing into consideration may be more appropriate. The competitive and complementary relationship between the annuals and perennials on the one hand, and between plants and animals on the other, needs to be better understood to generate required data before carrying out joint evaluation of various species.

Fodder trees are an important component of agroforestry system. Prediction of fodder and fuelwood yields within an acceptable limit is also important. New approaches in predicting yield of agroforestry crops are required because of the interactions between annual and perennial components, the long time to tree maturity, and the potential variety of harvested products and environmental services. Application of analytical tools which can grasp the multi-period and multi-crop scenarios common in the agroforestry system will certainly improve the design and subsequently the implementation of the agroforestry projects in Nepal.

**8.0 CONCLUSION:**

This study has demonstrated the use of research data and a mathematical tool in designing and analyzing an agroforestry scheme in Nepal. The intent of the study was to demonstrate a methodology. However, in the process, the conceptual feasibility of improving the production potentials of the existing resources in a typical village of Nepal has been described. In order to show the practical applicability of such analyses, continuation of such studies encompassing a larger area using additional and better quality data is needed. The implementation of such ideas will, however, be possible only if farmers participate in the decisions and have faith in the analysis. To meet this challenge, more on-farm agroforestry research needs to be carried out to be able to present to the farmers not only the figures of higher production potentials but also with the products such as food, fodder, and fuelwood which they so urgently need. This is the ultimate challenge to the agroforestry professionals both in Nepal and other Third World countries.

APPENDIX 4

## Appendix 4

**Table 4.1 Household labor use by farm activity in Nawalpur village as compared to national level figures in Nepal**

| Item | Estimated labor use (person days/year) | | | |
|---|---|---|---|---|
| | Nawalpur[1] | National average by farm size[2] | | |
| | | Small | Medium | Large |
| Cereals | | | | |
| - Major crops | 116 | 20 | 71 | 158 |
| - Minor crops | 24 | 7 | 20 | 31 |
| Other crop | 10 | 2 | 6 | 12 |
| Livestock | 589 | 372 | 490 | 671 |
| - Feed collection | 279 | NA | NA | NA |
| - Management | 310 | NA | NA | NA |
| Off-farm work | 170 | 129 | 78 | 75 |
| Total requirement | 909 | 536 | 665 | 947 |
| Total available | 1186[3] | 900 | 1140 | 1410 |
| Hired labor | 31 | 4 | 14 | 60 |
| Estimated surplus | 277 | 364 | 475 | 463 |

[1] Based on the Baseline Survey, 1986
[2] Based on the National Farm Management Study, 1983-1985 (DFMAS 1986)
[3] Based on the availability of 3.8 person days/HH @ 6 days/week for 52 weeks.

**Appendix 4. Table 4.2 - COEFFICIENT OF MATRIX FOR THE LINEAR PROGRAMMING MODEL OF THE AGROFORESTRY SYSTEM IN NAWALPUR VILLAGE, MAKWANPUR DISTRICT, NEPAL**
**Net returns (NRs '000) from a hectare i in alternative j in year t (j= 1,2,...,7 and t=1,2...,5)**

Year 1

| Row ID | | X11 | X21 | X31 | X41 | X51 | X61 | X71 |
|---|---|---|---|---|---|---|---|---|
| Obj.Fn. | | 7.1 | 3.4 | 2.6 | 3.5 | 7.4 | 2.7 | 6.8 |
| Food Kilo cal $10^6$ | Yr 1 | 4.1 | 4.5 | 3.7 | 4.5 | 0.0 | 0.0 | 0.0 |
| TDN Kg/ yr. | Yr 1 | 1.5 | .55 | .25 | .5 | 4.8 | 1.6 | 4.3 |
| Soil loss M. ton /yr. | Yr 1 | 4.0 | 4.5 | 3.0 | 6.8 | 3.0 | 3.5 | 3.5 |
| Peak seas. labor days/ year | Yr 1 | 35 | 20 | 6 | 2 | 21 | 10 | 26 |
| Fuel wood M.tn. /yr. | Yr 1 | 0.0 | .3 | .2 | .4 | 5 | 3 | 7 |
| Low land ha. | Yr 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 |

Year 2

| Row ID | | X12 | X22 | X32 | X42 | X52 | X62 | X72 |
|---|---|---|---|---|---|---|---|---|
| Obj.Fn. | | 7.1 | 3.5 | 2.6 | 3.5 | 7.4 | 2.9 | 6.8 |
| Food Kilo cal $10^6$ | Yr 2 | 4.1 | 4.5 | 3.8 | 4.6 | 0.0 | 0.0 | 0.0 |
| TDN Kg/ yr. | Yr 2 | 1.5 | .55 | .25 | .5 | 4.9 | 1.8 | 4.4 |
| Soil loss M. ton /yr. | Yr 2 | 4.0 | 4.5 | 3.0 | 6.7 | 3.0 | 3.4 | 3.2 |
| Peak seas. labor days/ year | Yr 2 | 37 | 20 | 6 | 3 | 32 | 15 | 38 |
| Fuel wood M.tn. /yr. | Yr 2 | 0 | .3 | .2 | .4 | 5.1 | 3.1 | 7.2 |
| Low land ha. | Yr 2 | 1 | 1 | 1 | 0 | 0 | 0 | 0 |

Year 3

| Row ID | | X13 | X23 | X33 | X43 | X53 | X63 | X73 |
|---|---|---|---|---|---|---|---|---|
| Obj.Fn. | | 7.2 | 3.5 | 2.6 | 3.6 | 7.5 | 3.8 | 7.0 |
| Food Kilo cal $10^6$ | Yr 3 | 4.2 | 4.5 | 3.9 | 4.6 | 0.0 | 0.0 | 0.0 |
| TDN Kg/ yr. | Yr 3 | 1.6 | .6 | .3 | .65 | 5.0 | 1.9 | 4.5 |
| Soil loss M. ton /yr. | Yr 3 | 3.8 | 4.3 | 2.9 | 6.5 | 2.9 | 3.0 | 3.4 |
| Peak seas. labor days/ year | Yr 3 | 39 | 21 | 3 | 4 | 35 | 16 | 40 |
| Fuel wood M.tn. /yr. | Yr 3 | 0 | .3 | .2 | .4 | 5.2 | 3.2 | 7.5 |
| Low land ha. | Yr 3 | 1 | 1 | 1 | 0 | 0 | 0 | 0 |

Year 4

| Row ID | | X14 | X24 | X34 | X44 | X54 | X64 | X74 |
|---|---|---|---|---|---|---|---|---|
| Obj.Fn. | | 7.3 | 3.6 | 2.8 | 3.7 | 8.6 | 4.5 | 7.2 |
| Food Kilo cal $10^6$ | Yr 4 | 4.3 | 4.6 | 3.9 | 4.6 | 0.0 | 0.0 | 0.0 |
| TDN Kg/ yr. | Yr 4 | 1.6 | .65 | .35 | .61 | 5.4 | 2.0 | 4.6 |
| Soil loss M. ton /yr. | Yr 4 | 3.7 | 3.8 | 2.8 | 6.0 | 3.0 | 3.5 | 2.8 |
| Peak seas. labor days/ year | Yr 4 | 40 | 22 | 4 | 5 | 37 | 18 | 46 |
| Fuel wood M.tn. /yr. | Yr 4 | 0.0 | .2 | .2 | .4 | 6.8 | 4.7 | 10.5 |
| Low land ha. | Yr 4 | 1 | 1 | 1 | 0 | 0 | 0 | 0 |

Year 5

| Row ID | | X15 | X25 | X35 | X45 | X55 | X65 | X75 |
|---|---|---|---|---|---|---|---|---|
| Obj.Fn. | | 7.4 | 3.8 | 2.8 | 3.9 | 9.2 | 3.1 | 7.8 |
| Food Kilo cal $10^6$ | Yr 5 | 4.3 | 4.7 | 4.0 | 4.7 | 0.0 | 0.0 | 0.0 |
| TDN Kg/ yr. | Yr 5 | 1.65 | .7 | .37 | .62 | 5.7 | 2.2 | 5.0 |
| Soil loss M. ton /yr. | Yr 5 | 3.5 | 3.0 | 2.0 | 5.5 | 2.7 | 3.2 | 3.0 |
| Peak seas. labor days/ year | Yr 5 | 40 | 20 | 5 | 5 | 40 | 20 | 50 |
| Fuel wood M.tn. /yr. | Yr 5 | 0 | .2 | .2 | .4 | 7 | 5 | 11 |
| Low land ha. | Yr 5 | 1 | 1 | 1 | 0 | 0 | 0 | 0 |

| | | | | | |
|---|---|---|---|---|---|
| Up- Yr 1 | 0 0 0 1 1 1 1 | | | | |
| land Yr 2 | | 0 0 0 1 1 1 1 | | | |
| ha. Yr 3 | | | 0 0 0 1 1 1 1 | | |
| Yr 4 | | | | 0 0 0 1 1 1 1 | |
| Yr 5 | | | | | 0 0 0 1 1 1 1 |
| Com-Yr 1 | 6.2 10 4.5 14.2 6.5 4.0 6.5 | | | | |
| postYr 2 | | 6.2 10.0 4.5 14.2 7.0 4.5 6.5 | | | |
| M. Yr 3 | | | 6.9 10 4.8 14.5 7.5 5.0 7.0 | | |
| ton Yr 4 | | | | 7.5 10.5 5.0 15.0 8.0 5.5 7.5 | |
| /yr.Yr 5 | | | | | 8.2 11.0 5.5 15.5 9 6 8 |

**Table 4.2 (contd...): Production targets, resource levels, and constraint type for the LP model for Nawalpur village***

| Products/resources | constraint type | Resource levels and production values year 1 | year 2 | year 3 | year 4 | year 5 |
|---|---|---|---|---|---|---|
| Food calories (m.k.cal) | >= | 2243 | 2310 | 2380 | 2450 | 2525 |
| TDN (Metric ton) | >= | 580 | 590 | 605 | 615 | 630 |
| Soil loss (M.ton) | <= | 2900 | 2870 | 2840 | 2785 | 2700 |
| Peak season labor (p.days) | <= | 11250 | 11590 | 11935 | 12293 | 12660 |
| Fuelwood (M.ton) | >= | 220 | 235 | 245 | 260 | 270 |
| Lowland (khet) (Ha.) | <= | 352 | 370 | 390 | 418 | 430 |
| Upland (bari) (ha.) | <= | 260 | 260 | 260 | 260 | 260 |
| Compost manures (M.ton) | <= | 3740 | 4114 | 4525 | 4980 | 5475 |

Note: These input/output constraint levels are for the original LP model. However, in the subsequent runs the constraints were relaxed based on the assumptions explained in section 5.3.2.

**Appendix 4. Table 4.3 Proposed management plan for *F.semicordata*, *B.variegata*, and *L.leucocephala* for the Inner Tarai region of Nepal**

| Year | Activities | Products | Inputs |
|---|---|---|---|
| Year 1 | Planting from stock seedlings | None | Improved stocks/labor |
| Year 2 | Weeding/fertilization | None | compost/weeding |
| Year 3 | Thinning | Fodder/fuelwood | compost/weeding |
| Year 4 | Thinning | Fodder/fuelwood | compos/weeding |
| Year 5 | Pollarding | Fodder/fuelwood | compost/sanitation |
| Year 6 | Coppice removal | Fodder/fuelwood | compost/sanitation |
| Year 7 | Coppice removal | Fodder/fuelwood | protection/management |
| Year 8 | Pollarding/lopping | Fodder/fuelwood | protection/management |
| Year 9 | Pollarding/lopping | Fodder/fuelwood | protection/management |
| Year 10 | Selective cutting/planting | Fodder/fuelwood | improved stocks/labor |

## Appendix 4

**Table 4.4 - Financial analysis of selected fodder tree species for agroforestry scheme at Nawalpur village in central Nepal**

| Item | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | Year 10[1] | 11 | 12 | 13 | 14 | 15 | 16-20 | 21-35 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | Output values (NRs '000) | | | | | | | | | |
| Species | | | | | | | | | | | | | | | | | | |
| - FS | -35.6 | -20.5 | -11.8 | 33.2 | 56.2 | 68.6 | 69.9 | 69.9 | 69.9 | 69.9 | -0.8 | 58.8 | 69.9 | 69.9 | 69.9 | 69.9 | 308.3 | 1013.3 |
| - BV | -32.4 | -18.5 | -10.6 | 5.6 | 12.6 | 17.2 | 20.3 | 20.3 | 20.3 | 20.3 | -23.8 | 15.8 | 20.3 | 20.3 | 20.3 | 20.3 | 57.3 | 260.3 |
| - LL | -44.5 | -25.6 | -14.8 | 33.3 | 53.4 | 68.3 | 69.4 | 69.4 | 69.4 | 69.4 | -7.3 | 57.9 | 69.4 | 69.4 | 69.4 | 69.4 | 306.5 | 1013.5 |
| | | | | | | | | | Net value of returns at discount rate of 12% | | | | | | | | | |
| Species | | | | | | | | | | | | | | | | | | |
| - FS | -35.6 | -18.31 | -9.4 | 23.6 | 35.7 | 38.9 | 35.4 | 31.6 | 28.2 | 25.2 | -.3 | 16.9 | 18.0 | 16.0 | 14.3 | 12.8 | 40.4 | 46.2 |
| - BV | -32.4 | -16.5 | -8.5 | 4.0 | 8.0 | 9.8 | 10.3 | 9.2 | 8.2 | 7.3 | -7.7 | 4.5 | 5.2 | 4.6 | 4.2 | 3.7 | 7.6 | 11.5 |
| - LL | -44.5 | -22.9 | -11.8 | 23.7 | 35.0 | 38.7 | 35.2 | 31.4 | 28.0 | 25.1 | -2.4 | 16.6 | 17.8 | 15.9 | 14.2 | 12.7 | 39.0 | 46.0 |
| | | | | | | | | | Financial rate of return (FRR) calculations | | | | | | | | | |
| Species: FS | | | | | | | | | | | | | | | | | | |
| NPV(50%) | -35.6 | -13.7 | -5.2 | 9.83 | 11.1 | 9.1 | 6.2 | 4.1 | 2.7 | 1.8 | -.1 | .7 | .6 | .3 | .2 | .1 | 0 | 0 |
| NPV(45%) | -35.6 | -14.1 | -5.6 | 10.9 | 12.7 | 10.7 | 7.5 | 5.2 | 3.6 | 2.4 | -.1 | 1.0 | .8 | .6 | .4 | .3 | .5 | 0 |
| | | | | | | | | | FRR = 45+5* (1.3/9.1)*100 = 45.7% | | | | | | | | | |
| Species: BV | | | | | | | | | | | | | | | | | | |
| NPV(20%) | -32.4 | -15.4 | -7.4 | 3.2 | 6.1 | 6.9 | 6.8 | 5.7 | 4.7 | 3.9 | -3.9 | 2.1 | 2.3 | 1.9 | 1.6 | 1.3 | 2.2 | 2.2 |
| NPV(15%) | -32.4 | -16.1 | -8.03 | 3.7 | 7.2 | 8.5 | 8.8 | 7.6 | 6.6 | 5.8 | -5.9 | 3.4 | 3.8 | 3.3 | 2.9 | 2.5 | 4.7 | 5.6 |
| | | | | | | | | | FRR = 15+5*(12/20.2)*100 = 17.97% | | | | | | | | | |
| Species: LL | | | | | | | | | | | | | | | | | | |
| NPV(40%) | -44.5 | -18.3 | -7.5 | 12.1 | 13.9 | 12.7 | 9.2 | 6.6 | 4.8 | 3.4 | -.3 | 1.5 | 1.2 | .9 | .6 | .4 | .8 | 0 |
| NPV(35%) | -44.5 | -19.0 | -8.1 | 13.5 | 16.1 | 15.2 | 11.5 | 8.5 | 6.3 | 4.6 | -.4 | 2.1 | 1.9 | 1.4 | 1.0 | .8 | 1.5 | .1 |
| | | | | | | | | | FRR = 35+5*(12.4/14.9)*100 = 39.16% | | | | | | | | | |

Notations: FS - Ficus semicordata; BV - Bauhinia variegata; LL - Leucaena leucocephala

[1] Net returns drops due to replanting costs

## Appendix 4

**Table 4.5 - Net Present Value (NPV) and Benefit Cost (B/C) ratio calculations for the selected trees in Nawalpur village, Nepal (Discount rate = 12%)**

**A:NPV calculations:**

| Item / Species | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | Year 10 | 11 | 12 | 13 | 14 | 15 | 16-20 | 21-35 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| - FS | -35.6 | -18.31 | -9.40 | 23.6 | 35.7 | 38.9 | 35.4 | 31.6 | 28.2 | 25.2 | -.3 | 16.9 | 18.0 | 16 | 14.3 | 12.8 | 40.4 | 46.2 |
| - BV | -32.4 | -16.8 | -8.5 | 4 | 8 | 9.8 | 10.3 | 9.2 | 8.2 | 7.3 | 7.7 | 4.5 | 5.2 | 4.6 | 4.2 | 3.7 | 7.6 | 16.7 |
| - LL | -44.5 | -22.9 | -11.8 | 23.7 | 34 | 38.7 | 35.2 | 31.4 | 28 | 25.1 | -2.4 | 16.6 | 17.8 | 15.9 | 14.2 | 12.7 | 39.8 | 46.0 |

Total NPV: FS - NRs. 317,210.00; BV - NRs. 37,200.00; and LL - NRs. 270,000.00

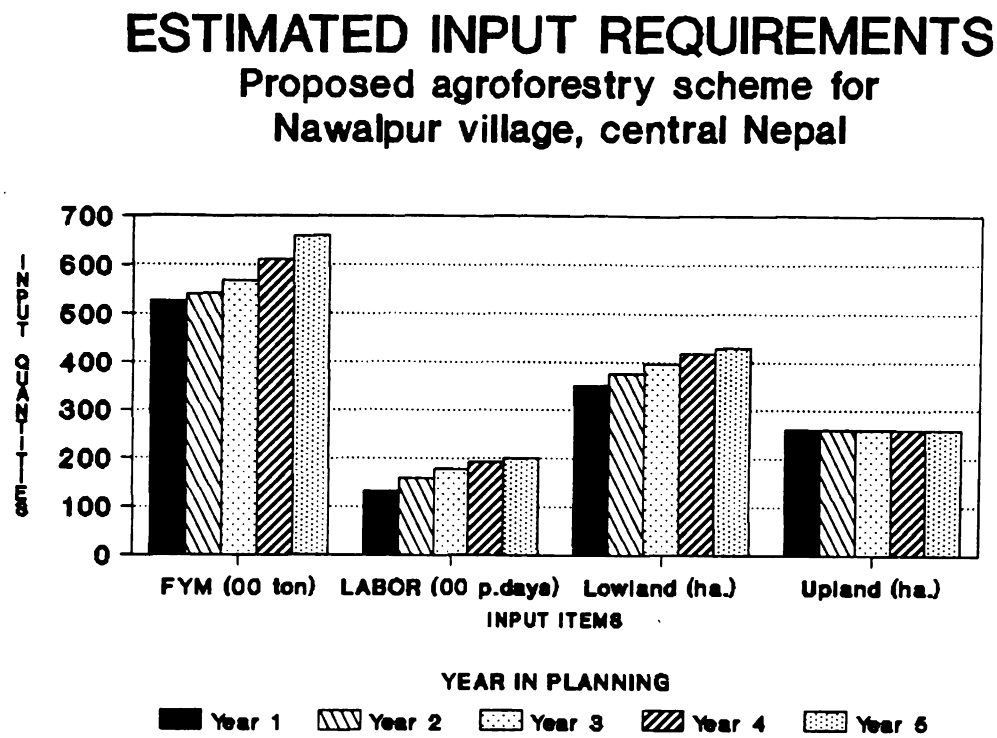
**b:B/C ratio calculations:**

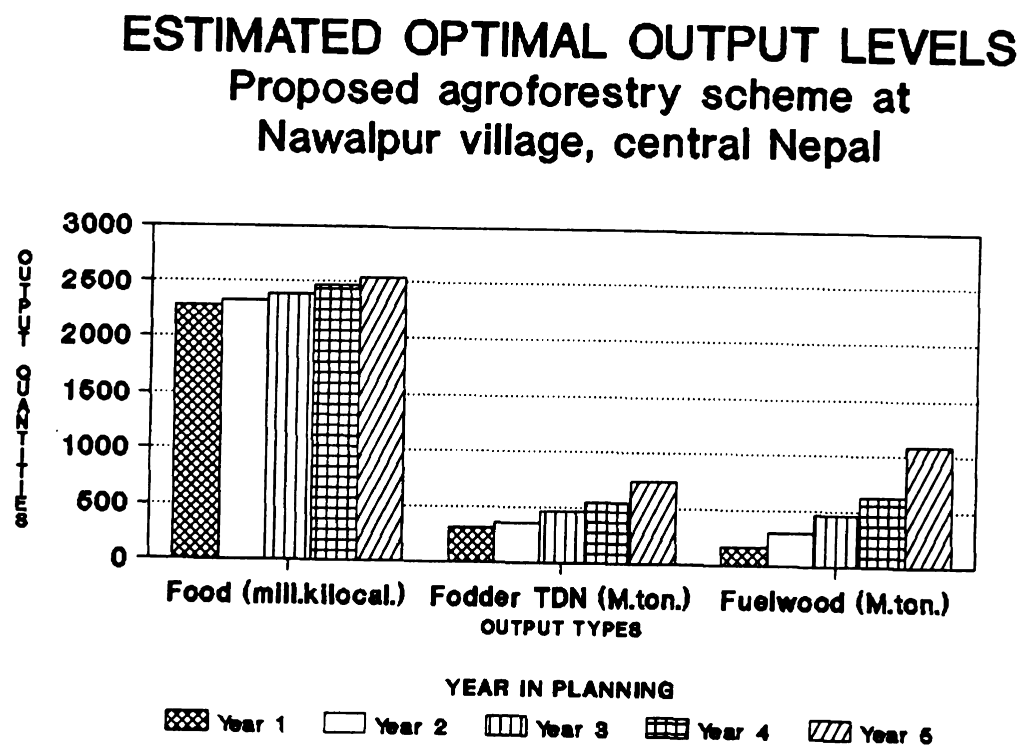
| Species | Present value of total costs | Present value of total benefits | B/C ratio |
|---|---|---|---|
| - FS | 125,750 | 442,960 | 3.52 |
| - BV | 113,180 | 162,950 | 1.44 |
| - LL | 157,190 | 427,980 | 2.72 |

FRR = 35+5*(12.4/14.9)*100 = 39.16%

Notations: FS - Ficus semicordata; BV - Bauhinia variegata; LL - Leucaena leucocephala

**Appendix 4. Figure 4.1 Estimated input requirements and output levels from the optimal LP models for the agroforestry scheme at Nawalpur**




Based on Linear Programming solution

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