CHAPTER III

REVIEW OF CANOPY AND ROOT

3.1 Canopy Structure

The canopy is the combination of all leaves, twigs, and small branches in a stand of vegetation. It is an aggregate of all crowns. Canopy structure is the organisation of space and time, including the position, extent, quantity and type of connectivity of the above-ground components of vegetation (Parker, 1995). It is often useful to consider the open space between canopy elements and the atmosphere contained within and between crowns as part of canopy.

3.1.1 Measurement of Canopy Structure

The proximate units of canopy structure are the crowns of trees, the ultimate units are its leaves and twigs. Canopy structure can be characterised by several levels of detail. It is most commonly summarised by characteristic dimension or descriptor, for example, maximum tree height, biomass density of the elements, leaf area index, total plant area index, etc. (Parker, 1995). There are many methods used by forester to estimate crown cover such as polar planimeter method, weight value method, and equal area segment method of which these methods give the difference only 1.5% (Dhanmanonda *et al*., 1983).

3.1.2 Temporal Changes of Canopy Structure

Canopy structure changes seasonally in all forest but is most dramatic in completely deciduous stands. Even in the ever green forest, the quantity of leaf area varies over the year (Parker *et al*., 1989 *cited by* Parker, 1995).

3.2 Microclimate

Canopy microclimate is ultimately determined by the tree stand which is subjected to crown characteristics, bole characteristics, and phenology characteristics. The rhythms of change of macroclimate set by cycle of annual, diurnal heating, air masses and cloud (Baldocchi and Collineau, 1994). But microclimate is modified from macroclimate by the vegetation, i.e., upper storey trees and under storey trees. The modification includes rainfall redistribution, interception of light, and modification of temperature, wind velocity and humidity.

3.2.1 Rainfall Redistribution

Under the tree canopy cover, the humidity, temperature and amount of rainfall is lower than outside. Rainfall is intercepted, retained, and redistributed by canopy. In the forest of 65% density of canopy showed 40% of incident rainfall is intercepted and evaporated from canopy (Chanphaka and Vajirajutipong, 1976).

3.2.2 Light Interception

The three factors affecting the frequency distribution of light are spatial position, height of canopy and crop structure (Baldocchi and Collineau, 1994). Radiation absorption in the canopy is depended on the distribution of leaves, absorption and transmission spectra of leaves which in turn depend on species, leaf area, age and angle of light (Parker, 1995). In most deciduous forest stands, solar radiation decreases with depth in monotonic or log linear fashion (Baldocchi and Collineau, 1994). Light appears to play an important role in burying seeds of many species, e.g., induced germination of buried seeds of *Datura fleox* and *Digitalis purpurea* (Ballare, 1994; Pearcy and Sims, 1994).

Stem elongation is influenced by many factors, including those that affect overall plant growth and others with specific morphogenic activity. Light, for instance, may stimulate stem elongation by promoting total growth, but under certain conditions, increased light intensity leads to inhibitory morphogenic effects. The shade tolerant species with orthotropic stems typically respond to leaf shading by accelerating internode elongation (Ballare, 1994).

3.2.3 Humidity and Temperature Modification

The microclimate under *Acacia tortilis* intercrop with cluster bean show the significant difference from the plot without the tree, e.g., the humidity is 7% higher than and temperature at ground level 0.5-1 °C is lower than outside (Shankarnarayan *et al.*, 1987). However, humidity can remain constant under canopy cover over the period of days, for instance, at the forest level (Parker, 1995).

3.3 Tree Characteristics

Above-ground effect of tree to crop as well as modification of microclimate may occur because of tree characteristics as follows:

3.3.1 Crown Characteristics

Many crown characteristics affecting the retention and redistribution of amount of rainfall include leaf shape, leaf texture, stem branching, bark roughness, crown height and crown closure (Doley, 1981). Trees having a dense and low crown position do not permit enough light on the ground which adversely affects the process of photosynthesis of agricultural crops. Several tree species such as *Mangifera indica* and *Citrus spp.* have a deep set crowns which affect the crops adversely (Dwivedi, 1992). The density of mustard (*Brassica campestris*) and biomass production declined with increasing babul's canopy depth (*Acacia nilotica*) towards tree trunk (Yadav *et al*., 1993).

3.3.2 Phenological Characteristics

Phenological characteristic is also one of the characteristic which results in above-ground interaction. Phenology characteristics, particularly litter fall, emergence of the new leaf, absence of leaf duration, etc., are important as well. Deciduous species are preferred in agroforestry since they cause less competition for light, rainfall, nutrients and water during the period of leaflessness. The leaf litter deposit due to litter adds organic matter in the soil and maintains productivity of the soil.

Under leaflessness deciduous forest, the relative illuminance may as high as 50-80% of full sunlight, under temperate hardwoods in foliage, values from 1-5%, while beneath the tropical rain forest may be as low as 0.25-2% (Spurr and Barnes, 1980). However, the evergreen trees usually prove to be more productive than deciduous trees (Kira and Kumura, 1983).

3.3.3 Bole Characteristics

Dwavedi (1992) suggested the ideal tree for agroforestry system which should be straight, has long clear bole and branches emerge at higher locations. Moreover, the tree should have self-pruning, unless it tolerates a high incidence of artificial pruning. He also suggested that trees should have low crown diameter to bole diameter ratio, that is, the width of their crown should be small relative to bole diameter. Tree species which are planted for fodder have to be lopped. Therefore, these species should be able to tolerate lopping with no damage to the tree or disease infection.

3.4 Root Architecture

Root architecture plays a role on below-ground interaction in agroforestry systems which concerns with water, nutrients, and physical relationships. Root system of trees may reduce loss of nutrients by leaching and soil erosion while enrich with organic matter, improve soil porosity, infiltration and aeration (Ruhigwa *et al.*, 1992; Schroth, 1995). The competition of below-ground in agroforestry system comes from the tree and the crop competing for water and nutrients (Ong *et al.*, 1992). When woody perennials are grown with annual crops, it is necessary that root distribution of trees and annual crops should be such that they are distributed in different areas. Most annual crops have their root distributed in upper 40 cm soil layers (Dwivedi, 1992), the tree's root, therefore, should not be occupied in this soil zone.

The parameters for water and nutrient competition are total root length, water uptake, number of root tips, and root dry weight. The total root length or surface area of live root will govern the exploitation of the most nutrients and water from the soil zones. The number of root tips governs nutrient uptake. Root dry weight indicates the amount of carbon in the root system, while the root horizontal spread and root angle indicate exploration in the soil zone (Van Noordwijk *et al.*, 1994).

3.5 Tree-crop Interaction Study

The nature of study of the three main interactions in agroforestry systems, i.e., above-ground interaction, below-ground interaction and allelopathy are listed in Table 3.1.

Table 3.1 The nature of study of the three main interactions in agroforestry systems

Interaction	Nature of study	References
1. Above-ground interaction	- Light interception, e.g., diffused light and direct light	Niemmongkol (1987)
	- Humidity	Shankarnarayan *et al.* (1987)
	- Wind velocity	Shankarnarayan *et al.* (1987)
	- Air and soil temperature	Shankarnarayan *et al.* (1987)
	- Rainfall, e.g., amount, drop's size	Marshell *et al.* (1992)
	- Transpiration rate	Marshell *et al.* (1992)
2. Below-ground interaction	- Total root length, the longest root length	Van Noordwijk *et al.* (1994) Van Noordwijk *et al.* (1995)
	- Root diameter	Dhyani *et al.* (1990) Toky and Bisht (1992)
	- Horizontal/vertical spread of root	Toky and Bisht (1992)
	- Root angle	Toky and Bisht (1992)
	- Number of root tips	Van Noordwijk *et al.* (1994)
	- Root dry weight	Dhyani *et al.* (1990)
	- Water uptake	Ong and Khan (1993)
3. Allelopathy	- Root morphology	Vaughan and Ord (1991)
	- Some physiological process, e.g., mineral uptake	Vaughan and Ord (1991)
	- Seed germination and growth	Vaughan and Ord (1991)
	- Leaf extraction	Suwannaphinan (1991) Vaughan and Ord (1991)

3.5.1 Above-ground Study

The important parameters for above-ground interaction are light intensity especially photosynthetically active radiation (PAR), temperature, rainfall, wind velocity, and transpiration rate. The light is absolutely necessary for photosynthesis process of plants. Rogers and Iosefa (1993) studied on effect of artificial shade on taro (*Colocasia esculenta*) showed that the height and leaf of taro plants were greater under shade conditions than full sunlight. Moreover, total plant biomass was increased by shade, but corm biomass was reduced. So, in the allocation of resource in agroforestry system, it is very important to select the shade-loving crop rather than sun-loving crop, while the tree should also has small canopy. The air and soil temperature, rainfall and humidity are also modified under tree's canopy.

The tree spacing arrangement has important effect to the crop. The low density of tree leads to the low crown and permits more light to the ground. Assmann (1970) classified crown cover into two parts, i.e., crown closure or crown density and real crown cover. Actually crown cover has lesser area cover than crown closure. The crown closure or crown density is the ratio of area covered with crown to the total area (Dhanmanonda, 1982; Dhanmanonda and Sahunalu, 1983).

$$\text{Crown closure} = \frac{\text{Area of crown coverage}}{\text{Total area}}$$

Hinchaem (1986) studied the macro gap of the dry dipterocarp forest showed the gap size has relationship with the diffuse light which affect germination and growth of tree's seed and small trees. Mickle and Woerheide

(1965) pointed out that the percentage of sunlight in forest increases when the index of size clearing (ISC) increases. The ISC is the ratio of diameter of canopy gap (D), and average height of tree around gap (H), or

$$ISC = \frac{D}{H}$$

Hinchaem (1986) also pointed out that relative illuminance of the similar canopy gap is different if the high of crown is different, that is higher imaginary canopy flat (ICF) results in higher relative illuminance. The relative illuminance tends to be higher if the measuring point is near the gap center (Hinchaem, 1986). The light intensity is also dependent upon distance to ground such as the study of Baldocchi and Collineau (1994), in most deciduous forest stands, solar radiation decreases with depth in a monotonic or log linear fashion.

3.5.2 Parameters in Root Study

Besides competing for water and nutrient between tree and crop, the root emergence or physical competition is also important. There are many parameters used as indicators of different root functions, such as root mass, turnover rates, root length density, length of the longest (deepest) root, total root length, number of root tips, lateral root extension, etc. Moreover, there are relation between these parameters which also being used, e.g., specific root length (Van Noordwijk *et al.*, 1994). Desirable root characteristics vary from system to another which also being used, e.g., limited lateral root extension and low length density in the top soil for low competitiveness, high root mass and turnover rates in the top soil for high carbon inputs, and high length density in the sub-soil and deep root systems for nutrient recycling (Schroth, 1995; Van Noordwijk *et al.*, 1994). The important parameters used in root study are as follows:

3.5.2.1 Number of Branching Point and Link

The links of a root related to the number of branching points. Each branching point is preceded by an internal link. The tree with high number of branching point and link lead to longer of total root length. However, number of branching point and link increase with increasing proximal root diameter at stem base (Spek and Van Noordwijk, 1994).

3.5.2.2 Total Root Length

Total root length or surface area of live roots, governs the exploitation of most nutrients and water from the soil zones explored (Van Noordwijk *et al.*, 1994). It is a better indicator of nutrient absorbing capacity due to more sensitive to soil factors than root mass (Mackie-Dawson and Atkinson, 1991). Increasing root length, a plant will also increase the ability to catch the nutrients (Ryser and Lambers, 1995).

3.5.2.3 Total Root Dry Weight

Total root dry weight indicates amount of carbon (C) in the root system and giving the initial estimate of the C cost of making and maintaining roots (Van Noordwijk *et al.*, 1994). The tree with high root dry weight will give or gain more organic matter to the soil. However, root dry weight is dependent upon the nutrient supply. Ryser and Lambers (1995) pointed out that the root dry weight per plant dry weight of grasses showed significant response to phosphorus supply.

3.5.2.4 Specific Root Length

Specific root length is the ratio of root length per unit dry weight which indicates the intensive and extensive root characters, the higher value means more intensive root. It is not correlated with nutrient supply such as nitrogen and phosphorus (Ryser and Lambers, 1995). Therefore, it is possible dependent upon species or accession characteristics solely.

3.5.2.5 Horizontal Root Spread

Shallow rootedness is the parameter to express degree of horizontal and vertical spread. Shallow rootedness has relation with root angle and proximal root diameter (Van Noordwijk *et al.,* 1994). Toky and Bisht (1992) studied on 9 tree species in India by whole excavation method, showed that root angle range from 67-85° in former type of root and 47-67° in latter type of roots. The lateral roots of trees, i.e., *Acacia nilotica,* were found extending in all direction, and as the distance from the tree increased, the horizontal roots penetrated deeper into the soil (Yadav *et al.*, 1993).

3.5.3 Methodologies in Root Study

Measurement of root parameters can be based on either *in situ* or *ex situ* (Table 3.2), there are measuring all roots belonging to a single plant, or sampling a known volume of soil and extrapolation to the soil volume per plant. Measurement the single plant root also has many methods such as excavation of whole plant root system, profile wall, pinboard, isotopes, resin embedding, nuclear magnetic resonance, proximal root geometry. Sampling a known volume of soil or coring method is the simple method, but it has no insight into structure or neighbour and root must be separated from the soil (Harper *et al*., 1991). The proximal root geometry is a practical method compared with other single plant root measurement. It uses no specific equipment and the result is compatible with whole root excavation.

Table 3.2 The conventional methods and new methods, type of data obtained, and disadvantages of each root study method.

Method	Type of data obtained	Disadvantages	References
1. Excavation of whole plant root system	Information on whole root system structure of individual plants	Limited data about precise distribution of roots. No data concerning the interactions between roots of neighbouring plants	Weaver (1926)
2. Profile wall Root distribution mapped or recorded on surface of trench wall	Information on vertical and horizontal distribution of roots	Only part root system studied. No data on structure - cannot tell which roots are connected to which plants	Schuurman and Goedewaagen (1971) Perry *et al.* (1983)
3. Pinboard Wooden board with grid made up of metal pins driven into surface of trench wall. Soil around board cut away to give block of soil and roots held on board in natural position	As profile wall, with additional data about root length, etc. indifferent part of the profile	Data limited to a slice of root system. Root have to be separated from the soil	Schuurman and Goedewaagen (1971) Kirby and Rackham (1971)
4. Coring Soil samples taken using auger	Information about root length/weight, number of root tip in soil samples taken from various areas	No insight into structure or neighbour effects. Roots must be separated from the soil	Barber (1971)

Table 3.2 (continued)

Method	Type of data obtained	Disadvantages	References
5. Isotopes Solution containing radioactive element injected into plant or into the soil around plant	Relative amounts of radioactive roots in soil sampled in the vicinity of plant fed with isotope, or amount of radioactivity in tops of plants when soils is labelled. With dual isotope techniques, some information can be obtained about the root systems of neighbours	No information on structure parameters	Baldwin and Tinker (1972) Fusseder (1983) Caldwell *et al.* (1985)
6. Resin embedding Technique developed by soil micromor-phologists in which soil samples are impregnated with liquid resin which hardens to give a solid block, preserving soil structure. Block is cut and surface polished to show details of pore sizes, distances between roots, etc.	Information on the precise spatial distribution of roots in the soil. Serial sections give data on the 3-D structure of root systems. Intermingling of root systems of neighbours can be studies in great detail	Time consuming. Requires special equipment	Gadgil (1963) Melhuish (1968) Tippkotter *et al.* (1986)
7. Nuclear magnetic resonance Use of static and radio-frequency magnetic fields to detect the relatively mobile protons of H in water molecules. Roots contain a high proportion of water so stand out from the background soil	Images of roots in soil can be analysed to give data on root system parameters. A non-destructive technique, so growth of individual plants can be followed over time	Cannot detect roots of less than 1 mm. in diameter. Image can be affected by soil water. Specialised and expensive equipment required. Works only when soil is dry	Bottomley *et al.* (1986) Rogers and Bottomley (1987)

Table 3.2 (continued)

Method	Type of data obtained	Disadvantages	References
8. Direct water uptake Sap-flow technique is used. One set of sap-flow sensors is fixed on an exposed lateral root, (since water and nutrients are absorbed by a tree from fine roots that are connected to the large primary root), the other sensors are fixed on branches which have similar size as root.	The flow rate pattern between shoot and root. The water uptake from the root matches, in proportion, the demand for water and nutrients from any portion of canopy.	Requires special equipment (datalogger). No information on physical parameter. Have to be used in conjunction with the standard neutron moisture probe system to compare the accuracy.	Ong and Khan (1993)
9. Proximal root geometry Measurement of proximal root diameter at the stem base and branching rules (such as number of branching point, length of internal length, number of root branch etc.) observed	Proximal root diameter at the stem base and branching rules observed predict total root length, root diameter distribution, root length per unit dry weight, (specific root length), shallow rootedness and etc.	No data on real water and nutrients uptake (but can approximate from calculation)	Van Noordwijk *et al.* (1994) Van Noordwijk *et al.* (1995)

Sources: Item 1-7 adapted from Harper *et al.* (1991)

Proximal root method uses only simple measurement such as proximal root diameter, link length, root tip diameter, root angle, and number of root branch per branch event. However, before applying the formula to calculate all parameters, fractal branching model has to be tested. Van Noordwijk and Purnomosidhi (1995) tested in a survey of 18 multipurpose trees growing in acid sulphate soil in Indonesia, the assumption appeared valid for all tree tested. The theory behind fractal branching model claimed that cross sectional area of the main stem is equal to the sum of cross-sectional areas of tree roots, or pipe stem model (Van Noordwijk *et. al.*, 1994). The fractal model is based on:

$$\frac{\pi D_o^2}{4} = \frac{\alpha\pi}{4} \sum_{k=1}^{N_k} D_{jk}^2$$

where,

D_o - proximal root diameter at stem base

D_{jk} - diameter at k^{th} branch roots after j^{th} branching event

and,

$$\alpha = \frac{D_{before}^2}{\Sigma D_{after}^2}$$

where,

D_{before} - diameter of root before branching

D_{after} - diameter of root after branching

In true pipe stem model the proportionality factor α is equal to one. A constant sum of cross sectional area in trees indicates a constant resistance to longitudinal water flow, if individual xylem cells have a constant diameter and functional xylem forms a constant proportion of total stem diameter (Mandelbrot, 1983 *cited by* Van Noordwijk *et al.*, 1994). So, this assumption can be applied to root system.