

**BIOMASS PRODUCTIVITY AND NUTRIENT BUDGETING  
IN DIFFERENT AGROECOSYSTEMS**

**THESIS**

By

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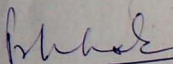
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CERTIFICATE-I

This is to certify that the thesis entitled "Biomass productivity and nutrient budgeting in different agroecosystems", submitted in partial fulfilment of the requirements for the degree of DOCTOR OF PHILOSOPHY in the subject of FORESTRY of Dr Y S Parmar University of Horticulture and Forestry, is a faithful record of bonafide research work carried out by Mr Hirendra Kumar Mazundar under my guidance and supervision and no part of this thesis has been submitted for any other degree or diploma.

The assistance and help received during the course of investigations have been fully acknowledged.

Dated: 27 May, 1991



( P K Khosla )  
Major Advisor

CERTIFICATE-II

This is to certify that the thesis entitled "Biomass productivity and nutrient budgeting in different agroecosystems", submitted by Mr Hirendra Kumar Mazumdar to the Dr Y S Parmar University of Horticulture and Forestry, Solan, in partial fulfilment of the requirements for the degree of DOCTOR OF PHILOSOPHY in the subject of FORESTRY has been approved by the Student's Advisory Committee after an oral examination on the same in collaboration with an External Examiner.

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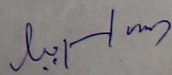
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# Chapter 1

## INTRODUCTION

The Himalaya embrace a well defined phyto-geographical region of India and form an important ecological zone imparting prosperity to the people living in this zone and northern Indian valleys. Nevertheless, the government and the present system see the Himalaya as a store house of resources for the material development of the country with excessive unplanned exploitation of natural wealth.

The existing ecosystem scenario and demographic structure of India vary widely in the major agroclimatic zones. In the hilly states, like Himachal Pradesh, where 90 per cent of its population (4.28 million) is ruralite, afresh look for alternative satisfying both environmental needs as well as tangible products on the village ecosystems seems to be ideal. The economy of the state is dependent on agriculture, horticulture, silviculture and animal husbandry. Its general land-use pattern signifies that less area is available for cultivation due to hilly terrain and rainfed conditions. Out of the total area, 18.05 per cent is under agriculture, 27.42 per cent under forest cover and 35.74 per cent under permanent pastures and grazing land (Anonymous, 1988). The orchards are on the increase at the cost of grasslands and other marginal lands in the temperate region of the state, occasionally forest lands were also diverted to this vocation. Attempts to achieve rapid increase in food production, relied on the extension of area can't be ignored in spite of modern technology,

ironically ignoring the commensurable increase of other biological entities. The population explosion is outpacing the forest lands and converting them for agricultural production in addition to their inhabitation and industrialization. Thus, the rural people particularly, are facing increasing problems in meeting their basic household demands viz. fuelwood, fodder, fibre, small timber, etc., day by day.

Studies on biomass production is of strategic importance as we are dependent on this renewable source for most of our needs. The biomass productivity rates of different vegetation units in any region are the result of the interaction of ecological, edaphic and climatic factors with human intervention. The feature of ecosystems sought after human users are durability, sustainability, adaptability and diversity. Each ecosystem consists of rejuvenation units of eco-units defined as the unit of vegetation which started its development at the same moment and on the same surface (Oldeman, 1983). In artificial ecosystems, eco-units generally, are developed and well separated by man-made limits to support their life and life style. Such land use systems are species rich and possess sophisticated spatial structures and dynamics for the mass of the rural population. Some of these systems have survived through the pre-historic past as a result of long-term adaptations of the plants justifying to be both ecologically and economically viable systems. The permanency

of the producing landscape throughout the year results in a combination of crops with different production rhythms because of man's intervention for the better ecological and phytosociological requirements. From the original natural ecosystem, plants have developed under the influence of human pressures and disturbances. Wild species have been replaced, thus producing an environment according to the people's need.

The ecosystem management programmes have failed to yield fruitful results because they have not been evaluated at the grassroot level (village level). Moreover, the resource personnels are not working in integration for decentralized development of the existing village ecosystems. Ecosystem cultures exist even today in hundreds of villages of this country which need to be tapped scientifically to develop a balanced and sustainable system. Needless to emphasize, there are locations specific problems within the broad agroclimatic zones which need to be looked precisely. Village ecosystems' dynamics need to be studied through scientific data collection in formulating proper strategy for the conservation of village natural resources and also in developing an ecologically sound ecosystem. In order to understand the structures and functions of the prevailed ecosystems, it is of prior importance to study the quantitative and qualitative aspects of the constituent eco-units.

Looking at the vital importance and the paucity of the data base information on current productivity potentials of the traditional ecosystems, the present investigation was undertaken so as to give enough first hand information of the area to mediate on future developmental studies of the vegetation of the locality. The present study was aimed:

- i) ✓ to delineate the present landuse pattern of the area,
- ii) to study the floristic composition and distribution pattern of the species,
- iii) to evaluate the standing biomass and its productivity, both species and system-wise,
- iv) to study the biomass distribution pattern of the species,
- v) to assess the soil and biological nutrient allocation in each system and
- vi) to make an economic evaluation of the derived biomass.

## Chapter 2 REVIEW OF LITERATURE

An attempt has been made to review the available literature including closely related studies pertaining to quantitative and qualitative aspects of the various eco-units comprising the ecosystems under the following headings:

- 2.1 Tree biomass estimation and prediction equations
- 2.2 Biomass productivity of ecosystems
- 2.3 Budget of major nutrients in ecosystems
- 2.4 Ecosystems economic evaluation

## **2.1 TREE BIOMASS ESTIMATION AND PREDICTION EQUATIONS**

Biomass measurements of individual tree components are of recent interest as compared to herbaceous plants meant for food and feed.

Biomass assessment can be divided into methods for measuring true weight of individual trees and for measuring the growth, volume and density of stands on a hectare basis. Measurements of individual trees can easily be separated into weights of wood plus stem and wood plus stem plus leaves.

It is especially desirable to be able to take simple measurements i.e. basal area, canopy volume, canopy diameter that are correlated with total weight.

Diameter at breast height (DBH) is very useful for many trees. However, for some trees there seldom is a single

stem at DBH which makes analysis based on this parameter difficult. Since most trees have only one stem at ground level, it is simpler to use the measurement in lieu of DBH (Felkar, 1986).

Telfer (1969) could find stem diameter at ground line to be closely correlated with both leaf and total weights for 22 species of trees and shrubs. Height was poorly correlated with biomass and the height x volume was no better correlated with biomass than basal diameter alone (Felkar et al., 1983).

Biomass estimation equations are typically regression equations relating paired data of weights versus basal diameter, height, diameter x height, etc.

Some of the researchers suggested various sampling methods and regression models for the biomass prediction of different tree components with reasonable accuracy. Singh (1975), Hase et al. (1985) and Pande et al. (1986) worked out regression models and used stratified random sampling methods for tree component biomass estimation in chir pine plantations, evergreen forests and Eucalyptus plantations, respectively.

A variety of predictable variables have been tested to know their comparative potentiality in biomass prediction equations. Among the variables tried, stem diameter was found to be better than others (Telfer, 1969; Alaback, 1986;

Jeanrenaud and Thompson, 1986).

Young et al. (1964) used height and DBH as independent variables in multiple log-linear regression analysis. For reliable prediction of stem biomass in red spruce, red maple and quaking aspen stands.

Krumlik and Kimmins (1973) and Krumlik (1974) compared linear and log-linear regression models keeping DBH, basal diameter and DBH x height as independent variables for biomass estimation of stemwood and stembark and found log-linear regression model.

Peterson et al. (1970) and Rai (1984) derived higher estimates with logarithms of  $DBH^2 \times$  height than DBH, height and basal diameter for stem biomass prediction.

On the basis of coefficient of determination ( $R^2$ ), Pathak et al. (1987) justified the validity of fitness of prediction equation based on simple growth data of Leucaena leucocephala at different age. They used simple regression and Cob-Douglas functions to predict the biomass components on growth data.

In a study on fractional biomass estimation of Robinia pseudoacacia, Thakur (1989) examined different regression models and predictable variables.

## 2.2 BIOMASS PRODUCTIVITY OF THE ECOSYSTEMS

Biomass is the total amount of living matter present

in a given moment in a biological system excluding dead roots and branches. It is expressed in terms of dry weight on ash free dry weight (=organic weight).

Production is fundamentally a physiological process involving the synthesis of organic matter through photosynthesis. In addition to genetic potentiality of the plants, production is controlled by a variety of environmental factors. Lieth and Box (1972) have summarized data on net primary production, temperature and precipitation in their development of a model of primary production on a world basis.

The conventional definitions of forest production, as used in the International Biological Programme (IBP), are quoted directly from Newbould (1967):

"The assimilation of organic matter by a plant community during a certain specified period (e.g. one year), including the amount used up by plant respiration is called gross primary production". Gross production minus respiration or the formation of plant tissues and reserve substances during the period is the net primary production or simply known as primary production. When production is measured as dry weight, it includes some mineral salts incorporated into the products of photosynthesis. If ash content is estimated and excluded, or some method is used which estimates only the formation of organic compounds, then organic production should be specified.

The general term "productivity" may be considered as the "rate of net primary production" or the rate of production of organic matter less that used in respiration but including all losses due to litter fall, root sloughing, grazing and fruit and seed fall (Egunjobi, 1969a). Ovington (1962) has clearly distinguished "mean annual net primary productivity" obtained by averaging the biomass over the age of the stand and the "current annual net productivity" which is the current rate of organic matter production. The later measurement is more useful. In ecological terms, primary productivity is the rate at which energy is bound or organic matter created by photosynthesis per unit of the earth's surface per unit of time (Whittaker, 1970). "Economic productivity" (Ovington, 1965) is also used in forestry for the rate of production of wood in the parts of the tree removed as the crop. This, of course, greatly underestimates "Productivity" (Miller, 1969).

, Studies on biological productivity of the forests considering their value and importance appear to be scanty. For the man-made forests, data on economic productivity are of course extensive and height, girth and volume growth have been measured for many species in many locations. This kind of data can't be expected to provide the precision required for productivity measurements in forestry or ecosystem studies. Many more factors particularly of climate and soil, need to be taken into account. Some of these have been discussed by Jackson (1965). Biological

productivity studies provide data to understand ecosystems and to their comparison.

The largest percentage of biomass on the earth is in the form of wood in the forests. The world's annual net biomass production was estimated at  $2 \times 10^{11}$  t (Hall and Coombs, 1983) of which  $9 \times 10^{10}$  t and  $1.5 \times 10^9$  t contributed by forest and cereals as starch.

The productivity of the temperate deciduous and coniferous forests has been worked out to be  $12-28 \text{ t ha}^{-1} \text{ yr}^{-1}$  (Westlake, 1963) which that of tropical forest averages  $25.3 \text{ t ha}^{-1} \text{ yr}^{-1}$  (Mathur et al., 1984b). The grasslands and mountain forest ecosystems appeared to yield 0.5 to 3.0  $\text{g m}^{-2} \text{ day}^{-1}$  of gross dry organic matter with the production potentials of  $20 \text{ g m}^{-2} \text{ day}^{-1}$ . The temperate forests and grasslands put the average biomass of 12.4 and 6.0  $\text{t ha}^{-1} \text{ yr}^{-1}$  (Whittaker and Likens, 1975).

Gupta (1987) observed the grasses as major contribution to the community biomass in grassland ecosystems of Himachal Pradesh, averaging the total above ground biomass (live) of  $358.08 \text{ g m}^{-2}$  in the month of August. An average dry matter yield ranging between  $93.9 \text{ g m}^{-2}$  to  $336.2 \text{ g m}^{-2}$  was reported by Melkania and Tandon (1988) from the grasslands situated at the altitude of 750 to 2000 m of mid-Himalaya at Almora.

Toky et al. (1989a) reported the highest biomass productivity upto  $25.8 \text{ t ha}^{-1} \text{ yr}^{-1}$  out of which 68 per cent

was contributed by the trees and the remainder by the annuals in an agri-hortisilvicultural system commonly practised in the mid-hills of western Himalaya (Himachal Pradesh). The lowest productivity of  $20.4 \text{ t ha}^{-1} \text{ yr}^{-1}$  with only 27 per cent contribution by trees in agrisilvicultural system was put in record. They further did estimate above ground biomass in agrihortisilvicultural or agri-horticultural system to be around  $48.0 \text{ t ha}^{-1}$  which was about 2-fold higher than agrisilvicultural system.

In another case study on agroforestry ecosystem dynamics in Himachal Himalaya, Nayar (1989) assessed the above ground plant biomass productivity @ 1.57, 2.25 and  $47.8 \text{ t ha}^{-1} \text{ yr}^{-1}$  for commonland and wasteland, grassland and orchard, respectively. Among the agricultural crops, Lycopersicon esculentum gave the highest productivity of  $31.83 \text{ t ha}^{-1}$ .

### 2.3 BUDGET OF MAJOR NUTRIENTS IN ECOSYSTEMS

The plant species vary widely in their nutrient accumulation status inherently in addition to their growing environment. Extensive studies on nutrient dynamics have been attempted with agricultural as well as horticultural crops as compared to forest crops. However, in forest ecosystems, quantification of litter fall and then nutrient cycling to the soil seemed to be a habitual practice.

Many of the nutrients in a mature ecosystem are in the living vegetation rather than in the soil. The removal of

vegetation leaves a site with very limited potential to sustain high rates of productivity, agricultural or otherwise. Nair (1984) emphasized the system analysis in quantitative and qualitative relationships among significant components of a system on the basis of convenient and abstract models. Further, he felt the need to be undertaken urgently in agroforestry relating to the nutrient cycling, nutrient budgeting and soil conservation aspects that would lead to establishing both the productivity potential of the system and the sustainability potential of the soil. Some examples of the successful application of the procedure in the biological fields were found in studies both of farming systems per se (Zandstra, 1977,1980; Zandstra et al.,1980; Collinson,1980), and of the studies on components of these systems, such as in nutrient cycling in agro-ecosystems (Frissel,1977; Ramakrishnan and Toky, 1981), forest ecosystem (Ulrich et al.,1979), grazing studies (Innis,1978) and nutrient cycling following slash and burn agriculture (Toky and Ramakrishnan,1983b).

During two years of studies, Gupta (1987) noticed a marked variation of per cent N, P and K contents in above ground biomass and soil on grassland ecosystem existing in the state. The nitrogen content in the herbage and soil ranged from 0.52 to 1.58 per cent and 0.322 to 0.476 per cent, respectively. Melkania and Tandon (1988) reported the crude protein range between 4.1 to 7.6 per cent of composite herbage from their study on grassland ecosystems at Almora (Uttar Pradesh).

Toky et al. (1989b) studied the budget of nutrients in plant and soil and their rates of recycling in three types of traditional agroforestry systems in mid elevations of the Western Himalaya. Maximum store of nutrients was estimated in above ground biomass of agrihortisilvicultural system: nitrogen 532, phosphorus 40, potassium 461, calcium 400 and magnesium 298 kg ha<sup>-1</sup>, it was closely followed by that in agrihorticultural system and both these had about 2-fold higher nutrient stock as compared to agri-silvicultural system. In case of the former two systems, considerable quantity of nutrients upto nitrogen 169, phosphorus 14, potassium 165, calcium 97 and magnesium 65 kg ha<sup>-1</sup> was recycled through debris of crops, weeds and tree leaf litter. The loss through agricultural crops and horticultural fruits for nitrogen in agrihortisilvicultural system was upto 75 and 38 per cent respectively of the total annual uptake. A similar approach on nutrient uptake and recycling in three traditional agroforestry systems was reported by Nayar (1989).

Concentric studies have been made for the leaf chemical composition of some arboreal species particularly fodder trees.

Seasonal variation in nutrient concentration in leaves, flowers and fruits were studied by Tolsma et al. (1987) in a semi-arid savanna ecosystem having trees, shrubs and grasses. N and P were more in young leaves than mature leaves in all the species. Ralhan and Singh (1987) observed

a similar trend of variation with central Himalayan forest trees and shrubs. Likewise, Rawat and Singh (1988) noted considerable variation in nutrient concentration of leaves of trees and shrubs while studying the nutrient dynamics in three evergreen forest sites near Nainital (UP).

The chemical composition of some fodder tree leaves in Kangra district (HP) has been studied by Sharma et al. (1966). They observed a range of crude protein content from 9.13 to 22.08 per cent on dry matter basis and the corresponding ranges of Ca and P contents were 0.50 to 6.31 per cent and 0.12 to 0.27 per cent, respectively. Some other workers have analysed the leaf chemical composition of important trees and shrubs of the state (Negi, 1977; Pal et al., 1979; Negi et al., 1980; Khatta and Katoch, 1983).

Debroy et al. (1980) made a conclusive estimation of calcium and protein content in the leaf fodder of 74 important trees and shrubs and recommended for the use of leaves as fodder.

Considerable seasonal variations in chemical composition were reported in the leaves of Grewia optiva (Khosla et al., 1980) and Robinia pseudoacacia (Kaushal et al., 1986 and Thakur, 1989).

#### 2.4 ECOSYSTEMS ECONOMIC EVALUATION

Data on economic evaluation of arable crops either in isolation or in association are available. But for other

farming systems viz. agroforestry, silvo-pastoral etc., such informations appear to be scanty. Riley (1986) suggested that it would be better to compare the biomass in terms of money to get a conclusive idea about the system.

Reddy and Korwar (1985) made a comparative economic evaluation of agroforestry, silvo-agriculture and silvo-pastoral system at the Research Farm, All India Coordinated Research Project for Dryland Agriculture (ICAR), Hyderabad by discounting technique. All the systems were found to be economical and viable with their corresponding benefit-cost ratios being 1.45, 1.29 and 2.25. Bavappa (1986) indicated higher benefit-cost ratio with ginger followed by pineapple, banana etc. while studying an economic consideration of cropping system with annuals in coconut.

In another comprehensive study on farming systems comprising of 10 selected villages of mid-western region of Uttar Pradesh, Singh and Sharma (1987) observed maximum potentialities of increasing income over the existing level exists in crop + dairy + goat farming followed by crop + goat farming and crop + dairy + poultry farming system in order. Crop farming system proved to be the poorest choice in terms of income and employment regeneration.



The present investigations entitled "Biomass productivity and nutrient budgeting in different agro-ecosystems" were undertaken in eight villages adjacent to the Dr Y S Parmar University of Horticulture and Forestry, Nauni, Solan, Himachal Pradesh during 1988-90. The details about the experimental sites, material used and methods adopted are given below:

### 3.1 LOCATION AND CLIMATE

The villages are situated about 13 km from Solan at 30°-51'N latitude and 77°-8'E longitude with the elevation ranging from 1050 to 1350 m above mean sea level in the mid hills subhumid agroclimatic zone of Himachal Himalaya.

The climate is subtemperate to subtropical with an average annual rainfall of 1089 mm mainly received during monsoon followed by light showers in winter. Spring (March-June), summer (July-September) with rains and winter (November-February) with severe frost are the three distinct seasons of the area.

Mean monthly meteorological data pertaining to the period of investigations are given in table A.

### 3.2 EXISTING ECOSYSTEMS

The farmers of the entire area under study used to practise the following dominant systems. The systems were categorized on the basis of structural composition of their

Table A: Monthly meteorological data for 1988-1989

Month	1988				1989			
	Mean temperature (°Celsius)	Relative humidity (%)	Rainfall (mm)	Sunshine hours	Mean temperature (°Celsius)	Relative humidity (%)	Rainfall (mm)	Sunshine hours
January	10.5	58.8	56.0	5.7	8.1	61.4	114.0	-
February	12.3	51.3	74.4	6.9	10.3	42.3	15.0	7.3
March	12.7	52.1	115.6	6.1	14.3	45.7	52.0	6.7
April	21.7	43.7	20.0	8.3	18.5	28.8	1.8	9.6
May	24.4	42.2	119.8	9.4	22.8	31.5	39.2	8.1
June	24.9	54.6	90.6	6.9	23.0	54.7	120.6	5.4
July	24.5	81.9	1066.4	2.7	23.8	72.1	251.8	6.5
August	23.7	79.8	513.4	5.1	22.7	80.6	429.3	6.0
September	21.3	74.8	382.6	-	21.9	54.1	72.0	7.7
October	17.8	55.5	0	-	18.5	50.8	5.2	9.4
November	13.5	68.0	1.0	-	13.6	48.8	68.8	7.7
December	10.8	63.2	166.2	-	10.2	59.8	63.4	6.0
Total			2606.0				1233.1	

Source: Meteorological Observatory, Nauni, Solan

constituent components and each of the following managed ecosystems were regarded as agroecosystem.

### 3.2.1 Agricultural (AG) system

Variety of arable crops are raised sequentially as monoculture or mixed on the permanent terraces prepared across the hill slopes for subsistence. Varied levels of productive inputs are also used.

### 3.2.2 Hortiagricultural (HAG) system

Selected agricultural crops are grown in the inter-spaces of horticultural trees sequentially like agricultural system above and simultaneously. Productive inputs are applied to the arables.

### 3.2.3 Hortisilvipastoral (HSP) system

It is practised on the bunds of the terraces particularly on boundaries and other uncultivable, unculturable and old fallow lands. Fruit trees have been only planted wheresoever other trees and the grasses regenerate naturally. No productive inputs are being served.

### 3.2.4 Grasslands (GL)

They cover the uncultivable lands with poor capabilities but more limitations to utilise as compared to aforesaid land use systems. Grasses as well as woody perennials regenerate naturally. These lands receive no

artificial inputs. The farmers harvest the grasses once annually by October and allow their animals to graze upto next March.

### 3.2.5 Grazing and wastelands

These are the uncultivable lands with maximum productive limitations. The animals are allowed to graze throughout the year. The vegetation develops naturally under open biotic disturbances.

Since the latter is an unmanaged system falling between agro and natural ecosystem, the investigations were not made on it.

## 3.3 METHODOLOGY

### 3.3.1 Selection of land holdings and land-use pattern

The investigations pertained to a sample of 35 land holders drawn proportionately and randomly on the basis of land holding size. The holdings were categorised into marginal (0-1 ha), small (> 1-2 ha), medium (> 2-5 ha) and large (> 5 ha). Average land use patterns of these selected land holdings were worked out and presented in table 2. The distribution of lands put into major agricultural crops is related to the agricultural year 1988-89.

### 3.3.2 Phytosociology

Structural analyses of the existing vegetations and studies on their biomass production as well as nutrient

allocation were carried out on three replicate sites of the mapped area for each type of ecosystem. These sites were heterogeneous in size and shape, embodying similar type of topography and vegetation. In each system, 24 quadrats (eight from each replication) each of 10 x 10 m i.e. 100 m<sup>2</sup> for trees and four quadrats of 1 x 1 m i.e. 1 m<sup>2</sup> each within the larger ones for herbaceous components were randomly laid out. The size and number of quadrats were determined using the "Species Area Curve" as reproduced by Misra (1968). The minimum sample size was kept at 24 for all the systems components under studies.

Per cent frequency, density, basal area, relative frequency, relative density, relative dominance and importance value index were calculated for each species with the formulae after representation by Misra (1968) as follows:

$$\% \text{ frequency} = \frac{\text{Number of sampling units in which the species occurred}}{\text{Total number of units studied}} \times 100$$

$$\text{Density} = \frac{\text{Total number of individuals}}{\text{Total number of quadrats studied}}$$

Basal area = It refers to the ground area actually penetrated by the stems and calculated through the following relation:

$$\text{Basal area} = \pi r^2, \text{ where } r = \text{radius}$$

Basal area was measured at 2.0 cm above ground level for all species.

$$\text{Relative frequency} = \frac{\text{Number of occurrences of the species}}{\text{Number of occurrences of all species}} \times 100$$

$$\text{Relative density} = \frac{\text{Number of individuals of the species}}{\text{Number of individuals of all species}} \times 100$$

$$\text{Relative dominance} = \frac{\text{Total basal area of the species}}{\text{Total basal area of all species}} \times 100$$

$$\text{Importance value index (IVI)} = \text{Relative frequency} + \text{relative density} + \text{relative dominance}$$

Species diversity for individual ecosystem was calculated using the formulae of Margalef (1968):

$$\bar{H} = - \sum \left[ \left( \frac{n_i}{N} \right) \log \left( \frac{n_i}{N} \right) \right]$$

where,

$\bar{H}$  = Shannon index of general diversity,

$n_i$  = importance value index of each species,

and  $N$  = total importance value indices of all species.

### 3.3.3 Determination of biomass

Performance of various vegetational units was studied in terms of biomass and nutrient dynamics.

The standing biomass and its productivity studies were dealt with above ground plant parts only for the agricultural year 1988-89.

The yields of the agricultural crops were determined at their individual harvesting time. Weed biomass yields associated with agricultural crops were recorded in March

and August for Rabi and Kharif seasons, respectively. Herbage yields of the grasslands were recorded during the first fortnight of October. Plants were harvested at 2.0 cm above ground level. Harvested plants and their plant parts were dried in hot air oven at 70° celsius to estimate the dry matter of each sample.

For estimation of bole/stem (>5 cm diameter) biomass, volume-weight relationship (Spurr, 1952) was used keeping in view the ecological and economical constraints. Individuals of each tree species were categorised into five collar girth (10 cm above ground level) classes keeping suitable class intervals specieswise with a minimum number of five trees in each girth class for the estimation of bole/stem volume. The bole volume of the individual trees was calculated using different formulae depending upon the shape of the segments. For bole biomass estimation, the green volume of the wood was multiplied by its corresponding wood density value as given below:

$$\begin{aligned} \text{Dry weight of wood} &= \text{Wood density (kg m}^{-3}\text{)} \times \text{green wood volume (m}^3\text{)} \\ &= \text{Wood specific gravity} \times 1000 \times \text{green wood volume} \\ &\quad \text{(m}^3\text{)} \end{aligned}$$

as  $\frac{\text{Density}}{1000} = \text{Specific gravity in MKS system}$

Wood samples were taken from each species with the help of a Pressler borer for specific gravity (Annexure-2) for values of different species) determination. The maximum

moisture content method was used to define specific gravity (Smith, 1954) by the formula:

$$G_f = \frac{1}{[(M_m - M_o)/M_o + (1/G_{so})]}$$

where,

$G_f$  = specific gravity based on green volume

$M_m$  = weight of saturated sample

$M_o$  = weight of oven dried sample

$G_{so}$  = average density of wood substance = 1.53

Branch (< 5 cm diameter) biomass of each tree species was determined by partial harvest method after categorising the branches into 5 diameter classes with an interval of 1 cm. Ten to twenty branches of each diameter class were harvested. The fresh weight of the branches and leaves were taken immediately after harvest. They were oven dried and total branch biomass was, thus, calculated by counting the number of branches and multiplying it with the corresponding dry weight of branches and leaves. Bole, branch and leaf were sampled when the leaves appeared to turn yellow except the fodder trees from which samples were collected at the time of their lopping.

Fresh fruit yields of individual horticultural tree were recorded at the time of fruit harvests during 1989.

The woody and nonwoody samples were oven dried at 90° and 70° celsius, respectively, for dry matter and nutrient estimation.

Collar girths of the classified trees were recorded in 1988 and their annual increments were measured in 1990. These increments were later used to calculate the annual biomass increment on the basis of species specific regression equations. For unclassified tree species, individual collar girth increment was used to assess the annual biomass. For lopped fodder trees, current branches were utilised to calculate the current branch biomass. Pruned biomass of the tree species other than fodder trees was recorded for two consecutive years and these values were divided by two to calculate a part of the annual productivity.

#### 3.3.4 Nutrient dynamics

It was studied under nutrient allocation in each plant part and soil reserve.

Three major nutrients were analysed. Composite plant samples collected from each replicate site in respect of species and ecosystems were cleaned, oven dried and powdered to pass through 2 mm sieve. The following methods (Allen et al., 1974) of analysis were employed:

1. Total nitrogen was determined by micro Kjeldahl method, digested with sulphuric acid, absorbed in boric acid and titrated with standard hydrochloric acid.
2. Total phosphorus was determined by colorimetric method, digested with a mixture of nitric acid

(4 parts) and perchloric acid (1 part) and determined by ammonium vanado-molybdo phosphoric yellow complex.

- Total potassium was determined by Flame photometer method using digital flamephotometer model CL 22D.

Five composite soil samples were collected from each of the two soil depths viz. 0-30 cm and 30-60 cm for each replicate site of the systems with the help of pickaxe and crow-bar in the month of September, 1988. The samples were air dried, ground and passed through a 2 mm seive to analyse for pH, organic carbon, available nitrogen, phosphorus and potassium. The results are given in table 43.

Particulars	Method employed	Reference
pH	1:2.5 water suspension Glass electrode pH meter	Jackson, 1967
Organic carbon	Walkley and Black's rapid titration method	Piper, 1966
Available nitrogen	Alkaline permanganate method	Subbiah and Asija, 1956
Available Phosphorus	Olsen's method of extraction with 0.5 N NaHCO <sub>3</sub> at pH 8.5	Olsen et al., 1954
Available potassium	Flame photometer method	Merwin and Peech, 1950

### 3.3.5 Regression models

Five regression models and their corresponding coefficients of determination ( $R^2$ ) were worked out between independent variable (collar girth) and dependent variables

(bole, branch, leaf and fruit) to predict the biomass of the tree species. The following regression models were tried and used the best fit.

$$Y = a+b X \quad \dots\dots\dots(1)$$

$$Y = a+b \ln X \quad \dots\dots\dots(2)$$

$$Y = a+b \sqrt{X} \quad \dots\dots\dots(3)$$

$$\ln Y = a+b X \quad \dots\dots\dots(4)$$

$$\ln Y = a+b \ln X \quad \dots\dots\dots(5)$$

where,

Y = biomass (kg)

X = collar girth (m)

### 3.3.6 Gross returns

For calculating the gross annual returns, different prices were attached to each kind of biomass derived from each system. The materials for which there existed market, the prevailing market prices were used while for non-marketed entities, imputed prices during their harvesting period were employed. The values are given in Annexure-1).

### 3.4 STATISTICAL METHODS

Random sampling of the quadrats was done for the collection of the information. 95 per cent confidence intervals were calculated for standing biomass, productivity and nutrient accumulation estimated with different systems and components as follows:

95% confidence interval =  $\bar{X} \pm$  S.E. of mean  $\times t_{0.05, n-1}$

$$\text{S.E. mean} = \frac{s}{\sqrt{n}} = \sigma_{\bar{X}}$$

where,

$n$  = sample size

$s^2$  = estimate of the population variance

given by

$$s^2 = \frac{1}{n-1} \sum (x_i - \bar{x})^2$$

EXPERIMENTAL RESULTS

The results on the "biomass productivity and nutrient  
 utilization by different ecosystems" are presented under  
 the following heads:

- 4.1 Land-use patterns
- 4.2 Phytosociological analysis
- 4.3 Production systems
- 4.4 Standing biomass of the trees
- 4.5 Biomass productivity patterns
- 4.6 Standing nutrient bank of the trees
- 4.7 Annual nutrient accumulation models
- 4.8 Chemical analysis of the soil
- 4.9

## Chapter 4 EXPERIMENTAL RESULTS

- 4.1 LAND-USE PATTERNS
- 4.1.1 Land distribution patterns

The data on land distribution model under the land  
 use of the study area are given in table 1.

Table 1. Land use distribution in different zones of the study area.

Zone of land use (ha)	Number of facilities	Number of facilities operated	Total land used	Average land used	Area of land used	Area of land available
Zone I (100)	10	10	1000	100	1000	1000
Zone II (200)	20	15	3000	150	3000	2000
Zone III (300)	30	20	6000	200	6000	3000
Total	60	45	19000	200	19000	10000

The average land use area of the study area is  
 1000 ha. The total area of the study area is 10000 ha.

The results on the "Biomass productivity and nutrient budgeting in different agroecosystems" are presented under the following heads:

- 4.1 Land-use patterns
- 4.2 Phytosociological analyses
- 4.3 Prediction equations
- 4.4 Standing biomass of the trees
- 4.5 Biomass productivity patterns
- 4.6 Standing nutrient bank of the trees
- 4.7 Annual nutrient accumulation models
- 4.8 Chemical status of the soil
- 4.9 Gross annual returns

#### 4.1 LAND-USE PATTERNS

##### 4.1.1 Land distribution pattern

The data on land distribution model among the land holders of the studied area are given in table 1.

Table 1. Actual land distribution patterns among the families

Size of land holding (ha)	Number of families	Number of families surveyed	Total land owned (ha)	Average land owned (ha)	Percentage of total land	Percentage of total families
Marginal(0-1)	21	10	9.02	0.43	4.9	29.2
Small(>1-2)	18	9	26.60	1.48	14.4	25.0
Medium(>2-5)	25	11	77.03	3.08	41.8	34.7
Large(>5)	8	5	71.53	8.94	38.8	11.1
<b>Total</b>	<b>72</b>	<b>35</b>	<b>184.18</b>	<b>2.56</b>	<b>100.0</b>	<b>100.0</b>

The average land owned by a family was 2.56 ha. Families with medium sized land holdings represented the

highest percentage (34.7) and also land (41.8) at their disposal. Large category of land holders comprised the least percentage (11.1) but occupied 38.8 per cent of the total land. Marginal land holdings covered only 4.9 per cent of the land describing their percentage of 29.2. The percentage of families surveyed was 48.7 for other studies.

#### 4.1.2 Average land-use patterns of the selected families

The entire land available was broadly classified as cultivable (42.2%) and noncultivable (57.8%) lands representing the ratio of 1:1.37 (Table 2).

Agriculture was the dominant ecosystem occupying 90.6 per cent of the cultivable land while HAG ecosystem totalled only 9.4 per cent both enjoying 51.9 per cent of the land put into them with inassured irrigation facilities depending upon the availability of rains.

Grassland covered the maximum area with an average of 1.0 ha and set up 69.0 per cent of the noncultivable land. HSP system existed on 11.7 per cent noncultivable land out of which contour bunds contributed to 52.9 per cent. A percentage of noncultivable area by 13.8 and 5.5 were utilised under waste and grazing land and permanent structures, respectively.

#### 4.1.3 Hectarage distribution of principal field crops

A perusal of the data given in table 3 revealed that

Table 2. Average land-use patterns of the selected families

Categories of land holdings	Average land owned (ha)	Average cultivable land (ha)			Average noncultivable land (ha)				Average irrigated land (ha)	
		Agri-cultural (AG)	Horti-agri-cultural (HAG)	Total	Hortisilvi-pastoral (HSP)	Grass-land (GL)	Waste & grazing land	Permanent structures		Total
Marginal	0.53	0.32	0.06	0.38	0.06 (0.04)	0.04	-	0.05	0.15	0.14
Small	1.52	0.85	0.05	0.90	0.14 (0.08)	0.40	-	0.08	0.62	0.59
Medium	3.01	1.30	0.11	1.41	0.26 (0.13)	1.02	0.23	0.09	1.60	0.77
Large	7.14	1.66	0.25	1.91	0.27 (0.17)	3.93	0.92	0.11	5.23	0.82
Average land	2.51	0.96	0.10	1.06	0.17 (0.09)	1.00	0.20	0.08	1.45	0.55
% of total land		38.2	4.0	42.2	6.8	39.8	8.0	3.2	57.8	21.9

Figures in parentheses indicate the contour bunds

Table 3. Average hectareage distribution of principal field crops

Categories of land holdings	Average cultivable land(ha)	Kharif (ha)					Rabi (ha)				
		Maize	Tomato	Ginger	Other including fallow	Pea	Wheat	Barley	Sarson and Taramira	Others including fallow	
Marginal	0.38	0.20	0.11	0.04	0.03	0.20	0.07	0.05	0.03	0.03	
Small	0.90	0.53	0.22	0.07	0.08	0.39	0.19	0.10	0.09	0.13	
Medium	1.41	0.73	0.30	0.13	0.25	0.49	0.24	0.13	0.11	0.47	
Large	1.91	0.90	0.48	0.16	0.37	0.58	0.25	0.12	0.09	0.87	
Average	1.06	0.55	0.25	0.09	0.17	0.39	0.18	0.10	0.08	0.31	
% of cultivable land		51.9	23.6	8.5	16.0	36.8	17.0	9.4	7.5	29.2	

maize, tomato and ginger, the principal Kharif crops utilised an area by 84.0 per cent leaving 16.0 per cent to other minor crops including fallow. In the Rabi season, the major crops viz. pea, wheat and barley covered 63.2 per cent of the total cropped area. Minor crops and fallow lands accounted for 36.7 per cent.

Among the dominant crops, maize in the Kharif and pea during Rabi occupied the maximum percentage of area by 51.9 and 36.8, respectively.

#### 4.2 PHYTOSOCIOLOGICAL ANALYSES

##### 4.2.1 Tree species

The ecosystems were heterogeneous in their species composition. The tree species had a wide diversification in the systems, i.e. five species in HAG, nineteen in HSP and sixteen in GL (Table 4).

The highest density ( $627 \text{ trees ha}^{-1}$ ) and corresponding basal area ( $13.08 \text{ cm}^2 \text{ m}^{-2}$ ) were recorded in HSP system with the maximum contribution by the fruit trees. The grasslands were furnished with the lowest density ( $205 \text{ trees ha}^{-1}$ ) as well as basal area ( $2.86 \text{ cm}^2 \text{ m}^{-2}$ ) with their major share from timber/fuelwood species. Prunus domestica in HAG and HSP formed the dominant species while Pinus roxburghii and Toona ciliata in GL ecosystem. The maximum basal area was rendered by P. domestica in HAG ( $7.32 \text{ cm}^2 \text{ m}^{-2}$ ), Grewia optiva in HSP ( $2.80 \text{ cm}^2 \text{ m}^{-2}$ ) and T. ciliata ( $0.50 \text{ cm}^2 \text{ m}^{-2}$ ) in



grasslands.

In case of horticultural trees, both P. domestica and Prunus armeniaca were predominant trees of HAG and HSP ecosystems. In case of silvicultural trees, G. optiva was ecologically more successful in HSP followed by T. ciliata, whereas T. ciliata emerged out to be the best followed by P. roxburghii in GL system. Most of the silvicultural as well as horticultural trees species had their representation in their respective systems but Prunus amygdalus - a fruit tree, Acacia catechu and Dalbergia sissoo - both timber/fuelwood species showed the system specificity. The tree species indicated an order of pre-dominance through their respective dispersion, numerical strength and relative dominance values.

Species diversity of trees was higher (1.150) in GL as compared to HSP (1.105) on HAG (0.496) ecosystems.

#### 4.2.2 Kharif crops and weeds

Phytosociological analyses of the three major agricultural crops and their associated weeds are given in table 5.

The dominant agricultural crops viz. Lycopersicon esculentum, Zea mays and Zingiber officinale were found to be cultivated both in AG and HAG systems. The weeds varied in their phytosociological parameters with specific crops and systems. Maximum number of eight weed species was

Table 3: Dynamics and ecological success of *Ustilis* species (grass and seeds) in the agricultural (A) and nonagricultural (NA) ecosystems

Plant species	S Frequency				Density (n <sup>-2</sup> )				Basal area (ca. m <sup>2</sup> )				Relative Frequency (%)			
	AG	NA	S1G	S1A	AG	NA	S1G	S1A	AG	NA	S1G	S1A	AG	NA	S1G	S1A
1. <i>Ustilis</i> sp.	100.0	-	100.0	-	5.4	-	5.5	-	3.0	-	2.2	-	21.8	-	24.5	-
2. <i>Ustilis</i> sp.	100.0	-	100.0	-	25.0	-	24.8	-	65.0	-	45.8	-	13.5	-	37.0	-
3. <i>Ustilis</i> sp.	100.0	-	100.0	-	49.0	-	47.0	-	27.2	-	27.2	-	25.2	-	25.7	-
4. <i>Ustilis</i> sp.	-	-	-	-	5.4	25.0	45.0	5.5	24.5	47.4	3.0	68.0	27.2	2.2	49.8	25.2
5. <i>Ustilis</i> sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
6. <i>Ustilis</i> sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
7. <i>Ustilis</i> sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
8. <i>Ustilis</i> sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
9. <i>Ustilis</i> sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
10. <i>Ustilis</i> sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
11. <i>Ustilis</i> sp.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Subtotal	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
2. <i>Ustilis</i> sp.	6.8	50.0	54.2	75.0	4.1	32.2	5.3	3.2	33.1	5.3	0.8	0.8	1.0	0.7	6.0	1.0
3. <i>Ustilis</i> sp.	41.7	23.2	33.3	20.8	25.0	4.2	14.3	2.0	2.1	12.0	1.0	3.5	0.5	0.6	2.9	9.1
4. <i>Ustilis</i> sp.	15.7	-	-	-	4.0	-	-	-	-	-	0.4	-	-	-	3.2	-
5. <i>Ustilis</i> sp.	58.3	-	-	-	29.2	-	-	-	15.2	-	0.8	13.0	-	-	5.4	11.4
6. <i>Ustilis</i> sp.	4.7	45.3	54.2	58.3	5.2	14.9	2.7	7.5	33.1	3.5	1.1	2.0	0.5	1.4	5.2	0.5
7. <i>Ustilis</i> sp.	31.7	50.0	50.0	54.3	50.0	6.8	36.0	6.0	26.0	134.0	4.0	0.6	15.1	0.5	2.0	10.4
8. <i>Ustilis</i> sp.	75.0	20.8	-	70.8	-	12.0	6.0	-	14.1	-	4.3	2.5	-	5.3	-	16.4
9. <i>Ustilis</i> sp.	43.3	100.0	70.8	54.2	50.0	56.7	25.0	14.4	8.5	24.4	62.5	8.0	2.2	12.6	0.8	2.1
Subtotal	-	-	-	-	53.4	47.1	24.5	77.4	289.9	20.8	11.5	57.9	3.3	12.5	34.4	2.8
Total	-	-	-	-	68.8	518.1	73.5	83.0	314.7	67.8	14.5	123.9	30.5	14.4	44.2	25.0

Cont....

Plant species	Relative Density (t)						Relative Dominance (t)						Importance Value Index (IVI)						Species Diversity						
	46	316	61	62	63	64	46	316	61	62	63	64	46	316	61	62	63	64	46	316	61	62	63	64	
A. <i>Agrostoides</i> (Cyperoid)																									
1. <i>Uromyza esculenta</i> L.	7.8	-	6.7	-	-	26.7	-	-	-	14.9	-	-	50.3	-	-	46.1	-	-	-	-	-	-	-	-	-
2. <i>Poa annua</i> L.	5.0	-	7.9	-	-	53.3	-	-	59.1	-	-	77.8	-	-	94.0	-	-	-	-	-	-	-	-	-	-
3. <i>Eleocharis acicularis</i> Zacc.	-	65.7	-	-	59.3	-	-	39.2	-	-	90.3	-	-	-	182.6	-	-	198.2	-	-	-	-	-	-	-
B. <i>Reeds</i>																									
4. <i>Coenocloa brevipennis</i> L.	6.0	7.6	7.2	3.8	10.5	7.8	5.5	6.4	3.3	4.7	8.1	3.4	21.5	23.7	28.3	21.8	33.2	32.8	-	-	-	-	-	-	-
5. <i>Coenocloa rotundifolia</i> L.	6.1	2.9	2.7	2.5	3.8	-	6.9	2.8	1.6	4.0	3.4	-	22.1	11.4	13.2	11.6	13.9	-	-	-	-	-	-	-	-
6. <i>Coenocloa distachya</i> (L.) Pers.	-	0.8	-	-	-	-	-	0.3	-	-	-	-	-	4.3	-	-	-	-	-	-	-	-	-	-	-
7. <i>Distachya sparganii</i> (L.) Scop.	7.3	14.0	-	-	4.8	-	6.2	10.5	-	-	3.2	-	18.9	35.9	-	-	15.9	-	-	-	-	-	-	-	-
8. <i>Echinochloa polystachya</i> (L.) Link.	9.0	2.9	3.6	9.2	19.5	5.2	7.8	2.2	1.8	9.5	7.4	2.1	25.7	14.0	19.8	33.0	32.5	24.0	-	-	-	-	-	-	-
9. <i>Echinochloa crusgalli</i> (L.) Beauv.	10.0	37.8	8.2	31.3	42.6	5.9	4.1	12.2	1.6	13.5	12.3	1.4	24.1	67.9	23.2	57.0	70.6	21.6	-	-	-	-	-	-	-
10. <i>Echinochloa indica</i> (L.) Gaertn.	17.4	1.1	-	-	17.0	-	-	33.8	2.0	-	39.2	-	-	67.6	7.2	-	73.5	-	-	-	-	-	-	-	-
11. <i>Salinicola nauriflora</i> Cav.	36.3	27.9	11.6	29.4	19.9	11.8	15.2	10.2	2.6	14.2	6.4	2.8	69.7	57.6	33.0	56.9	33.6	-	-	-	-	-	-	-	-
Total	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	0.444	0.314	0.556	0.791	0.762	0.181

registered with Z. mays under AG and the diversity reduced to four being the minimum with Z. officinale under HAG system. The density and basal area of the weeds appeared to be such like their diversity.

Echinochloa crusgalli dominated over other weed species both in AG and HAG with Z. mays showing its IVI of 67.9 and 70.6, respectively. It was followed by Galinsoga parviflora which also claimed as dominant weed species with Z. officinale in both systems and closer to Commelina benghalensis. The highest IVI by 73.5 was calculated for Eleusine indica with L. esculentum in HAG system.

Values on weed species diversity were found to vary between 0.381 (in HAG with Z. officinale) and 0.844 (in AG with L. esculentum).

#### 4.2.3 Rabi crops and weeds

Data on the phytosociology of Rabi crops and weeds are presented in table 6.

Hordeum vulgare, Pisum sativum and Triticum aestivum were the major crops in AG and HAG systems. The crops with their weeds particular to ecosystems ascribed phytosociological variations. Highest number of eight weed species occurred with both the cereal crops in AG system. P. sativum had the lowest weed numerical strength under HAG system. Weed density and its basal area followed a similar pattern to diversity.

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Table 6. Dominance and ecological success of *Pabi* species (crops and weeds) in the agricultural (AG) and horticultural (HG) ecosystems

Plant species	I. Frequency		II. Density (n <sup>2</sup> )		III. Area (m <sup>2</sup> )		IV. Relative Frequency (%)	
	N	%	N	%	N	%	N	%
<b>A. Agricultural Ecosystem</b>								
1. <i>Portulaca oleraceae</i> L.	198.0	100.0	151.0	158.0	45.4	46.9	20.3	21.4
2. <i>Panicum polyanthum</i> L. var. <i>polyanthum</i> L.	100.0	100.0	22.2	33.0	8.4	8.7	26.7	27.9
3. <i>Portulaca oleraceae</i> L.	-	-	151.0	158.0	45.4	46.9	20.3	21.4
<b>B. Horticultural Ecosystem</b>								
4. <i>Portulaca oleraceae</i> L.	20.4	25.0	25.0	2.3	4.5	0.6	1.3	4.2
5. <i>Portulaca oleraceae</i> L.	39.3	49.0	37.5	11.2	18.0	3.8	7.6	24.2
6. <i>Portulaca oleraceae</i> L.	25.0	31.3	20.8	3.9	2.8	0.2	0.3	0.9
7. <i>Portulaca oleraceae</i> L.	41.7	52.1	41.7	50.0	52.2	10.1	1.2	1.3
8. <i>Portulaca oleraceae</i> L.	17.5	21.9	15.7	1.7	1.7	0.2	0.2	0.6
9. <i>Portulaca oleraceae</i> L.	17.5	21.9	15.7	1.7	1.7	0.2	0.2	0.6
10. <i>Portulaca oleraceae</i> L.	17.5	21.9	15.7	1.7	1.7	0.2	0.2	0.6
11. <i>Portulaca oleraceae</i> L.	17.5	21.9	15.7	1.7	1.7	0.2	0.2	0.6
12. <i>Portulaca oleraceae</i> L.	17.5	21.9	15.7	1.7	1.7	0.2	0.2	0.6
13. <i>Portulaca oleraceae</i> L.	17.5	21.9	15.7	1.7	1.7	0.2	0.2	0.6
14. <i>Portulaca oleraceae</i> L.	17.5	21.9	15.7	1.7	1.7	0.2	0.2	0.6
15. <i>Portulaca oleraceae</i> L.	17.5	21.9	15.7	1.7	1.7	0.2	0.2	0.6
<b>Total</b>	70.8	88.0	66.7	65.8	65.8	65.8	65.8	65.8

Contd.....

Plant species	Relative Density (D)				Relative Frequency (F)				Importance Value Index (IVI)				Species Diversity				
	65	116	16	316	65	116	16	316	65	116	16	316	65	116	16	316	
1. <i>Andropogon distachyos</i> L.	53.9	-	54.0	-	53.5	-	57.1	-	133.6	-	132.5	-	-	-	-	-	
2. <i>Panicum maximum</i> L. var. <i>burneri</i> L.	32.2	-	31.3	-	43.5	-	44.6	-	102.4	-	105.3	-	-	-	-	-	
3. <i>Trichlorus verticillatus</i> L.	-	49.3	-	48.1	-	53.2	-	52.7	-	123.2	-	122.2	-	-	-	-	
B. Trees																	
4. <i>Marrugo asiaticus</i> L.	0.7	-	1.6	0.0	-	1.5	0.8	-	1.5	5.7	-	8.3	5.8	-	-	-	
5. <i>Acacia farnesiana</i> L.	4.9	-	7.1	3.4	-	6.2	5.1	-	7.0	21.0	-	25.4	23.0	-	-	-	
6. <i>Casearia indica</i> L.	0.7	4.2	1.1	-	4.1	0.9	0.3	1.6	0.5	-	1.5	6.8	-	13.7	5.8	-	
7. <i>Salweenia indica</i> L.	3.7	5.1	3.0	3.2	7.5	3.4	1.7	2.1	1.4	1.5	13.9	16.2	12.1	13.7	21.7	15.7	
8. <i>Albizia leucacantha</i> Brong.	-	24.2	-	-	22.8	-	23.8	-	22.1	-	58.0	-	-	55.4	-	-	
9. <i>Sparganium angustifolium</i> Willd.	17.0	20.8	14.8	17.2	23.6	18.1	15.3	21.8	13.4	15.2	24.6	17.5	50.1	62.6	46.3	51.2	
10. <i>Hydrocotyle sphenoloba</i> Wedd.	2.1	1.7	1.3	2.2	3.3	1.7	0.8	0.5	0.5	0.9	1.0	0.6	13.1	7.7	8.7	14.7	
11. <i>Phyllanthus niruri</i> Beauv.	4.3	-	8.2	4.3	-	8.3	5.5	-	10.1	5.2	-	7.8	17.4	-	31.2	17.5	
12. <i>Phyllanthus cordifolius</i> L.	5.4	-	-	-	-	-	3.6	-	-	-	-	14.5	-	-	-	-	
13. <i>Trichostema</i> L.	13.7	5.4	13.6	14.9	5.4	12.8	11.0	3.1	10.6	11.3	3.6	10.1	39.1	21.8	38.3	-	
Total	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
													0.742	0.785	0.772	0.725	0.723

A. Agricultural Station

B. Trees

On an average, species diversity of Rabi weeds was comparatively higher (0.760 in AG and 0.739 in HAG) than that of Kharif (0.738 in AG and 0.645 in HAG). Predominant weeds included Medicago denticulata and Vicia faba with the cereal crops while Linum mysorense and M. denticulata with P. sativum in both the systems imparting IVI of more than 35.

#### 4.2.4 Grass species

Phytosociological data of grasses and their associates are given in table 7.

A perusal of the data reveals that all the twelve grass species except Imperata cylindrica and Mnesithea laevis were common both in HSP and GL ecosystems by an uneven frequency distribution. The highest per cent frequency (83.3) was observed with Apluda mutica in HSP closely followed (79.2) by Chrysopogon montanus in GL system.

GL system had more grass population density ( $454.8 \text{ m}^{-2}$ ) as compared to HSP ( $399.8 \text{ m}^{-2}$ ). Among the grass species, A. mutica noted the highest numerical strength ( $127.9 \text{ m}^{-2}$ ) which was followed by C. montanus ( $122.9 \text{ m}^{-2}$ ) and Themeda anathera ( $31.7 \text{ m}^{-2}$ ) in HSP system. The species viz. C. montanus, A. mutica and Heteropogon contortus in GL ranked in descending order of 164.4, 124.8 and  $40.2 \text{ m}^{-2}$ , respectively for their population density.



Higher basal area ( $21.4 \text{ cm}^2 \text{ m}^{-2}$ ) was recorded in GL system constituting 96.8 per cent of the total than HSP ( $18.3 \text{ cm}^2 \text{ m}^{-2}$ ). While comparing the species within the system, C. montanus attributed the maximum basal area ( $9.9$  and  $7.5 \text{ cm}^2 \text{ m}^{-2}$ ) followed by A. mutica ( $4.7$  and  $4.5 \text{ cm}^2 \text{ m}^{-2}$ ) in GL and HSP systems, respectively.

A. mutica and C. montanus were the predominant grasses with IVI of more than 59. For the rest species, IVI was less than 23. Species diversity of grasses showed close resemblance ( $0.995$  and  $0.994$ ) between GL and HSP systems.

In addition to grasses, two species of climbers (Cissampelos pareira and Rhynchosia himalensis), single sedge species (Fimbristylis complanata) and three species of weeds (Artemisia scoparia, Bidens pilosa and Dipsacus inermis) were present in these two ecosystems. Among them, D. inermis appeared as most important species having frequency of more than 75 per cent and IVI above 15 with an average basal area of  $0.4 \text{ cm}^2 \text{ m}^{-2}$ .

#### 4.3 PREDICTION EQUATIONS

The best fits out of the five regression equations scrutinised on the basis of their highest value of coefficient of determination ( $R^2$ ) are summarised in table 8.

The equation  $\ln Y = a + b \ln X$  was found to be the best single fit for predicting the bole and total biomass of all the size tree species attempted. The value of  $R^2$

Table 8: Summary of the best fit prediction equations

	Bole	Branch	Leaf	Fruit	Total
<i>Grewia optiva</i> Drummond	$\ln Y = 5.345 + 2.471 \ln X$ $R^2 = 0.978$	$\ln Y = 0.435 + 2.419 X$ $R^2 = 0.731$	$\ln Y = -1.071 + 2.503 X$ $R^2 = 0.787$		$\ln Y = 5.386 + 2.353 \ln X$ $R^2 = 0.980$
<i>Celtis australis</i> L.	$\ln Y = 5.567 + 2.862 \ln X$ $R^2 = 0.978$	$Y = -0.817 + 11.108 X$ $R^2 = 0.516$	$\ln Y = -0.447 + 1.912 X$ $R^2 = 0.692$		$\ln Y = 5.598 + 2.529 \ln X$ $R^2 = 0.968$
<i>Tournefortia ciliata</i> H.J. Roem.	$\ln Y = 5.587 + 2.700 \ln X$ $R^2 = 0.988$	$\ln Y = 2.811 + 1.682 \ln X$ $R^2 = 0.797$	$\ln Y = 1.923 + 1.363 \ln X$ $R^2 = 0.882$		$\ln Y = 5.647 + 2.489 \ln X$ $R^2 = 0.986$
<i>Prunus domestica</i> L.	$\ln Y = 5.185 + 3.005 \ln X$ $R^2 = 0.978$	$\ln Y = 4.384 + 1.986 \ln X$ $R^2 = 0.960$	$\ln Y = 2.600 + 1.996 \ln X$ $R^2 = 0.960$	$\ln Y = 3.191 + 2.175 \ln X$ $R^2 = 0.931$	$\ln Y = 5.653 + 2.424 \ln X$ $R^2 = 0.980$
<i>Prunus armeniaca</i> L.	$\ln Y = 5.551 + 3.158 \ln X$ $R^2 = 0.970$	$\ln Y = 4.427 + 2.079 \ln X$ $R^2 = 0.943$	$\ln Y = 2.534 + 2.002 \ln X$ $R^2 = 0.945$	$\ln Y = 2.134 + 1.894 \ln X$ $R^2 = 0.958$	$\ln Y = 5.839 + 2.604 \ln X$ $R^2 = 0.980$
<i>Pyrus communis</i> L.	$\ln Y = 5.325 + 2.748 \ln X$ $R^2 = 0.998$	$\ln Y = 4.514 + 2.069 \ln X$ $R^2 = 0.976$	$\ln Y = 2.677 + 1.762 \ln X$ $R^2 = 0.914$	$Y = 12.059 + 7.279 \ln X$ $R^2 = 0.914$	$\ln Y = 5.795 + 2.386 \ln X$ $R^2 = 0.998$

ranged from 0.968 to 0.990. It also proved its best acceptance to prophesy the branch, leaf and fruit biomass of the said tree species except Celtis australis, Grewia optiva and Pyrus communis. The equation by  $\ln Y = a + b X$  represented as the second best fit to predict the branch biomass of G. optiva and leaf biomass of C. australis and G. optiva ranging the  $R^2$  values 0.692-0.787. Other prediction models viz.  $Y = a + b X$  and  $Y = a + b \ln X$  attributed as superior only with the branch biomass of C. australis ( $R^2 = 0.516$ ) and fruit biomass of P. communis ( $R^2 = 0.914$ ), respectively.  $Y = a + b \sqrt{X}$  could not be able to predict the biomass attributes as the best while comparing with other equations.

#### 4.4 STANDING BIOMASS OF THE TREES

Standing biomass in different plant parts of the tree species existed on HAG, HSP and GL ecosystems is given in tables 9, 10, 11 and 12.

It is evident from the data presented in table 9 that among the fruit trees, Prunus domestica represented the highest standing biomass of  $210.6 \text{ q ha}^{-1}$  in HAG and  $67.8 \text{ q ha}^{-1}$  in HSP system thereby contributing 69.8 and 19.0 per cent of the total biomass in the respective systems. It was followed by Prunus armeniaca (20.5%) in HAG and Pyrus communis (9.2 and 4.1%) in HSP and GL with respect to total standing biomass of these two systems.

Table 3. Standing biomass (kg ha<sup>-1</sup>) in different components of tree species in horticultural (HM), hortisilvipastoral (HSP) and grassland (GL) ecosystems

Tree species	Bole			Branches			Leaves			Fruits			Total		
	HM	HSP	GL	HM	HSP	GL	HM	HSP	GL	HM	HSP	GL	HM	HSP	GL
<b>A. Fodder Trees</b>															
1. <i>Alluzia stipulata</i> (Roth.) Boiv.	-	544.2	480.5	-	91.7	87.7	-	25.0	27.2	-	-	-	-	661.7	515.4
2. <i>Bambusa variata</i> L.	-	346.8	174.6	-	45.3	29.9	-	22.3	16.2	-	-	-	-	414.4	228.7
3. <i>Celtis australis</i> L.	-	1356.8	254.6	-	172.2	34.2	-	65.9	12.8	-	-	-	-	2394.1	381.6
4. <i>Erebia ovata</i> Prunard	-	6674.3	788.2	-	273.3	35.2	-	154.8	23.3	-	-	-	-	7103.4	845.7
5. <i>Morus serrata</i> Roth.	-	336.3	116.2	-	33.8	19.5	-	28.5	13.3	-	-	-	-	369.8	145.8
Subtotal	-	10871.6	1734.1	-	615.5	286.5	-	283.3	91.8	-	-	-	-	10952.4	2032.4
<b>B. Timber/Furniture trees</b>															
6. <i>Acacia catechu</i> (L.) Willd.	-	241.7	-	-	68.6	-	-	-	24.8	-	-	-	-	575.0	488.9
7. <i>Bombax ceiba</i> L.	-	472.5	387.4	-	69.3	63.4	-	53.2	36.1	-	-	-	-	229.2	-
8. <i>Balberia siissoo</i> Roth.	-	199.6	-	24.3	-	-	-	5.3	-	-	-	-	-	184.7	84.1
9. <i>Ficus palatia</i> Forst.	-	131.3	55.0	-	34.4	18.1	-	19.0	11.0	-	-	-	-	712.5	756.6
10. <i>Ficus tonburghii</i> Forst.	-	611.6	689.8	-	68.0	86.6	-	32.1	51.0	-	-	-	-	800.1	582.1
11. <i>Distasia integraria</i> Stewart ex Brandis	-	652.1	488.2	-	182.5	69.4	-	45.5	30.5	-	-	-	-	292.2	177.0
12. <i>Prunus pudica</i> Roth.	-	227.7	129.8	-	46.3	32.5	-	21.2	14.7	-	-	-	-	527.9	175.8
13. <i>Pyrus pashia</i> Bugh. - Ha. ex D. Don	-	495.5	132.7	-	83.4	28.2	-	39.0	13.0	-	-	-	-	681.1	189.8
14. <i>Salix insigne</i> Roth.	-	48.2	124.4	-	13.8	38.3	-	6.1	15.1	-	-	-	-	747.5	1316.7
15. <i>Torreia ciliata</i> N.J. Rose	-	6562.1	1126.2	-	557.9	126.6	-	239.5	63.9	-	-	-	-	10859.2	2386.2
Subtotal	-	9405.6	3156.4	-	1082.7	525.7	-	468.9	254.1	-	-	-	-	10859.2	2386.2
<b>C. Fruit Trees</b>															
16. <i>Prunus avicula</i> Persch.	651.4	-	-	688.8	-	-	113.3	-	-	57.2	-	-	1655.9	-	-
17. <i>Prunus avicula</i> L.	3574.3	1661.6	-	2847.7	948.8	-	321.8	156.6	-	229.0	112.6	-	6172.0	2568.0	-
18. <i>Prunus domestica</i> L.	1835.8	3867.0	-	7434.9	2586.4	-	1241.1	431.4	-	2848.7	691.3	-	21824.3	6726.1	-
19. <i>Prunus persica</i> (L.) Persch.	185.3	211.1	-	257.5	288.9	-	42.9	33.5	-	55.7	44.6	-	351.4	498.1	-
20. <i>Punica granatum</i> L.	-	158.6	59.9	-	96.7	48.4	-	21.0	8.7	-	22.9	-	-	329.9	131.9
21. <i>Prunus coccinea</i> L.	326.1	1741.9	123.9	243.4	1864.8	88.6	49.6	198.4	17.6	79.6	275.1	28.9	698.7	3288.2	259.2
Subtotal	15262.9	6788.2	183.8	18651.5	4940.6	129.2	1768.7	848.9	26.3	2478.2	1175.2	51.8	30153.3	13737.1	291.1
Total	15262.9	26249.4	3644.3	18651.5	6599.8	861.4	1768.7	1591.1	372.2	2478.2	1175.2	51.8	30153.3	35568.7	6297.7

The data further revealed that Grewia optiva, among the fodder tree species contributed maximum standing biomass amounting  $71.0 \text{ q ha}^{-1}$  (20.0%) in HSP as well as in GL ( $8.4 \text{ q ha}^{-1}$  and by 13.4%) to the systems. Celtis australis and Albizia stipulata ranked next to G. optiva in HSP and GL, respectively.

While comparing the contribution of the timber/fuelwood species towards the over all system biomass, Toona ciliata paid the highest of 74.8 and  $13.2 \text{ q ha}^{-1}$  corresponding the percentage to the tune of 21.0 and 20.8 for the HSP and GL. Pistacia integerrima in HSP and Pinus roxburghii in GL were the second highest contributors forming only 2.2 and 11.9 per cent of their respective system biomass. P. domestica in HAG and T. ciliata in HSP system showed the highest standing biomass of 210.6 and  $74.8 \text{ q ha}^{-1}$ , respectively.

Biomass accumulation in different components of trees in the three systems presented a highly variable structure. It ranged from  $8.7 \text{ kg ha}^{-1}$  leaf production in Punica granatum in GL system to the highest  $10,335.8 \text{ kg ha}^{-1}$  bole biomass in P. domestica of HAG system.

Tree components exhibited a great extent of their percentage differences with species (Table 10). In the bole biomass of HSP system, the contribution of Prunus persica was minimum (43.1%), while that of G. optiva was maximum

Table 10: Standing biomass in different tree components (% values) of the ecosystems

Tree species	Bole						Branches						Leaves						Fruits					
	Systems:		HAG	HSP	GL	HAG	HSP	GL	HAG	HSP	GL	HAG	HSP	GL	HAG	HSP	GL	HAG	HSP	GL				
<b>A. Podder Trees</b>																								
1. <i>Albizia stipulata</i> (Roxb.) Boiv.	-	82.2	77.7	-	13.9	17.0	-	3.9	5.3	-	-	-	-	-	-	-	-	-	-	-				
2. <i>Bauhinia variegata</i> L.	-	83.7	79.2	-	10.9	13.5	-	5.4	7.3	-	-	-	-	-	-	-	-	-	-	-				
3. <i>Celtis australis</i> L.	-	90.1	84.4	-	7.2	11.3	-	2.7	4.3	-	-	-	-	-	-	-	-	-	-	-				
4. <i>Crewia optiva</i> Brummond	-	94.0	93.2	-	3.8	4.2	-	2.2	2.6	-	-	-	-	-	-	-	-	-	-	-				
5. <i>Morus serrata</i> Roxb.	-	86.3	78.0	-	8.5	13.1	-	5.2	8.9	-	-	-	-	-	-	-	-	-	-	-				
<b>B. Timber/Fuelwood Trees</b>																								
6. <i>Acacia catechu</i> (L.f.) Willd.	-	-	73.9	-	-	18.5	-	-	7.6	-	-	-	-	-	-	-	-	-	-	-				
7. <i>Bombax ceiba</i> L.	-	82.2	76.7	-	12.1	15.8	-	5.7	7.5	-	-	-	-	-	-	-	-	-	-	-				
8. <i>Dalbergia sissoo</i> Roxb.	-	87.1	-	-	10.6	-	-	2.3	-	-	-	-	-	-	-	-	-	-	-	-				
9. <i>Picus palmeta</i> Poirsk.	-	71.1	65.4	-	18.6	21.5	-	10.3	13.1	-	-	-	-	-	-	-	-	-	-	-				
10. <i>Pinus torquarhii</i> Sar.	-	85.8	80.5	-	9.7	12.8	-	4.5	6.7	-	-	-	-	-	-	-	-	-	-	-				
11. <i>Pistacia indicerrima</i> Stevar: ex. Brandis	-	81.5	80.0	-	12.8	13.9	-	5.7	6.1	-	-	-	-	-	-	-	-	-	-	-				
12. <i>Prunus puduon</i> Roxb.	-	76.2	73.3	-	16.5	18.4	-	7.3	8.3	-	-	-	-	-	-	-	-	-	-	-				
13. <i>Pyrus pashia</i> Bush. - Has. ex D. Don	-	76.8	76.3	-	15.8	16.2	-	7.4	7.5	-	-	-	-	-	-	-	-	-	-	-				
14. <i>Sapina insignis</i> Benth.	-	70.8	73.3	-	20.3	17.8	-	8.9	8.9	-	-	-	-	-	-	-	-	-	-	-				
15. <i>Toona ciliata</i> M.J. Roem	-	89.1	85.5	-	7.4	9.6	-	3.5	4.9	-	-	-	-	-	-	-	-	-	-	-				
<b>C. Fruit Trees</b>																								
16. <i>Prunus amygdalus</i> Batsch.	49.0	-	-	-	40.0	-	-	6.0	-	-	-	-	-	3.4	-	-	-	-	-	-				
17. <i>Prunus armeniaca</i> L.	57.9	56.0	-	33.2	34.6	-	-	5.2	5.5	-	-	-	-	3.7	3.9	-	-	-	-	-				
18. <i>Prunus domestica</i> L.	49.1	45.3	-	35.3	38.2	-	-	5.9	6.4	-	-	-	-	9.7	10.1	-	-	-	-	-				
19. <i>Prunus persica</i> (L.) Batsch.	35.4	43.1	-	46.7	41.0	-	-	7.8	6.8	-	-	-	-	10.1	9.1	-	-	-	-	-				
20. <i>Punica granatum</i> L.	48.1	48.1	54.4	-	29.9	30.6	-	6.4	6.6	-	-	-	-	15.6	17.4	-	-	-	-	-				
21. <i>Pyrus communis</i> L.	46.7	53.1	47.8	34.8	32.5	34.3	-	7.1	6.0	6.8	11.4	8.4	11.1	-	-	-	-	-	-	-				

(94.0%). But their branches displayed a reverse relationship, i.e. 41.0 and 3.8 per cent, respectively. Contribution of leaf biomass was minimum (2.2%) in case of G. optiva and maximum (10.3%) in case of Ficus palmata. In HAG system, though P. armeniaca recorded maximum (57.9%) bole biomass, yet its fruit production was not maximum (3.7%). But P. communis produced the highest fruit biomass (11.4%). In GL system, the bole (47.8%) and fruits (11.1%) of P. communis, branches (4.2%) and leaves (2.6%) of G. optiva contributed least, whereas the maximum contributions (93.2, 34.3, 13.1 and 17.4%) were made through bole, branches, leaves and fruits of G. optiva, P. communis, F. palmata and P. granatum, respectively.

Data in table 11 revealed the accumulation and partitioning of biomass in three different groups viz. fodder, timber/fuelwood and fruit trees irrespective of their species.

In HAG system, the entire biomass was contributed by fruit trees in the per cent distribution pattern of 50.6, 35.3, 5.9 and 8.2 corresponding to bole, branches, leaves and fruits. Fruit trees also constituted the major part of the total biomass (38.6%) in HSP keeping 30.8 and 30.5 by percentage to fodder and timber/fuelwood trees, respectively. The respective allocation of biomass to bole, branches, leaves and fruits on per cent basis of the whole system were represented (28.3, 1.7, 0.8 and 0.0) by fodder trees,

Table 11. Standing biomass ( $q \text{ ha}^{-1}$ ) of tree components in the ecosystems

Tree species	Components	Systems		
		HAG	HSP	GL
A. Fodder Trees	Boles	-	100.6	17.3
	Branches	-	6.1	2.1
	Leaves	-	2.9	0.9
	Fruits	-	-	-
	Subtotal		109.6 (30.8)	20.3 (32.1)
B. Timber/Fuelwood Trees	Boles	-	94.0	31.3
	Branches	-	10.0	5.2
	Leaves	-	4.6	2.5
	Fruits	-	-	-
	Subtotal		108.6 (30.5)	39.0 (61.7)
C. Fruit Trees	Boles	152.6	67.8	1.8
	Branches	106.5	49.4	1.3
	Leaves	17.7	8.4	0.3
	Fruits	24.7	11.7	0.5
	Subtotal	301.5 (100.0)	137.3 (38.6)	3.9 (6.2)
	Total	301.5	355.5	63.2

Values in the parentheses indicate the percentage of the total for each category

(26.4, 2.8, 1.3 and 0.0) timber/fuelwood trees and (19.1, 13.9, 2.4 and 3.3) fruit trees. Timber/fuelwood trees assigned the highest share (61.7%) through bole, branches and leaves (49.5, 8.2 and 4.0%, respectively) to the total biomass of GL system. Bole, branches and leaves of the fodder trees contributed 27.4, 3.3 and 1.4 per cent, respectively to this system biomass with a total of 32.1. Fruit trees shared 6.2 per cent only.

Standing biomass of the system along with the contributions of the tree components are given in table 12.

A perusal of the data reflected that HSP system had the highest standing biomass ( $355.5 \text{ q ha}^{-1}$ ) as compared to HAG ( $301.5 \text{ q ha}^{-1}$ ), and GL  $63.2 \text{ q ha}^{-1}$  being 1.18 and 5.63 times higher, respectively. Bole alone represented more than 50.0 per cent of the total biomass in all systems which was followed by branches, leaves and fruits except the fruit component in HAG system. Fruit biomass ( $24.7 \text{ q ha}^{-1}$ ) was more than leaves ( $17.7 \text{ q ha}^{-1}$ ) in HAG system by 1.4 times. Bole attributed the highest percentage (79.7) in GL, branches (35.3%) in HAG, leaves (5.9%) in HAG as well as in GL and fruits (8.2%) in HAG systems corresponding to their lowest per cent value of 50.6 (in HAG), 13.6 (in GL), 4.5 (in HSP) and 0.8 (in GL).

#### 4.5 BIOMASS PRODUCTIVITY PATTERNS

##### 4.5.1 Trees

The data on annual biomass increment/productivity of

Table 12: Standing biomass ( $\text{q ha}^{-1}$ ) of tree components in the ecosystems

Components	Systems		
	HAG	HSP	GL
Boles	152.6 $\pm$ 53.3 (50.6)	262.3 $\pm$ 9.8 (73.8)	50.4 $\pm$ 1.6 (79.7)
Branches	106.5 $\pm$ 37.9 (35.3)	65.6 $\pm$ 3.0 (18.4)	8.6 $\pm$ 0.2 (13.6)
Leaves	17.7 $\pm$ 6.3 (5.9)	15.9 $\pm$ 0.5 (4.5)	3.7 $\pm$ 0.1 (5.9)
Fruits	24.7 $\pm$ 10.8 (8.2)	11.8 $\pm$ 3.4 (3.3)	0.5 $\pm$ 0.4 (0.8)
Total	301.5 $\pm$ 108.1	355.5 $\pm$ 12.1	63.2 $\pm$ 1.8

Values in the parentheses indicate the percentage of the total for each category

maximum rate by more than 15.0 per cent among the timber/fuelwood species. Pistacia integerrima is HSP and Pinus roxburghii in GL appeared next after T. ciliata. P. communis exhibited a biomass yield of  $6.9 \text{ q ha}^{-1} \text{ yr}^{-1}$  following P. domestica in HSP system.

Biomass productivity of the tree components in the ecosystems varied from 0.8 kg branch with Sapium insigne to 2089.0 kg fruits  $\text{ha}^{-1} \text{ yr}^{-1}$  for P. domestica in HSP and HAG systems, respectively. Bombax ceiba recorded the highest rate (7.0%) of annual accumulation in bole against, the lowest (3.5%) in P. granatum. Maximum rate (104.1%) of biomass accumulation in branches and leaves (108.1%) was attributed by G. optiva and Acacia catechu, respectively. P. granatum showed the lowest rate for branches and leaves. For fruit biomass, P. communis amassed a higher rate (108.4%) than other species while Prunus amygdalus accumulated at the lowest rate of 99.8 per cent.

Data on table 14 pointed out that the horticultural trees in HAG system produced the maximum biomass of  $55.8 \text{ q ha}^{-1} \text{ yr}^{-1}$  at the highest rate of 18.5 per cent. They also put the major portion of the annual biomass ( $53.3 \text{ q ha}^{-1}$ ) by 53.3 per cent to HSP system followed by fodder trees (26.0%) and timber/fuelwood trees (20.7%). Horticultural component exhibited the highest increment rate of 19.6 per cent and the lowest in timber/fuelwood (9.6%) against the average rate of 14.2. In GL system, timber/fuelwood species

Table 14. Biomass productivity ( $q \text{ ha}^{-1} \text{ yr}^{-1}$ ) of tree components in the ecosystems

Tree species	Components	Systems		
		HAG	HSP	GL
A. Fodder Trees	Boles	-	4.2	0.7
	Branches	-	6.0	1.7
	Leaves	-	3.0	1.0
	Fruits	-	-	-
	Subtotal	-	13.2 (26.0)	3.4 (37.8)
B. Timber/Fuelwood Trees	Boles	-	5.0	1.6
	Branches	-	0.6	0.3
	Leaves	-	4.9	2.7
	Fruits	-	-	-
	Subtotal	-	10.5 (20.7)	4.6 (51.1)
C. Fruit Trees	Boles	7.0	3.5	0.1
	Branches	5.0	2.6	0.1
	Leaves	18.5	8.9	0.3
	Fruits	25.3	12.0	0.5
	Subtotal	55.8 (100.00)	27.0 (53.3)	1.0 (11.1)
Total		55.8	50.7	9.0

Values in the parentheses indicate the percentage of the total for each category

contributed the maximum by 51.1 per cent to the system productivity ( $9.0 \text{ q ha}^{-1}\text{yr}^{-1}$ ) while fruit trees had the least contribution in the tune of 11.1 per cent only. The average rate of biomass accumulation was 14.3 per cent.

The data presented in table 15 indicated that the system did vary in their annual biomass productivity as well as contribution of the tree components made within the system. The tree components demonstrated varied contributions specific to the system. Leaves contributed the maximum towards the systems biomass in HSP (33.1%) and GL (44.4%) whereas fruits in HAG (45.3%) system. Branches had the least impact in all systems except fruits in GL. On an average, the annual rates of biomass accumulation were worked out at 4.7, 9.0, 105.4 and 102.2 per cent for bole, branches, leaves and fruits, respectively, irrespective of the systems (Tables 12 and 15).

#### 4.5.2 Agricultural crops

##### 4.5.2.1 Kharif crops and their associated weeds

Biomass yields of the Kharif crops and weeds have been summarized in table 16.

Zea mays yielded the highest biomass of  $68.5 \text{ q ha}^{-1}$  in AG and  $42.1 \text{ q ha}^{-1}$  in HAS system with the yield reduction by 38.5 per cent in the later. Vegetative yield was less affected in HAG as compared to grain yield. Like Z. mays, more yield reduction by 52.7 per cent was estimated with

Table 15: Biomass productivity ( $q \text{ ha}^{-1} \text{ yr}^{-1}$ ) of tree components in the ecosystems

Components	Systems		
	HAG	HSP	GL
Boles	$7.0 \pm 2.5$ (12.5)	$12.7 \pm 0.5$ (25.0)	$2.4 \pm 0.1$ (26.7)
Branches	$5.0 \pm 1.8$ (9.0)	$9.2 \pm 0.4$ (18.1)	$2.1 \pm 0.1$ (23.3)
Leaves	$18.5 \pm 6.6$ (33.2)	$16.8 \pm 0.6$ (33.1)	$4.0 \pm 0.1$ (44.4)
Fruits	$25.3 \pm 11.0$ (45.3)	$12.0 \pm 3.4$ (23.7)	$0.5 \pm 0.4$ (5.6)
Total	$55.8 \pm 22.0$	$50.7 \pm 1.8$	$9.0 \pm 0.2$

Values in the parentheses indicate the percentage of the total for each category

Table 16. Biomass yields ( $q\ ha^{-1}$ ) of Kharif crops and weeds in the agricultural (AG) and horticultural (HAG) ecosystems.

Plant species	Systems:			Biomass Yield		
	AG			HAG		
	C-1	C-2	C-3	C-1	C-2	C-3
<b>A. Agricultural Crops (C)</b>						
1. <u>Lycopersicon esculentum</u> L.	36.6+8.9 (32.6)	-	-	17.3+9.1 (14.7)	-	-
2. <u>Zea mays</u> L.	-	68.5+11.2 (23.3)	-	-	42.19+9.3 (10.5)	-
3. <u>Zingiber officinale</u> Rosc.	-	-	28.3+3.1 (17.8)	-	-	28.4+3.9 (16.9)
Subtotal	36.6 (32.6)	68.5 (23.3)	28.3 (17.8)	17.3 (14.7)	42.1 (10.5)	28.4 (16.9)
<b>B. Weeds</b>						
4. <u>Commelina benghalensis</u> L.	0.2	1.4	0.2	0.1	1.2	0.2
5. <u>Cyperus rotundus</u> L.	0.1	0.5	0.1	0.1	0.4	-
6. <u>Cynodon dactylon</u> (L.) Pers.	-	0.1	-	-	-	-
7. <u>Digitaria sanguinalis</u> (L.) Scop.	0.3	5.0	-	-	1.0	-
8. <u>Echinochloa colonum</u> (L.) Link.	0.3	0.7	0.1	0.4	1.5	0.2
9. <u>Echinochloa crusgalli</u> (L.) Beauv.	0.3	7.0	0.2	0.9	4.8	0.1
10. <u>Eleusine indica</u> (L.) Gaertn.	1.2	0.6	-	1.4	-	-
11. <u>Galinsoga parviflora</u> Cav.	0.9	5.2	0.3	0.9	2.3	0.3
Subtotal	3.3	20.5	0.9	3.8	11.2	0.8
Total	39.9	89.0	29.2	21.1	53.3	29.2

Figures in parentheses indicate grain/fruit biomass

Lycopersicon esculentum in HAG system. But Zingiber officinale produced approximately same biomass yields (28.3 and 28.4 q ha<sup>-1</sup>) in both the systems.

Total and species-wise weed biomass differed with the crops and systems. More weed biomass was recorded in AG than HAG system, while this trend was reverse with L. esculentum. Contribution of weeds to the total biomass production ranged from 0.8 to 20.5 q ha<sup>-1</sup>, accounting for 6.5 to 31.2 per cent with Z. officinale (in HAG) and Z. mays (in AG), respectively. Echinochloa crusgalli, Galinsoga parviflora and Digitaria sanguinalis were important Kharif weeds and they collectively contributed 77.7 and 65.2 per cent of the total weed biomass in AG and HAG systems, respectively.

#### 4.5.2.2 Rabi crops and their associated weeds

Biomass yields of the Rabi crops and weeds are given in table 17.

Both the cereal crops yielded higher total biomass than the vegetable crop i.e. Pisum sativum in both the systems. On an average, the biomass yields were less affected (6.2%) in HAG system as compared to Kharif crops. The average grain/fruit yield was reduced by 11.7 per cent in HAG as compared to AG system. P. sativum yielded the maximum grain/fruit biomass of 22.0 and 20.1 q ha<sup>-1</sup> in AG and HAG systems followed by Triticum aestivum (18.8 q ha<sup>-1</sup>

Table 17. Biomass yields ( $q\ ha^{-1}$ ) of Rabi crops and weeds in the agricultural (AG) and horticultural (HAG) ecosystems

Plant species	Systems:			Biomass yield		
	AG	HAG		C-1	C-2	C-3
<b>A. Agricultural Crops (C)</b>						
1. <i>Hordeum vulgare</i> L.	47.5±9.8 (18.2)	-	-	45.1±8.2 (16.1)	-	-
2. <i>Pisum sativum</i> L. var. <i>arvense</i> L.	39.2±7.1 (22.0)	-	-	-	36.96±6.9 (20.1)	-
3. <i>Triticum aestivum</i> L.	-	-	48.5±8.2 (18.8)	-	-	44.8±7.4 (15.9)
Subtotal:	47.5 (18.2)	39.2 (22.0)	48.5 (18.8)	45.1 (16.1)	36.9 (20.1)	44.8 (15.9)
<b>Weeds</b>						
4. <i>Artemisia mexicana</i> L.	0.1	-	0.3	0.1	-	0.1
5. <i>Avena fatua</i> L.	0.8	-	1.6	0.7	-	1.5
6. <i>Chenopodium album</i> L.	0.2	0.2	0.3	-	3.2	0.2
7. <i>Lathyrus aphaca</i> L.	0.3	0.1	0.3	0.3	0.2	0.2
8. <i>Linum mysorense</i> Heyne.	0.8	0.8	-	-	0.1	-
9. <i>Medicago denticulata</i> Willd.	1.6	0.6	1.7	1.8	0.6	2.4
10. <i>Melilotus alba</i> Medik.	0.2	0.1	0.2	0.2	0.1	0.2
11. <i>Phalaris minor</i> Retz.	1.0	-	2.0	1.0	-	1.5
12. <i>Rubia cordifolia</i> L.	0.1	0.1	-	-	0.1	-
13. <i>Vicia faba</i> L.	1.2	0.1	1.3	1.4	0.1	1.2
Subtotal:	5.4	2.0	7.7	5.5	1.3	7.4
Total:	52.9	41.2	56.2	50.6	38.2	52.2

Figures in parentheses indicate grain/fruit biomass

in AG) and Hordeum vulgare (16.1 q ha<sup>-1</sup> in HAG).

Weed biomass varied with the crops and systems. Average yield was more in AG (5.0 q ha<sup>-1</sup>) when compared with HAG (4.7 q ha<sup>-1</sup>) and ranged from 1.3 to 7.7 q ha<sup>-1</sup> contributing 3.4 to 13.7 per cent to the total biomass with P. sativum (in HAG) and T. aestivum (in AG), respectively. Medicago denticulata, Phalaris minor, Vicia faba and Avena fatua were important weeds and they constituted 78.8 and 85.9 per cent of the total weed biomass, irrespective of crops in AG and HAG systems, respectively. M. denticulata contributed a major part in both the systems.

#### 4.5.2.3 Kharif - Rabi crops and associated weeds

Annual biomass productivity of Kharif - Rabi crops and their respective weeds under tentative crop combinations has been summarily presented in table 18.

A perusal of the data reveals that irrespective of the Kharif - Rabi crop combinations tentated, biomass productivity declined with a mean of 20.7 per cent in HAG system. On an average, all yield contributing components reflected a reduction in productivity with the maximum rate of 28.9 per cent in grain/fruit as compared to AG system. Grain/fruit productivity of the crop combinations suffered a wide extend varying from 7.0 (in Z. officinale-P. sativum) to 40.5 (in L. esculentum - T. aestivum) per cent. Total

Table 18: Biomass productivity ( $\text{q ha}^{-1} \text{yr}^{-1}$ ) of Kharif-Rabi crops and associated weeds under tentative crop combinations

Kharif and Rabi crops combinations	AG			HAG				
	Grain/Fruit	Vegetative	Weeds	Total	Grain/Fruit	Vegetative	Weeds	Total
T+B	32.6+18.2=50.8	4.0+29.3=33.3	3.3+5.4	92.8	14.7+16.1=30.8	2.6+29.0=31.6	3.8+5.5	71.7
T+P	32.6+22.0=54.6	4.0+17.2=21.2	3.3+2.0	81.1	14.7+20.1=34.8	2.6+16.8=19.4	3.8+1.3	59.3
T+W	32.6+18.8=51.4	4.0+29.7=33.7	3.3+7.7	96.1	14.7+15.9=30.6	2.6+28.9=31.5	3.8+7.4	73.3
M+B	23.3+18.2=41.5	45.2+29.3=74.5	20.5+5.4	141.9	10.5+16.1=26.6	31.6+29.0=60.6	11.2+5.5	103.9
M+P	23.3+22.0=45.3	45.2+17.2=62.4	20.5+2.0	130.2	10.5+20.1=30.6	31.6+16.8=48.4	11.2+1.3	91.5
M+W	23.3+18.8=42.1	45.2+29.7=74.9	20.5+7.7	145.2	10.5+15.9=26.4	31.6+28.9=60.5	11.2+7.4	105.5
G+B	17.8+18.2=36.0	10.5+29.3=39.8	0.9+5.4	82.1	16.9+16.1=33.0	11.5+29.0=40.5	0.8+5.5	79.8
G+P	17.8+22.0=39.8	10.5+17.2=27.7	0.9+2.0	70.4	16.9+20.1=37.0	11.5+16.8=28.3	0.8+1.3	67.4
G+W	17.8+18.8=36.6	10.5+29.7=40.2	0.9+7.7	85.4	16.9+15.9=32.8	11.5+28.9=40.4	0.8+7.4	81.4
Pooled mean**	24.6+19.6=44.2	19.9+25.4=45.3	13.3	102.8	14.0+17.4=31.4	15.2+24.9=40.1	10.0	81.5

\* Yields obtained on a sole crop on the basis of sample

\*\* Average Biomass irrespective of crop combination

T-Triticum aestivum; B-Hordeum vulgare; M-Zea mays; P-Pisum sativum; G-Zingiber officinale; W-Triticum aestivum

productivity ranged from 59.3 q (in HAG with L. aesculentum-P. sativum) to 145.2 q ha<sup>-1</sup>yr<sup>-1</sup> (in AG with Z. mays - T. aestivum). An identical trend was observed for crop productivity alone with the same crop combinations and systems.

#### 4.5.3 Grasses

Biomass productivity of the grasses and their herbaceous associates is presented in table 19.

GL ecosystem contributed higher grass biomass annually (26.48 q ha<sup>-1</sup>) than HSP (23.48 q ha<sup>-1</sup>) by 1.13 time. Annual biomass production ranged from 10.3 to 42.7 in HSP and 20.8 to 46.4 q ha<sup>-1</sup> in GL system. Species differed to each other in their contributions for both the systems varying from 0.13 to 8.90 q ha<sup>-1</sup>yr<sup>-1</sup> with Imperata cylindrica and Chrysopogon montanus in HSP and GL ecosystems, respectively. C. montanus, Apluda mutica, Themeda anathera and Heteropogon contortus were the dominant grass species in their descending order accounting 65.9 and 72.3 per cent towards the total grass biomass production in HSP and GL ecosystems, respectively.

The herbaceous associates viz. climbers, sedges and weeds constituted only 7.2 and 7.6 per cent of the total biomass respective to HSP and GL systems. Among the associates, weeds played the major role particularly by Dipsacus inermis in the system productivity.

Table 19: Biomass productivity ( $q \text{ ha}^{-1} \text{ yr}^{-1}$ ) of grasses and their herbaceous associates in hortisilvipastoral (HSP) and grassland (GL) ecosystem

Plant species	Systems	
	HSP	GL
<b>A. Grasses</b>		
1. <u>Apluda mutica</u> L.	6.23	6.74
2. <u>Arundinella bengalensis</u> (Spreng.)Druce	1.76	1.15
3. <u>Arundinella nepalensis</u> Trin.	1.09	0.31
4. <u>Bothriochloa odorata</u> (Lisboa)A.Camus	0.46	1.23
5. <u>Capillipedium assimile</u> (Steud.)A.Camus	1.20	1.64
6. <u>Chrysopogon montanus</u> Koen.ex Trin.	6.62	8.90
7. <u>Cymbopogon martinii</u> (Roxb.)Wats.	0.31	1.04
8. <u>Heteropogon contortus</u> (L.)P.Beauv.	1.17	1.86
9. <u>Imperata cylindrica</u> (L.)P.Beauv.	0.13	-
10. <u>Microstegium vagans</u> (Nees)A.Camus	0.45	0.14
11. <u>Mnesithea laevis</u> (Retz.)Kunth.	-	0.19
12. <u>Pennisetum orientale</u> L.c.Rich	1.68	0.67
13. <u>Sorghum halepense</u> (L.)Pers.	0.92	0.95
14. <u>Themeda anathera</u> (Nees)Hack.	1.46	1.66
Subtotal	23.48	26.48
	+1.28	+1.61
<b>B. Climbers</b>		
1. <u>Cissampelos pareira</u> L.	-	0.05
2. <u>Rhynchosia himalensis</u> Benth.ex Baker	0.73	0.93
Subtotal	0.73	0.98
<b>C. Sedges</b>		
1. <u>Fimbristylis complanata</u> Link.	0.11	0.12
<b>D. Weeds</b>		
1. <u>Artemisia scoparia</u> Waldst.	0.16	0.19
2. <u>Bidens pilosa</u> L.	0.19	0.15
3. <u>Dipsacus inermis</u> Wall.	0.63	0.73
Subtotal	0.98	1.07
Total	25.30	28.65
	+3.53	+2.39

#### 4.5.4 Trees and herbaceous components

Over all productivity of the four ecosystems with their participants has been summarised in table 20.

HAG system recorded the highest productivity of  $137.3 \text{ q ha}^{-1} \text{ yr}^{-1}$  and it was followed by AG (102.8), HSP (76.0) and GL (37.7), yielding 1.3-, 1.8- and 3.6-fold higher than the aother systems, respectively.

In AG system, the crops formed 87.1 per cent (43% grain/fruit + 44.1% vegetative parts) of the total productivity. The weeds claimed only 12.9 per cent being the maximum among the systems. Agricultural crops also had major contribution to HAG, representing 52.1 per cent of the system productivity.

The grasses assigned maximum by 70.3 per cent to the annual productivity in GL as compared to 30.9 per cent in HSP system. The herbacious associates of grasses contributed less than 5.9 per cent in both the systems.

The trees played the major role in biomass productivity of HSP system and their contribution was 66.7 per cent of the total. They put only 23.9 per cent in GL following 40.6 per cent in HAG system. Leaves accounted more than other tree components in HSP and GL systems productivity totalling 22.1 and 10.6 per cent, respectively. But in HAG, fruits ruled over other components adding 18.4 per cent to the total annual productivity.

Table 20. Biomass productivity ( $g\ ha^{-1}yr^{-1}$ ) of trees and herbaceous components in the ecosystems

Plant components	Systems			
	AG	HAG	HSP	GL
<b>A. Trees</b>				
Boles	-	7.0	12.7	2.4
Branches	-	5.0	9.2	2.1
Leaves	-	18.5	16.8	4.0
Fruits	-	25.3	12.0	0.5
Subtotal		55.8 (40.6%)	50.7 (66.7%)	9.0 (23.9%)
<b>B. Crops</b>				
Grains/Fruits	44.2	31.4	-	-
Vegetative parts	45.3	40.1	-	-
Subtotal	89.5 (87.1%)	71.5 (52.1%)		
<b>C. Weeds</b>				
Shoots	13.3	10.0	1.0	1.1
Subtotal	13.3 (12.9%)	10.0 (7.3%)	1.0 (1.3%)	1.1 (2.9%)
<b>D. Grasses</b>				
Shoots	-	-	23.5	26.5
Subtotal			23.5 (30.9%)	26.5 (70.3%)
<b>E. Climbers</b>				
Shoots	-	-	0.7	1.0
Subtotal			0.7 (0.9%)	1.0 (2.6%)
<b>F. Sedge</b>				
Shoots	-	-	0.1	0.1
Subtotal			0.1 (0.1%)	0.1 (0.3%)
<b>Total</b>	<b>102.8</b>	<b>137.3</b>	<b>76.0</b>	<b>37.7</b>

## 4.6 STANDING NUTRIENT BANK OF THE TREES

### 4.6.1 Bole

The amounts of nutrients (N, P and K) stored in bole by the various tree species in their respective systems are given in table 21.

Accumulated N was maximum ( $115.11 \text{ kg ha}^{-1}$ ) in HSP system followed by HAG (54.19) and GL (24.31), respectively. Storage of P and K in bole followed a similar pattern to N. Prunus domestica in HAG system had the highest N storage of  $36.17 \text{ kg ha}^{-1}$ . Highest amounts of P and K were stored in the bole of Toona ciliata and Grewia optiva, respectively, both pertain to HSP system with their corresponding value of 7.99 and  $47.39 \text{ kg ha}^{-1}$ . Punica granatum had the minimum deposits of all the three nutrient elements. G. optiva, T. ciliata and P. domestica retained more of all the nutrients in their boles than those of the others fodder, timber/fuel-wood and fruit tree species in their respective systems.

### 4.6.2 Branch

Data on the quantitative patterns of NPK accumulation in the branches are given in table 22.

In general, HAG reserved more amounts of NPK in the branches ( $50.19$ ,  $8.62$  and  $35.82 \text{ kg ha}^{-1}$  of N, P and K, respectively) than the other two systems in varied proportions. GL had the least amounts of all the three nutrients. P. domestica retained the highest amounts of NPK

Table 21. Total standing nutrient bank (kg ha<sup>-1</sup>) in bole of different tree species in the ecosystems

Tree species	Nutrients:			N			P			K		
	HAG	HSP	GL	HAG	HSP	GL	HAG	HSP	GL	HAG	HSP	GL
<b>A. Fodder Trees</b>												
Systems:												
1. <i>Albizia stipulata</i> (Roxb.)Boiv.	-	3.05	2.24	-	0.43	0.32	-	2.12	1.56	-	2.12	1.56
2. <i>Bambusa variegata</i> L.	-	1.49	0.75	-	0.31	0.16	-	2.63	1.33	-	2.63	1.33
3. <i>Celtis australis</i> L.	-	11.86	1.40	-	1.51	0.18	-	8.62	1.02	-	8.62	1.02
4. <i>Grewia optiva</i> Drummond	-	28.03	3.31	-	4.67	0.55	-	47.39	5.60	-	47.39	5.60
5. <i>Morus serrata</i> Roxb.	-	1.65	0.57	-	0.23	0.08	-	1.51	0.52	-	1.51	0.52
Subtotal	-	46.08	8.27	-	7.15	1.29	-	62.27	10.03	-	62.27	10.03
<b>B. Timber/Fuelwood Trees</b>												
6. <i>Acacia catechu</i> (L.f.)Willd.	-	-	2.05	-	-	0.26	-	-	1.33	-	-	1.33
7. <i>Bombax ceiba</i> L.	-	2.50	1.63	-	0.33	0.21	-	3.68	2.40	-	3.68	2.40
8. <i>Dalbergia sissoo</i> Roxb.	-	0.76	-	-	0.12	-	-	0.72	-	-	0.72	-
9. <i>Ficus palmata</i> Forsk.	-	0.67	0.28	-	0.13	0.05	-	0.63	0.26	-	0.63	0.26
10. <i>Pinus roxburghii</i> Sar.	-	2.32	2.31	-	0.18	0.18	-	1.71	1.70	-	1.71	1.70
11. <i>Pistacia integerrima</i> Stewart ex Brandis	-	2.93	1.80	-	0.26	0.16	-	4.63	2.84	-	4.63	2.84
12. <i>Prunus puddum</i> Roxb.	-	1.07	0.62	-	0.13	0.08	-	0.73	0.43	-	0.73	0.43
13. <i>Pyrus pashia</i> Bush. -Ham. ex D. Don	-	1.70	0.56	-	0.12	0.04	-	1.30	0.44	-	1.30	0.44
14. <i>Sapium insigne</i> Benth.	-	0.26	0.67	-	0.03	0.07	-	0.24	0.61	-	0.24	0.61
15. <i>Toona ciliata</i> M.J.Roem	-	31.98	5.40	-	7.99	1.35	-	34.64	5.86	-	34.64	5.86
Subtotal	-	44.19	15.32	-	9.29	2.40	-	48.28	15.87	-	48.28	15.87
<b>C. Fruit Trees</b>												
16. <i>Prunus amygdalus</i> Batsch.	3.41	-	-	-	0.50	-	2.99	-	-	-	-	-
17. <i>Prunus armeniaca</i> L.	12.51	5.60	-	-	0.71	0.32	9.65	4.32	-	-	-	-
18. <i>Prunus domestica</i> L.	36.17	10.73	-	5.17	1.53	-	27.91	8.28	-	-	-	-
19. <i>Prunus persica</i> (L.)Batsch.	0.76	0.82	-	0.09	0.08	-	0.47	0.51	-	-	-	-
20. <i>Punica granatum</i> L.	-	0.55	0.21	-	0.06	0.02	-	0.54	0.20	-	0.54	0.20
21. <i>Pyrus communis</i> L.	1.34	7.14	0.51	0.19	1.04	0.07	1.27	6.79	0.48	-	6.79	0.48
Subtotal	54.19	24.84	0.72	5.66	3.03	0.09	42.29	20.44	0.60	-	42.29	20.44
Total	54.19	115.11	24.31	6.66	19.47	3.78	42.29	130.99	26.58	-	42.29	26.58

Table 22. Total standing nutrient bank ( $\text{kg ha}^{-1}$ ) in branches of different tree species in the ecosystems

Tree species	N			P			K		
	HAG	HSP	GL	HAG	HSP	GL	HAG	HSP	GL
<b>A. Podder Trees</b>									
Systems:									
1. <i>Albizia stipulata</i> (Roxb.) Boiv.	-	0.07	0.86	-	0.10	0.11	-	0.60	0.60
2. <i>Bauhinia variegata</i> L.	-	0.25	0.17	-	0.06	0.05	-	0.37	0.26
3. <i>Celtis australis</i> L.	-	1.51	0.30	-	0.17	0.04	-	0.95	0.20
4. <i>Grewia optiva</i> Drummond	-	2.13	0.28	-	0.44	0.05	-	2.40	0.31
5. <i>Morus serrata</i> Roxb.	-	0.24	0.15	-	0.04	0.02	-	0.20	0.13
Subtotal	-	5.00	1.76	-	0.81	0.27	-	4.52	1.50
<b>B. Timber/Fuelwood Trees</b>									
6. <i>Acacia catechu</i> (L.f.) Willd.	-	0.45	0.65	-	0.08	0.10	-	0.72	0.41
7. <i>Bombax ceiba</i> L.	-	0.13	0.41	-	0.03	0.08	-	0.10	0.66
8. <i>Dalbergia sissoo</i> Roxb.	-	0.22	0.12	-	0.06	0.03	-	0.18	0.10
9. <i>Eicus palmata</i> Forsk.	-	0.38	0.54	-	0.04	0.06	-	0.21	0.34
10. <i>Pinus loxburghii</i> Sar.	-	0.70	0.47	-	0.08	0.05	-	0.91	0.64
11. <i>Pistacia integerrima</i> Stewart ex Brandis	-	0.45	0.30	-	0.05	0.04	-	0.21	0.15
12. <i>Prunus puddum</i> Roxb.	-	0.51	0.17	-	0.07	0.03	-	0.30	0.14
13. <i>Pyrus pashia</i> Bush. - Ham. ex D. Don	-	0.09	0.20	-	0.01	0.03	-	0.12	0.30
14. <i>Sapium insigne</i> Benth.	-	0.96	1.16	-	0.89	0.20	-	3.79	0.85
15. <i>Toona ciliata</i> M.J. Roem	-	7.89	4.02	-	1.31	0.62	-	6.63	3.59
Subtotal	-	5.00	1.76	-	0.81	0.27	-	4.52	1.50
<b>C. Fruit Trees</b>									
16. <i>Prunus amygdalus</i> Batsch.	5.68	-	0.73	0.73	-	3.87	-	-	-
17. <i>Prunus armeniaca</i> L.	9.83	5.05	1.43	1.43	0.59	7.78	3.86	-	-
18. <i>Prunus domestica</i> L.	31.23	11.38	5.94	5.94	2.33	21.56	7.50	-	-
19. <i>Prunus persica</i> (L.) Batsch.	2.14	1.71	0.28	0.28	0.22	1.03	0.86	-	-
20. <i>Punica granatum</i> L.	-	0.64	0.26	-	0.06	0.02	-	0.55	0.24
21. <i>Pyrus communis</i> L.	1.31	5.54	0.47	0.24	0.96	0.08	1.58	6.81	0.56
Subtotal	50.19	24.32	7.73	8.62	4.16	0.10	35.82	10.50	0.80
Total	50.19	37.01	6.81	8.62	6.28	0.99	35.82	37.72	5.80

in its specific systems. No species specificity was observed for sorting out them on the basis of their minimum NPK in reserve. G. optiva and Albizia stipulata accumulated more each of N, P and K in their branches than other fodder tree species in HSP and GL systems, respectively. T. ciliata was unique to the timber/fuelwood species in the systems of its occurrence.

#### 4.6.3 Leaf

Quantities of N, P and K stored in the leaves of tree species in different systems are presented in table 23.

Like branches, HAG retained higher quantities of N, P and K in the leaves (31.02, 5.07 and 22.98 kg ha<sup>-1</sup> of N, P and K, respectively) when compared with other systems. GL totalled the minimum and HSP being intermediate in behaviour. P. domestica had the highest amounts of N, P and K in its specific systems. Dalbergia sissoo and Sapium insigne shared in minimum. G. optiva except to N in GL system and T. ciliata accumulated more of all the nutrients in the leaves than those of the other fodder and timber/fuelwood species.

#### 4.6.4 Fruit

Total N, P and K storage patterns in fruits specific to systems were similar to branches and leaves (Table 24). Among the fruit tree species, P. domestica had the maximum amounts of N, P and K followed by Prunus armeniaca in HAG

Table 23: Total standing nutrient bank ( $\text{kg ha}^{-1}$ ) in leaves of different tree species in the ecosystems

Tree species	N				P				K			
	HAG	RSP	GL	HAG	HSP	GL	HAG	HSP	GL	HAG	HSP	GL
<b>A. Fodder Trees</b>												
1. <i>Albizia stipulata</i> (Roxb.) Boiv.	-	0.86	0.90	-	0.05	0.06	-	0.23	0.22	-	0.23	0.22
2. <i>Bauhinia variegata</i> L.	-	0.44	0.32	-	0.05	0.04	-	0.12	0.08	-	0.12	0.08
3. <i>Celtis australis</i> L.	-	1.49	0.28	-	0.09	0.02	-	0.41	0.09	-	0.41	0.09
4. <i>Cordia alliodora</i> Lam.	-	4.49	0.65	-	0.42	0.06	-	1.81	0.27	-	1.81	0.27
5. <i>Morus serrata</i> Roxb.	-	0.51	0.23	-	0.06	0.04	-	0.40	0.25	-	0.40	0.25
Subtotal	-	7.79	2.48	-	0.67	0.22	-	2.97	0.91	-	2.97	0.91
<b>B. Timber/Fuelwood Trees</b>												
6. <i>Acacia catechu</i> (L.f.) Willd.	-	0.51	0.57	-	0.07	0.04	-	0.40	0.14	-	0.40	0.14
7. <i>Bombax ceiba</i> L.	-	0.10	0.40	-	0.01	0.07	-	0.05	0.36	-	0.05	0.36
8. <i>Dalbergia sissoo</i> Roxb.	-	0.36	0.21	-	0.03	0.02	-	0.33	0.19	-	0.33	0.19
9. <i>Ficus palmata</i> Forsk.	-	0.23	0.37	-	0.04	0.06	-	0.18	0.30	-	0.18	0.30
10. <i>Pinus roxburghii</i> Sar.	-	0.69	0.47	-	0.06	0.04	-	0.44	0.28	-	0.44	0.28
11. <i>Pistacia integerrima</i> Stewart ex Brandis	-	0.41	0.28	-	0.09	0.06	-	0.22	0.15	-	0.22	0.15
12. <i>Prunus pumila</i> Roxb.	-	0.49	0.16	-	0.05	0.02	-	0.37	0.12	-	0.37	0.12
13. <i>Prunus pashia</i> Bush.-Ham. ex D. Don	-	0.30	0.24	-	0.01	0.02	-	0.06	0.16	-	0.06	0.16
14. <i>Sapium insigne</i> Benth.	-	4.06	1.23	-	0.47	0.11	-	1.71	0.43	-	1.71	0.43
15. <i>Toona ciliata</i> N.J. Roem	-	7.85	3.93	-	0.83	0.44	-	3.76	2.13	-	3.76	2.13
Subtotal	-	24.33	12.56	-	2.02	0.83	-	7.53	2.27	-	7.53	2.27
<b>C. Fruit Trees</b>												
16. <i>Prunus amygdalus</i> Batsch.	2.43	-	-	0.28	-	-	2.04	-	-	-	-	-
17. <i>Prunus armeniaca</i> L.	5.92	2.83	-	0.93	0.45	-	5.41	2.16	-	5.41	2.16	-
18. <i>Prunus domestica</i> L.	21.10	7.46	-	3.72	1.34	-	14.52	3.97	-	14.52	3.97	-
19. <i>Prunus persica</i> (L.) Batsch.	0.93	0.71	-	0.07	0.06	-	0.50	0.45	-	0.50	0.45	-
20. <i>Punica granatum</i> L.	-	0.26	0.11	-	0.03	0.01	-	0.28	0.09	-	0.28	0.09
21. <i>Pyrus communis</i> L.	0.64	1.30	0.23	0.07	0.14	0.02	0.51	0.67	0.18	0.51	0.67	0.18
Subtotal	31.02	12.56	0.34	5.07	2.02	0.83	22.98	7.53	2.27	22.98	7.53	2.27
Total	31.02	28.20	6.75	5.07	3.52	0.69	22.98	14.26	3.31	22.98	14.26	3.31

Table 24: Total standing nutrient bank (kg ha<sup>-1</sup>) in fruits of different tree species in the ecosystems

Tree species	N				P				K			
	Nutrients:											
	HAG	HSP	GL		HAG	HSP	GL		HAG	HSP	GL	
<b>A. Fodder Trees</b>												
1. <i>Albizia stipulata</i> (Roxb.) Boiv.	-	-	-	-	-	-	-	-	-	-	-	-
2. <i>Bauhinia variegata</i> L.	-	-	-	-	-	-	-	-	-	-	-	-
3. <i>Celtis australis</i> L.	-	-	-	-	-	-	-	-	-	-	-	-
4. <i>Grewia optiva</i> Drummond	-	-	-	-	-	-	-	-	-	-	-	-
5. <i>Morus serrata</i> Roxb.	-	-	-	-	-	-	-	-	-	-	-	-
Subtotal	-	-	-	-	-	-	-	-	-	-	-	-
<b>B. Timber/Fuelwood Trees</b>												
6. <i>Acacia catechu</i> (L.f.) Willd.	-	-	-	-	-	-	-	-	-	-	-	-
7. <i>Bombax ceiba</i> L.	-	-	-	-	-	-	-	-	-	-	-	-
8. <i>Dalbergia sissoo</i> Roxb.	-	-	-	-	-	-	-	-	-	-	-	-
9. <i>Ficus palmata</i> Forsk.	-	-	-	-	-	-	-	-	-	-	-	-
10. <i>Pinus roxburghii</i> Sar.	-	-	-	-	-	-	-	-	-	-	-	-
11. <i>Pistacia integerrima</i> Stewart ex Brandis	-	-	-	-	-	-	-	-	-	-	-	-
12. <i>Prunus puddua</i> Roxb.	-	-	-	-	-	-	-	-	-	-	-	-
13. <i>Pyrus pashia</i> Bush. - Nam. ex D. Don	-	-	-	-	-	-	-	-	-	-	-	-
14. <i>Sapium insigne</i> Benth.	-	-	-	-	-	-	-	-	-	-	-	-
15. <i>Toona ciliata</i> M.J. Roem	-	-	-	-	-	-	-	-	-	-	-	-
Subtotal	1.37	1.63	-	-	0.07	0.35	-	-	0.79	1.55	-	-
16. <i>Prunus amygdalus</i> Batsch.	3.34	5.60	-	-	0.66	0.97	-	-	3.09	6.36	-	-
17. <i>Prunus armeniaca</i> L.	15.58	1.00	-	-	2.66	0.06	-	-	17.00	0.61	-	-
18. <i>Prunus domestica</i> L.	1.00	0.94	-	-	0.07	0.13	-	-	0.81	0.68	-	-
19. <i>Prunus persica</i> (L.) Batsch.	-	0.36	0.39	0.15	-	0.30	0.06	-	-	1.87	0.32	0.20
20. <i>Punica granatum</i> L.	-	-	-	-	-	-	-	-	-	-	-	-
21. <i>Pyrus communis</i> L.	-	-	-	-	-	-	-	-	-	-	-	-
Subtotal	22.05	10.33	0.54	0.09	3.53	1.81	0.09	22.21	11.07	0.52	0.52	0.52
Total	22.05	10.33	0.54	0.09	3.53	1.81	0.09	22.21	11.07	0.52	0.52	0.52
<b>C. Fruit Trees</b>												

and HSP system. P. granatum stored more N, P and K in the fruits than Pyrus communis in GL system.

#### 4.6.5 Total standing nutrients in different tree species

Standing nutrient mass in different tree species accommodated to the systems has been quoted in table 25A.

A wide variation of nutrient allocation was noticed among the species ranging from 0.05 to 104.48 kg ha<sup>-1</sup>. Among the fruit tree species, P. domestica followed by P. armeniaca and P. communis respective to HAG and HSP systems had the largest nutrient pool. For instance, P. domestica alone kept a storage of 104.48, 17.49 and 80.99 kg ha<sup>-1</sup> of N, P and K, respectively, in HAG system representing 66.3, 73.2 and 65.7 per cent of the total for fruit trees. T. ciliata, timber/fuelwood species recorded the maximum of all the three nutrients in its respective systems except K in HSP, thus claiming 21.9, 30.1 and 21.4 per cent of the system N, P and K. Among the fodder trees, G. optiva ranked within third, for citation, it ranked first for K in HSP, second for N as well as P in GL and third for N in HSP system.

#### 4.6.6 Total standing nutrients in different components of tree groups

N, P and K accumulation in the components of different tree groups has been summarised in table 25B.

From the data, it is clear that the tree groups

Table 25A: Total standing nutrient bank (kg ha<sup>-1</sup>) in different tree species

Tree species	Nutrients:				P				K							
	N		P		HAG		HSP		GL		HAG		BSP		GL	
	HAG	HSP	GL	HAG	HSP	GL	HAG	HSP	GL	HAG	HSP	GL	HAG	HSP	GL	
<b>A. Fodder Trees</b>																
1. <i>Albizia stipulata</i> (Roxb.)Boiv.	-	4.78	4.08	-	0.58	0.49	-	2.95	2.38	-	-	-	-	-	-	-
2. <i>Bauhinia variegata</i> L.	-	2.18	1.24	-	0.42	0.25	-	3.12	1.67	-	-	-	-	-	-	-
3. <i>Celtis australis</i> L.	-	14.86	1.98	-	1.77	0.24	-	9.98	1.31	-	-	-	-	-	-	-
4. <i>Grewia optiva</i> Drummond	-	34.65	4.24	-	5.53	0.66	-	51.60	6.18	-	-	-	-	-	-	-
5. <i>Morus serrata</i> Roxb.	-	2.40	1.05	-	0.33	0.14	-	2.11	0.90	-	-	-	-	-	-	-
Subtotal	-	58.87	12.51	-	8.63	1.78	-	69.76	12.44	-	-	-	-	-	-	-
<b>B. Timber/Fuelwood Trees</b>																
6. <i>Acacia catechu</i> (L.f.)Willd.	-	3.27	2.44	-	0.48	0.36	-	4.88	3.42	-	-	-	-	-	-	-
7. <i>Bombax ceiba</i> L.	-	3.46	2.44	-	0.16	-	-	0.87	-	-	-	-	-	-	-	-
8. <i>Berbergia zissoo</i> Roxb.	-	0.99	-	-	0.22	0.10	-	1.14	0.55	-	-	-	-	-	-	-
9. <i>Ficus palmata</i> Forst.	-	1.25	0.61	-	0.26	0.30	-	2.10	2.34	-	-	-	-	-	-	-
10. <i>Pinus roxburghii</i> Sar.	-	2.93	3.22	-	0.40	0.25	-	5.98	3.76	-	-	-	-	-	-	-
11. <i>Pistacia integerrima</i> Stewart ex Brandis	-	4.32	2.74	-	0.27	0.18	-	1.16	0.73	-	-	-	-	-	-	-
12. <i>Prunus pindum</i> Roxb.	-	1.93	1.20	-	0.24	0.09	-	2.05	0.70	-	-	-	-	-	-	-
13. <i>Pyrus pashia</i> Bush.-Ham. ex D. Don	-	2.70	0.89	-	0.05	0.12	-	0.43	1.07	-	-	-	-	-	-	-
14. <i>Sapium</i> Insigne Benth.	-	0.45	1.11	-	0.05	0.12	-	0.43	1.07	-	-	-	-	-	-	-
15. <i>Toona ciliata</i> M.J. Roem	-	41.98	7.79	-	9.35	1.66	-	48.14	7.14	-	-	-	-	-	-	-
Subtotal	-	59.93	23.27	-	11.43	3.46	-	58.67	21.59	-	-	-	-	-	-	-
<b>C. Fruit Trees</b>																
16. <i>Prunus amygdalus</i> Batsch.	12.89	-	-	1.58	-	-	9.69	-	-	-	-	-	-	-	-	-
17. <i>Prunus armeniaca</i> L.	31.60	15.11	-	3.73	1.71	-	25.93	11.89	-	-	-	-	-	-	-	-
18. <i>Prunus domestica</i> L.	104.48	35.17	-	17.49	6.17	-	80.99	26.11	-	-	-	-	-	-	-	-
19. <i>Prunus persica</i> (L.)Batsch.	4.83	4.05	-	0.51	0.42	-	2.81	2.43	-	-	-	-	-	-	-	-
20. <i>Punica granatum</i> L.	-	2.39	0.97	-	0.28	0.11	-	2.05	0.85	-	-	-	-	-	-	-
21. <i>Pyrus communis</i> L.	3.65	15.33	1.36	0.57	2.44	0.20	3.88	16.14	1.42	-	-	-	-	-	-	-
Subtotal	157.45	72.05	2.33	23.88	11.02	0.31	123.30	58.62	2.27	-	-	-	-	-	-	-
Total	157.45	190.85	38.11	23.88	31.08	5.55	123.30	187.05	36.30	-	-	-	-	-	-	-

Table 25B: Total standing nutrient bank ( $\text{kg ha}^{-1}$ ) in different tree components

Tree species and components	N				P				K			
	Nutrients:				Nutrients:				Nutrients:			
	HAG	HSP	GL	HAG	HSP	GL	HAG	HSP	GL	HAG	HSP	GL
<b>A. Fodder Trees</b>												
Boles	46.08		8.27		7.15	1.29					62.27	10.03
Branches	5.00		1.76		0.81	0.27					4.52	1.50
Leaves	7.79		2.48		0.67	0.22					2.97	0.91
Fruits												
Subtotal	58.87 (30.8)		12.51 (32.8)		8.63 (27.8)	1.78 (32.1)					69.76 (37.3)	12.44 (34.3)
<b>B. Timber/Fuelwood Trees</b>												
Boles	44.19		15.32		9.29	2.40					48.28	15.87
Branches	7.89		4.02		1.31	0.62					6.63	3.59
Leaves	7.85		3.93		0.83	0.44					3.76	2.13
Fruits												
Subtotal	59.93 (31.4)		23.27 (61.1)		11.43 (36.8)	3.46 (62.3)					58.67 (31.4)	21.59 (59.5)
<b>C. Fruit Trees</b>												
Boles	54.19		0.72	6.66	3.03	0.09	42.29				20.44	0.68
Branches	50.19		0.73	8.62	4.16	0.10	35.82				19.58	0.80
Leaves	31.02		0.34	5.07	2.02	0.03	22.98				7.53	0.27
Fruits	22.05		0.54	3.53	1.81	0.09	22.21				11.07	0.52
Subtotal	157.45 (100.0)		2.33 (6.1)	23.80 (100.0)	11.02 (35.4)	0.31 (5.6)	123.30 (100.00)				58.62 (31.3)	2.27 (6.2)
Total	157.45	190.85	38.11	23.88	31.08	5.55	123.30				187.05	36.30

Values in the parentheses indicate the percentage of the total for each category

accounted for varied amounts of N, P and K in their respective systems and plant components. Fruit trees collectively stored the highest amount of  $72.05 \text{ kg ha}^{-1}$  N followed by timber/fuelwood and fodder trees in HSP system. Their respective contributions were 37.8, 31.4 and 30.8 per cent in this system. Fruit trees retained more N in their boles than branches, leaves and fruits with the exception to GL system. For example, bole N was 1.1-, 1.7- and 2.4-fold higher than branches, leaves and fruits, respectively, in HAG system. But the branches of fodder trees recorded the least amount of N following their leaves and boles. The trees of this group had bole N by 9.2- and 5.9-fold higher than branches and leaves in HSP system. In this system, timber/fuelwood tree components were similar to fruit trees in HAG in respect of N accumulation pattern. They deposited 1.3-fold higher P than fodder trees and approximated to fruits trees. Bole had more P but to different extents than the other components with the exceptions to the branches and fruits in HSP and GL systems, respectively. Timber/fuelwood trees reserved K at the same rate of N (31.4%) in HSP system. Unlike N, the other two groups of trees showed a reverse trend of K deposits being more in fodder than the fruit trees in the same system. In GL system, timber/fuelwood trees had the maximum storage of NPK each and they were followed by fodder and fruit trees. Bole K was more than the other components. The leaves in HSP and GL systems stored less K than the fruits.

#### 4.6.7 Total nutrients present in the systems

A summary of the accumulated N, P and K in different tree components irrespective to the species but specific for the system is given in table 26.

On an average, HSP accumulated highest amounts of N, P and K (190.85, 31.08 and 187.05 kg ha<sup>-1</sup>, respectively) as compared to other systems. It stored these nutrients in the range of 1.2-1.5 and 5.0-5.6-fold more than HAG and GL systems, respectively. The quantities present were estimated to vary with the components and systems. They fluctuated (kg ha<sup>-1</sup>) from 0.54 (1.4%) to 115.11 (60.3%) for N, 0.09 (1.6%) - 19.47 (62.6%) for P and 0.52 (1.4%) - 130.99 (70.0%) for K irrespective to systems. Bole component in HSP recorded the highest amounts of each nutrient while fruits in GL system had the lowest deposition. Bole, branches, leaves and fruits ranked in their descending order of NPK accumulation except the amounts of leaf N in GL and branch P in HAG where they stored more than branch and bole, respectively.

#### 4.7 ANNUAL NUTRIENT ACCUMULATION MODELS

##### 4.7.1 Tree species

Data on annual nutrient accumulation by the tree species and their components in respective systems are presented in tables 27, 28, 29, 30 and 31.

Table 26: Total standing nutrient bank ( $\text{kg ha}^{-1}$ ) of tree components in the systems

Components	N		P		K			
	HAG	HSP	HAG	HSP	HAG	HSP		
Boles	54.19±18.58 (34.4)	115.11±4.39 (68.3)	6.66±2.68 (27.9)	19.47±0.96 (62.6)	3.78±0.17 (68.1)	42.29±14.26 (34.3)	130.99±6.03 (70.0)	26.58±0.93 (73.2)
Branches	50.19±15.33 (31.9)	37.21±1.39 (19.5)	8.62±2.99 (36.1)	6.28±0.27 (20.2)	0.99±0.02 (17.8)	35.82±10.55 (29.1)	30.73±1.09 (16.4)	5.89±0.13 (16.2)
Leaves	31.02±10.69 (19.7)	28.20±0.98 (14.8)	5.07±1.93 (21.2)	3.52±0.15 (11.3)	0.69±0.01 (12.4)	22.98±7.34 (18.6)	14.26±0.48 (7.6)	3.31±0.05 (9.1)
Fruits	22.05±8.17 (14.0)	10.33±2.49 (5.4)	3.53±1.40 (14.8)	1.81±0.45 (5.8)	0.09±0.02 (1.6)	22.21±8.83 (18.0)	11.07±2.96 (5.9)	0.52±0.08 (1.4)
Total	157.45	190.85	23.88	31.88	5.55	123.50	187.05	36.30

Values in the parentheses indicate the percentage of the total for each category

#### 4.7.1.1 Nitrogen (N)

It is evident from the data given in table 27 that the tree species with their components absorbed N to varying levels in the systems. In HAG and HSP systems, Prunus domestica showed the maximum uptake of N into its leaves as well as fruits and the same was reflected in over all accumulation values. Grewia optiva ranked next to P. domestica in HSP and third in GL systems due to higher amounts of N accumulation into the leaves and branches. But Toona ciliata showed more N uptake among the timber/fuelwood species mostly through the leaves and bole in its respective systems. Celtis australis following G. optiva accumulated more N in leaves and branches to reflect the over all uptake in HSP system. Albizia stipulata in GL system absorbed the maximum N in a similar fashion to C. australis.

#### 4.7.1.2 Phosphorus (P)

P uptake was also noticed to vary with species, tree components and system (Table 28). The pattern of P uptake was identical with N for most of the species viz. P. domestica (in HAG and HSP system), G. optiva and T. ciliata (in HSP system). In GL system, maximum amount of P was absorbed by T. ciliata through the leaves and bole and it was followed by A. stipulata by virtue of its branches and leaves.

Table 77: Annual nitrogen (N) accumulation (kg ha<sup>-1</sup>) in free components (species-wise)

Tree species	Bole			Branch			Leaf			Fruit			Total		
	HAG	HSP	GL	HAG	HSP	GL	HAG	HSP	GL	HAG	HSP	GL	HAG	HSP	GL
	Systems:			Systems:			Systems:			Systems:			Systems:		
<b>A. Fodder Trees</b>															
1. <i>Albizia stipulata</i> (Forb.) Boiv.	-	0.102	0.466	-	0.072	0.020	-	0.918	0.960	-	-	1.972	-	0.707	1.046
2. <i>Bambusa variegata</i> L.	-	0.066	0.136	-	0.100	1.123	-	0.461	0.457	-	-	0.707	-	3.466	0.854
3. <i>Celtis australis</i> L.	-	1.134	0.132	-	2.218	0.266	-	1.546	0.707	-	-	0.827	-	0.827	1.105
5. <i>Morus serrata</i> Forb.	-	0.079	0.023	-	0.130	0.116	-	0.538	0.533	-	-	0.807	-	0.807	0.678
<b>B. Timber/Fuelwood Trees</b>															
6. <i>Acacia catechu</i> (L.f.) Willd.	-	0.073	-	-	0.023	0.023	-	0.550	0.496	-	-	0.757	-	0.757	0.639
7. <i>Bombax ceiba</i> L.	-	0.176	0.114	-	0.031	0.023	-	0.111	-	-	-	0.159	-	-	-
8. <i>Balbesgia sisson</i> Forb.	-	0.062	0.013	-	0.011	0.006	-	0.376	0.222	-	-	0.449	-	0.449	0.241
9. <i>Ficus palmata</i> Forst.	-	0.008	0.008	-	0.015	0.021	-	0.240	0.307	-	-	0.345	-	0.345	0.496
10. <i>Pinus roxburghii</i> Ser.	-	0.146	0.087	-	0.043	0.029	-	0.727	0.490	-	-	0.316	-	0.316	0.606
11. <i>Platycladus integririma</i> Stewart ex Brandis	-	0.042	0.025	-	0.018	0.012	-	0.422	0.297	-	-	0.482	-	0.482	0.334
12. <i>Prunus pindana</i> Forb.	-	0.067	0.022	-	0.021	0.007	-	0.514	0.163	-	-	0.602	-	0.602	0.192
13. <i>Pyrus pashia</i> Buch.-Ham. ex D. Don	-	0.015	0.037	-	0.005	0.011	-	0.102	0.253	-	-	0.122	-	0.122	0.301
14. <i>Sapota insigne</i> Penh.	-	1.760	0.315	-	0.352	0.006	-	5.237	1.305	-	-	7.349	-	7.349	1.706
15. <i>Yoonia ciliata</i> M.J. Roen	-	0.144	-	-	0.242	-	-	2.539	-	-	-	1.370	-	4.295	-
<b>C. Fruit Trees</b>															
16. <i>Prunus amygdalus</i> Batsch.	-	0.400	0.274	-	0.384	0.204	-	6.153	2.950	-	-	3.557	-	10.502	5.044
17. <i>Prunus armeniaca</i> L.	-	1.730	0.537	-	1.512	0.576	-	22.122	7.842	-	-	16.284	-	41.650	14.670
18. <i>Prunus domestica</i> L.	-	0.030	0.041	-	0.107	0.005	-	0.977	0.743	-	-	1.031	-	2.153	1.607
19. <i>Prunus persica</i> (L.) Batsch.	-	0.019	0.008	-	0.022	0.010	-	0.267	0.109	-	-	0.950	-	1.258	0.533
20. <i>Punica granatum</i> L.	-	0.095	0.507	-	0.090	0.300	-	0.684	2.790	-	-	0.388	-	1.257	5.000
21. <i>Pyrus communis</i> L.	-	0.095	0.507	-	0.090	0.300	-	0.684	2.790	-	-	0.388	-	1.257	5.000



#### 4.7.1.3 Potassium (K)

Annual uptake of K was found to change with species and their components in the systems (Table 29). Like N and P, P. domestica recorded the highest K absorption mostly by fruits and leaves in the respective systems. Prunus armeniaca absorbed more K following P. domestica in HAG system but by means of leaves and fruits. C. optiva was able to show its second highest K uptake through a descending sequence of its branches, bole and leaves in HSP system. T. ciliata and A. stipulata followed a descending order of K absorption in GL system by means of leaves and bole in the former species whereas by branches and leaves in the latter.

#### 4.7.1.4 Tree groups

Annual N, P and K accumulation in the tree components pertaining to different groups and systems has been presented in table 30.

The tree groups (viz. fodder, timber/fuelwood and fruit trees) as well as their components differed in respect of annual nutrient allocation in the systems. Fruit trees in HAG system exclusively accumulated the highest amounts of nutrient (N 59.945, P 9.680 and K 50.544 kg ha<sup>-1</sup>yr<sup>-1</sup>). They also accumulated the highest amounts of N, P and K in HSP system representing 51.5, 58.1 and 58.4 per cent of the total N, P and K, respectively while



Table 30: Annual nutrient accumulation (kg ha<sup>-1</sup>) in tree components (group-wise)

Tree species and components	N				P				K			
	Systems:		Nutrients:		Systems:		Nutrients:		Systems:		Nutrients:	
	HAG	HSP	GL	HAG	HSP	GL	HAG	HSP	GL	HAG	HSP	GL
<b>A. Fodder Trees</b>												
Boles		1.917	0.321		0.298	0.050		2.565	0.403		2.565	0.403
Branches		4.924	1.609		0.797	0.249		4.444	1.342		4.444	1.342
Leaves		8.138	3.169		0.693	0.219		3.089	0.968		3.089	0.968
Fruits												
Subtotal		14.979	5.099		1.788	0.518		10.098	2.713		(24.5)	(40.0)
		(27.8)	(45.0)		(23.1)	(39.4)						
<b>B. Timber/Fuelwood Trees</b>												
Boles		2.399	0.774		0.507	0.130		2.624	0.840		2.624	0.840
Branches		0.503	0.224		0.086	0.061		0.433	0.207		0.433	0.207
Leaves		8.279	4.235		0.868	0.462		3.964	2.120		3.964	2.120
Fruits												
Subtotal		11.181	5.233		1.461	0.653		7.021	3.167		(17.0)	(46.7)
		(20.7)	(46.2)		(18.8)	(49.6)						
<b>C. Fruit Trees</b>												
Boles		2.495	0.044		0.170	0.006		1.952	1.115		1.115	0.041
Branches		2.335	0.042		0.222	0.006		1.673	1.064		1.064	0.047
Leaves		32.475	0.350		2.268	0.038		24.042	10.571		10.571	0.288
Fruits		22.640	10.544		1.846	0.095		22.877	11.313		11.313	0.528
Subtotal		59.945	0.991		4.506	0.145		50.544	24.063		24.063	0.904
		(100.00)	(8.8)		(58.1)	(11.0)		(100.00)	(58.4)		(58.4)	(13.3)
Total		59.945	11.323		7.755	1.316		50.544	41.182		41.182	6.784

Values in the parentheses indicate the percentage of the total for each category

the timber/fuelwood trees presented the lowest quantities of each of the nutrients. But in GL system, timber/fuelwood trees showed the maximum amount of N constituting 46.2 per cent of the system accumulation and they were closely followed by fodder trees (45.0%). P and K accumulation also followed an identical trend with N.

#### 4.7.1.5 Tree components and systems

Data on N, P and K accumulation in the various systems along with the tree components are given in table 31.

In general, annual P accumulation was less than N and K in all the systems. The pattern of uptake was:  $N > K > P$ . Accumulation of N, P and K in HAG and HSP systems was approximately the same; it was much higher than that of GL system. For example, the rate of uptake in HAG system was 5.3-, 7.3- and 7.4-fold higher for N, P and K, respectively, than in GL system. In all the systems, maximum quantities of all the three nutrients were absorbed into the leaves followed by that into fruits except GL system where branches absorbed more following the leaves.

#### 4.7.2 Agricultural crops

##### 4.7.2.1 Kharif crops and weeds

The amount of nutrient accumulated in the Kharif crops and their weed associates has been presented in tables 32, 33 and 34.

Table 31: Annual nutrient accumulation ( $\text{kg ha}^{-1}$ ) in the tree components (system-wise)

Components	N			P			K		
	Nutrients:			P			K		
	HAG	HSP	GL	HAG	HSP	GL	HAG	HSP	GL
Bolles	2.495±0.084 (4.2)	5.644±0.216 (10.5)	1.139±0.039 (10.0)	0.313±0.128 (3.2)	0.975±0.050 (12.6)	0.186±0.009 (14.1)	1.952±0.677 (3.9)	6.304±0.277 (15.3)	1.284±0.049 (18.9)
Branches	2.335±0.742 (3.9)	6.694±0.283 (12.4)	1.075±0.110 (16.5)	0.406±0.144 (4.2)	1.105±0.052 (14.2)	0.316±0.015 (24.0)	1.673±0.507 (3.3)	5.941±0.282 (14.4)	1.596±0.080 (23.5)
Leaves	32.475±11.206 (54.2)	31.071±1.034 (57.5)	7.754±0.594 (68.5)	5.324±2.027 (55.0)	3.029±0.160 (49.4)	0.719±0.014 (54.6)	24.042±7.694 (47.6)	17.624±0.622 (42.0)	3.376±0.055 (49.8)
Fruits	22.640±0.320 (37.7)	10.544±2.544 (19.6)	0.555±0.150 (4.9)	3.637±1.425 (37.6)	1.846±0.457 (23.8)	0.095±0.010 (7.2)	22.077±9.023 (45.2)	11.313±3.026 (27.5)	0.528±0.076 (7.8)
Total	59.945±21.137	53.899±1.020	11.323±0.931	9.680±3.723	7.755±0.305	1.316±0.027	50.544±17.019	41.182±1.511	6.784±0.127

Values in the parentheses indicate the percentage of the total for each category

The crops and weeds accumulated more N but with wider variation from 37.352 to 89.626 and 0.145 to 16.80 kg ha<sup>-1</sup> in AG system than in HAG (Table 32). Among the crops, Lycopersicon esculentum removed the highest amount of N in both the systems followed by Zea mays and Zingiber officinale. The amounts absorbed by the grains/fruits and vegetative parts were specific to the crops and their respective systems. More N accumulation by weeds was observed in AG than that in HAG system with all crops except L. esculentum. Weeds associated with Z. mays had the highest N accumulation in both the systems while the minimum being with Z. officinale. Among the weed species, Echinochloa crusgalli absorbed the maximum amount of N (16.80 kg ha<sup>-1</sup>) contributing about 46.0 per cent of their total uptake in association with Z. mays in AG system.

Uptake of P was also observed to vary with crops and weeds in their respective systems (Table 33).

P uptake ranged from 8.061 in Z. officinale to 23.621 in Z. mays for crops and 0.014 in Cynodon dactylon to 0.988 kg ha<sup>-1</sup> in Galinsoga parviflora for weeds in AG system. The range was comparatively narrow with lesser values of the extremes in HAG system. Weeds accumulated higher amount of P in AG as compared to HAG system with all crops except L. esculentum. Accumulation by weeds was the highest with Z. mays in both the systems and the lowest with Z. officinale.

Table 32: Nitrogen accumulation ( $\text{kg ha}^{-1}$ ) in Kharif crops and weeds

Plant species	AG						BAG							
	Systems:			Systems:			Systems:			Systems:				
	C-1	C-2	C-3	C-1	C-2	C-3	Total	C-1	C-2	C-3	C-1	C-2	C-3	Total
<b>A. Agricultural Crops (C)</b>														
Nitrogen ( $\text{kg ha}^{-1}$ ): Grain/Fruit														
1. <i>Lycopersicon esculentum</i> L.	81.876	-	-	7.800	-	-	89.676	37.338	-	-	5.140	-	-	42.486
2. <i>zea mays</i> L.	-	26.795	-	-	37.858	-	59.645	-	12.705	-	-	23.700	-	36.405
3. <i>Zingiber officinale</i> Rosc.	-	-	21.182	-	-	16.170	37.352	-	-	-	19.773	-	-	36.900
Subtotal	81.876	26.795	21.182	7.800	32.858	16.170	-	37.338	12.705	19.773	5.140	23.700	17.135	-
<b>B. Weeds</b>														
4. <i>Commelina benghalensis</i> L.	-	-	-	0.404	2.828	0.404	-	-	-	-	0.205	2.450	0.410	-
5. <i>Cyperus rotundus</i> L.	-	-	-	0.188	0.940	0.188	-	-	-	-	0.182	0.720	-	-
6. <i>Synodon dactyloides</i> (L.) Pers.	-	-	-	-	0.145	-	-	-	-	-	-	-	-	-
7. <i>Dactyloctenium aegyptium</i> (L.) Scop.	-	-	-	0.456	7.600	-	-	-	-	-	-	1.510	-	-
8. <i>Eleusine indica</i> (L.) Gaertn.	-	-	-	0.588	1.372	0.196	-	-	-	-	0.404	3.015	0.402	-
9. <i>Chenopodium album</i> (L.) Beauv.	-	-	-	0.720	16.800	0.480	-	-	-	-	2.169	11.560	0.241	-
10. <i>Eleusine indica</i> (L.) Gaertn.	-	-	-	2.052	1.076	-	-	-	-	-	2.366	-	-	-
11. <i>Galinsoga parviflora</i> Cav.	-	-	-	0.999	5.772	0.333	-	-	-	-	0.981	2.507	0.327	-
Subtotal	-	-	-	5.407	36.403	1.601	-	-	-	-	6.707	21.700	1.300	-
Total	81.876	26.795	21.182	13.207	69.333	17.771	-	37.338	12.705	19.773	11.055	45.400	18.515	-

Table 33: Phosphorus accumulation (kg ha<sup>-1</sup>) in Kharif crops and weeds

Plant species	RAC												
	AG					BAG							
	Phosphorus(kg ha <sup>-1</sup> ):Grain/Fruit					Phosphorus(kg ha <sup>-1</sup> ):Vegetative							
Crops:	C-1	C-2	C-3	Total	C-1	C-2	C-3	Total	C-1	C-2	C-3	Total	
<b>A. Agricultural Crops(C)</b>													
1. <i>Lycopersicon esculentum</i> L.	17.684	-	-	1.288	18.884	7.791	-	-	8.832	-	-	-	8.832
2. <i>zea mays</i> L.	-	11.417	-	12.284	23.621	-	5.145	-	9.796	-	-	-	14.941
3. <i>Zingiber officinale</i> Rosc.	-	-	4.886	-	8.861	-	-	5.239	-	3.688	-	-	8.919
Subtotal	17.684	11.417	4.886	12.284	32.255	7.791	5.145	5.239	8.832	9.796	3.688	-	
<b>B. Weeds</b>													
4. <i>Commelina benghalensis</i> L.	-	-	-	8.834	8.834	-	-	-	8.816	0.192	0.832	-	
5. <i>Cyperus rotundus</i> L.	-	-	-	8.816	8.816	-	-	-	8.814	0.056	-	-	
6. <i>Cynodon dactylon</i> (L.)Pers.	-	-	-	8.814	8.814	-	-	-	-	-	-	-	
7. <i>Digitaria sanguinalis</i> (L.) Scop	-	-	-	8.848	8.848	-	-	-	-	8.168	-	-	
8. <i>Echinochloa colona</i> (L.)Link.	-	-	-	8.851	8.851	-	-	-	8.864	8.248	0.832	-	
9. <i>Echinochloa crusgalli</i> (L.) Beauv.	-	-	-	8.836	8.848	-	-	-	8.117	8.624	8.813	-	
10. <i>Gleusine indica</i> (L.) Gaertn.	-	-	-	8.128	8.868	-	-	-	8.196	-	-	-	
11. <i>Gallusoga parviflora</i> Cav.	-	-	-	8.171	8.888	-	-	-	8.162	8.414	8.554	-	
Subtotal	-	-	-	8.476	3.139	8.248	-	-	8.569	1.686	8.171	-	
Total	17.684	11.417	4.886	17.756	15.343	3.583	7.791	5.145	5.239	14.481	11.482	3.811	

K uptake patterns are given in table 34. The crops other than Z. officinale absorbed approximately same amount (63.806 and 63.947 kg ha<sup>-1</sup>) but more than the latter of total K in AG system. In contrast, Z. officinale accumulated more K (53.962 kg ha<sup>-1</sup>) in HAG nearly equal to the former system than those of the two crops. In general, higher K absorption by weeds was observed in AG system. Weeds associated with Z. mays showed the maximum uptake of 26.475 and 15.688 kg ha<sup>-1</sup> out of which E. crusgalli exclusively accounted for about 58.4 and 66.7 per cent of the total uptake by weeds in AG and HAG systems, respectively. Weed species differed in their uptake with associated crops and systems.

#### 4.7.2.2 Rabi crops and weeds

The uptake patterns of N, P and K by Rabi crops and their associated weeds are presented in tables 35, 36 and 37.

All the Rabi crops removed comparatively less N in HAG than in AG system (Table 35). Pisum sativum recorded the highest uptake of 106.392 and 101.889 kg ha<sup>-1</sup> N in AG and HAG systems, respectively. It accumulated about 2.6- and 3.0-fold higher N irrespective of the systems than Hordeum vulgare and Triticum aestivum, respectively. In general, the grains/fruits of the crops removed more than their vegetative parts. Weeds associated with the cereals showed higher N removal ranging from 3.5 to 5.6 time as compared to the legume crop. For example, weeds growing

Table 34: Potassium accumulation ( $\text{kg ha}^{-1}$ ) in Kharif crops and weeds

Plant species	AG						BAG									
	Systems:			Systems:			Systems:			Systems:						
	Potassium( $\text{kg ha}^{-1}$ ):			Potassium( $\text{kg ha}^{-1}$ ):			Potassium( $\text{kg ha}^{-1}$ ):			Potassium( $\text{kg ha}^{-1}$ ):						
Crops:	Grain/Fruit		Vegetative		Total	Grain/Fruit		Vegetative		Total	Grain/Fruit		Vegetative		Total	
	C-1	C-2	C-3	C-1		C-2	C-3	C-1	C-2		C-3	C-1	C-2	C-3		C-1
<b>A. Agricultural Crops(C)</b>																
1. <i>Lycopersicon esculentum</i> L.	59.006	-	-	4.800	-	-	63.806	26.754	-	-	3.190	-	-	-	-	29.952
2. <i>Zea mays</i> L.	-	14.679	-	-	49.268	-	63.947	-	7.140	-	-	36.444	-	-	-	41.504
3. <i>Zingiber officinale</i> Rosc.	-	-	30.616	-	-	23.100	53.716	-	-	29.237	-	-	-	-	24.725	53.962
Subtotal	59.006	14.679	30.616	4.800	49.268	23.100	-	26.754	7.140	29.237	3.190	36.444	24.725	-	-	-
<b>B. Weeds</b>																
4. <i>Convolvulus bengalensis</i> L.	-	-	-	0.130	0.910	0.130	-	-	-	-	0.062	0.744	0.124	-	-	-
5. <i>Cyperus rotundus</i> L.	-	-	-	0.217	1.005	0.217	-	-	-	-	0.223	0.092	-	-	-	-
6. <i>Cynodon dactylon</i> (L.) Pers.	-	-	-	-	6.189	-	-	-	-	-	-	-	-	-	-	-
7. <i>Digitaria sanguinalis</i> (L.) Scop.	-	-	-	0.204	3.400	-	-	-	-	-	-	0.620	-	-	-	-
8. <i>Echinochloa colonum</i> (L.) Link.	-	-	-	0.351	0.819	0.117	-	-	-	-	0.356	1.335	0.178	-	-	-
9. <i>Echinochloa crusgalli</i> (L.) Beauv.	-	-	-	0.663	15.470	0.442	-	-	-	-	1.962	10.464	0.218	-	-	-
10. <i>Mesquite indica</i> (L.) Gaertn.	-	-	-	2.028	1.014	-	-	-	-	-	2.394	-	-	-	-	-
11. <i>Gallinsoga parviflora</i> Cav.	-	-	-	0.621	3.588	0.207	-	-	-	-	0.090	1.633	0.213	-	-	-
Subtotal	-	-	-	4.214	26.475	1.113	-	-	-	-	5.007	15.600	0.733	-	-	-
Total	59.016	14.679	30.616	9.014	75.743	24.213	-	26.754	7.140	29.237	8.285	50.132	25.458	-	-	-



with T. aestivum had 5.6-fold higher uptake than P. sativum in HAG system representing 33.1 per cent of the total uptake. Similarities in their uptake behaviour were observed in both the systems for all the crops. On an average, Medicago denticulata, Vicia faba and Avena fatua appeared as prominent weed species in respect of N removal.

All the three Rabi crops differed with their P uptake being low in HAG system (Table 36). Among the crops, H. vulgare removed at least 1.6 time more P than the other crops in the systems. Removal of P by the weeds was higher in AG system except their association with H. vulgare. Among the weeds, Phalaris minor and M. denticulata were the dominant species with T. aestivum and absorbed the maximum of 0.380 and 0.456 kg ha<sup>-1</sup> P in AG and HAG systems, respectively.

Data on K accumulation given in table 37 reflect that T. aestivum accumulated the highest K amounting 40.427 and 38.902 kg ha<sup>-1</sup> in AG and HAG systems, respectively. A similar trend was also exhibited by the other two crops. Associated weeds of P. sativum absorbed the minimum when compared with the maximum amount of K with T. aestivum in both the systems. Among the weed species, P. minor accounted for the highest K absorption of 6.020 and 4.410 kg ha<sup>-1</sup> in AG and HAG systems, respectively, followed by A. fatua in association with T. aestivum.



Table 37. Potassium accumulation ( $\text{kg ha}^{-1}$ ) in Rabi crops and weeds

Plant species	Systems:				HAS								
	AB				HAS								
	Potassium ( $\text{kg ha}^{-1}$ )		Total		Grain/Fruit		Vegetative		Total				
C-1	C-2	C-3	C-1	C-2	C-3	C-1	C-2	C-3	C-1	C-2	C-3		
<b>A. Agricultural Crops(C)</b>													
1. <i>Hordeum vulgare</i> L.	9.464	-	-	25.784	-	-	35.248	9.982	-	21.750	-	31.732	
2. <i>Pisum sativum</i> L. var. <i>arvense</i> L.	-	19.580	-	17.544	-	-	37.124	-	18.492	-	17.384	35.796	
3. <i>Trifolium aestivum</i> L.	-	-	8.648	-	-	31.779	48.427	-	-	8.268	-	38.982	
Subtotal	9.464	19.580	8.648	25.784	17.544	31.779	-	9.982	18.492	8.268	21.750	17.384	38.634
<b>B. Weeds</b>													
4. <i>Arcanotoma mexicana</i> L.	-	-	-	0.143	-	0.429	-	-	-	0.150	-	0.150	
5. <i>Avena fatua</i> L.	-	-	-	2.168	-	4.336	-	-	-	1.968	-	4.200	
6. <i>Chenopodium album</i> L.	-	-	-	0.562	0.562	0.843	-	-	-	-	0.566	0.566	
7. <i>Lathyrus aphaca</i> L.	-	-	-	0.681	0.227	0.681	-	-	-	0.639	0.426	0.639	
8. <i>Linum catharticum</i> Heyne.	-	-	-	0.384	-	0.384	-	-	-	0.875	-	0.875	
9. <i>Medicago denticulata</i> Willd.	-	-	-	2.464	0.924	2.618	-	-	-	2.664	0.888	3.552	
10. <i>Melilotus alba</i> Medit.	-	-	-	0.284	0.142	0.284	-	-	-	0.278	0.139	0.278	
11. <i>Phalaris minor</i> Retz.	-	-	-	3.010	-	6.020	-	-	-	2.940	-	4.410	
12. <i>Pubia cordifolia</i> L.	-	-	-	-	0.211	-	-	-	-	-	-	-	
13. <i>Vicia faba</i> L.	-	-	-	2.532	0.211	2.743	-	-	-	2.982	0.213	2.556	
Subtotal	-	-	-	11.844	2.861	17.954	-	-	-	11.613	2.307	16.351	
Total	9.464	19.580	8.648	37.628	20.405	49.733	-	9.982	18.492	8.268	33.363	19.611	46.985

#### 4.7.2.3 Kharif - Rabi crops and weeds

Total nutrients accumulated by Kharif - Rabi crops and their respective weeds under tentative crop combinations in AG and HAG systems are given in tables 38, 39 and 40.

Data given in table 38 pertaining to annual N accumulation reveal that in AG system, removal ( $148.928 \text{ kg ha}^{-1} \text{ yr}^{-1}$ ) was 1.3-fold higher than in HAG system ( $117.047 \text{ kg ha}^{-1} \text{ yr}^{-1}$ ) mostly through the grains/fruits of the agricultural crops followed by their vegetative parts and then weeds. Irrespective of the system, Z. mays - P. sativum and Z. officinale - T. aestivum removed the maximum and minimum amounts of N annually.

Like N, P removal was also higher in AG system by almost equal rate but at least 4.4 time less than N (Table 39). The crop combination, Z. mays - H. vulgare could remove the highest amounts of 48.155 and 35.123  $\text{kg ha}^{-1} \text{ yr}^{-1}$  in AG and HAG systems, respectively. Lowest amount was shared by Z. officinale - T. aestivum/P. sativum. The crops averaged out about 93.0 per cent of the total uptake.

Data on annual removal of K by different crop combinations as given in table 40 signified its comparatively higher removal in AG system than that in HAG system but with a lesser extent to N and P. Z. mays - T. aestivum recorded the maximum absorption of 148.803 and 112.525  $\text{kg ha}^{-1} \text{ yr}^{-1}$  while P. sativum following Z. officinale and L.

Table 38: Nitrogen accumulation ( $\text{kg ha}^{-1} \text{yr}^{-1}$ ) in Kharif-Rabi crops and associated weeds under tentative crop combinations

Kharif-Rabi

Crops

Systems:

Nitrogen* ( $\text{kg ha}^{-1}$ )	AG				HAG			
	Grain/Fruit	Vegetative	Weeds	Total	Grain/Fruit	Vegetative	Weeds	Total
T	81.826	7.800	5.407	149.429	37.338	5.148	6.707	101.401
+ B	26.208	15.822	12.366		23.823	16.240	12.945	
T	81.826	7.800	5.407	204.914	37.338	5.148	6.707	153.964
+ P	66.660	39.732	3.489		62.913	38.976	2.822	
T	81.826	7.800	5.407	147.425	37.338	5.148	6.707	97.681
+ V	24.816	11.286	16.290		21.147	11.271	16.870	
M	26.795	32.850	36.484	150.524	12.705	23.700	21.780	110.401
+ B	26.208	15.822	12.366		23.823	16.240	12.945	
M	26.795	32.850	36.483	206.009	12.705	23.700	21.780	162.994
+ P	66.660	39.732	3.489		62.913	38.976	2.822	
M	26.795	32.850	36.483	148.520	12.705	23.700	21.780	106.681
+ V	24.816	11.286	16.290		21.147	11.271	16.870	
G	21.182	16.170	1.601	93.349	19.773	17.135	1.300	90.496
+ B	26.208	15.822	12.366		23.823	16.240	12.934	
G	21.182	16.170	1.601	140.834	19.773	17.135	1.300	143.059
+ P	66.660	39.732	3.489		62.913	38.976	2.822	
G	21.182	16.170	1.601	91.345	19.773	17.135	1.300	86.776
+ V	24.816	11.286	16.290		21.147	11.271	16.870	
Pooled mean**	82.496	41.220	25.212	148.928	58.966	37.490	28.591	117.047

\* Nitrogen accumulation calculated as a sole crop on the basis of sample

\*\* Average nitrogen accumulation irrespective of crop combination

T = Lycopersicon esculentum;

B = Hordeum vulgare

M = Tea;

P = Pisum sativum

G = Zingiber officinale;

V = Triticum aestivum

Table 39: Phosphorus accumulation ( $\text{kg ha}^{-1}\text{yr}^{-1}$ ) in Kharif-Rabi crops and associated weeds under tentative crop combinations

Kharif-Rabi Crops		AG				HAG			
Systems:	Grain/Fruit	Vegetative	Weeds	Total	Grain/Fruit	Vegetative	Weeds	Total	
Phosphorus* ( $\text{kg ha}^{-1}$ )									
T	17.604	1.200	0.476	40.755	7.791	0.832	0.569	27.620	
+									
B	8.554	11.720	1.121		6.923	10.440	1.133		
T	17.604	1.200	0.476	31.977	7.791	0.832	0.569	20.796	
+									
P	7.920	4.300	0.397		6.834	4.032	0.320		
T	17.604	1.200	0.776	31.529	7.791	0.832	0.569	20.759	
+									
V	6.760	3.861	1.540		6.042	4.046	1.479		
M	11.417	12.204	3.139	40.155	5.145	9.796	1.606	25.120	
+									
B	8.554	11.720	1.121		6.923	10.440	1.133		
M	11.417	12.204	3.139	39.377	5.145	9.796	1.606	27.821	
+									
P	7.920	4.300	0.397		6.834	4.032	0.320		
M	11.417	12.204	3.139	31.929	5.145	9.796	1.606	28.194	
+									
V	6.760	3.861	1.540		6.042	4.046	1.479		
G	4.006	3.255	0.240	29.704	5.239	3.600	0.131	27.546	
+									
B	8.554	11.720	1.121		6.923	10.440	1.133		
G	4.006	3.255	0.240	20.926	5.239	3.600	0.131	20.244	
+									
P	7.920	4.300	0.397		6.834	4.032	0.320		
G	4.006	3.255	0.240	20.478	5.239	3.600	0.131	20.617	
+									
V	6.760	3.861	1.540		6.042	4.046	1.479		
Pooled mean**	19.023	12.207	2.307	33.537	12.658	10.942	1.775	25.375	

\* Phosphorus accumulation calculated as a sole crop on the basis of sample

\*\* Average phosphorus accumulation irrespective of crop combination

T = Lycopersicon esculentum; B = Hordeum vulgare  
M = Tea sags; P = Pisum sativum  
C = Zingiber officinale; V = Triticum aestivum

Table 40: Potassium accumulation ( $\text{kg ha}^{-1} \text{yr}^{-1}$ ) in Kharif-Rabi crops and associated weeds under tentative crop combinations

Systems:	AG				HAG			
	Grain/Fruit ( $\text{kg ha}^{-1}$ )	Vegetative	Weeds	Total	Grain/Fruit	Vegetative	Weeds	Total
T	52.006	4.800	4.214	100.112	26.754	3.198	5.007	70.384
F								
B	9.464	25.784	11.844		9.982	21.750	11.613	
T	52.006	4.800	4.214	101.005	26.754	3.198	5.007	73.142
F								
P	19.500	17.544	2.861		18.492	17.304	2.307	
T	52.006	4.800	4.214	119.401	26.754	3.198	5.007	92.292
F								
V	8.648	31.779	17.954		8.268	30.634	16.351	
M	14.679	49.268	26.475	137.514	7.140	34.444	15.680	100.617
F								
B	9.464	25.784	11.844		9.982	21.750	11.613	
M	14.679	49.268	26.475	130.407	7.140	34.444	15.680	95.375
F								
P	19.500	17.544	2.861		18.492	17.304	2.307	
M	14.679	49.268	26.475	140.803	7.140	34.444	15.680	112.525
F								
V	8.648	31.779	17.954		8.268	30.634	16.351	
G	30.616	23.100	1.113	101.921	29.237	24.725	0.733	98.040
F								
B	9.464	25.784	11.844		9.982	21.750	11.613	
G	30.616	23.100	1.113	94.814	29.237	24.725	0.733	92.793
F								
P	19.500	17.544	2.861		18.492	17.304	2.307	
G	30.616	23.100	1.113	113.210	29.237	24.725	0.733	109.940
F								
V	8.648	31.779	17.954		8.268	30.634	16.351	
Pooled mean**	44.997	50.758	21.487	117.243	33.291	44.810	17.260	94.569

\* Potassium accumulation calculated as a sole crop on the basis of sample

\*\* Average potassium accumulation irrespective of crop combination

T = Lycopersicon esculentum; B = Hordeum vulgare  
M = Tea mays; P = Pisum sativum  
G = Zingiber officinale; V = Triticum aestivum

esculentum absorbed the minimum in AG and HAG systems, respectively. Vegetative parts of the crops played the major role for K absorption.

#### 4.7.3 Grasses

Data on N, P and K absorption by the grasses and their herbaceous associates annually in their respective systems are displayed in table 41.

A perusal of the data reveals that the grasses and their associates absorbed more N, P and K in GL than in HSP system. The order of removal was:  $N > K > P$ . The grasses constituted about 87.7 to 91.7 per cent of the total N, P and K uptake.

The nutrient removal differed with species and systems. For example, in GL system, the grass species were found to vary in their extent of N uptake from 0.123 to 8.010 whereas in HSP system it varied from 0.120 to 5.892 kg ha<sup>-1</sup> yr<sup>-1</sup>. Chrysopogon montanus and Apluda mutica were the prominent grass species for their distinction in NPK uptake. Arundinella bengalensis in HSP and Heteropogon contortus in GL system appeared next to the aforesaid species contributing collectively about 62.0, 67.0 per cent of the total N and K removal by the grasses in both the systems. In respect of P uptake, Pennisetum orientale and H. contortus ranked third following C. montanus and A. mutica in HSP and GL systems, respectively and they formed a body

Table 41: Nutrient accumulation ( $\text{kg ha}^{-1} \text{yr}^{-1}$ ) in grasses and their herbaceous associates

Plant species	N		P		K	
	HSP	GL	HSP	GL	HSP	GL
<b>A. Grasses</b>						
1. <i>Apluda mutica</i> L.	5.669	6.133	1.308	1.483	5.545	6.066
2. <i>Arundinella bengalensis</i> (Sprong.) Druce	1.461	0.966	0.334	0.230	1.602	0.943
3. <i>Arundinella nepalensis</i> Trin.	0.927	0.260	0.196	0.059	1.014	0.282
4. <i>Bothriochloa odorata</i> (Lisboa) A. Camus	0.428	1.132	0.106	0.258	0.391	1.082
5. <i>Capillipedium assimile</i> (Steud.) A. Camus	1.008	1.361	0.216	0.312	0.996	1.378
6. <i>Chrysopogon montanus</i> Koen. ex Trin.	5.892	8.010	1.456	1.958	5.230	7.921
7. <i>Cymbopogon martinii</i> (Roxb.) Wats.	0.264	0.905	0.056	0.187	0.251	0.853
8. <i>Heteropogon contortus</i> (L.) P. Beauv.	1.065	1.730	0.234	0.391	0.995	1.544
9. <i>Imperata cylindrica</i> (L.) P. Beauv.	0.120	-	0.030	-	0.130	-
10. <i>Microstegium vagans</i> (Nees) A. Camus	0.392	0.123	0.095	0.031	0.387	0.120
11. <i>Mnesithea laevis</i> (Retz.) Kunth.	-	0.173	-	0.044	-	0.158
12. <i>Pennisetum orientale</i> L. C. Rich	1.428	0.570	0.386	0.147	1.243	0.529
13. <i>Sorghum halepense</i> (L.) Pers.	0.856	0.874	0.212	0.209	0.745	0.770
14. <i>Themeda anathera</i> (Nees) Hack.	1.416	1.544	0.307	0.315	1.329	1.527
Subtotal	20.926 $\pm$ 1.150	23.781 $\pm$ 1.457	4.936 $\pm$ 0.277	5.624 $\pm$ 0.356	19.831 $\pm$ 1.071	23.173 $\pm$ 1.455
<b>B. Climbers</b>						
	1.621	2.166	0.183	0.235	0.737	1.009
<b>C. Sedges</b>						
	0.096	0.106	0.019	0.022	0.100	0.107
<b>D. Weeds</b>						
	0.990	1.049	0.294	0.300	0.960	1.081
Total	23.633 $\pm$ 0.932	27.102 $\pm$ 1.176	5.432 $\pm$ 0.225	6.181 $\pm$ 0.287	21.628 $\pm$ 0.872	25.370 $\pm$ 1.166

of 63.8 and 68.1 per cent each of the total in their respective systems. The herbaceous associates viz. climbers, sedges and weeds used to absorb the highest percentage by 12.2 of the total N and the lowest being with K by 8.3 per cent in GL and HSP systems, respectively.

#### 4.7.4 Trees and herbaceous components

Over all nutrient uptake estimated on the basis of annual productivity of the ecounits in their respective systems has been summarised in table 42.

It is evident from the table that the systems had followed the sequence of annual N, P and K accumulation rate as: HAG > AG > HSP > GL. The amount of nutrients taken up by the vegetation ranged from 38.375 to 176.992 for N, 7.497 to 35.055 for P and 32.154 to 145.113 kg ha<sup>-1</sup>yr<sup>-1</sup> for K. The rate of uptake by the agricultural crops was estimated to be higher (N 123.716, P 31.230 and K 95.755 kg ha<sup>-1</sup>yr<sup>-1</sup>) in AG than in HAG system and most of them were allocated towards the grains/fruits. The uptake pattern of the weeds in AG and HAG systems was similar to the agricultural crops and they removed from 5.1 to 18.3 per cent of the total system's uptake. The trees removed the higher amounts of nutrients (N 59.945, P 9.680 and K 50.544 kg ha<sup>-1</sup>yr<sup>-1</sup>) in HAG as compared to HSP and GL system, the largest portion being absorbed by their leaves. In contrast, trees in HSP system showed the highest percentage of the total uptake. For example, 69.5 per cent N

Table 42: Nutrients accumulation (kg ha yr<sup>-1</sup>) in trees and herbaceous components

Plant components	N			P			K		
	AG	HAG	HSP	AG	HAG	HSP	AG	HAG	HSP
<b>A. Trees</b>									
Bark	2,495	5,644	1,139	0.313	0.975	0.186	1.952	6.304	1.284
Branches	2,335	6,694	1,875	0.486	1.185	0.316	1.673	5.941	1.596
Leaves	32,475	31,017	7,754	3.324	3.029	0.719	24,642	17,624	3,376
Fruits	22,640	10,544	0,555	3.637	1.846	0.095	22,877	11,313	0,528
Subtotal	59,945 (33.9)	53,899 (69.5)	11,323 (23.5)	9.600 (27.6)	7.755 (58.9)	1.316 (17.6)	50,544 (34.8)	41,182 (55.6)	6,704 (21.1)
<b>B. Crops</b>									
Grains/Fruits	82,496	58,966		19,023	12,558		44,937	33,291	
Vegetative parts	41,220	37,430		12,207	10,942		50,758	44,018	
Subtotal	123,716 (83.1)	96,456 (54.5)		31,230 (93.1)	23,500 (57.3)		95,755 (81.7)	77,309 (53.3)	
<b>C. Herbs</b>									
Shoots	25,212	20,591	0,990	2,307	1,775	0,294	0,300	21,487	17,260
Subtotal	25,212 (16.9)	20,591 (11.6)	0,990 (1.3)	2,307 (6.7)	1,775 (5.1)	0,294 (2.2)	0,300 (4.0)	21,487 (18.3)	17,260 (11.9)
<b>D. Grasses</b>									
Shoots	20,926	23,781		4,936	5,624		19,831	23,173	
Subtotal	20,926 (27.0)	23,781 (62.0)		4,936 (37.4)	5,624 (75.0)		19,831 (31.6)	23,173 (72.1)	
<b>E. Climbers</b>									
Shoots	1,621	2,116		0,183	0,235		0,737	1,009	
Subtotal	1,621 (2.1)	2,116 (5.5)		0,183 (1.4)	0,235 (3.1)		0,737 (1.2)	1,009 (3.1)	
<b>F. Sedge</b>									
Shoots	0,896	0,106		0,019	0,022		0,100	0,107	
Subtotal	0,896 (8.1)	0,106 (0.3)		0,019 (8.1)	0,022 (8.3)		0,100 (8.1)	0,107 (8.3)	
<b>Total</b>	148,928	176,992	77,532	36,375	33,537	35,055	13,187	7,497	117,242
				145,113	62,810	32,154			

Values in the parentheses indicate the percentage of the total

contribution in HSP against 33.9 in HAG system was concentrated towards the tree component. The grasses in GL system absorbed major portion of nutrients (N 23.781, P 5.624 and K 23.173 kg ha<sup>-1</sup>yr<sup>-1</sup>) corresponding to 62.0, 75.0 and 72.1 per cent of the total and they had about 2-fold higher N, P and K on per cent basis when compared with HSP system. The maximum contribution of the weeds in these two systems never exceeded 4.0 per cent of the total uptake while the sedges and climbers managed to represent the highest per cent by 5.8 for N in GL system.

#### 4.8 CHEMICAL STATUS OF THE SOIL

Chemical characteristics of the soil were different in the ecosystems (Table 43). The pH was in the range of 6.3 to 7.3, increasing with the soil depth. It ascended from slightly acidic to mostly neutral in nature. AG system had the lowest and highest pH values in both the soil depths than in other systems.

In general, the soil was high in organic carbon, available P and K but low in available N. The nutrients irrespective of elements and systems showed a descending order from top to the bottom layer. In cultivated ecosystems (viz. AG and HAG), nutrient status was comparatively lower than the noncultivated (viz. HSP and GL) but in the lower layer this difference was not so pronounced. AG system retained the highest amount of available N but the lowest percentage of organic carbon and available P in the

Table 43: Chemical characteristics of the soil in the ecosystems

Chemical status	Systems				
	Soil depth (cm)	AG	HAG	HSP	GL
pH	0-30	6.3	6.4	6.7	6.6
	30-60	7.3	7.0	7.1	7.1
Organic carbon(%)	0-30	0.92	1.16	1.41	1.39
	30-60	0.70	0.88	0.83	0.79
Available N(kg ha <sup>-1</sup> )	0-30	195.0	221.0	295.0	269.0
	30-60	176.0	158.0	162.0	169.0
Available P(kg ha <sup>-1</sup> )	0-30	53.0	68.0	76.0	62.0
	30-60	43.0	46.0	47.0	51.0
Available K(kg ha <sup>-1</sup> )	0-30	382.0	400.0	441.0	448.0
	30-60	348.0	333.0	365.0	346.0

deeper layer as compared to other systems.

#### 4.9 GROSS ANNUAL RETURNS

Annual gross return of the components estimated with different systems has been briefly presented in table 44.

HAG system furnished the highest gross return amounting Rs.91,577.2 annually and approximated to AG system. The return was about 6.6- and 31.5-fold higher than those of HSP and GL systems, respectively. Agricultural crops were the major contributors even in HAG system providing 69.4 per cent of the total return mostly through their grains/fruits (98.0% of the crop). About 30.5 and 29.4 per cent of the total return of the said system corresponded to the trees and their fruits. Trees mostly through the fruits recorded the highest per cent return by 85.9 in HSP system while the grasses put only 13.5 per cent. In contrast, grasses solely formed 72.8 per cent gross return of the total leaving 23.9 per cent to the tree components with the highest share by the wood in GL system.

Table 44. Gross returns (Rs. ha<sup>-1</sup>yr<sup>-1</sup>) of perennial and annual components

Plant components	Systems				
	AG	HAG	HSP	GL	
<b>A. Trees</b>					
Boles					
Branches	Wood	-	780.0	1423.5	292.5
Leaves		-	223.4*	459.3**	127.4**
Fruits			26915.5	10033.8	275.9
Subtotal			27918.5 (30.5)	11916.6 (85.9)	695.8 (23.9)
<b>B. Crops</b>					
Grains/Fruits		86538.3	62261.7	-	-
Vegetative parts		2269.3**	1255.9**	-	-
Subtotal		88807.6 (99.8)	63517.6 (69.4)	-	-
<b>C. Weeds</b>					
Shoots		173.8*	141.1*	7.6*	8.1*
Subtotal		173.3	141.1	7.6	8.1
<b>D. Grasses</b>					
Shoots		-	-	1878.4	2118.4
Subtotal		-	-	1878.4 (13.5)	2118.4 (72.8)
<b>E. Climbers and sedge</b>					
Shoots		-	-	67.2	88.0
Subtotal		-	-	67.2	88.0
<b>Total</b>		<b>88981.4</b>	<b>91577.2</b>	<b>13869.8</b>	<b>2910.3</b>

\* Computed value in terms of N, P and K

\*\* Partly computed value in terms of N, P and K

Figures in the parentheses indicate the per cent value of total in each category

Quantification of the ecosystem particularly those with woody perennials has always been a difficult task because of their inherent complexity and the problems faced in getting up suitable experimental designs as well as concrete statistical analysis. In the context of the traditional agroforestry systems, Coakley and Sponberg (1976) rightly pointed out these difficulties. Therefore, most of the studies have been attempted in conceptual development rather than an aid in evaluating and analyzing the existing study. Various types of agroforestry systems with agroforestry are practiced in different parts of the tropics have been described by Sponberg (1980). However, a few researchers recently the quantitative and qualitative studies on the traditional agroforestry systems available with the farmers of various Pradesh (Majumdar, 1989 and others).

## Chapter 5 DISCUSSION

There has been some claim that agroforestry systems confer stability to natural ecosystems and that agroforestry or man-made forest systems often incorporating traditional may be sustainable (Sponberg 1980). However, it is incorrect to compare agroforestry to natural ecosystems (Sponberg et al., 1981). It is further pointed out that agroforestry is the process of transformation of natural ecosystems into agroforestry systems. A study on the agroforestry systems in the tropics has been conducted by Sponberg (1980) and others. The study has shown that agroforestry systems are more stable than natural ecosystems. The study has also shown that agroforestry systems are more stable than natural ecosystems. The study has also shown that agroforestry systems are more stable than natural ecosystems.

Quantification of the ecosystems particularly those with woody perennials has always been a difficult task because of their inherent complexity and the problems faced in setting up suitable experimental designs as well as concrete statistical analysis. In the context of the traditional agroforestry systems, Combe and Budowski (1979) rightly pointed out these difficulties. Therefore, most of the studies have been attempted in conceptual development rather than an aid in evaluating and analysing the existing ecosystems. The various types of cropping systems with perennial crops that are practised in different parts of the tropics have been described by Ruthenberg (1980). However, a few researchers recently made quantitative and qualitative studies on the traditional agroforestry systems available with the farmers of Himachal Pradesh (Nayar, 1989 and Toky et al., 1989a, 1989b).

There has been many claims that species diversity confers stability in natural ecosystems and that agricultural or man-made forest systems often approaching monocultures, may be unstable (Harpar, 1974). Depletion of inherited germplasm particularly in the tropics (Ramakrishnan et al., 1981) is another phenomenon that takes place in the process of transformations of natural ecosystem into tree monoculture. A change in the recent past from export-oriented agriculture towards agroforestry system based upon local resource utilization in the Himalaya

is viewed with increasing interest (Borthakur et al., 1978; Khosla and Toky, 1985; Singh, 1987 and Toky and Ramakrishnan, 1982). Diversity of crops in time can extend growing seasons and assure adequate ground cover as protection against wind and water erosion. The genetic variability both within and among plant species often helps providing natural protection against pest.

The degree of species variability signifies the evolution of the ecosystems. Integration of agriculture with the trees is an excellent example of evolutionary change taking place from shifting cultivation, a primitive system of production particularly in the tropic. However, with the increasing demographic and economic pressures, the shift has been towards horticulture more particular in the hilly states of the country. In view of the present studies, grassland (GL) and hortisilvipastoral (HSP) system can be regarded to be more old than hortiagriculture (HAG) considering their tree species diversity indices, being higher (1.150) in GL as compared to 1.105 and 0.496 in HSP and HAG, respectively. Even, in the former two systems, higher species diversity values have been attributed by the herbaceous unit.

Perennial crops are often considered a basis for a family's wealth and security. The synchronization of fruit trees with agriculture clearly indicated the farmer's awareness towards the dual benefits, i.e. they ensured not

only the immediate economic gains (Nair,1979) but also tended to enjoy insurance against the agricultural crops failure. In addition, it can also be inferred that the farmers are aware of the fact that this cropping system has the potential to provide more basic needs than pure cropping (Budowski, 1983).

The farmers maintained fodder and timber/fuelwood trees in specific ecosystems along with different herbaceous plant species emphasizing the importance of need for a particular species adoption in the system. This not only ensured increased productivity but also assured the maintenance of ecological balance. The International Union of Biological Sciences also noted that knowledge of species structure, function and of interactions among species in groups, communities and ecosystems is the foundation upon which rests "the rational management of natural and artificial ecosystems" (Dover and Talbot, 1988). Predominance of the tree species viz. Prunus domestica, Grewia optiva and Toona ciliata supported the adoption of economically and nutritionally better species. In fact, farmers have long recognized the importance of trees. They almost invariably incorporate trees in production systems in areas where they lived for an extended period of time (Niamir,1989). Inquiry into current and past farming systems has clearly shown that rural people have a wealth of knowledge as to which trees make agricultural crops grow more successfully, which

provide fodder during dry seasons and which help to hold soils for more successful farming on sloping land (Hoskins, 1990).

Standing biomass of annuals is a function of its specific season, whereas in case of perennials, it depicts the accumulation of the resources as a consequence of their ecophysiological activities over a number of seasons. It reflects the over all productivity of the system, which is also a function of relative density and basal area of the species. In the present studies, these two parameters of each tree as well as herbaceous component in their respective systems have quantified the standing biomass in a clear fashion. For an indepth inventory of the reserve, the system entities have been described according to their components, i.e. bole, branches, leaves, fruits/grains, shoot etc. Alpizar et al.(1986) have also advocated this approach for evaluating agroforestry systems.

Annual biomass productivity of the trees is basically the reflection of the standing biomass on which the increment is made. It is largely governed by soil fertility (Holdridge et al.,1971), soil depth, climate, age of the stand, genetic potentiality of the individuals and level of management. In the present studies, HAG system was noted for its highest annual productivity of 137.3 g ha<sup>-1</sup>. It may be attributed to the higher potency of the horticultural trees in isolation to produce more annually

mostly through their fruits in addition to the advantage met during the management period of the agricultural crops. Under such a land management system, several species with diverse growth habits, root system and mineral requirements enable optimum use of available space and resources (Huxley, 1983). Rate of mean annual stemwood biomass increment (MABI) in tropics is reported to range from 1 to 38 t ha<sup>-1</sup>yr<sup>-1</sup>, with a clear differences among species and age of the plantation. Fairly high productivity rate estimated in HAG and agricultural (AG) ecosystems is similar to the range given to be 12-28 t ha<sup>-1</sup>yr<sup>-1</sup> for temperate deciduous and coniferous forest (Westlake, 1963) and traditional agroforestry systems (Toky et al., 1989a).

Extent of plant interaction tends to regulate the crop performance (Connor, 1983). The Kharif crops excluding Zingiber officinale in HAG system were able to produce but with the yield reduction by 38.5 to 52.7 per cent when compared with the performance in AG system. This may be because of shading effect (Kang et al., 1981 and Balasubramanian, 1983) as the fruit trees have extensive branching with a larger crown volume. Under this environment, Z. officinale remained unaffected may be due to its genetic potentiality. On the other hand, the Rabi crops in HAG system suffered only to a little extent because the over storeyed plants remained dormant and naked from leaves for a greater part of agricultural crop growth. There may be fair competition for growth factors other than light.

In the present studies, weed biomass yields were likely to be monitored by the magnitude of intercultural practices given to agricultural crops irrespective to the systems.

Grasslands yielded higher grass biomass ( $26.48 \text{ q ha}^{-1} \text{ yr}^{-1}$ ) than HSP system by 1.13-fold. This may be due to the fact that the higher canopy density of the trees in HSP system reduces the growth of their ground-floor vegetation. Walker et al. (1972) and Kirmse et al. (1987) reported impressive increase in herbaceous yields after reducing over-storey canopies. The average grass biomass yields find a similar support from the findings of Gupta (1987) and Melkania and Tandon (1988). Present biomass productivity estimated at  $76.0$  and  $37.7 \text{ q ha}^{-1} \text{ yr}^{-1}$  in HSP and GL systems, respectively, has resemblance to the range given for many ecosystems. Some of the values reported are  $12.4$  and  $6.0 \text{ t ha}^{-1} \text{ yr}^{-1}$  for a temperate forest and grasslands (Whittaker and Likens, 1975). However, the existing production capacity is low due to poor management and over-exploitation of the areas. The contribution of herbaceous legumes is insignificant. Introduction of desirable indigenous and exotic trees, grasses and legumes according to their habitat and climatic conditions to the area may be the only recourse for improving the grasslands within a short period. Some fast growing trees such as Albizia lebbeck, Ailanthus excelsa, Populus deltoides, etc. could be tried in agroforestry systems in the Himalaya (Toky and Khosla, 1984).

Production and decomposition of the organic residues particularly the debris of weeds/crops and shed leaves play an important role in biomass production of the systems. In the present studies, a significant amount of litter through the leaves, above-ground weed biomass and left over agricultural crop residues ranging from 4.1 (in GL) to 33.2 (in HAG)  $q\ ha^{-1}yr^{-1}$  was noted to add into the soil (Table 45). The values are comparable with the production of litter in traditional agroforestry systems of the western Himalaya. About 3.8 to 4.9  $t\ ha^{-1}yr^{-1}$  was reported for the said systems (Toky et al., 1989a).

Table 45. A. Biomass input ( $q\ ha^{-1}yr^{-1}$ ) to the ecosystems

Components	Systems			
	AG	HAG	HSP	GL
Leaf litter	-	18.5	13.8	3.0
Weed	13.3	10.0	1.0	1.1
Crop residue	4.8	4.7	-	-
Total	18.1	33.2	14.8	4.1

B. Biomass removal ( $q\ ha^{-1}yr^{-1}$ ) from the ecosystems

Branch	-	-	6.0	1.7
Leaf	-	-	3.0	1.0
Fruit	-	25.3	12.0	0.5
Crop/grasses etc.	84.7	66.8	24.3	27.6
Total	84.7	92.1	45.3	30.8
Annual storage in trees	-	12.0	15.9	2.8

Maintenance of soil quality is recognized as one of the ecological principles for ecosystems' sustainability. It can also be designed with growing plants. A knowledge of nutrient budgeting is indispensable to maintain the soil fertility status for sustained biomass production. Intensive studies have been made in agriculture and forest ecosystems in this direction. Data on allied systems such as taungya and shifting agriculture are also not scanty (Nye and Greenland, 1960; Toky and Ramakrishnan, 1983b). Nayar (1989) and Toky et al. (1989b) also studied the nutrient dynamics in traditional agroforestry systems. Living biomass behaves as a reservoir of nutrients of the ecosystems. Studies on nutrient cycling in forests indicated that most of the nutrients are held up in above-ground biomass (Nye, 1961; Toky and Ramakrishnan, 1983b). Under storey may or may not contribute significantly in total biomass of the ecosystem, but it certainly plays an important role in nutrient cycling (Turner et al., 1976).

Resource sharing of nutrients in an ecosystem and the exploitation of available soil nutrients is enhanced by the system entities. This contributed significantly to the agroforestry sustainable strategy (Heuveldop et al., 1988). In the present studies, the plant species having higher biomass accumulation happened to entrap higher amount of nutrients in the systems. However, the trees contributed more towards N economy of the systems followed by K and P in that order (Table 46). Nutrient accumulation

in different systems was species and their components specific. This may be owing to the variable affinity of each species for various nutrients.

Litterfall is the major pathway for the return of organic matter to the soil. In forests, litterfall has often been studied for estimating net primary production, decomposition rates, flow of energy and cycling of nutrients (Bray and Gorham, 1964). Tree leaf litterfall was observed to add a sizeable amount of all the three major nutrients to the ecosystems (Table 46). For example, in HAG system it accounted for the addition of 32.475 kg N per hectare annually, thus contributing 53.7 per cent of the total input. In HSP system, comparatively lower amount of N was estimated to add by the leaf litter, in spite of the fact that this component accumulated a total of 31.017 kg ha<sup>-1</sup> yr<sup>-1</sup> approximating to HAG system. This difference is inherent in the fact that in case of former, the leaves of the fodder trees were harvested prior to their falling in spring season which depleted a sizeable quantity of nutrients from the system while in the latter, all the leaves were allowed to shed completely. Nayar (1989) also observed maximum nutrient addition in soil through leaf litter in HAG system. The amount of nutrients recycled through tree leaf litter, debris of crop, and weeds was recorded to vary to a greater extent in all types of ecosystems investigated. Highest quantity of nutrients were recycled from soil to vegetation

Table 46. A. Nutrient input ( $\text{kg ha}^{-1} \text{yr}^{-1}$ ) to the ecosystems

Components	AG			HAG			HSP			GL		
	N	P	K	N	P	K	N	P	K	N	P	K
Leaf	-	-	-	32.475	5.324	24.042	22.879	3.136	14.535	4.585	0.500	2.408
Weed	25.212	2.307	21.487	20.591	1.775	17.260	0.990	0.294	0.960	1.049	0.300	1.081
Crop residue	7.990	1.512	9.300	7.428	1.504	9.308	-	-	-	-	-	-
Total	33.202	3.819	30.787	60.494	8.603	50.610	23.869	3.430	15.495	5.634	0.800	3.489

B. Nutrient removal ( $\text{kg ha}^{-1} \text{yr}^{-1}$ ) from the ecosystems

Branch	-	-	-	-	-	-	6.694	0.797	4.444	1.609	0.249	1.342
Leaf	-	-	-	-	-	-	8.138	0.693	3.089	3.169	0.219	0.968
Fruit	-	-	-	22.640	3.637	22.877	10.544	1.846	11.313	0.555	0.095	0.528
Crop/grasses etc.	115.726	29.718	86.455	89.028	22.096	68.001	22.643	5.138	20.668	26.003	5.881	24.289
Total	115.726	29.718	86.455	111.668	25.733	90.878	48.019	8.474	39.514	31.336	6.444	27.127
Annual storage in trees	-	-	-	4.830	0.719	3.625	5.644	1.303	7.801	1.405	0.253	1.536

and vice versa in HAG followed by AG, HSP and GL systems due to the fact that higher biomass productivity of the system and also the nature of utilization of the produce i.e. annual removal from the respective systems. These values are comparable with other similar studies (Nayar, 1989 and Toky et al., 1989b). The quantity of N lost through the removal of biomass is higher in GL and AG systems (81.0 and 77.7% of the total accumulation) as compared to HAG (63.1%) and HSP (61.9%) signifying their degrees of unstability to produce until external inputs are added. Bole and branches of the trees in their respective systems played a role to conserve these three essential elements depending upon the amount of biomass accumulation.

Plant growth ameliorates the soil by various activities. In the present investigations, the chemical properties of the soil were noticed to vary with the ecosystems. The variation may be due to the nature of the vegetation and their management specific to the systems in addition to inherent soil fertility status. Zinke (1962) observed lower pH and higher N near the tree. Higher accumulation of N, available P and organic carbon in the surface 30 cm beneath Prosopis glandulosa was also reported by Virginia and Jarrel (1983).

The present studies entitled "Ecosystem productivity and nutrient budgeting in different agroecosystems" were attempted in the farmers' land of eight villages situated neighboring to the Dr YS Parmar University of Horticulture and Forestry, Nauni, Solan during 1978-83. The salient features of the aforesaid investigations are summarized under the following sections:

### 6.1 LAND USE PATTERNS

Average land owned by a family was 1.55 ha. The land-use pattern was as follows: 45.2 per cent of the total land was cultivated and 54.8 per cent was non-cultivated. Agriculture (AG) was the dominant ecosystem occupying about 76.4 per cent of the cultivable land while semi-agricultural (SAC) ecosystem shared only 2.4 per cent. The land had 91.7 per cent of the total cultivated area with measured irrigation facilities. Grasslands (GL) constituted 48.9 per cent of the non-cultivated land. Horticultivopastoral (HSP) system represented 11.7 per cent of the noncultivable land out of which pasture lands contributed to 52.3 per cent. A percentage of 11.3 and 3.3 were utilized as crop waste and grazing land and permanent structures, respectively.

## Chapter 6 SUMMARY

Raise, ground and winter were the principal kharif crops occupying 24.0 per cent of the cultivable land. During Rabi season, the major crops were wheat and

The present studies entitled "Biomass productivity and nutrient budgeting in different agroecosystems" were attempted in the farmers' land of eight villages situated neighbouring to the Dr YS Parmar University of Horticulture and Forestry, Nauni, Solan during 1988-90. The salient features of the aforesaid investigations are summarised under the following sections:

#### 6.1 LAND-USE PATTERNS

Average land owned by a family was 2.56 ha. The land-use pattern had only 42.2 per cent of the total land as cultivated and 57.8 per cent was uncultivated. Agriculture (AG) was the dominant ecosystem occupying about 90.6 per cent of the cultivable land while horticultural (HAG) ecosystem shared only 9.4 per cent. The land had 51.9 per cent of the total cultivated area with inassured irrigation facilities. Grasslands (GL) constituted 69.0 per cent of the noncultivable land. Hortisilvipastoral (HSP) system represented 11.7 per cent of the noncultivable land out of which contour bunds contributed to 52.9 per cent. A percentage of noncultivable area by 13.8 and 5.5 were utilised under waste and grazing land and permanent structures, respectively.

Maize, tomato and ginger were the principal Kharif crops occupying 84.0 per cent of the cultivable land. During Rabi season, the major crops viz. pea, wheat and

barley covered 63.2 per cent of the total cropped area. Among the dominant crops, maximum percentage of land was occupied by maize and pea.

## 6.2 PHYTOSOCIOLOGY

The ecosystems were heterogeneous in their species composition and comprised of both woody perennials and herbaceous units.

Fruit tree Prunus domestica, fodder tree Grewia optiva and timber/fuelwood tree Toona ciliata were the dominant species specific to the systems viz. HAG, HSP and GL.

Echinochloa crusgalli and Galinsoga parviflora during Kharif while Medicago denticulata, Vicia faba and Linum mysorense during Rabi season were the major weed species on the cultivated fields. Dipsacus inermis appeared to be the most important weed on uncultivated land.

Apluda mutica and Chrysopogon montanus were the predominant grasses developed on the uncultivated ecosystems viz. HSP and GL.

## 6.3 STANDING BIOMASS

Standing biomass of the trees specific to the ecosystems was a function of their numerical strength and basal area.

Prunus domestica, Grewia optiva and Toona ciliata exhibited the maximum standing biomass in their respective

systems in varied quantities of their components among the fruit, fodder and timber/fuelwood tree species.

HSP system had in highest standing biomass (355.5 q ha<sup>-1</sup>) as compared to HAG (301.5 q) and GL (63.2 q) systems. Bole alone displayed more than 50.0 per cent of the total tree biomass in all the systems which was followed by branches, leaves and fruits except the fruit component in HAG system. In this system, fruit biomass was higher than the leaves.

#### 6.4 BIOMASS PRODUCTIVITY

Horticultural trees in HAG system produced the maximum biomass of 55.8 q ha<sup>-1</sup>yr<sup>-1</sup> at the highest rate of 18.5 per cent. They also put the major portion of the annual biomass by 53.3 per cent to HSP system followed by fodder trees (26.0%) and timber/fuelwood trees (20.7%). In GL system, timber/fuelwood species contributed the maximum by 51.1 per cent to the system productivity.

The tree components did vary in their contributions to the systems' annual productivity. Leaves contributed the maximum both in HSP and GL systems, whereas fruits in HAG system.

Biomass yields of the Kharif crops viz. Zea mays and Lycopersicon esculentum were affected to a greater extent in HAG system but Zingiber officinale remained unaffected.

During Rabi season, biomass yields of the agricultural crops were less affected by only 6.2 per cent in HAG system as compared to Kharif crops.

Weed biomass varied with the agricultural crops and systems. AG system recorded more weed biomass particularly in the Kharif season.

GL ecosystem furnished higher biomass of the grasses ( $26.48 \text{ q ha}^{-1}$ ) annually than HSP ( $23.48 \text{ q ha}^{-1}$ ). Among the grass species, Chrysopogon montanus, Apluda mutica, Themeda anathera and Heteropogon contortus accounted for more than 65 per cent of the total grass production.

HAG system recorded the highest annual productivity of  $137.3 \text{ q ha}^{-1}$  and it was followed by AG (102.8), HSP (76.0) and GL (37.7) systems.

Agricultural crops not only contributed 87.1 of the total productivity in AG system but also they formed the major share in HAG system. The grasses assigned the maximum by 70.3 per cent for the annual productivity in GL whereas the trees played the key role in HSP system.

Leaves both in HSP and GL systems and fruits in HAG ruled over other tree components to the systems' annual productivity.

#### 6.5 ACCUMULATION AND BUDGET OF NUTRIENTS

The pattern of annual nutrient uptake was:  $N > K > P$ .

HAG system accumulated annually the highest amount of each nutrient (N 59.9, P 9.7 and K 50.5 kg) per hectare exclusively by the fruit trees. They also accumulated the maximum of the nutrients in HSP system followed by fodder and timber/fuelwood trees. In GL system, timber/fuelwood trees showed the maximum absorption closely followed by fodder trees. In all systems, maximum quantities of the nutrients were accumulated into the leaves followed by that into fruits except GL system where branches absorbed more following the leaves.

The rate of uptake by the agricultural crops was higher in AG system than in HAG.

The grasses in GL system absorbed major portion of nutrients (N 23.8, P 5.6 and K 23.2 kg ha<sup>-1</sup>yr<sup>-1</sup>) corresponding to about 62.0, 75.0 and 72.1 per cent of the total uptake and they had about 2-fold higher N, P and K on per cent basis when compared with HSP system.

Over all annual N, P and K accumulation was: HAG (N 177.0, P 35.1 and K 145.1 kg ha<sup>-1</sup>) > AG > HSP > GL.

A sizeable amounts of all the three nutrients were added to the soil through the tree leaves, above-ground weed biomass and left over agricultural residues. The pattern was HAG (N 60.494, P 8.603 and K 50.610 kg ha<sup>-1</sup>yr<sup>-1</sup>) > AG > HSP > GL.

Leaf litter was the major source of nutrients addition in the ecosystems, HAG > HSP > GL. HAG system accounted for the addition of 32.475 kg N per hectare annually, thus contributing 53.7 per cent of the total input. Annual storage of nutrients in trees was more in HSP than HAG and GL systems.

Nutrient removal in the form of biomass was the maximum in AG system (N 115.726, P 29.718 and K 86.455 kg ha<sup>-1</sup>yr<sup>-1</sup>) closely followed by HAG while the minimum in GL system.

#### 6.6 GROSS ANNUAL RETURNS

HAG system furnished the highest gross return amounting Rs.91,577.2 annually and approximated to AG system. Agricultural crops were the major contributors even in HAG system providing 69.4 per cent of the total return mostly through their grains/fruits. Trees primarily through their fruits gave the highest per cent return by 85.9 in HSP while the grasses put only 13.5 per cent. The grasses solely formed 72.8 per cent of the gross return leaving 23.9 per cent to the trees with the highest share by their wood in GL system.

#### 6.7 CHEMICAL STATUS OF THE SOIL

Chemical characteristics were found to vary with the ecosystems. In general, the soil was high in organic carbon, available P and K but low in N.

In the cultivated ecosystems, nutrient status was comparatively inferior in the uncultivated ones but in lower layer, the difference was not so pronounced.

#### **CONCLUSIONS**

In the context of the increasing awareness about the efficacious value of ecosystems as a scientific approach to sustainable land-use, the present studies on the biological evaluation of the prevalent land-use systems are really of immense importance to build up the scientific information by a synthesis of the existing knowledge. Based on available evidence, some hypotheses can be made on the improvement of the agroecosystems not only on biological grounds but also on ecological and socio-economical considerations. The studies will further help in identifying out the most suitable ecosystems in situations similar and relevant to this locality for protection, conservation and restoration of the global ecosystem.

Alshack, P.S. 1968. Biomas regression equations for understorey plants in Coastal slash: Effects of species and sampling design on estimates. *North West Botany* 6(2): 10-15.

Allen, S.E., Grimshaw, H.M., Parkinson, J.A. and Chambers, P. 1974. *Chemical analysis of ecological materials*. Blackwell Scientific Publications, Oxford, London.

Alpirar, L., Paschender, H.M., Neveling, J.J., Pieter, A. and Smitow, G. 1984. Modelling agroforestry systems of cacao (*Theobroma cacao*) with *Cordia alliodora* and *Erythrina poeppigiana* in Costa Rica. I. Inventory of organic matter and nutrients. *Agroforestry Systems*, 4: 211-257.

Anonymous. 1969. Statistical outline of Mysore. *Pradesh Directors of Economics and Statistics, Mysore, S.P., India*, pp. 198.

## REFERENCES

Balanubramanian, V. 1981. Cropping: Can it be an alternative to chemical fertilizers in Ghana? An invited paper presented at the 2nd National Youth Workshop held at Theodor Agricultural College, Kumasi, Ghana, February 1-3, 1981.

Basappa, L.V.A. 1981. Mixed multi-strata cropping. Paper presented at the 1981-1982 Training-Workshop on Agroforestry, 16-20 September, 1981, ICRAR, Hyderabad.

Borthakur, B.M., Singh, A., Awasthi, J.P. and Jain, S.M. 1978. Shifting cultivation in the north-eastern region. In: *Resources, Farm Systems and Development in the Himalayan Region*, pp. 110-142. Soil and Tech. Depart. Govt. of India.

Bry, J.A. and Gorham, E. 1964. Linear production of forests of the world. *Adv. Ecol. Syst.*, 2: 181-194.

Budwell, G. 1983. An attempt to quantify some aspects of agroforestry practices in Costa Rica. In: *Agroforestry*, P.A. (ed.), Plant Resources and Agroforestry, pp. 11-22. ICRAF, Nairobi, Kenya.

Collinson, M.P. 1980. Some of methodology in present and future systems - Farming systems research in the context of an agricultural research programme. In: *Agroforestry: A Farming System in the Tropics*, 2nd ed., pp. 181-187, Oxford: Clarendon Press.

- Alaback, P.B. 1986. Biomass regression equations for understorey plants in Coastal Alaska: Effects of species and sampling design on estimates. North West Science, 60(2): 90-103. ✓
- Allen, S.E.; Grimshaw, H.M.; Parkinson, J.A. and Quarmby, C. 1974. Chemical analysis of ecological materials. Blackwell Scientific Publications, Oxford, London.
- Alpizar, L.; Fassbender, H.W.; Heuvelop, J.; Folster, H. and Enriquez, G. 1986. Modelling agroforestry systems of cacao (Theobroma cacao) with Cordia alliodora and Erythrina poeppigiana in Costa Rica. I. Inventory of organic matter and nutrients. Agroforestry Systems. 4: 231-257.
- Anonymous, 1988. Statistical outline of Himachal Pradesh. Directorate of Economics and Statistics, Shimla, H.P., India, pp. 198.
- Balasubramanian, V. 1983. Alley cropping: Can it be an alternative to chemical fertilizers in Ghana? An invited paper presented at the 3rd National Maize Workshop held at Kwadeso Agricultural College, Kumasi, Ghana, February 1-3, 1983.
- Bavappa, K.V.A. 1986. Mixed multi-storeyed cropping. Paper presented at the ICAR-ICRAF Training-cum-Workshop on Agroforestry, 16-30 September, 1986, CRIDA, Hyderabad. ✓
- Borthakur, D.N.; Singh, A.; Awasthi, R.P. and Rai, R.N. 1978. Shifting cultivation in the north-eastern region. In: Resources Development and Environment in the Himalayan Region, pp 330-342. Sci. and Tech. Depart, Govt of India.
- Bray, J.R. and Gorham, E. 1964. Litter production in forests of the world. Adv. Ecol. Res., 2: 101-154.
- Budowski, G. 1983. An attempt to quantify some current agroforestry practices in Costa Rica. In: Huxley, P.A. (ed.). Plant Research and Agroforestry, pp 43-62. ICRAF, Nairobi, Kenya. ✓
- Collinson, M.P. 1980. Notes on methodology in cropping and farming systems - Farming systems research in the context of an agricultural research organization. In: Ruthenberg, H. Farming Systems in the Tropics, 3rd ed., pp 381-389, Oxford: Clarendon Press.

- ✓ Combe, J. and Budowski, G. 1979. Classification of agroforestry techniques. In: de Las, G. (ed.). Proc. Workshop Agroforestry Systems in Latin America, pp 17-47. CATIE, Turrialba, Costa Rica. ✓
- ✓ Cannor, D.J. 1983. Plant stress factors and their influence on production of agroforestry plant associations. In: Huxley, P.A. (ed.) Plant Research and Agroforestry pp 401-426, ICRAF, Nairobi, Kenya. ✓
- ✓ Debroy, R.; Shankar Narayan, K.A. and Pathak, P.S. 1980. Fodder trees and their importance in India. Indian For. 106: 306-311.
- ✓ Dover, M.J. and Talbot, L.M. 1988. To feed the earth: Agro-Ecology for Sustainable Development. Oxford & IBH Publishing Co. Pvt. Ltd., New Delhi, pp 50. ✓
- ✓ Egunjobi, J.K. 1969a. Primary productivity and nutrient cycling in terrestrial ecosystems - a review with particular reference to New Zealand. Tuatara 17. ✓
- ✓ Felkar, P.; Clark, P.R.; Oxborn, J.F. and Cannell. 1983. Biomass estimation in a young stand of mesquite etc. J. Range Manage. 25: 87-89. ✓
- ✓ Felkar, P. 1986. Biomass assessment. Paper presented at the ICAR - ICRAF Training - cum - Workshop on Agroforestry, 16-30 September, 1986, CRIDA, Hyderabad.
- Frissel, M.J. (ed.) 1977. Cycling of Mineral Nutrients in Agricultural Ecosystems. Agro-Ecosystems 4, i-viii+1-354.
- ✓ Gupta, B. 1987. Structure, net primary productivity and nutrient cycling in grazed and ungrazed grassland ecosystems at Shardaghat, Shimla. Ph.D. Thesis, Himachal Pradesh University, Shimla, India. ✓
- (c) ✓ Hall, D.O. and Coombs, J. 1983. Biomass production in agroforestry for fuels and food. In: Huxley, P.A. (ed.) Plant Research and Agroforestry, pp 137-160, International Council for Research in Agroforestry, P.O. Box 30677, Nairobi, Kenya. ✓
- Harper, J.L. 1974. Agricultural ecosystems. Agro-Ecosystems 1: 1-6. ✓
- Hase, H.; Foelster, H. and Lindheim, M. 1985. On the accuracy of estimating above ground tree biomass in an evergreen forest near Manaus Brazil. A simulation study. Biotropica, 17(3): 191-95. ✓

- ✓ Heuvelod, J.; Fassbender, H.W.; Alpizar, L.; Enriquez, G. and Folster, H. 1988. Modelling agroforestry systems of cacao (Theobroma cacao) with laurel (Cordia alliodora) and poro (Erythrina poeppigiana) in Costa Rica. II Cacao and wood production, litter production and decomposition. *Agroforestry systems*, 6: 37-48. ✓
- Holdridge, L.R.; Grenke, W.C.; Hathaway, W.H.; Liang, T. and Tosi, H.A. 1971. *Forest Environments in Tropical Life Zone, a Pilot Study*, pp 474. Pergamon Press, New York.
- Hoskins, M. 1990. The contribution of forestry to food security. *Unasylva*, 41: 3-13.
- ✓ Huxley, P.A. 1983. Phenology of tropical woody perennials and seasonal crop plants with reference to their management in agroforestry systems. In: Huxley, P.A. (ed.) *Plant Research and Agroforestry*, pp 503-525. ICRAF, Nairobi, Kenya. ✓
- Innis, G.S. (ed.) 1978. *Grassland Simulation Model*. *Ecol. studies* 26. New York: Springer Verlag. pp 298.
- ④ Jackson, D.S. 1965. Species siting: climate, soil and productivity. *N.Z.J. For.* 10: 90-102.
- ✓ Jackson, M.L. 1967. *Soil Chemical Analysis*. Prentice Hall, New Delhi, pp 183-90, 331-34..
- Jeanrenaud, J.P. and Thompson, I. 1986. Daphne (Lokta) bark biomass production, management implications for paper making in Nepal. *Commonw. For. Rev.* 65(2): 117-129.
- ✓ Kang, B.T.; Wilson, G.F. and Sipkens, L. 1981. Alley cropping maize (Zea mays) and Leucaena leucocephala (Lam.) in southern Nigeria. *Plant and Soil*, 63: 165-179. ✓
- ✓ Kaushal, A.N.; Rattan, J. and Bhardwaj, S.D. 1986. Effect of locality, tree size and season on nutrient content of Robinia pseudacacia L. leaves in Himachal Pradesh. *Journal of Tree Sciences* 5(1): 43-45. ✓
- ✓ Khatta, V. and Katoch, B.S. 1983. Nutrient composition of some fodder tree leaves available in sub-mountainous region of Himachal Pradesh. *Indian For.* 109: 17-24.
- Khosla, P.K.; Pal, R.N.; Negi, S.S. and Kaushal, P.S. 1980. Phenotypic variation of nutritional parameters in Grewia optiva. *Proc. IUFRO Symp. and Workshop on Genetic Productivity of Fast Growing Trees, Brazil. silvicultura* 30: 296.

- Khosla, P.K. and Toky, O.P. 1985. Renewed scientific interest in agroforestry. In: Khosla, P.K., Khurana, D.K. and Puri, S. (eds.). *Agroforestry Systems: A New Challenge*, pp 7-23. Indian Society of Tree Scientists, Solan, India. ✓
- ✓ Kirmse, R.D.; Provenza, F.D. and Malechek, J.C. 1987. Clearcutting Brazilian eaatinga: assessment of a traditional forest management practice. *Agroforestry Systems* 5(4): 429-441. ✓
- Krumlik, J.G. and Kimmins, J.P. 1973. Studies on biomass distribution and tree form in old virgin forests in the mountains of south Coastal British Columbia. In: *IUFRO Biomass Studies* (Young, H.E. ed.). Coll Life Sci. & Agric. Univ. Maine at Orono: 363-74. ✓
- Krumlik, J.G. 1974. Biomass and nutrient distribution in two old growth forest ecosystems in South Coastal British Columbia. M.Sc. Thesis, University of British Columbia, Vancouver, BC Faculty of forestry, pp 180. ✓
- Lieth, H. and Box, E. 1972. Evapotranspiration and primary productivity: C.W. thornthwaite memorial model. In: Mather, J.R. (ed.). *Papers on selected topics in climatology*. 2: 37-46. New York, Elmer, Thornthwaite memorial 2.
- Margalef, R. 1968. *Perspective in Ecological Theory*. University of Chicago Press, Chicago.
- ✓ Mathur, R.S.; Kimothi, M.M. and Gurumurti, K. 1984b. Quest for improving the production of forest biomass - a review. *Indian For.* 110(8): 695-725. ✓
- ✓ Melkania, N.P. and Tandon, J.P. 1988. Improving grasslands in the mid-Himalayas. *Indian Farming* June: 22-25.
- Merwin, H.D. and Peech, M. 1950. Exchangeability of soil potassium in sand, silt and clay fractions as influenced by nature of complementary exchange cation. *Proc. Soil Sci. Am.* 15: 125-28.
- Miller, R.B. 1969. Forest productivity in the temperate - humid zone of the Southern Hemisphere. *Unesco*. 1971. *Productivity of forest ecosystems*. *Proc. Brussels Symp.*, 1969 (Ecology and Conservation, 4): 299-305. ✓
- Misra, R. 1968. *Ecology workbook*. Oxford IBH Publishing Co. Calcutta, Indi, pp 244. ✓
- Nair, P.K.R. 1979. *Intensive multiple cropping with coconuts in India: Principles, programmes and prospects*. Verlag Paul Parey, Berlin (West) ✓

- ✓ Nair, P.K.R. 1984. Science and Practice of Agroforestry 1: Soil productivity aspects of agroforestry. pp 68-72, International Council for Research in Agroforestry. P.O. Box 30677, Nairobi, Kenya. ✓
- ✓ Nayar, P. 1989. Agroforestry ecosystem dynamics in Himachal Himalaya. Ph.D. Thesis, Panjab University, Chandigarh, India. ✓
- ✓ Negi, S.S. 1977. Fodder trees of Himachal Pradesh. Indian For. 103: 616-622.
- Negi, S.S.; Pal, R.N. and Ehrick, C. 1980. Tree fodders in Himachal Pradesh (India). German Agency for Technical Cooperation (GTZ), Eshborn, Federal Republic of Germany. pp 68.
- Newbould, P.J. 1967. Methods for estimating the primary production of forests. London, Blackwell Scientific Publications, IBP Handbook No.2. ix+pp 62.
- Niamir, M. 1989. Herder decision-making in natural resource management in arid and semi-arid Africa. Rome, FAO, Forestry Department.
- Nye, P.H. and Greenland, D.J. 1960. The Soil Under Shifting Cultivation. Technical Communication, No.51, Commonw Bur Soils, Harpenden.
- Nye, P.H. 1961. Organic matter and nutrient cycles under moist tropical forest. Plant Soil, 13: 233-346. ✓
- ✓ Oldeman, R.A.A. 1983. The design of ecologically sound agroforests. In: Huxley, P.A. (ed.) Plant Research and Agroforestry, pp 173-207. International Council for Research in Agroforestry, P.O. Box 30677, Nairobi, Kenya. ✓
- Olsen, S.R.; Cole, C.V.; Watanabe, F.S. and Dean, L.A. 1954. Estimation of available phosphorus by extraction with sodium bicarbonate. In: Black, C.A. (ed.) 1965. Methods of Soil Analysis, Madison, Wisconsin, Am. Soc. Agron. pp 1044-46.
- Ovington, J.D. 1962. Quantitative ecology and the woodland ecosystem concept. Adv. Ecol. Res. 1: 103-192. ✓
- Ovington, J.D. 1965. Organic production, turnover and mineral cycling in woodlands. Biol. Rev. 40: 295-336.
- ✓ Pal, R.N.; Dogra, K.K.; Singh, L.N. and Negi, S.S. 1979. Chemical composition of some fodder trees in Himachal Pradesh. For. Res. 5: 109-115.

- ✓ Pande, M.C., Tandon, V.N. and Negi, M. 1986. Biomass production and its distribution in an age series plantations of Eucalyptus hybrid and Acacia auriculaeformis in Bihar. Indian For. 112(11): 975-85. ✓
- ✓ Pathak, P.S.; Khan, T.A. and Gupta, S.K. 1987. Biomass relationship in Leucaena leucocephala (LAM) DE WIT. Int. J. Ecol. Environ. Sci. 13: 19-32. ✓
- Peterson, E.B.; Chan, Y.H. and Cragg, J.B. 1970. Above ground standing crop, leaf area and caloric value in an aspen clone near Calgary Alberta. Can. J. Bot. 48: 1459-69.
- ✓ Piper, C.S. 1966. Soil and plant analysis. Hans publication, Bombay, India, pp 368.
- ✓ Rai, S.N. 1984. Bole, branches, current twigs and root biomass production in tropical rain (wet evergreen) forests of Western Ghats of Karnataka. Indian For. 110(9): 901-14. ✓
- ✓ Ralhan, R.K. and Singh, S.P. 1987. Dynamics of nutrients and leaf mass in central Himalayan forest trees and shrubs. Ecology 68(6): 1974-1983. ✓
- ✓ Ramakrishnan, P.S. and Toky, O.P. 1981. Soil nutrient status of hill agro-ecosystems and recovery pattern after slash and burn agriculture (jhum) in north-eastern India. Plant Soil 60: 41-64. ✓
- Ramakrishnan, P.S.; Toky, O.P.; Mishra, B.K. and Saxena, K.G. 1981. Slash and burn agriculture in northeastern India. In: Mooney, H.A., Bonnicksen, T.M., Christensen, N.L., Lotan, J.E. and Reiners, W.A. (eds.). Fire Regimes and Ecosystem Properties, pp 570-586. USDA Forest Service General Technical Report WO-26, Honolulu, Hawaii.
- ✓ Rawat, Y.S. and Singh, J.S. 1988. Structure and function of oak forest in central Himalaya. II. Nutrient dynamics. Ann. Bot. 62(4): 413-427. ✓
- Reddy, Y.V.R. and Korwar, G.R. 1985. A Comparative Economic Evaluation of Agroforestry, Silvo-Agriculture and Silvo-Pastoral Systems in Drylands. Agricultural Situation in India (Nov., 1985): 705-708. ✓
- Riley, J. 1986. Biomass comparisons. Paper presented at the ICAR-ICRAF Training-cum-workshop on Agroforestry, 16-30 September, 1986, CRIDA, Hyderabad..
- Ruthenberg, H. 1980. Farming Systems in the Tropics (3rd edn.). Clarendon Press, Oxford, U.K.

- ✓Sharma, D.D.; Gill, R.S.; Chander, S. and Negi, S.S. 1966. Chemical composition of some fodder tree leaves in Kangra district, HP. J. Res., PAU, Ludhiana 3: 438-442.
- ✓Singh, A.K. and Sharma, J.S. 1987. A farming system approach for growth with equity of small farmers. Journal of Rural Development. 6(4): 396-405.
- ✓Singh, G.B. 1987. Agroforestry in the Indian subcontinent: past, present and future. In: Steppler, W.A. and Nair, P.K.R. (eds.). Agroforestry: A Decade of Development, pp 117-137. ICRAF, Nairobi, Kenya.
- Singh, R.V. 1975. Dry matter production in pine (Pinus roxburghii Sargent) plantations. Ph.D. Thesis, Himachal Pradesh University, Shimla, India, pp 235.
- Smith, D.M. 1954. Maximum moisture content method for determining specific gravity of small wood samples. U.S. For. Serv. FPL Rep. 2014. Forest Products Lab., Madison, WI. pp 3.
- Spurr, S.H. 1952. Forest Inventory. The Ronald Press Co., New York, pp 476.
- Subbiah, B.V. and Asija, G.L. 1956. A rapid procedure for the estimation of available nitrogen in soils. Curr. Sci. 25: 259-60.
- Telfer, E.S. 1969. Weight diameter relationship for 22 woody plant species. Can. J. Bot. 47: 1851-1855.
- Thakur, R.C. 1989. Evaluation of black locust (Robinia pseudacacia L.) for foliar nutrients, calorific value and pulping characteristics. Ph.D. Thesis, Dr YS Parmar University of Horticulture and Forestry, Solan, H.P., India.
- ✓Tokyo, O.P. and Khosla, P.K. 1984. Comparative growth of agroforestry trees (indigenous vs exotic) in sub-tropical western Himalaya. J. Tree Sci. 3: 93-98. ✓
- ✓Tokyo, O.P.; Kumar, P. and Khosla, P.K. 1989a. Structure and function of traditional agroforestry systems in the western Himalaya.I. Biomass and productivity. Agroforestry Systems 9: 47-70. ✓
- ✓Tokyo, O.P.; Kumar, P. and Khosla, P.K. 1989b. Structure and function of traditional agroforestry systems in the western Himalaya.II. Nutrient cycling. Agroforestry Systems 9: 71-89. ✓

- ✓ Toky, O.P. and Ramakrishnan, P.S. 1982. A comparative study of the energy budget of hill agro-ecosystems with emphasis on the slash and burn agriculture (jhum) at lower elevations of north-eastern India. Agric Syst 9: 143-154. ✓
- ✓ Toky, O.P. and Ramakrishnan, P.S. 1983b. Secondary succession following slash and burn agriculture in north-eastern India.II. Nutrient cycling. J Ecol. 71: 747-757.
- ✓ Tolsma, D.J.; Ernst, W.H.O.; Verweij, R.A. and Vooijs, R. 1987. Seasonal variation on nutrient concentrations in a semi-arid savanna ecosystem in Botswana. J. Ecol. 75(3): 755-770.
- ✓ Turner, J.; Cole, D.W. and Gassel, S.P. 1976. Mineral nutrient accumulation and cycling in a stand of alder (Alnus rubra). J. Ecol. 64: 965-974.
- Ulrich, B.; Mayer, R. and Khanna, P.K. 1979. Deposition von Luftverunreinigungen und ihre Auswirkungen in Waldkosystem im Solling. Schriften aus der Forstl. Fakultät d. Univ. Göttinger u.d. Niedersach. Forstl. Versuchsanstalt, 58. Frankfurt am Main: J.D. Sauerlander's Verlag. pp 291.
- Virginia, R.A. and Jarrel, W.M. 1983. Soil properties in a mesquite-dominated Sonoran Desert ecosystem. Soil Sci. Soc. Am. J., 47: 138-144.
- Walker, J., Moore, R.M. and Robertson, J.A. 1972. Herbage response to tree and shrubs thinning in Eucalyptus populnea shrub woodlands. Aust. J. Agric. Res. 23: 405-410.
- Westlake, D.F. 1963. Comparisons of plant productivity. Biol. Rev. 38: 385-425.
- Whittaker, R.H. 1970. Communities and Ecosystems. The MacMillan Co., New York. pp 162.
- Whittaker, R.H. and Likens, G.E. 1975. In: Leith, H. and Whittaker, R.H. (eds.) Primary productivity of biosphere, pp 305-308, springer Verlag, Berlin and New York.
- Young, H.E.; Strand, L. and Attenberger, R. 1964. Preliminary fresh and dry weight tables for seven tree species in Maine. Maine Agric. Expt. Sta. Univ. Maine at Orono. Tech. Bull. 12. pp 76.
- Zandstra, H.G. 1977. Cropping system research for the Asian rice farmer. In: Symposium on Cropping Systems Research and Development for the Asian Rice Farmer, pp 11-30. Los Banos: Int. Rice Res. Inst. The Philippines.

Zandstra, H.G. 1980. Notes on methodology in cropping and farming systems research methods to identify and evaluate improved cropping systems. In: Ruthenberg, H. *Farming Systems in the Tropics*, 3rd ed., pp 367-380. Oxford: Clarendon Press.

Zandstra, H.G.; Price, E.C.; Litsinger, J.A. and Morris, R.A. 1980. A Methodology for Onfarm Cropping System Research. Los Banos: Int. Rice Res. Inst. Mimeo. 169 p + appendices.

✓ Zinke, P.J. 1962. The pattern of influence of individual forest trees on soil properties. *Ecol.*, 43: 130-133.

ANNEXURE



## Annexure-1

Average price (Rs kg<sup>-1</sup>) of different commodities for 1988-89

Plant species	Commodities	Price	
		Fresh	Dry
<u>Prunus amygdalus</u> Batsch.	Nut	20.00	79.30
<u>Prunus armeniaca</u> L.	Fruit	2.50	13.20
<u>Prunus domestica</u> L.	Fruit	1.50	8.60
<u>Prunus persica</u> (L.)Batsch.	Fruit	2.25	12.10
<u>Punica granatum</u> L.	Fruit	1.00	4.30
<u>Pyrus communis</u> L.	Fruit	1.00	5.90
<u>Lycopersicon esculentum</u> L.	Fruit	3.50	33.30
<u>Zea mays</u> L.	Grain	-	2.30
<u>Zingiber officinale</u> Rosc.	Rhizome	6.50	44.00
<u>Hordeum vulgare</u> L.	Grain	-	2.70
<u>Triticum aestivum</u> L.	Grain	-	2.80
<u>Pisum sativum</u> L.	Pod	3.75	26.00
-	Fodderleaf	0.40*	1.02*
-	Grass	-	0.80*
-	Cereal & legume straw	-	0.80*
-	Wood	-	0.65
-	Nitrogen	-	5.11
-	Phosphorus	-	2.62
-	Potassium	-	1.81

\* Imputed price

## Annexure-2

Average specific density ( $\text{g cm}^{-3}$ ) of wood

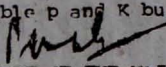
Tree species	Specific density ( $\text{g cm}^{-3}$ )
<b>A. Podder Trees</b>	
1. <u>Albizia stipulata</u> (Roxb.) Boiv.	0.464
2. <u>Bauhinia variegata</u> L.	0.638
3. <u>Celtis australis</u> L.	0.647
4. <u>Grewia optiva</u> Drummond	0.618
5. <u>Morus serrata</u> Roxb.	0.468
<b>B. Timber/Fuelwood Trees</b>	
6. <u>Acacia catechu</u> (L.f.) Willd.	0.653
7. <u>Bombax celba</u> L.	0.410
8. <u>Dalbergia sissoo</u> Roxb.	0.624
9. <u>Ficus palmata</u> Forsk.	0.404
10. <u>Pinus roxburghii</u> Sar.	0.454
11. <u>Pistacia integerrima</u> Stewart ex. Brandis	0.598
12. <u>Prunus puddum</u> Roxb.	0.648
13. <u>Pyrus pashia</u> Bush.-Ham. ex D. Don	0.663
14. <u>Sapium insigne</u> Benth.	0.421
15. <u>Toona ciliata</u> M.J. Roem	0.595
<b>C. Fruit Trees</b>	
16. <u>Prunus amygdalus</u> Batsch.	0.645
17. <u>Prunus armeniaca</u> L.	0.673
18. <u>Prunus domestica</u> L.	0.653
19. <u>Prunus persica</u> (L.) Batsch.	0.642
20. <u>Punica granatum</u> L.	0.669
21. <u>Pyrus communis</u> L.	0.641



HSP system exhibited the highest standing tree biomass of 335 g ha<sup>-1</sup> whereas H2G put the maximum total plant biomass annually @ 137.3 g ha<sup>-1</sup> followed by AG (102.8), HSP (76.0) and GL (37.7). Leaves both in HSP and GL and fruits in H2G system contributed the major share towards annual productivity. Agricultural crops not only assigned 87.1 percent of the annual productivity in AG but also they formed the major part in H2G system. The grasses shared about 70.3 percent in GL whereas the tree played the key role in HSP system.

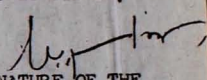
The pattern of annual nutrient uptake was N > K > P. Over all removal of these nutrients figured: H2G (N 177.0, P 35.1 and K 145.1 kg ha<sup>-1</sup>) > AG > HSP > GL. This system added the highest amount of the nutrients (N 60.5, P 8.6 and K 50.6 kg ha<sup>-1</sup>) as compared to AG, HSP and GL in their descending order.

In general, the soil was high in organic carbon, available P and K but low in N.

  
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