CHAPTER 4  
ECOLOGY AND DISTRIBUTION  

4.1 INTRODUCTION

The Indian sub-continent presents a striking variety of ecological conditions. Enormous diversity in the range of ecological conditions in this vast country offers a great many vegetational types in different sites. It consists of a peninsula to the south of the tropic of cancer with fairly high hill ranges - The Western Ghats. These hill ranges with a length of about 1600 km, covers a tropical, sub tropical and a cool temperate zone. The climate of this region is tropical - warm and humid to sub humid due to the alternation of seasons known as monsoons. The climate of this area supports large area of rain forests or seasonally dry forests and has a flora drawn from both the northern and southern hemisphere. In addition, the tropical wet evergreen forests can offset the drought by generating their own moisture climate.

Ferns and fern allies constitute an important part of the plant kingdom and well flourish in the tropical sub tropical, and temperate forests. Jermy (1990) has commented that these plants have evolved to fill almost every ecological niche but the greatest species diversity is clearly found in the tropical rain forests. The morphological structure of ferns is simple with a limited vegetative and reproductive ability. They generally prefer a warm and humid environment. They constitute an important component of the herbaceous layer especially in the tropics and particularly in the tropical rain forests. (Bir and Vasudeva, 1971; Manickam and Irudayaraj, 1992; Nayar and Geevarghese, 1993) They play a vital role in ecological structure and equilibrium and consequently are considered as ecological indicators.

The Western Ghats is one of the fern rich areas of the world because of high rainfall, moderate climate and complex topography, all favouring the formation of different types of habitats. Out of about 1000 fern species reported from India (Bir, 1977) about 270 occur in South India (Manickam and Irudayaraj, 1992). The reason for this high number of species diversity in this area is the extent and variety of suitable
habitats which are dependent upon vegetational types, a climate with regular and seasonal rainfall (Theurkauf, 1993). A remarkable feature of fern distribution in this area is the high percentage of endemism due to diverse and localised environmental conditions. (Chandra and Kaur, 1984; Bir 1987) This is particularly observed in many small and widely scattered populations at different elevations. Secondly, the physiognomy of numerous sharp ridges and profound valleys result in circumstances that severely limit the movement of both spore dispersal and agents of spore dispersal.

Ferns are delicate and lack the strength of woody plants and would prefer to live in the moist soils of woods and swamps. They usually grow in protected ravines or under forest canopy of leaves where the sun rays are filtered. Partial sun and semi shade can also be suitable for ferns. Ferns establish well and grow luxuriantly in the area of heavy rainfall and moderate temperature. Next to rainfall, temperature along with high humidity enables the healthy growth and development of ferns. Apart from climatic factors, fern growth is also influenced much by the soil in which they grow. Moist and damp soils with lot of humus content promote the growth of ferns. Light textured soils with more amount of mulch not only retain lot of water but also provides more amount of organic nutrients to the ferns. Deep soils with higher amount of essential elements and high water holding capacity are essential for flourishing fern colonies. This type of soils are seen along the deposits of the valleys. A variety of other factors like pH, soil temperature, soil aeration, soil tilth, drainage capacity and soil organisms are chief factors that are essential for the growth and distribution of ferns.

This chapter deals with detailed observations on the different climatic conditions under which the Dryopteridaceous ferns grow, their altitudinal range, main habitats, distribution and geography and the characteristics of soil in which they grow.
4.2 REVIEW OF LITERATURE

The earliest British Collectors did not record anything regarding the ecology of Indian ferns. Later authors, enumerating species of various regions and mountains of India do not furnish adequate ecological data but make only a passing mention of habitats. First major treatment of various fern species growing in Mussoorie (Himalaya) under different habitats came from Mehra (1939). Mehra and Bir (1964) gave an illustrated and most comprehensive account of the ecology of pteridophytes in India for Darjeeling and Sikkim Himalayas. They described members growing in different habitats and forest systems such as tropical to sub-tropical types (upto 900 m and 700 - 1500 m) and wet tropical types (upto 2700 - 3600 m) and alpine scrubs and grass lands (3600 m - 4300 m or above). The epiphytic, climbing and terrestrial and lithophytic species, ravine ferns and thicket forming species flourishing under different climatic zones, were described with complete notes on ecological contrivances. In subsequent years ecology of ferns and fern allies of Simla (Bir, 1963) Kodaikanal (Bir and Vasudeva 1971) Pachmarchi (Bir and Vasudeva, 1972) Garhwal Himalaya (Bir et al., 1982) Megalaya (Baishya and Rao, 1982) Rajasthan (Gena et al., 1987) Nepal (Gurung, 1985) Nagaland (Jasmir and Rao, 1988) and Madyapradesh (Dixit, 1989) was also complied giving information on various forest systems and species growing therein.

A detailed account on the ecology of Polypodiaceous ferns of India was given by Bir et al., (1982). They stressed the importance of altitudinal range for the relative abundance of species. Dealing with the phytogeographic distribution of these ferns, they showed that 29% Himalayan members are common with Malaya; 20% common with Burma, 26% with Philippines and as many as 48% are common with China. Bir (1985) classified the Himalayan polypods on the basis of altitude and forest types as well as ecological habitats they occupy. Describing the ecology of Asplenoid ferns of India, Singh and Bir (1989) pointed out that these ferns primarily grow as lithophytes and epiphytes and rarely as terrestrial members. The non-terrestrial Asplenia grow mostly on moist shaded substratum between 1500 to 2400 m in Himalayas. Bir et al., (1991) also studied the ecological, distributional and phytogeographical account of the pteridophytic
flora of North eastern India. According to Bir and Vasudeva (1992) the pteridophytic flora of Pachmarhi hills is interesting from phytogeographic point of view because the fern flora is more similar to South Indian members as compared to the Himalayas.

A comprehensive geographical pre-treatment has been provided by Fraser-Jenkins (1984) for *Athyrium, Polystichum* and *Dryopteris* growing in Indian Sub-continent. The genus *Dryopteris* was revised for the Indian sub-continent by Fraser-Jenkins (1989). He has included 57 species to *Dryopteris* and placed them under sub-genera and sections. He has provided full description together with details of cytology, ecology and range of distribution. *Polystichum* and *Tectarioid* ferns were also revised along with ecological notes for the Indian subcontinent by Fraser-Jenkins (1991). In addition, valuable information on some Indian taxa are available in works dealing with pteridophytes of neighbouring countries such as Ching’s (1963) studies on the chinese ferns, Sledge’s (1972) on ‘Tectaroid ferns of Ceylon’ and *Dryopterioid* ferns of Ceylon.

The ecological studies on the fern flora of Palni hills by Manickam and Ninan (1984) is the first of its kind regarding ecology in South India. They have recognised four main climatic zones in the Palnis namely the Eastern Slopes, Western slopes and Southern slopes, the Northern slopes and the plateau. This method of study brought out the ecological relationship better than presenting the field data for each species separately. Based on altitudinal ranges the following main groups were distinguished among the ferns of Palni hills; species of low altitude (generally below 1200 m), species of medium altitude found between 1200 - 1800 m, species of montane zone (1800-2400 m) and orophilious ferns having wide altitudinal range. Leena and Madhusoodanañ (1992) studied the ecology and distribution of Thelypteroid ferns of South India and reported that most species grow in humid, well shaded forest floors and stream banks of Western Ghats above 700 m altitude. However, most of the species are highly sensitive to human interactions and deforestation. Nayar and Gee Varghese (1993) observed different types of habitats for fern growth in Western Ghats. The ecology of the Thelypteroid ferns of the Western Ghats of South India was also studied by Britto et al., (1994).
Different factors are affecting the diversity and the distribution of plants. The number of fern species in any area is influenced by suitable habitat which depends upon the vegetational types, climate and geology (Parris, 1985).

Iwatsuki and Kato (1980) observed that the climatic factors influence the vegetation and distribution of ferns in Japan. In Africa low rainfall and water deficiency are the chief factors affecting the distribution of pteridophytes (Kornas, 1985, 1993). In addition, mist and cloud cover are also affecting plant distribution (Berrie, 1989). Rainfall is a major climatic factor determining the principal types of forest in an area (Ewusie, 1986). In the forest, shelter of trees provide shade and prevent rapid air movements to a considerable extent and thus a suitable habitat is provided for the ferns. The amount of rainfall and distribution of rainfall have severe repercussion. Parris et al., (1992) observed a relationship between rainfall, altitude and distribution of ferns in Mount Kinnabalu. Distributional range of species expresses the relationship between the species and the environment. Each species has a unique distribution and each defines its environment in its own way (Tryon, 1986). Oldland et al., (1990) studied the quantitative vegetation - environment relationship in tall-fern vegetation dominated by Athyrium distentifolium, Mattenecia, Struthiopteris and Thelypteris limosperma. It has been reported that the main environmental variables associated with fern floristical composition are altitude and richness of the soil.

Soil is the natural medium for the growth of terrestrial ferns which covers land as a continuum and has many forms and characteristics. Indian scientists had for a long time distinguished the South Indian soils into four main categories: alluvial soils, lateritic soils, red soils and black soils (Ray Chaudury et al., 1963). Seth (1977) made an extensive study of South Indian forest soils with regard to their physical and chemical properties and management of soils for afforestation. Seth et al., (1963) made some observations on nutrition cycle and return of nutrients in plantations at new forest. Seth and Yadav (1960) made a study on the soils of the tropical moist evergreen forests of India. Ferns are observed to grow in soils of widely varying physical characteristics but consistently associated with a particular type of rock with more or less uniform chemical
composition. Mineral content of the substratum, texture of fronds and the water relations of the species appear to influence the mineral content of the foliage of pteridophytes of different habitats within the rainforest ecosystem (Balasubramanian and Glatzce 1992).

Jones (1987) provides the physical, chemical characteristics and soil types suitable for fern growth. He has also concluded that a well drained soil, with suitable pH and rich organic matter, having adequate aeration and sufficient moisture retention capacity is ideal for fern growth. Gurung (1985) is also of the opinion that humus rich soil is a good substratum for the terrestrial plants. The Western Ghats region has rich forest soil with lot of humus but here and there the soil cover is interrupted by granite (Nayar and Gee Varghese, 1993). According to Meher - Homji (1967) the average temperature in the forest is low and hence the decomposition of organic matter is slow thus leading to the accumulation of humus in the top layers.

The forest soils are generally organic soils with acidic pH. Soil pH is an important factor that determines the solubility and availability of other elements in the soil (Peterson, 1985). Page (1979) noted a better growth of ferns in slightly acidic soils and optimal range is between 5.5 to 7.5 but the gametophyte can tolerate a broad overlapping of pH conditions. The establishment and development of sporophyte would be possible only in the slight acidic soils. The acidity and alkalinity of a soil is extremely important because it critically affects the growth of ferns (Jones, 1987). Soils which have an excess of Ca salts have a higher pH. They are called calcareous soils. Calcium and Magnesium are chiefly responsible for soil alkalinity (Zonn, 1986). The soil pH affects the morphological characteristics of some ferns like Pteridium because it grows in a wider pH range (Sheffield et al., 1989).

Like other plants, ferns also extract nutrients from the soil in order to grow and multiply. These nutrients or elements are present in the soil in various chemical forms and are taken up through the roots of ferns. Hshioh-Yu-Hou (1950) reported that ecological distribution of ferns and fern allies is not related to the supply of Fe, P, Ca or K in soil because there is no much chemical distinction between calcifugous and calcicolous ferns with reference to these elements. Brooks et al., (1985) observed strong
correlations between the occurrence of metalliferous deposits and the distribution of heavy metal tolerant pteridophytes. Twenty two species of pteridophytes are known to occur on copper bearing soils in Shaba province of South Zaire. A metal tolerant fern *Athyrium yokoscense* is capable of growing in highly copper contaminated soil. The copper binding substances extracted from the soluble cytoplasmic fraction contribute to the copper tolerance of the fern (Nishizono *et al.*, 1989). The mineral content of the dried leaf samples of eight species of pteridophytes collected from different habitats in Srilanka were determined by Balasubramanian and Glatzel (1992). It was found that the ferns growing in shady moist habitats had higher mineral contents than the ferns growing in the deep shade of natural forests on well drained slopes and ridge tops.
4.3 MATERIALS AND METHODS

The present work was carried out in order to study the distribution of Dryopteridaceous ferns and their soil characteristics collected at different localities in the Western Ghats of south India.

4.3.1 COLLECTION OF ECOLOGICAL DATA

The ecological data viz. habitat, vegetational type, frequency in the field, distribution, soil humidity, light conditions and the altitudinal range of distribution are collected from the field note books of Dr. V.S. Manickam, Department of Botany, St. Xavier's College, Palayamkottai, South India. He has done much field work (1984-1996) for his two projects. His field work was intensive and extensive, covering practically all the forests in the Western Ghats from Coorg in Karnataka to Balamore in Kanyakumari district, Tamil Nadu. The herbarium (XCH) of St. Xavier's College has approximately 7500 field numbers with more than 50,000 pteridophyte specimens collected from this area. Table 4.1 shows the number of herbarium specimens of Dryopteridaceous studied for the present work.

4.3.2 PHYTOGEOGRAPHICAL ANALYSIS

Phytogeographical analysis is entirely based on information given about the distribution of various species in different floras or on the analysis of flora contents for various regions / areas / countries as the case may be.

4.3.3 COLLECTION OF PLANT SAMPLES

For the purpose of plant analysis, samples were collected from the field at different locations during winter months (October - December). The specimens were identified by Dr. V.S. Manickam, Department of Botany, St. Xavier's College, Palayamkottai. Voucher specimens are documented in the herbarium. Name of the taxa, place of collection and altitude, voucher number and name of the collector(s) are given in Table 4.2.
Table 4.1  Number of Herbarium specimens examined from various Hill ranges of Western Ghats

<table>
<thead>
<tr>
<th>Name of the species</th>
<th>Tirunelveli hills</th>
<th>Palani hills</th>
<th>Anamalai hills</th>
<th>Nilgiri hills</th>
<th>Kerala Ghats</th>
<th>Karnataka Ghats</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hypodematium crenatum</td>
<td>-</td>
<td>1</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Tectaria paradoxa</td>
<td>31</td>
<td>12</td>
<td>16</td>
<td>37</td>
<td>11</td>
<td>4</td>
</tr>
<tr>
<td>Tectaria wightii</td>
<td>9</td>
<td>-</td>
<td>4</td>
<td>4</td>
<td>8</td>
<td>-</td>
</tr>
<tr>
<td>Tectaria coadunata</td>
<td>4</td>
<td>-</td>
<td>18</td>
<td>9</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Dryopsis scabrosa</td>
<td>-</td>
<td>4</td>
<td>5</td>
<td>38</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Lastreopsis tenera</td>
<td>11</td>
<td>2</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Polystichum harpophyllum</td>
<td>10</td>
<td>6</td>
<td>8</td>
<td>14</td>
<td>4</td>
<td>-</td>
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<tr>
<td>Polystichum subinerme</td>
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<td>-</td>
<td>7</td>
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<td>-</td>
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<tr>
<td>Polystichum piceopaleaceum</td>
<td>-</td>
<td>14</td>
<td>-</td>
<td>16</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Polystichum squarrosum</td>
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<td>13</td>
<td>4</td>
<td>5</td>
<td>6</td>
<td>-</td>
</tr>
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<td>Polystichum tacticopterus</td>
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<td>-</td>
<td>-</td>
<td>6</td>
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<tr>
<td>Phanerophlebia caryotidea var micropteris</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>7</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Phanerophlebia caryotidea var caryotidea</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>2</td>
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<td>-</td>
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<tr>
<td>Arachniodes tripinnata</td>
<td>17</td>
<td>15</td>
<td>11</td>
<td>8</td>
<td>10</td>
<td>4</td>
</tr>
<tr>
<td>Arachniodes aristata</td>
<td>32</td>
<td>8</td>
<td>11</td>
<td>6</td>
<td>7</td>
<td>3</td>
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<td>Arachniodes amabilis</td>
<td>6</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Dryopteris hirtipes</td>
<td>21</td>
<td>19</td>
<td>18</td>
<td>16</td>
<td>17</td>
<td>6</td>
</tr>
<tr>
<td>Dryopteris madrasensis</td>
<td>-</td>
<td>7</td>
<td>9</td>
<td>19</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Dryopteris cochleata</td>
<td>12</td>
<td>9</td>
<td>13</td>
<td>9</td>
<td>17</td>
<td>6</td>
</tr>
<tr>
<td>Dryopteris sparsa</td>
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<td>27</td>
<td>16</td>
<td>25</td>
<td>15</td>
<td>5</td>
</tr>
<tr>
<td>Dryopteris approximata</td>
<td>-</td>
<td>8</td>
<td>2</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Dryopteris juxtaposita</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>3</td>
<td>2</td>
<td>-</td>
</tr>
</tbody>
</table>
Table 4.2 Species of Dryopteridaceae collected from various hills of Western Ghats of South India

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Name</th>
<th>Locality</th>
<th>Voucher No.</th>
<th>Altitude</th>
<th>Name of the collector</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td><em>Tectaria paradoxa</em> (Fee) Sledge</td>
<td>Kuthiravetty Kothayar</td>
<td>XCH 00112</td>
<td>1200 m</td>
<td>Henry &amp; Manickam</td>
</tr>
<tr>
<td>2</td>
<td><em>Tectaria wightii</em> (Clarke) Ching</td>
<td>Cuddalore - Keelnadugani Road - Nilgris</td>
<td>XCH 01520</td>
<td>2300 m</td>
<td>Henry &amp; Manickam</td>
</tr>
<tr>
<td>3</td>
<td><em>Tectaria coadunata</em> (J.Sm.) C. Chr.</td>
<td>Cuddalore road Nilgris</td>
<td>XCH 00632</td>
<td>2200 m</td>
<td>Henry &amp; Manickam</td>
</tr>
<tr>
<td>4</td>
<td><em>Lastreopsis tenera</em> (R.Br) Tindale</td>
<td>Seithur hills (Devathanum - Deviyar estate)</td>
<td>XCH 02953</td>
<td>900 m</td>
<td>Manickam</td>
</tr>
<tr>
<td>5</td>
<td><em>Polystichum harpophyllum</em> (Zenker ex Kunze) Sledge</td>
<td>Pamban shola road Kodaikanal</td>
<td>XCH 31949</td>
<td>1700 m</td>
<td>Henry &amp; Manickam</td>
</tr>
<tr>
<td>6</td>
<td><em>Polystichum piceopaleaceum</em> Tagawa</td>
<td>Near Avalanchi, Nilgris</td>
<td>XCH 00831</td>
<td>2100 m</td>
<td>Henry &amp; Manickam</td>
</tr>
<tr>
<td>7</td>
<td><em>Polystichum moluccense</em> (Bl.) T. Moore</td>
<td>Shenbanganur Kodaikanal</td>
<td>XCH 31525</td>
<td>1800 m</td>
<td>Henry &amp; Manickam</td>
</tr>
<tr>
<td>8</td>
<td><em>Polystichum squarrosum</em> (D.Don) Fee.</td>
<td>Muthorai - Nilgris</td>
<td>XCH 00738</td>
<td>2100 m</td>
<td>Henry &amp; Manickam</td>
</tr>
<tr>
<td>9</td>
<td><em>Arachniodes tripinnata</em> (Goldm.) Sledge</td>
<td>Periakulam path Shenbanganur - Kodaikanal</td>
<td>XCH 35344</td>
<td>1500 m</td>
<td>Henry &amp; Manickam</td>
</tr>
<tr>
<td>10</td>
<td><em>Arachniodes aristata</em> (Forst. f.) Tindale.</td>
<td>Periakulam path Kodaikanal</td>
<td>XCH 35345</td>
<td>1700 m</td>
<td>Henry &amp; Manickam</td>
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<tr>
<td>11</td>
<td><em>Arachniodes amabilis</em> (Bl.) Tindale.</td>
<td>Shola near Nalumukku Kothayar hills</td>
<td>XCH 35237</td>
<td>1500 m</td>
<td>Henry &amp; Manickam</td>
</tr>
<tr>
<td>12</td>
<td><em>Dryopteris hirtipes</em> (Bl.) Kuntze</td>
<td>Pamban shola Kodaikanal</td>
<td>XCH 35346</td>
<td>1700 m</td>
<td>Henry &amp; Manickam</td>
</tr>
<tr>
<td>13</td>
<td><em>Dryopteris madrasensis</em> Fraser - Jenkins</td>
<td>Berijam shola near Hotel, Kodaikanal</td>
<td>XCH 32834</td>
<td>2050 m</td>
<td>Henry &amp; Manickam</td>
</tr>
<tr>
<td>14</td>
<td><em>Dryopteris cochleata</em> (Buch. Ham. ex. D. Don) C. Chr.</td>
<td>Topslip - Varagarial Anamalays</td>
<td>XCH 31550</td>
<td>750 m</td>
<td>Henry &amp; Manickam</td>
</tr>
<tr>
<td>15</td>
<td><em>Dryopteris sparsa</em> (Buch. Ham. ex. D. Don) Kuntze.</td>
<td>Coonoor - Nilgris</td>
<td>XCH 35395</td>
<td>1900 m</td>
<td>Henry &amp; Manickam</td>
</tr>
<tr>
<td>16</td>
<td><em>Dryopteris approximata</em> Sledge</td>
<td>Tiger shola Kodaikanal</td>
<td>XCH 03311</td>
<td>1500 m</td>
<td>Henry &amp; Manickam</td>
</tr>
</tbody>
</table>
4.3.4 ANALYSIS OF SOIL PARAMETERS

4.3.4.1 COLLECTION OF SOIL SAMPLES

Soil samples were collected at specific sites where the individual species grows luxuriantly and abundantly in a colonial habit. Composite sampling was adopted to take representative samples from specific sites. Soil samples were collected in polythene bags using borer samplers or augers to rooting depth of the ferns (10 - 15 cm). Usually fragmental samples were taken from the individual sites by loosening the materials. Some parameters were determined immediately. For other parameters, the soil samples were air dried at low temperature, ground and sieved through 2 mm mesh and stored.

4.3.4.2 PREPARATION OF HYDROCHLORIC EXTRACT

20 gram of soil was ignited in a muffle furnace at 500 - 600 °C for 6 h. The ignited soil samples was digested with 1:1 HCl on a sand bath for six hours and then filtered and the extract was made upto 500 ml for use in different analysis.

4.3.4.3 DETERMINATION OF TOTAL NITROGEN (KJELDAHL DIGESTION METHOD PIPER, 1966)

a. Principle:

Nitrogen in the soil is present mostly in the organic form, together with small quantities of ammonium and nitrate forms. Kjeldahl method measures only organic and ammonium forms; nitrate is excluded. The soil is digested with con. Sulphuric acid in presence of a catelyst. As the proper digestion takes place at higher temperature (360 - 410 °C) Sodium sulphate is added to raise the boiling point of Sulphuric acid. Finally after digestion, the nitrogen is converted into ammonium sulphate, and can be determined after distillation in alkaline condition.

b. Reagents:

1. Sulphuric acid - Salicylic acid mixture (1 g of Salicylic acid / 30 ml of Concentrated Sulphuric acid).

2. Sodium thiosulphate.
3. Potassium sulphate - copper sulphate mixture (10:1)
4. 40% Sodium hydroxide
5. 10% Sodium Sulphide
6. 0.1 N Sulphuric acid
7. 0.1 N Potassium hydroxide
8. Methyl red indicator

c. Procedure:

Digestion: 10 g of soil and 30 ml of sulphuric acid-salicylic acid mixture were mixed thoroughly in a dry Kjeldahl flask. It was allowed to stand for 15 mts. Then, 5 g of solid sodium thiosulphate was added and shaken well. It was allowed to stand for half an hour. 10 g of potassium sulphate - copper sulphate mixture was added and digested over a bunsen burner till the contents of the flask become colourless.

Distillation: The flask was cooled and the contents were shaken well with 100 ml of distilled water. The supernatant liquid was transferred to the distillation flask. 25 ml of 0.1 N sulphuric acid into an ice tumbler was placed at the delivery end of the distillation flask. 2-3 drops of methyl red indicator was added to the 0.1 N sulphuric acid. Few zinc and porcelain pieces were added to the distillation flask followed by 120 ml of 40% sodium hydroxide and 10 ml of 10% sodium sulphide. Immediately the mouth was closed and distillation started. Ammonia evolved was collected in 0.1 N sulphuric acid. If the indicator turned yellowish, another 25 ml of 0.1 N sulphuric acid was taken in the ice tumbler. Completion of distillation was tested using moist red litmus paper. The ice tumbler was removed and the excess acid was titrated against 0.1 N potassium hydroxide. The end point was the change of colour from pink red to straw yellow.
d. Calculation:

Weight of soil taken = 10 g

Volume of N/10 sulphuric acid taken in excess = A ml

Volume of N/10 potassium hydroxide consumed in back titration = B ml

:. Actual volume of N/10 sulphuric acid consumed for absorbing the ammonia = (A-B) ml

1 ml of N/10 sulphuric acid = (0.0014) g of N

:. (A-B) ml of N/10 sulphuric acid = (0.0014) (A-B) g of N

This is the amount of nitrogen present in 10 g of soil.

4.3.4.4 DETERMINATION OF TOTAL PHOSPHOROUS: (PEMBERTON, 1945)

a. Principle:

All the forms of phosphorous are converted to inorganic forms (phosphates) after digestion or oxidation of the sample, concentrated Nitric acid is used for digestion of the sample. The phosphates in water react with ammonium molybdate to form ammonium phosphomolybdate and volumetrically estimated using phenolphthalein indicator.

b. Reagents:

1. 1:1 Hydrochloric acid
2. 1:1 Nitric acid
3. 1:4 Nitric acid
4. Concentrated ammonium hydroxide
5. Con. Nitric acid
6. Solid ammonium nitrate
7. 20% ammonium molybdate solution
8. 0.1619 N potassium hydroxide
9. 0.1619 N Nitric acid
10. Phenolphthalein indicator
c. Procedure:

200 ml of HCl extract was evaporated to a small bulk. It is transferred to a silica basin using hot water and evaporated to dryness over a water bath. The silica basin was kept in an air oven at 105° - 110°C for 3 hrs to dehydrate the silica and rendering it insoluble. The residue was dissolved in a small quantity of 1:1 hydrochloric acid and evaporated to dryness over a water bath. The residue was dissolved again in 1:1 nitric acid, adding just sufficient amount of nitric acid to dissolve the same. The insoluble silica was allowed to settle down overnight.

It was filtered using Whatmann No. 42 filter paper and the residue in the silica basin and on the filter paper was washed with small quantities of 1:4 nitric acid till no yellow colour was left either in the basin or in the filter paper. The filtrate and the washings were collected in a 250 ml beaker. The extract was made alkaline with concentrated ammonium hydroxide and then distinctly acidic with concentrated nitric acid (use red litmus paper). 5 g of solid ammonium nitrate was added and kept in a thermostat at 65°C for 15 mts. In the mean time the precipitant mixture was prepared by taking 7 ml of concentrated nitric acid and 3 ml of distilled water in a 100 ml beaker and 10 ml of 20% ammonium molybdate was added to this solution drop by drop with constant stirring (the precipitant mixture should be clear without any turbidity). 10 ml of this precipitant mixture was added to the beaker in the thermostat, drop by drop with constant stirring, taking care not to touch the sides of the beaker. The beaker was kept in the thermostat for another 1/2 hr at 65°C and the precipitate was allowed to settle well, leaving a clear supernatant liquid. It was filtered through Whatmann No.40 filter paper by decantation, pouring only the supernatant liquid to the filter paper and retaining as much of the precipitate as possible in the beaker itself. The precipitate was washed with cold distilled water till the filtrate runs free of acid (1 drop of 0.1619 N KOH + 1 drop of phenolphthalein indicator + 2/3 filtrate in a test tube appearance of a faint but permanent pink colour showed free of acid). The filter paper was transferred with the precipitate to the same beaker in which precipitation was done and enough water was added to make
the filter paper into a pulp. 0.1619 N KOH was added from the burette till the yellow precipitate was completely dissolved leaving a colourless solution. Another 5 ml of 0.1619 N KOH was added to keep the alkali in fair excess quantity. Note down the volume of the alkali added. A drop of phenolphthalin indicator was added and the excess alkali was titrated against 0.1619 N nitric acid. Disappearance of the pink colour indicated the end point.

d. Calculation:

\[
\begin{align*}
\text{Weight of soil taken} & = W \text{ g} \\
\text{Volume of HCl extract prepared} & = 500 \text{ ml} \\
\text{Volume of HCl extract pipetted out for analysis} & = 200 \text{ ml} \\
\text{Volume of 0.1619 N KOH added in excess} & = 'A' \text{ ml} \\
\text{Volume of 0.1619 N HNO}_3 \text{ used up in back titration} & = 'B' \text{ ml} \\
\end{align*}
\]

\[
\therefore \text{Actual volume of 0.1619 N KOH used to dissolve the precipitate} = (A-B) \text{ ml}
\]

\[
\begin{align*}
(\text{Standard}) - 1 \text{ ml of 0.1619 N KOH} & = 0.0005 \text{ g of } P_2O_5 \\
(A-B) \text{ ml of 0.1619 N KOH} & = 0.0005 \times (A-B) \text{ g of } P_2O_5 \\
\text{This is the amount of phosphorous present in } 200 \text{ ml of HCl extract} & = 500 \\
\therefore \text{Amount of phosphorous in } 500 \text{ ml} & = (0.0005) (A-B) \times \frac{500}{200}
\end{align*}
\]

This is the amount of phosphorous present in W g of soil.

4.3.4.5 DETERMINATION OF TOTAL POTASSIUM (FLAME PHOTOMETRIC METHOD - STANFORD AND ENGLISH, 1949)

a. Principle:

A characteristic light is produced due to excitation of electrons when the sample with potassium is sprayed into a flame. The intensity of this characteristic radiation is
proportional to the concentration of potassium and can be read at 768 n.m by using a suitable filter device.

b. Reagents:

1. Stock potassium solution (1000 mg/1K) 1.907 g of dried at 110 \degree C was dissolved in 1 litre of distilled water. (deionised water was taken after passing through activated charcoal).

2. Intermediate potassium solution (100 mg/1K) 100 ml of the stock solution was diluted to 1000 ml.

3. Standard potassium solution (10 mg/1K) 100 ml of the Intermediate solution was diluted to 1000 ml other dilutions were made by the same method.

c. Procedure:

1. The lead from the gas cylinder was attached to the burner.

2. The automizer was fixed in its place and distilled water was introduced into it.

3. The gas was opened and the burner lighted, Gas flow was adjusted to get a central bluish cone.

4. Compressor was started and the air pressure adjusted to 10 psi.

5. With distilled water, zero was set. 10 mg K solution was introduced and the scale adjusted to read 10. Again distilled water was introduced and adjusted to zero. This process was repeated till the spot of light adjusted to zero and hundred, without adjustment.

6. The various standard solution were introduced and the readings recorded to draw the standard curve.

7. Samples were introduced through the automizer. The readings of the galvanometer were recorded.

d. Calculation:

Potassium mg/l = (mg / 1 k in diluted aliquot) X dilution factor
4.3.4.6 DETERMINATION OF TOTAL CALCIUM AND MAGNESIUM (JACKSON, 1973)

a. Principle:

Indicator like muroxide form a complex with only calcium but not with magnesium at higher pH. Calcium and magnesium form a complex of wine red colour with Eriochrome Black T indicator at pH 10.0. The EDTA has got a stronger affinity for Ca\(^{+2}\) and Mg\(^{+2}\) the former complex is broken down and a new complex of blue colour is formed. The value of Mg\(^{+2}\) can be obtained by subtracting the value of calcium from the total of Ca\(^{+2}\) + Mg\(^{+2}\). However, EDTA has a property to combine with both Ca\(^{+2}\) and Mg\(^{+2}\), therefore, magnesium is largely precipitated as its hydroxide at sufficiently higher pH.

b. Reagents:

1. 0.02 N EDTA.
2. 10% sodium hydroxide
3. Ammonium chloride - ammonium hydroxide buffer
4. Murexide indicator
5. Eriochrome Black - T indicator

c. Procedure:

For calcium alone: 10 ml of triple acid extract of the filtrate was taken in a porcelain basin. To this 10% sodium hydroxide solution was added drop by drop to neutralise the acidity (red litmus turns blue) and another 5 ml was added to maintain the pH at 12. A pinch of (50 mg) murexide indicator was added and titrated against 0.02 N EDTA. The end point was the change of colour from pinkish red to purple or violet.

d. Calculation:

\[
\frac{x \times 400.8}{\text{ml of sample}} = \text{Calcium, mg/l}
\]

where, \(x\) = volume of EDTA used.
For Calcium and Magnesium: 10 ml of the triple acid extract of the filtrate was taken in a porcelain basin. Ammonium chloride - ammonium hydroxide buffer solution was added drop by drop to neutralise the acidity and another 5 ml was added to maintain the pH at 10. 2.3 drops of Eriochrome Black - T indicator was added and titrated against 0.02N EDTA. The end point was the change of colour from purplish red to sky blue.

e. Calculation:

\[
\text{Magnesium, mg/l} = \frac{y - x \times 400.8}{\text{volume of sample} \times 1.645}
\]

where \( y \) = EDTA used in Ca, Mg titration.

\( x \) = EDTA used in calcium determination for the same volume of the sample.

4.3.4.7 DETERMINATION OF TOTAL SODIUM [FLAME PHOTOMETRIC METHOD]

a. Principle:

A characteristic light is produced due to excitation of electrons when the sample with sodium is sprayed into a flame. The intensity of this characteristic radiation is proportional to the concentration of sodium and can be read at 589 nm by using a suitable filter device in a flame photometer.

b. Reagents:

1. Stock sodium solution (1000 mg/l Na) 2.542 g of dried NaCl at 140 °C was dissolved in distilled water to make 1 litre of solution.

2. Intermediate sodium solution (100 mg/l Na) 100 ml of stock sodium solution was made to 1000 ml with distilled water.

3. Standard sodium solution (10 mg/l Na) 100 ml of intermediate solution was made upto 1000 ml with distilled water.
c. Procedure:

The same procedure as described for determination of potassium was followed except that the filter used was 589 nm wavelength.

d. Calculation:

\[ \text{Na, mg/l = [mg/l Na in diluted aliquot]} \times \text{dilution factor.} \]

4.3.4.8. DETERMINATION OF TOTAL ORGANIC MATTER AND TOTAL CARBON
(WALKLEY AND BLACK, 1934)

a. Principle:

The organic matter present in the soil is digested with excess of potassium dichromate and sulphuric acid, and the residual unutilized dichromate is then titrated with ferrous ammonium sulphate. The elementary carbon present as graphite, charcoal etc. is not attacked in this method and only organic carbon is determined. The recovery of the carbon in this method is not 100 percent. Only about 60-90% of the total organic matter is recovered.

b. Reagents:

1. Potassium dichromate solution, 1 N. 49.04 g of \( \text{K}_2\text{Cr}_2\text{O}_7 \) was dissolved in distilled water and made upto 1 litre.

2. Sulphuric acid

3. Phosphoric acid

4. Ferrous ammonium sulphate 0.4 N. 156.86 g of \( \text{Fe(NH}_4\text{)}_2\text{(SO}_4\text{)}_2 \cdot 6\text{H}_2\text{O} \) was dissolved in distilled water adding 14 ml Con. \( \text{H}_2\text{SO}_4 \), and made upto 1 litre.

5. Diphenylamine indicator:

0.5 g of diphenylamine was dissolved in a mixture of 20 ml of distilled water and 100 ml of con. sulphuric acid.
c. Procedure:

10 g of dried soil sample was taken in a conical flask. A mixture of 10 ml of 1 N \( \text{K}_2\text{Cr}_2\text{O}_7 \) solution and 20 ml of con. \( \text{H}_2\text{SO}_4 \) was added and mixed by gentle swirling. The mixture was kept for 30 minutes to complete the reaction. After the reaction was over the content was diluted with 200 ml of distilled water along with 10 ml of phosphoric acid followed by 1 ml of diphenylamine indicator. This sample was titrated against 0.4 N ferrous ammonium sulphate till the colour changes to brilliant green at the end. A blank was run with same quantity of the chemicals without soil.

d. Calculation:

\[
\begin{align*}
\text{a. } \% \text{ of carbon} & = \frac{3.951 \times T}{S} \\
\text{b. } \% \text{ of organic matter} & = \frac{\% C \times 1.724}{g}
\end{align*}
\]

where, \( g \) = weight of the sample in g.

\( S = \) ml ferrous solution with blank titration

\( T = \) ml ferrous solution with sample titration

Note: The factor 1.724 is based on the assumption that carbon is only 58 \% of the organic matter. In the estimation of carbon a factor for average recovery of about 75\% organic matter by this method has been taken into consideration in the above formula.

4.3.4.9 DETERMINATION OF SOIL pH

pH of the soil is the measure of the hydrogen ion activity and depends largely on relative amounts of the absorbed hydrogen and metallic ions. Thus, it is a good measure of acidity and alkalinity of a soil-water suspension, and provides a good identification of the soil chemical nature. The pH of the soil was determined using Elico pH meter [digital] in a soil-water suspension of 1:5 ratio.
4.3.4.10 DETERMINATION OF LIME STATUS [PIPER, 1966]

a. Principle:

Calcium carbonate in the soil sample is neutralised with excess of standard acid and the excess acid is determined by back titration with standard alkali using phenolphthalein as indicator.

b. Reagents:
1. 0.1N Sulphuric acid.
2. 0.1N Potassium hydroxide.
3. Phenolphthalein indicator.

c. Procedure:

5g of soil sample was taken with 100 ml of 0.1N sulphuric acid in a beaker. The content was stirred well and allowed to stand for one hour to complete the reaction. 25 ml of the clear supernatant from the above content was taken along with 2 drops of phenolphthalein indicator and titrated against 0.1N potassium hydroxide till the appearance of faint permanent pink colour.

d. Calculation:

Weight of the soil taken = 5 g.
Volume of 0.1N sulphuric acid added = 100 ml.
Volume of 0.1N KOH consumed for 25 ml of the aliquot = A ml.
Volume of 0.1N KOH consumed for 25 ml of 0.1N H₂SO₄ [blank] = B ml.

\[ \text{Actual amount of 0.1N H₂SO₄ used up to neutralise the CaCO₃} = (B-A) \text{ ml.} \]

1 ml of 0.1N H₂SO₄ = 0.005 g of CaCO₃

\[ (B-A) \text{ ml of 0.1N H₂SO₄} = (0.005) (B-A) \]

This is present in 25 ml of the aliquot.

\[ \text{In 100 ml} = (0.005) (B-A) \times 100 / 25 \]

This is the amount of lime present in 5g of soil.
4.3.4.11 DETERMINATION OF WATER HOLDING CAPACITY OF THE SOIL
[PIPER, 1966]

a. Principle:

The ability of the soil to retain water depends upon its texture, nature of mineral colloids, content of soil organic matter and structural characteristics of the soil profile. The water holding capacity is determined after the saturated soil is allowed to drain for 24 hours. Within the period most of the excess non-capillary water is drained away by gravity, and the soil attains “field capacity”. This value serves as a reasonably reliable expression of the moisture and aeration conditions of soils. It can be determined with sufficient accuracy by the use of core sampling cylinders.

b. Procedure:

The soil sample collected was filled in a metal core cylinders, which was kept in a flat pan. Water was gradually poured into the pan until it nearly reached the upper edge of the cylinders. Care was taken not to flood the samples from the top. The samples were left until they attained complete saturation, which was indicated by the shiny film of free water on the surface. The sample was taken out and in case the soil had swelled, the excess soil material is removed with a sharp knife from both ends of the cylinders. The cylinders are placed on a double layer of ordinary smooth 200 pound weight desk blotter and allowed to drain for exactly 24 hours. The sample was weighed, dried in an oven at 100 °C, and weighed again. The content of moisture was reported on a volume basis.

c. Calculation:

\[
\begin{align*}
\text{Weight of drained 100 cc sample} & = A \text{ g.} \\
\text{Weight of oven dry sample} & = B \text{ g.} \\
\text{Content of water} & = A - B \text{ g.}
\end{align*}
\]
4.3.4.12 TOTAL ALKALINITY

a. Principle:

Total alkalinity is the measure of the capacity of soil solution to neutralize a strong acid. The alkalinity in the soil solution is generally imparted by the salts of carbonates, bicarbonates, phosphates, nitrates, borates, silicates etc. together with the hydroxyl ions in free salts. Total alkalinity can be estimated by titrating the sample with a strong acid. First to pH 8.3 using phenolphalein as an indicator and then further to pH between 4.2 and 5.4 with methyl orange or mixed indicator. In first case, the value is called as phenolphalein alkalinity (PA) and in second case, it is total alkalinity (TA).

b. Reagents:

A. Hydrochloric acid, 0.1 N.
B. Methyl orange indicator, 0.05%
C. Phenolphthalene indicator
D. Sodium carbonate, 0.1 N

c. Procedure:

The soil solution was prepared by adding 100 ml of distilled water to 20 g of soil. The suspension was stirred mechanically for about one hour and the suspension was filtered through whatman No. 50 filter paper using Buchner funnel and Vacuum pump. 100 ml of filtrate was taken in an erlenmeyer flask and added with 2 drops of phenolphthalene indicator. The pink coloured solution was titrated with 0.1 N HCl until the colour disappears at end point. Then 2 - 3 drops of methyl orange to the same sample and titration was continued further, until the yellow colour changes to pink at end point.

d. Calculation:

\[
\text{Total alkalinity, mg} / 100 \text{ g} = \frac{(A \times \text{Normality}) \text{ of HCl} \times 500}{\text{ml of sample solution}}
\]

where \( A \) = ml of total HCl used with phenolphthalein and methyl orange.
4.3.5 ELEMENTAL ANALYSIS OF PLANT SAMPLES

4.3.5.1 ESTIMATION OF TOTAL NITROGEN

a. Principle:

Total nitrogen content in plant sample is measured spectrophotometrically in digests obtained by treating the samples with a mixture of concentrated sulphuric acid and salicylic acid. To prevent loss of nitrate nitrogen during digestion the nitrate is coupled to salicylic acid, a reaction proceeds easily in the acid medium. In this way, 3-nitrosalicylic acid and/or 4-nitrosalicylic acid are formed. These compounds are reduced to their corresponding amino forms. The actual digestion is then started by Hydrogen peroxide and in this step the organic matter is oxidized. After decomposition of the excess Hydrogen peroxide and evaporating of water, the digestion is completed by concentrating sulphuric acid at elevated temperature under the influence of selenium as a catalyst. The digested sample is diluted, after dialysis against a buffer solution to complex cations. Thereafter salicylate, a catalyst and active chlorine are added to form a green coloured complex with ammonium ion. The absorption is measured at 660 nm and in relation to the concentration of the ammonia, using Technical Auto analyser II. Industrial model No. 334-74 W/B.

b. Reagents:

a) Sulphuric acid selenium mixture: 3.5 g of selenium powder is mixed in 1000 ml of 97% sulphuric acid by heating and constant mixing.

b) Digestion mixture: 72 g of salicylic acid is dissolved in 1000 ml of sulphuric acid selenium mixture.

c) Hydrogen peroxide solution (30%)

d) Pumic stones (± 10 mosh washed and boiled)

e) Glass distilled water
f) Citrate buffer pH 5.2

33 g of potassium sodium tartrate and 24 gms of sodium citrate dissolved in 800 ml of distilled water 3 ml of 30% Brij 35 added and pH is adjusted to 5.2 with 0.1 N hydrochloric acid. The final volume is made up to 1000 ml.

g) Sodium salicylate.

25 g of sodium hydroxide dissolved in distilled water and made upto 750 ml where 80 g of sodium salicylate is added and the final volume made upto 1000 ml.

h) Sodium nitroprusside:

1 g of sodium nitroprusside dissolved in distilled water and the final volume made upto 1000 ml.

i) Sodium dichloroisocyanurate:

2 g of sodium dichloroisocyanurate dissolved in distilled water and made upto 1000 ml.

j) Rinsing liquid sampler 1 N sulphuric acid

k) Standard stock solution 1000 ppm

3.8207 g of Ammonium chloride dissolved and made upto 1000 ml with distilled water. Further dilutions are made by mixing with ammonium sulphate solutions.

c. Procedure:

500 mg of dried plant sample was mixed with 2.5 ml of digestion mixture and kept for two hours at room temperature. Just to avoid bubbling 3 pumic stones were added. After two hours it was heated for two hours at 100°C. Tubes were taken out from the heating device and added with 3 ml of Hydrogen peroxide in portions of 1 ml drop wise along with swirling the tube. The tube was again heated for 2 h at 330°C in the digestion block. The tubes were taken out and cooled down to room temperature and diluted to 50 ml with distilled water. Standards and blanks were treated under the same conditions. The samples were dialysised against citrate buffer to complex cations. The salicylate catalyst and active chloric was added to form a green coloured complex. The absorption was measured at 660 nm against the standard ammonium chloride.
4.3.5.2 ESTIMATION OF PHOSPHOROUS, POTASSIUM, CALCIUM, MAGNESIUM, AND SODIUM

The elements such as phosphorous, potassium, calcium, magnesium and sodium were analysed using standard methods with Integrated Coupled Plasma Spectrometer (Thomson and Walsh, 1989 - Model ARL. 3410, U.S.A).

a. Principle:

ICP - spectrometer is a powerful instrument used to analyse a number of metals. The working principle is closely related to Atomic absorption spectrophotometry in as much as the sample is aspirated into a hot flame to convert the element to its atomic vapour. After atomisation the element in the flame can be raised to a excited state by giving some specific radiation by a hollow cathode lamp made up to the same element. The absorption of this radiation follows Beer's law as applicable to the absorption spectrometry.

ICP spectrometer analyzes samples in solution form, which is drawn through the uptake tube to the nebulizer and spray chamber is conditioned to form a fine aerosol spray. A stream of argon carries the aerosol upward through the central channel of the torch to the plasma. (Plasma is a cloud of electrons and argon ions which is held at a high temperature. The energy required to maintain the plasma is supplied by applying several hundred watts of radio frequency [RF] power to the induction coil. This RF power creates an oscillating magnetic field which is oriented axially through the torch. The electrons and ions of the plasma are forced by the magnetic field to follow circular paths inside the torch at very high velocities, changing their directions twice during each cycle of the RF power, or 54 million times per second. The electrons and ions meet with resistance to their motion and moving against this resistance raise their temperature. Neutral argon atoms which are continually introduced into the plasma suffer collisions with the charged particles moving about in the plasma, raising their temperature until they too become ionized, thus ensuring the continuity of the plasma).
The sample injected into this high temperature environment of the argon plasma experiences temperatures of approximately 6000 K. This dissociates the sample into free atoms and ions that emit light at wavelengths characteristic of the elements present in the analyte.

The emitted light passes through the monochromator eminance slit and falls on the diffraction grating. This grating divides the light into its constituent wavelengths or spectral lines. The monochromator has a single exist slit. Light from an extremely narrow portion of the spectrum can pass through this slit at any one time. The grating moves by small increments known as steps so that light from different parts of the spectrum can pass through the exit slit consecutively.

When examining a specific wavelength for emissions, the stepper motor positions the grating so that light near to the expected peak passes through the exist slit. Then the grating moves slowly, in steps, scanning up to and past the expected wavelength. The grating pauses for the specified integration time at each step for light to pass through the exit slit. The light is collected by the photomultiplier tube (PMT) on the other side of the exit slit. The PMT converts the photos into electrons that charge a capacitor. The capacitor is discharged at the end of integration time. The discharge signal is digitized by the instrument electronics to a number of counts proportionate to the strength of the signal received by the PMT. The number of counts generated by an emission is passed to the computer, which converts them to an actual concentration in micrograms per milliliter (μg/ml), by comparing these counts generated by a known concentrations of the same element.

**b. Reagents:**

i) concentrated Nitric acid

ii) 70% perchloric acid

iii) concentrated sulphuric acid

iv) 5% (w/v) lanthanum solution
v) standard solutions

All standard solutions were prepared by suitable dilution of stock solutions. Standard solution for calcium and magnesium contained 5% (w/v) lanthanum.

c. Preparation of samples:

One gram of powdered material was digested in 10 ml of triple acid mixture in a kjeldhal flask for 24 h (HNO$_3$:HClO$_4$:H$_2$SO$_4$; 10:4:1). The clear, solid free digest was diluted to 20 ml with glass distilled water and filtered through whatman No. 42 filter paper and stored in acid washed (HNO$_3$) Polythene bottles. The sample in solution form was directly loaded to ICP Spectrometer.

d. Analysis:

The elements were analysed in the fronds using the standard methods (APHA, 1975) with ICP (ARL 3410, U.S.A. make) Spectrophotometer (Thomson and Walsh, 1989).

4.3.6. STATISTICAL ANALYSIS

Using Turbo Pascal programme simple linear correlation and linear regression coefficient were calculated between certain interlinked pairs of parameters to observe their dependence.
4.4 OBSERVATIONS, RESULTS AND DISCUSSIONS

4.4.1 ECOLOGY, DISTRIBUTION AND GEOGRAPHY

Dryopteridaceae sensu Ching (1963) includes 14 genera and about 1400 species which are widely distributed in the temperate zone and at higher elevations in warmer parts of the world. Among the 14 genera of this family, six are endemic in the Sino-Himalayan region and Japan.

Dixit (1984) reported 109 species under seven genera to this family from India. Fraser - Jenkins (1989, 1991) reported 57 species for Dryopteris and 45 species for Polystichum from Indian sub-continent. Manickam and Irudayaraj (1992) reported twenty one species and a variety under eight genera, in the Western Ghats south of Palghat gap. In the present study twenty two species and a variety under eight genera have been encountered.

The ecological data and distributional pattern are based purely on field collections and largely from the informations available in the field books of Manickam (1984-1998) who has done extensive field work. His field work was intensive and extensive, covering practically all the forests in the Western Ghats from Capecomerin in Tamil Nadu to Coorg in Karnataka state and he has now 7500 field numbers with more than 50,000 specimens collected from this area.

The observations related to the ecology viz. altitudinal range, main habitats, frequency and abundance, distribution in different hills, soil humidity and light conditions are given in tables 4:3-8 and maps 4.1-22.

Phytogeographical analysis is entirely based on information given about distribution of various species in different floras or on the analysis of flora contents for various regions/areas/countries as the case may be.

*Hypodematum crenatum* (Forssk.) Kuhn subsp. *crenatum* (Map 4.1)

It is evidently a very rare and endangered species in South India (Manickam, 1995). It is an epilithic growing on fully exposed dry stone crevices or in schist rock face and wall crevices along road sides between 900 - 1400 m. It is a pretty xerophytic
Map 4.1 Distribution of *Hypodematum crenatum* (Forssk.) Kuhn. in the Western Ghats - South India.
The dorsiventrally creeping rhizome covered with beautiful orange-yellow chaffy scales is characteristically fixed in the crevices of dry rocks. There are only a few records viz., one on an exposed stone wall at the entrance to Pannaikadu, in the Palnis at 1400 m and another on the roadside at Yercaud Tamil Nadu. Fraser-Jenkins (nos. 9125-9127 BM) found it more commonly in the Shevaroy Hills of Eastern Ghats. It prefers a calcareous substrate and is less common in the absence of calcium.

In India, it is also present in Himalayas (Dixit, 1984). It is a rare species in Sri Lanka (Sledge, 1972) An old world genus found in Asia east to Japan, west Kasempe district of Zambia and in South Africa. It is sporadic in tropical Africa to Ethiopia, Yemen, Malay Peninsula, Sumatra and Pacific Islands, Cape Verde Islands, Madagascar and Mauritius (Tryon and Tryon, 1982).

*Tectaria cay*

It is a large pantropical and sub tropical genus of 150 species, predominantly a genus of wet forests. It is represented by three species in the Western Ghats (Manickam and Irudayaraj, 1992).

*Tectaria paradoxa* (Fee) Sledge. (Map 4.2)

It is the most common species of *Tectaria* usually growing in rainforests on mountain slopes, on stream banks or in wet ravines as big colonies. It is a terrestrial plant found especially along fully shaded waysides between 750-1300 m. Sometimes it occurs in partially exposed habitats as the borders of forests or in disturbed sites such as muddy stream banks, and along roadsides. It is evidently confined to lime stone and calcareous deposits or old masonry. It is common in Tirunelvelly hills, Anamallays, Nilgris and Kerala Ghats but not encountered in Palnis and Coorg.

Holttum (1988) restricted the area of distribution to South India and Sri Lanka.

*Tectaria wightii* (Clarke) Ching (Map 4.3)

It is terrestrial growing as solitary or as small colonies along fully or partially shaded moist stream banks between 100 - 1100 m. They are seen dispersed occasionally
Map 4.2 Distribution of *Tectaria paradoxa* (Fee.) Sledge in the Western Ghats - South India.
Map 4.3 Distribution of *Tectaria wightii* (Clarke) Ching in the Western Ghats - South India.
in dry deciduous forests of Tirunelveli hills and Anaimalais. It is rare in the Palnis and Coorg. In Nilgris, it is common and dispersed. It is frequently found in the open vallicolic forests of Kerala.


**Tectaria coadunata (J.Sm) C. Chr. var hirsuta Holttum** (Map 4.4)

This is an uncommon species of *Tectaria* in Western Ghats. It is terrestrial along fully or partially shaded roadsides, along waysides inside the forest or on the forest floor at about 1600 m. It is collected from a few localities in shola type forest floor at 1500 m in Tirunelveli hills. In Anaimalais it grows between 950-1300 m. It colonises big areas of selected patches in Nilgris between 1100 - 1500 in Vallicolic forests. A few specimens are collected from Kerala Ghats (700 - 1400) and Coorg (600 - 1200). There is a wide altitudinal range observed for this fern. Altitude, light conditions and forest types affect the size of the plant and moreover in fully shaded sholas they form big colonies.

It is an uncommon fern in Sri Lanka (Sledge, 1972). Holttum (1988) extended the distribution to North east India especially the Darjeeling Himalayas.

**Dryopsis scabrosa (Kunze) Holttum and Edwards** (Map 4.5)

The genus *Dryopsis* was first described as a natural group by Holttum and Edwards (1986) and distinguished from the genera *Dryopteris* and *Ctenitis* in one or both of which the species hither to known has been included. The genus was distinguished from *Ctenitis* based on the nature of hairs on fronds. There are also structures intermediate between hairs and scales, which are termed ‘hair scales’ by the authors.

It is endemic to South India. It is a terrestrial plant growing along fully or partially exposed roadsides or at the edges of all forest types from 1700 - 2600 m.

In Nilgris, *Dryopsis scabrosa* occurs at an altitudinal range of 1700 - 2600 m. 42 specimens have been collected. In Anaimalais, it grows between 1100 - 1300 m (5 specimens) and only 2 specimens have been collected from Palnis (2200 m).
Map 4.4 Distribution of *Tectaria coadunata* (J.Sm) C.Chr in the Western Ghats - South India.
Map 4.5 Distribution of *Dryopsis scabrosa* (Kunz) Holttum & Edwards in the Western Ghats - South India.
It is not recorded outside S. India but other 25 species of *Dryopsis* are found in east-central to east, south and southeast Asia; Nepal to Taiwan and New Guinea, South China (Holttum and Edwards 1986).

*Lastreopsis tenera* (R.Br.) Tindale (Map 4.6)

It is an uncommon, terrestrial fern, usually growing in fully shaded or in partially shaded situations such as forest margins between 1000 - 12000 m. Fronds are lacy, pale green and soft to touch. It grows in slowly spreading patches. A rare species collected from three localities only viz. Kannikatty (600 m) and Kalakad hills (1000 m) of Tirunelveli Ghats and Sethur hills (900 m) Devarimalai.

It is a rare and endangered fern in Western Ghats (Manickam, 1995). He has collected this species in the vellagavi dry deciduous forest at 1100 m on the southern slopes of Palnis but not seen here now. In the present study, all the specimens are collected along the dry places of waysides either in the margin of evergreen forests or interior of dry deciduous forests. These localities are prone to human disturbances.

A widely distributed species in Australia, Philippines, Sri Lanka, Indonesia, Fiji and New Caledonia (Jones, 1987).

**Note:** This fern is widely cultivated for its beauty in the gardens of Australia, where it adopts to well lit situations and becomes hardy.

*Polystichum* Roth.

*Polystichum* with more than 225 species is primarily a temperate genus in Northern and Southern hemispheres and in mountainous regions of the tropics. It grows especially in wet forests and also, at higher altitudes or latitudes, in more open shrubby or grassy places, particularly among rocks.

In India, *Polystichum* is represented with 45 species (Fraser - Jenkins, 1991), of which 40 occur in wet montane evergreen forests of Himalayas. Manickam and Irudayaraj (1992) reported five species in the Western Ghats south of Palghat gap.
Map 4.6 Distribution of *Lastreopsis tenera* (R.Br) Tindale in the Western Ghats - South India.
*Polystichum harpophyllum* (Zenker ex Kunze) Sledge (Map 4.7)

It is terrestrial, shade and moisture loving solitary fern rather frequent on the Palani hills between 2000 - 2200 m, occasional on Kerala Ghats (900 - 1450 m) and on Tirunelveli hills (800 - 1500), rare in Anamalais (1600 - 1800) and Nilgris (1800 - 2600 m). It is not encountered in Coorg. It is a polymorphic fern usually growing in the wet forests along stream banks and sometimes in more open shrubby or grassy places or in rocky woods, on cliffs and talus slopes. It is also common in forests of Sri Lanka (Sledge, 1982) Fraser - Jenkins (1991) confined the distribution to South India and Sri Lanka.

*Polystichum subinerme* (Kunze) Fraser - Jenkins (Map 4.8)

It is a large terrestrial species occurring as an apparent endemic. It is a rare species in Tirunelveli hills between 1200 - 1300 m (5 specimens alone are collected from 3 localities). In Nilgris it grows occasionally in big colonies in Vallicolic forests along fully shaded stream banks between 1700 - 2000 m. It is highly a polymorphic fern but can readily be distinguished by its pinkish stipe scales, absence of inducim, and presence of one or two buds on the rachis, shortly below the frond - apex.

Fraser - Jenkins (1991) reported it as an apparent endemic to South India.

*Polystichum piceopaleaceum* Tagawa (Map 4.9)

It is terrestrial and a solitary fern, commonly found on fully exposed stream banks in Nilgris between 2000 - 2300 m in open vallicolic forests. It loves muddy organic rich soils with more moisture content. It is a rare species in Palnis and collected from Kodaikanal at an altitude of 2100 m.

It is also reported from Sri Lanka, Afghanistan to Bhutan and in Mishmis, Manipur, the Khasi hills of North India, Tibet, China (Yunnan) Burma and Taiwan.

*Polystichum moluccense* (Bl.) T. Moore. (Map 4.10)

It is terrestrial and highly variable in size and cutting of pinnules, growing inside the forest, at the forest edge or along fully or partially exposed roadsides. A hardy fern
Map 4.7 Distribution of *Polystichum harpophyllum* (Zenker ex Kunze) Sledge in the Western Ghats - South India.
Map 4.8 Distribution of Polystichum subinerme (Kunze) Fraser - Jenkins in the Western Ghats - South India.
Map 4.9  Distribution of *Polystichum piceopalaceum* Tagawa in the Western Ghats - South India.
Map 4.10  Distribution of *Polystichum moluccense* (Bl.) T.Moore in the Western Ghats - South India.
with stiff leathery, dark glossy - green fronds. It has also been collected on moist, shaded situations with deep root system. It is very common on Palnis between 1800 - 2400 m. A few specimens are collected between 2200 - 2400 m in Nilgris and Anaimalais (1000 - 1300 m). From Kerala hills, it has been collected from Munnar and Ponmudi (900 - 1400 m). It is also said to be present in Kolli and Shervaroy hills of Eastern Ghats (Manickam and Irudayaraj, 1992).

It occurs in Sri Lanka and in Sarawak, Java Sabah (North Borneo) Sulawesi (Celebes), the Moluccas, the Phillipines and New Guinea.

**Polystichum squarrosurn (D. Don) Fee. (Map 4.11)**

It is a terrestrial plant growing abundantly on the fringes of the forests and forest floor in rather exposed situations in big colonies. A few specimens are also collected along stream banks in sholas, some from clearings and partially exposed dry places. It is a hardy fern with dark brown tufted scales. It tolerates light and drought to some extent. It grows gregariously in the well lit forest edges along roadsides and waysides of slopes as big colonies in the forests of Nilgris between 2000 - 2600 m. It is common and abundant in Kerala Ghats (1800 - 2000 m) Manickam (1986) reported this species from the Palnis in his collections during 1969 - 74.

It occurs from Hazara to Kameng Frontier Division and in Kohima, the Khasi Hills, Mahabaleswar, Pachmarhi Hills in central India. Tibet and Burma (Fraser - Jenkins, 1991).

**Polystichum tacticopterum (Kunze) T. Moore. (Map 4.12)**

It is evidently a rare species in the Western Ghats because only five specimens are collected from Nilgris between 2200 - 2400 m. It grows in fully shaded sholas along the stream banks. It is occasional on the forest floor of closed vallicolic forest. It is not encountered in other areas of the present study. Sledge (1973) reported it from Sri Lanka, Megalaya, Sikkim and Khasi hills (Dixit, 1984).
Map 4.11 Distribution of *Polystichum squarrosum* (D.Don) Fee. in the Western Ghats - South India.
Map 4.12  Distribution of *Polystichum tacticopterum* (Kunze) T.Moore in the Western Ghats - South India.
**Phanerophlebia caryotidea var. caryotidea (wall. ex Hook and Grev.) Copel. (Map 4.13)**

An elegant rare terrestrial plant growing along with the flowering plants in bushes. It has been collected along the stream banks, fully shaded valllicolic forest above 2000 m. There are only four specimens in the herbarium collected at three different localities around Rockland forests in Nilgris. It was also collected from Palnis by Manickam (1986) but, it is not seen there now.

**Phanerophlebia caryotidea var. micropteris (Kunze) C. Chr. (Map 4.13)**

It is terrestrial and solitary or as small colonies on the forest floor. It prefers a fully shaded situation and grows along the stream banks in the interior of the 'Shola' and closed valllicolic forest. There are only eight gatherings collected from five localities in Nilgris between 1600 - 2100 m. It is a rare species in Nilgris and found in places which are prone to human interferences. Manickam (1976, 1984) collected it from a single locality on Palni hills.

It is an old world species. It is distributed through North and Eastward to the Himalayas in India, China, Northern Vietnam, Formosa, Japan and Korea, and also in Hawaiian Islands. Other species of this genera are reported from America, Africa, Madagascar. (Tryon and Tryon 1982).

**Arachniodes Blume**

It is an elegant genus with three species in South India. All the three prefer moist humid condition and well drained soil. Popularly known as prickly shield ferns with glossy, dark green fronds with a sub erect or creeping rhizome. The members of this genus are distributed well in Malaysia, South - East Asia, Polynesia, Sri Lanka, New Guinea and Australia. Dixit (1984) has listed ten species for India.

**Arachniodes tripinnata (Goldm.) Sledge (Map 4.14)**

It is a terrestrial plant, very common and wide spread throughout all types of forests between 1800 - 2400 m in all regions of the Western Ghats. It often grows along
Map 4.13  Distribution of *Phanerophlebia caryotidea* var *caryotidea* *(Wall. ex Hook & Grev.) Copel.* and
*Phanerophlebia caryotidea* var. *micropteris* *(kunze) C.Chr.* in the Western Ghats - South India.
Map 4.14 Distribution of *Arachniodes tripinnata* (Goldm.) Sledge in the Western Ghats - South India.
road sides and waysides or stream banks which are fully or partially shaded. It is also reported from Himalayas, Sri Lanka, Java, Sarawak, Philippines and Borneo.

*Arachniodes aristata* (Forst. f.) Tindale (Map 4.15)

It is terrestrial and often seen as colonies. It is common inside the forest especially along fully shaded stream banks between 750 - 1800 m collected from lower montane forests of all the hills of the Western Ghats except Coorg. An attractive, evergreen fern with creeping rhizome dark green glossy leaves. It loves well drained soils, capable of tolerating dryness. Sledge (1973) extended the distribution to China, Japan, Korea southwards to Malesia and E. Australia and eastwards to Polynesia, Burma, Sri Lanka and Borneo.

*Arachniodes amabilis* (Bl.) Tindale (Map 4.16)

It is terrestrial growing in fully shaded stream banks between 1100 - 1250 m. It is a very rare species collected occasionally from few localities of Tirunelveli hills. Sledge (1973) reported it from the elevated hills of Nilgris. It is not seen elsewhere in the Western Ghats. It is also reported from North India, Nepal, Assam, S. China, Japan, Formosa, Philippines and Java (Sledge, 1973).

*Dryopteris* Adans

It is a genus of about 225 species, largely of temperate regions, with the others mostly occurring in high elevations of tropical areas. The centre of the genus is in the Sino - Himalayan region of west China (including SE. Tibet, Yunnan and Szechuan) the east Himalaya, and north Burma. It is also widely distributed, on all continents and in the Pacific Islands east to the Hawaiian Islands and Easter Island. It is absent from Southern South America, Central and Western Australia and Newzealand. Primarily a genus of wet forests, where it grows in ravines or shaded slopes, often among rocks which may be igneous, sand stone, lime stone or shale. It also occurs in thickets, in swamps, in grassy areas and on cliffs.
Map 4.15 Distribution of *Arachniodes aristata* (Forst. F.) Tindale in the Western Ghats - South India.
Map 4.16 Distribution of *Arachniodes amabilis* (Bl.) Tindale. in the Western Ghats - South India.
Fraser - Jenkins (1989) reported 57 species for Indian sub-continent, of which 8 are endemic to South India and Sri Lanka. It grows luxuriantly in wet montane forests and cloud forests of Himalayas and tropical rain forests of South India.

**Dryopteris hirtipes** (Bl.) Kuntze, Sub sp. *atrata* (Kunze) Fraser - Jenkins, Comb. nov. (Map 4.17)

This distinctive species can be recognized by the masses of long, slender, black scales which clothe the stipes and underside of the rachises. It is a large, solitary fern with a broad lamina. Frequently it is seen growing along fully or partially exposed stream banks with well drained soils and plenty of moisture. Very common on Palni hills between 1600 -2200 m, on Kerala Ghats (800 - 1200 m) on Nilgris (1700 - 2100 m) on Anamalais (1400 - 1700 m) and occasionally present in Tirunelveli Ghats (1200 - 1500).

It has a wide range of distribution from Kashmir to Assam in Himalayas, Tibet, S. China, Borneo, Thailand, Java, Phillipines, Formosa and Samoa, S. Vietnam, East Nepal and Bhutan, Burma and Sri Lanka. (Sledge, 1973; Tryon and Tryon, 1982).

**Dryopteris madrasensis** Fraser - Jenkins (Map 4.18)

It is a terrestrial growing plant along fully or partially shaded stream banks and also in moist forest floor. Very rare species collected only at one location in Bambar shola of Palni hills at an altitude above 2200 m but abundant on the higher plateau (2300 m) of Nilgris. There is also a record from Anamalais at an altitudinal range of 800 - 1600 m in the mid-level forests. There is no record from Tirunelveli, Kerala and Coorg.

An endemic of Sino-Himalayan or South east Asian affinity. Also found on the hills of Sri Lanka (Fraser - Jenkins, 1989).

**Dryopteris cochleata** (Buch. Ham. ex D.Don.) C. Chr. (Map 4.19)

It is a terrestrial plant frequently seen along fully exposed road sides, dry places or clearings. It is a hardy fern, growing luxuriantly under partially shaded banks. It flourishes well on the humus covered forest slopes and forest floors. It has been found to
Map 4.17 Distribution of *Dryopteris hirtipes* (Bl.) Kuntze in the Western Ghats - South India.
Map 4.18 Distribution of *Dryopteris madrasensis* Fraser - Jenkins in the Western Ghats - South India.
Map 4.19 Distribution of *Dryopteris cochleata* (Buch.Ham.ex.D.Don)C.Cr in the Western Ghats - South India.
occur in all the hills of the present study area but the frequency and abundance differs in various hill ranges. It is a rare species in Palnis (1200 - 1700 m), occasional on Kerala (1100 - 1800) and Anaimalais (1300 - 1700 m), frequent in Nilgris (2100 - 2500) and Tirunelveli hills (800 - 1300 m) and Coorg. (800 - 1200 m).

It is found from central and eastern parts of the W. Himalaya, E. Himalaya in Sikkim and N. Assam, Assam, mountain ranges of the west, central and east Indian plains in Madhya Pradesh, Bihar, and Orissa in the Indian subcontinent. It is present in Nepal, Bhutan, Bangladesh, Burma, China, Thailand, N. Vietnam; Java, Bali, Timor, Philippines. It is a south-east Asian element (Fraser - Jenkins 1989).

**Dryopteris sparsa** (Buch. - Ham. ex D. Don.) Kuntze (Map 4.20)

It is the most common species found all over the Western Ghats. It is terrestrial along fully or partially shaded streams and stream banks between 1200 - 2400 m. A pleasant fern preferring shady atmosphere and humus rich loamy soil. It is usually seen on slopes and often colonises the disturbed earth. It is an ornamental plant often grown in gardens of Australia and Europe (Jones, 1987). In Tirunelveli hills, it is dispersed and occasionally collected in vallicolic forests between 900 - 1500, abundant in big colonies above 1500 m in Palnis. It is sparse in Anamalais growing at the range of 1300 - 1500 m. It is frequent in Nilgris (1700 - 2100), dispersed in Kerala Ghats (900 - 1400) and occasional in Coorg (1200 - 1400). It adapts exceedingly well to cultivation at plains.

A south east Asian element distributed in the following political area of the world. It is distributed throughout the Himalayas; Sri Lanka; Nepal; Butan; Burma; Tibet; China; Hongkong; Taiwan; Japan; Cambodia; Vietnam; Malaya; Thailand; Philippines; Borneo; Sumatra; Java; Sumbawa; Flores; New Guinea; Australia. (Sledge, 1973; Fraser - Jenkins, 1989).

**Dryopteris approximata** Sledge (Map 4.21)

It is a terrestrial fern growing as partially exposed road sides. It is a readily distinguished by its dense scaly bases of the stipe. It is a rare and slow growing fern. A few specimens are collected from Kodaikanal (Palnis) on the way to Perumalmalai.
Map 4.20 Distribution of *Dryopteris sparsa* (Buch.Ham.ex.D.Don) Kunt: in the Western Ghats - South India.
Map 4.21 Distribution of *Dryopteris approximata* Sledge. in the Western Ghats - South India.
(2100 m) along the roadside in dense woods. There is a single record from Tirunelveli hills (Kannikatty). It has also been reported from Munnar hills and Anaimalais by Fraser - Jenkins (1989). There is no record from other places of Western Ghats. It is an endemic to South India and Sri Lanka probably having Sino-Himalayan affinity.

*Dryopteris juxtoposita* Christ. (Map 4.22)

It is terrestrial but grows on little soil over the rocky substratum. A few plants were found growing on stone walls of roadsides, towards pillar rocks in Kodaikanal (Palni) (Fraser - Jenkins, 1989). It occurs on exposed stone-walls and among bushes on the high plateau of the Nilgris (2300 m). It is a rare and endangered fern (Manickam, 1995). Beddome (1864) has given Anamalais and Nilgris as the area of distribution but in the present investigation it was not found. It is distributed in Himalayas, Nepal, Bhutan, S.E. Tibet, S.W. China, Thailand, Vietnam.

4.4.2 DISTRIBUTION IN DIFFERENT HILL RANGES

The members of Dryopteridaceae grow in a variety of ecological habitats and have a wide range of specific distribution pattern. The members of this family in this study area are entirely terrestrial except *Hypodematium crenatum*. As the region receives a fairly high rainfall and has numerous ravines with extreme dense forests, the Dryopteridaceae members are growing in abundance and constitute a conspicuous element in the forest floor. On account of the presence of everflowing streams, availability of deep shades, extremely damp soil with more humus on the surface and cool climatic conditions, the ravines of the Western Ghats provide the most congenial conditions for the luxuriant growth of the ferns. The conditions in the forest floor and forest margins are moderate. The tall lofty trees and shrubs provide shade and prevent the rapid movement of air. The slopes are often fully or partially shaded with well drained soils. These factors in the hill ranges of Western Ghats render a conducive atmosphere for the rich growth of ferns.
Map 4.22 Distribution of *Dryopteris juxtaposita* Christ in the Western Ghats - South India.
The richness of an area can be judged not only by the number of species peculiar to it but also by the total number of species growing in that area and more important, by the frequency and abundance of these species (Manickam and Ninan, 1984). Based on the total number of species represented by this family, Nilgiris with 18 taxa is the richest area for Dryopteridaceae members. (Table 4.3) The reasons are: The hill ranges have a complex topography with variety of climatic conditions suitable for individual taxa. Most of the taxa for this family have been collected from the high mountains on the western side of the Ghats which receives heavy rainfall. So the richness of the species is related to high altitude and heavy rainfall. Another interesting feature about this range is that it houses in abundance all the species of Polystichum. This fact is uncommon in other hill ranges. Dryopsis scabrosa is found to grow in the high plateau above 2300 m in Nilgris alone. The relative abundance and frequency of the fern taxa are found to be richer in the western slope than in the northern and eastern slopes. This is due to the fact that the western slope receives heavier rainfall during south-west monsoon and the dry period is also very short i.e. 2-3 months in a year.

Next to Nilgiris, Palnis shelters more taxa of Dryopteridaceae. Here the distribution follows a specific pattern i.e. with the increase of rainfall there is a corresponding increase in the number of species and again the increase in the number of species corresponds with the rise in altitude (Table 4.4). The ecological conditions of Palnis favour the growth of many Dryopteris species. Hypodematum crenatum and Dryopteris approximata have been collected only from Palnis. Unlike Nilgiris, Palnis still shelter many virgin forests, thus forming an ideal habitat for Dryopteridaceae members.

Though Anamallays differ from Tinnelveli hills in altitudinal range, both are more or less similar in richness of ferns. There are dense forests in the Anamallays particularly at the periphery of the high plateau, though the central parts of the plateau are almost totally converted for tea plantations. They provide a suitable habitat for the growth of Dryopteridaceae members. (Table 4.5 and 4.6)
<table>
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<th>Soil Humidity</th>
<th>Distribution</th>
<th>Frequency on the field</th>
<th>Rhizome</th>
<th>Name of the Pteridophyte</th>
<th>Altitude in Meters</th>
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</table>

- **Rhizome**: E = Erect, S = Sub-erect
- **Distribution**: a = abundant in big colonies, d = dispersed, T = Terrestrial, EP = Epiphyte & Terrestrial
- **Habitat**: D = Dry deciduous forest, VC = Vallicolic forest, F = All forest types, Sa = Savannas
- **Vegetational type**: S = Shola, V = Vallicolic open and closed forest, x = All vegetational types
- **Frequency on the field**: C = Common, F = Frequent, O = Occasional, R = rare
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<td></td>
<td>R</td>
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<td></td>
<td>Dryopteris approximata</td>
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</table>

- **Rhizome**
  - e = Erect
  - Sc = Short creeping

- **Distribution**
  - a = Abundant in big colonies
  - d = Dispersed

- **Habitat**
  - T = Terrestrial
  - L = Lithophyte

- **Vegetational type**
  - D = Dry deciduous forest
  - V = Vallicollic open and closed forest
  - Sh = Shola

- **Frequency on the field**
  - C = Common
  - F = Frequent
  - O = Occasional
  - R = Rare

- **Vegetational type**
  - S = Savannahs
  - Cl = Clearings

- **Vegetational type**
  - X = All vegetational types
  - VO = Vallicollic open forest

- **Vegetational type**
  - EP = Epiphyte & Terrestrial

- **Vegetational type**
  - VC = Vallicollic forest

- **Vegetational type**
  - Fr = All forest types
Table 4.5

ALTITUDINAL RANGE, DISTRIBUTION AND ECOLOGY OF THE FERNS OF DRYOPTERIDACEAE IN ANAMALAI HILLS

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<thead>
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<th>1100 - 1300</th>
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<td>e</td>
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<td>Lc</td>
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<td>e</td>
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<td>e</td>
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<td>T</td>
<td>T</td>
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<td>T</td>
<td>T</td>
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<td>D</td>
<td>Sl</td>
<td>Sl</td>
<td>Vc</td>
<td>Sl</td>
<td>Sl</td>
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<td>Fr</td>
<td>Cl</td>
<td>Vc</td>
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<td>Sp</td>
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</tr>
</tbody>
</table>

Legend:
- E = Erect
- Se = Sub-erect
- Sc = Scaly
- D = Decumbent
- V = Vallicolic open forest
- Vc = Vallicolic forest
- Sl = Shola
- C = Common
- F = Frequent
- S = Sparse
- T = Terrestrial
- D = Dry deciduous forest
- O = Occasional
- R = Rare.
<table>
<thead>
<tr>
<th>Altitude in Meters</th>
<th>750 - 1300</th>
<th>400 - 1000</th>
<th>250 - 1500</th>
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<th>1200 - 1500</th>
<th>800 - 1300</th>
<th>900 - 1500</th>
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<tr>
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<td>Tectaria coondnata</td>
<td>Lastrepia tenera</td>
<td>Polystichum harkophyllum</td>
<td>Polystichum subterreneum</td>
<td>Athamnides arvinoida</td>
<td>Athamnides amabilis</td>
<td>Athamnides orbilis</td>
<td>Athamnides albina</td>
<td>Athamnides orbilis</td>
<td>Athamnides orbilis</td>
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### Table 4.6

**Altitudinal Range, Distribution and Ecology of the Ferns of Dryopteridaceae in Tirunelvelly Hills**

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<tr>
<th>Rhizome</th>
<th>E</th>
<th>Se/Sc</th>
<th>Se</th>
<th>Lc</th>
<th>e/Se</th>
<th>e/Si</th>
<th>e</th>
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<th>Se</th>
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<th>Se</th>
<th>E</th>
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<tr>
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<td>T</td>
<td>T</td>
<td>T</td>
<td>T</td>
<td>T</td>
<td>T</td>
<td>T</td>
<td>T</td>
<td>T</td>
<td>T</td>
<td>T</td>
</tr>
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<td>Vegetational type</td>
<td>Vc</td>
<td>D</td>
<td>S</td>
<td>Vc</td>
<td>Vc</td>
<td>X</td>
<td>S</td>
<td>S</td>
<td>S</td>
<td>Cl</td>
<td>Vc</td>
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<td>R</td>
<td>R</td>
<td>O</td>
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<td>C</td>
<td>C</td>
<td>O</td>
<td>R</td>
<td>R</td>
<td>O</td>
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</tbody>
</table>

<table>
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<tr>
<th>Soil Humidity</th>
<th>Stream waters</th>
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<td>Marshy places</td>
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<table>
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<tr>
<td>Forest interior</td>
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<tr>
<td>Forest edge</td>
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</tbody>
</table>
Though only a very few forests remain south of Palghat gap in the state of Kerala because of intensive cultivation of economically useful plants, 12 taxa belonging to this family are found to be growing. Very interestingly it is seen that some of the high altitude species like *Polystichum squarrosum*, *Polystichum mollucense* and *Polystichum harpophyllum* are also growing at a lower altitudes from 900 m onwards. This is because of heavy rainfall received from the south-west monsoon, a higher percentage of humidity and a short dry period of about 3-4 months in a year. Ghats in Kerala are found to render a very suitable habitat for the ferns. The Ghats in the north of Palghat gap, especially in the western slope, for example Silent valley and forests of Nilambur are having a very thick undisturbed vegetation where number of fern taxa grow. (Table 4.7)

In Karnataka, the forests of Coorg district alone is included in the present study. Compared to Palnis, Anamallays and Nilgris the mountains of Coorg are less elevated but receives a higher rainfall with a short dry period. The taxa collected revealed that they are growing in the medium altitude (800 - 1200 m). (Table 4.8)

Based on the altitudinal ranges the following groups are distinguished. Generally, species of *Polystichum* grow at an altitude of 2000 m or above. They flourish well in the higher altitudes of Nilgris, Anamallays and to some extent in Palnis. But they are also seen occasionally in the Tirunelveli, Kerala and Karnataka Ghats possibly because of heavy rain and short dry periods. Members belonging to *Dryopteris* grow at an altitudinal range of 1800 to 2100 m. A few species of *Dryopteris* and species of *Arachniodes* are growing in a wide altitudinal range. Species belonging to *Tectaria* generally grow between 1500 - 2100 m but they thrive below 800 m in Kerala Ghats.

A remarkable and characteristic feature is the presence of a few endemic species of Dryopteridaceae in Western Ghats. It was already remarked by Sledge (1982) and Fraser-Jenkins (1989, 1991). The following taxa of this family are endemic to Srilanka and South India: *Tectaria paradoxa*, *Polystichum harpophyllum*, *Polystichum subinermae*, *Dryopteris approximata*. 
<table>
<thead>
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<th>Attitude in Meters</th>
<th>700 - 1200</th>
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<th>700 - 1400</th>
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<th>700 - 1200</th>
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<td>Polystichum viridescens</td>
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<td>Arachnodes artplata</td>
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<td>Vc</td>
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<td>Name of the taxa</td>
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<td>Arachnites triptera</td>
<td>Arachnites arctata</td>
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<td>Dryopteris spicata</td>
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<td>Sd</td>
<td>X</td>
<td>C</td>
<td>Cl</td>
<td>Vc</td>
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<td>R</td>
<td>C</td>
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<td>R</td>
<td>O</td>
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<tr>
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<td>a</td>
<td>-</td>
<td>Sp</td>
<td>d</td>
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<td>+</td>
<td>+</td>
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<tr>
<td>Fully shaded</td>
<td>+</td>
<td>-</td>
<td>+</td>
<td>+</td>
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<td>+</td>
<td>-</td>
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<td>Forest edge</td>
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<td>-</td>
<td>+</td>
<td>-</td>
<td>+</td>
<td>-</td>
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<td>Rhizome</td>
<td>e</td>
<td>e</td>
<td>d</td>
<td>a</td>
<td>d</td>
<td>e</td>
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<tr>
<td>Distribution</td>
<td>Sp</td>
<td>Sp</td>
<td>a</td>
<td>-</td>
<td>Sp</td>
<td>d</td>
</tr>
<tr>
<td>Habitat</td>
<td>T</td>
<td>T</td>
<td>T</td>
<td>T</td>
<td>T</td>
<td>T</td>
</tr>
<tr>
<td>Vegetational type</td>
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<td>Sd</td>
<td>X</td>
<td>C</td>
<td>Cl</td>
<td>Vc</td>
</tr>
<tr>
<td>Frequency on the field</td>
<td>R</td>
<td>R</td>
<td>C</td>
<td>a</td>
<td>R</td>
<td>O</td>
</tr>
</tbody>
</table>

Note: A = Abundant, B = Common, C = Common, D = Dry deciduous forest, E = Epiphyte & terrestrial, F = Frequent, L = Lithophyte, N = Nutria, O = Occasional, P = Prevalent, R = Rare, S = Sparsely, T = Terrestrial, V = Vallicolic open and closed forest, X = All vegetational types, Y = Young.
Fraser-Jenkins (1984) considered that the genera of *Dryopteris* and *Polystichum* in the Indian subcontinent, are the most complex and difficult genera, on account of their large size, presence of polyploids and apomicts. He has also pointed out that the ranges of intraspecific variation and polymorphism in the two genera are due to the combination of distinct genomes resulting in the diversity of forms within the genus. Manickam and Irudayaraj (1988) worked out the degree of ploidy level in members of Dryopteridaceae.

It is true that regional species diversity occurs in the wet mountainous regions of the tropics, where there is a greatest ecological diversity and maximal opportunity for speciation and persistence (Tryon, 1986). The general latitudinal diversity of species is the basis of the regional diversity of ferns and most species occur in between Tropic of cancer and the Tropic of capricon in relatively warm and slightly seasonal areas of the world. This closely coincides with the distribution of tropical vegetation, where ferns form a good percentage of ground flora. Tryon (1986) reported 3600 species of homosporous ferns in a latitudinal zone of 15 degrees, in which South India is located.

Endemism occurs especially in a region where conditions for geographic and alloploid speciation are maximal. A high ecological diversity patterned in a mosaic provides special opportunity for geographic speciation by peripheral divergence and for species hybridization leading to alloplody (Tryon, 1986). All these conditions are proved to prevail in the Western Ghats of South India because a moderate environmental change has been broughout by pleistone glaciation in the historical past. The topography is so complex and the peninsula is sufficiently away from the landmass due to the Indian Ocean on the south and Bay of Bengal in the east, the two main hill ranges with higher elevations do avoid the opportunities for migration and extinction.

High species diversity is also based on a higher number of non endemic species which have originated either within the region and migrated elsewhere or, conversely have migrated into the region from elsewhere (Tryon, 1986). Fraser-Jenkins (1984) have pointed out that *Dryopteris* and *Polystichum* are predominantly temperate with their main evolutionary centres in south-west China because maximum number of species occurring today are seen there. The two genera also have some apparent secondary areas of
evolution in South East Asia, Europe, East Africa, North Africa and the Far East. South Indian members of Dryopteridaceae show affinity either to Sino-Himalayan members or to South East Asian members (Fraser-Jenkins, 1989, 1991). Hence they might have migrated either from the primary centre of origin or from the secondary centre of evolution.

4.4.3. CHEMICAL CHARACTERISTICS OF SOILS AND FERNS

Soil is one of the most important ecological factors. Ferns depend upon soil for their nutrients, water supply, and anchorage. The soil is a dynamic layer of surface material which is constantly changing and developing under the process of adjustment to conditions of climate, parent material, topography, and vegetation. Soils are made up of substances existing in solid, liquid, and gaseous states, with colloidal particles of organic and inorganic origin playing an important function in spore germination, size, and erectness of sporophyte and vigour of the fronds and depth of the root system of ferns. Soil has a unique combination of both internal and external characteristics that have definable ranges of expression. Each individual kind of soil has a modal set of characteristics within the limits, having influence in the growth of land plants. The present study was carried out with a view to finding out the soil characteristics of different habitats where the different fern species grow and flourish. Foliar mineral analysis was also carried out in order to find out the existence of correlation between the soil nutrients and plant elements.

The results of soil analysis where Dryopteridaceous ferns collected, foliar mineral contents, summary of soil and plant analysis, and simple linear regression and correlation analysis of the data are given in tables 4.9 to 4.13.

SOIL TOTAL NITROGEN

The values of soil nitrogen content range from 1.16 % (Tectaria paradoxa) to 3.18 % (Lastreopsis tenera). In general, the 'N' content is medium in rating (Metson, 1961). Soil total nitrogen in the present study has significant negative correlation with
Table 4.9 Soil characteristics of different sites at which Dryopteridaceous ferns were collected (percentage of dry weight)

<table>
<thead>
<tr>
<th>Name of the species</th>
<th>N</th>
<th>P</th>
<th>K</th>
<th>Ca</th>
<th>Mg</th>
<th>Na</th>
<th>Organic matter</th>
<th>C</th>
<th>C/N</th>
<th>soil pH</th>
<th>Total alkalinity</th>
<th>Lime status</th>
<th>Water holding capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td><em>Tectaria paradoxa</em></td>
<td>1.16</td>
<td>0.20</td>
<td>1.60</td>
<td>4.81</td>
<td>2.12</td>
<td>0.76</td>
<td>22.71</td>
<td>13.17</td>
<td>11.35</td>
<td>5.90</td>
<td>0.09</td>
<td>6.29</td>
<td>47.35</td>
</tr>
<tr>
<td><em>Tectaria wightii</em></td>
<td>2.25</td>
<td>0.35</td>
<td>1.80</td>
<td>4.32</td>
<td>2.08</td>
<td>0.93</td>
<td>32.66</td>
<td>18.95</td>
<td>8.42</td>
<td>6.08</td>
<td>0.04</td>
<td>6.40</td>
<td>52.05</td>
</tr>
<tr>
<td><em>Tectaria coadunata</em></td>
<td>1.17</td>
<td>0.40</td>
<td>1.50</td>
<td>4.72</td>
<td>2.02</td>
<td>0.84</td>
<td>22.65</td>
<td>13.14</td>
<td>11.23</td>
<td>6.21</td>
<td>0.13</td>
<td>6.01</td>
<td>51.00</td>
</tr>
<tr>
<td><em>Lastreopsis tenera</em></td>
<td>3.18</td>
<td>0.68</td>
<td>1.30</td>
<td>2.42</td>
<td>2.43</td>
<td>0.77</td>
<td>34.29</td>
<td>19.89</td>
<td>6.22</td>
<td>6.33</td>
<td>0.03</td>
<td>4.60</td>
<td>35.00</td>
</tr>
<tr>
<td><em>Polystichum harpophyllum</em></td>
<td>2.18</td>
<td>0.17</td>
<td>1.70</td>
<td>2.80</td>
<td>2.24</td>
<td>0.68</td>
<td>41.28</td>
<td>23.95</td>
<td>10.98</td>
<td>6.03</td>
<td>0.03</td>
<td>3.81</td>
<td>60.58</td>
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<tr>
<td><em>Polystichum piceopaleaeum</em></td>
<td>2.24</td>
<td>0.60</td>
<td>1.50</td>
<td>3.42</td>
<td>2.42</td>
<td>0.89</td>
<td>33.89</td>
<td>19.66</td>
<td>8.77</td>
<td>6.12</td>
<td>0.06</td>
<td>4.21</td>
<td>46.31</td>
</tr>
<tr>
<td><em>Polystichum moluccense</em></td>
<td>1.19</td>
<td>0.80</td>
<td>1.80</td>
<td>2.41</td>
<td>2.31</td>
<td>0.69</td>
<td>23.65</td>
<td>13.72</td>
<td>11.52</td>
<td>6.81</td>
<td>0.05</td>
<td>4.40</td>
<td>49.85</td>
</tr>
<tr>
<td><em>Polystichum squarrosum</em></td>
<td>3.16</td>
<td>0.25</td>
<td>1.20</td>
<td>2.40</td>
<td>2.00</td>
<td>0.85</td>
<td>46.22</td>
<td>26.81</td>
<td>8.48</td>
<td>6.35</td>
<td>0.10</td>
<td>4.54</td>
<td>53.25</td>
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<tr>
<td><em>Arachniodes tripinnata</em></td>
<td>2.26</td>
<td>0.81</td>
<td>1.10</td>
<td>2.24</td>
<td>2.42</td>
<td>0.76</td>
<td>34.10</td>
<td>19.78</td>
<td>8.75</td>
<td>6.50</td>
<td>0.03</td>
<td>4.80</td>
<td>39.43</td>
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<tr>
<td><em>Arachniodes aristata</em></td>
<td>2.23</td>
<td>0.69</td>
<td>1.60</td>
<td>2.28</td>
<td>2.82</td>
<td>0.89</td>
<td>17.05</td>
<td>19.89</td>
<td>8.91</td>
<td>6.20</td>
<td>0.06</td>
<td>3.81</td>
<td>43.72</td>
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<tr>
<td><em>Arachniodes amabilis</em></td>
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<td>0.51</td>
<td>1.90</td>
<td>2.28</td>
<td>2.46</td>
<td>0.93</td>
<td>23.52</td>
<td>13.64</td>
<td>11.46</td>
<td>5.89</td>
<td>0.02</td>
<td>4.23</td>
<td>55.60</td>
</tr>
<tr>
<td><em>Dryopteris hirtipes</em></td>
<td>2.23</td>
<td>0.80</td>
<td>1.80</td>
<td>2.28</td>
<td>2.62</td>
<td>0.78</td>
<td>30.27</td>
<td>17.56</td>
<td>7.87</td>
<td>6.01</td>
<td>0.07</td>
<td>4.01</td>
<td>50.08</td>
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<tr>
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<td>1.19</td>
<td>0.60</td>
<td>1.70</td>
<td>3.12</td>
<td>1.95</td>
<td>0.48</td>
<td>24.43</td>
<td>13.59</td>
<td>11.42</td>
<td>6.50</td>
<td>0.03</td>
<td>4.80</td>
<td>46.73</td>
</tr>
<tr>
<td><em>Dryopteris cochlata</em></td>
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<td>0.70</td>
<td>1.40</td>
<td>2.24</td>
<td>2.28</td>
<td>0.76</td>
<td>22.88</td>
<td>13.27</td>
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<td>6.99</td>
<td>0.03</td>
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<td>48.43</td>
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<td>1.90</td>
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<td>0.35</td>
<td>32.70</td>
<td>18.97</td>
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<td>5.90</td>
<td>0.03</td>
<td>3.24</td>
<td>55.45</td>
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<td><em>Dryopteris approximata</em></td>
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<td>1.70</td>
<td>2.48</td>
<td>2.91</td>
<td>0.46</td>
<td>40.79</td>
<td>23.66</td>
<td>10.37</td>
<td>6.90</td>
<td>0.04</td>
<td>4.62</td>
<td>41.85</td>
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</tbody>
</table>

N - Total nitrogen          P - Total phosphorus   K - Total potassium  Ca - Total calcium
Mg - Total magnesium       Na - Total sodium       C - Total carbon       C/N - Carbon / Nitrogen ratio
Table 4.10 Foliar mineral content of Dryopteridaceous ferns of the Western Ghats
(Percentage of dry weight)

<table>
<thead>
<tr>
<th>Name of the species</th>
<th>N</th>
<th>P</th>
<th>K</th>
<th>Ca</th>
<th>Mg</th>
<th>Na</th>
<th>K/N ratio</th>
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</thead>
<tbody>
<tr>
<td>Tectaria paradoxa</td>
<td>2.08</td>
<td>0.11</td>
<td>0.04</td>
<td>1.98</td>
<td>0.47</td>
<td>0.04</td>
<td>0.02</td>
</tr>
<tr>
<td>Tectaria wightii</td>
<td>1.35</td>
<td>0.10</td>
<td>0.08</td>
<td>1.88</td>
<td>0.13</td>
<td>0.07</td>
<td>0.06</td>
</tr>
<tr>
<td>Tectaria coadunata</td>
<td>2.12</td>
<td>0.19</td>
<td>0.17</td>
<td>1.85</td>
<td>0.59</td>
<td>0.09</td>
<td>0.08</td>
</tr>
<tr>
<td>Lastreopsis tenera</td>
<td>1.77</td>
<td>0.18</td>
<td>0.09</td>
<td>1.02</td>
<td>0.17</td>
<td>0.47</td>
<td>0.05</td>
</tr>
<tr>
<td>Polystichum harpophyllum</td>
<td>2.22</td>
<td>0.16</td>
<td>0.14</td>
<td>1.24</td>
<td>0.61</td>
<td>0.20</td>
<td>0.06</td>
</tr>
<tr>
<td>Polystichum piceopalaceum</td>
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<td>0.15</td>
<td>0.12</td>
<td>1.09</td>
<td>0.59</td>
<td>0.06</td>
<td>0.05</td>
</tr>
<tr>
<td>Polystichum moluccense</td>
<td>1.56</td>
<td>0.14</td>
<td>0.11</td>
<td>1.31</td>
<td>0.67</td>
<td>0.09</td>
<td>0.07</td>
</tr>
<tr>
<td>Polystichum squarrosum</td>
<td>1.45</td>
<td>0.15</td>
<td>0.07</td>
<td>1.02</td>
<td>0.50</td>
<td>0.07</td>
<td>0.05</td>
</tr>
<tr>
<td>Arachniodes tripinnata</td>
<td>1.60</td>
<td>0.14</td>
<td>0.06</td>
<td>1.16</td>
<td>0.53</td>
<td>0.06</td>
<td>0.04</td>
</tr>
<tr>
<td>Arachniodes aristata</td>
<td>1.79</td>
<td>0.15</td>
<td>0.11</td>
<td>1.79</td>
<td>0.43</td>
<td>0.05</td>
<td>0.06</td>
</tr>
<tr>
<td>Arachniodes amabilis</td>
<td>1.91</td>
<td>0.14</td>
<td>0.13</td>
<td>1.69</td>
<td>0.69</td>
<td>0.20</td>
<td>0.07</td>
</tr>
<tr>
<td>Dryopteris hirtipes</td>
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<td>0.13</td>
<td>0.11</td>
<td>1.71</td>
<td>0.12</td>
<td>0.27</td>
<td>0.05</td>
</tr>
<tr>
<td>Dryopteris madrasensis</td>
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<td>0.15</td>
<td>0.07</td>
<td>1.89</td>
<td>0.57</td>
<td>0.09</td>
<td>0.03</td>
</tr>
<tr>
<td>Dryopteris cochleata</td>
<td>1.70</td>
<td>0.14</td>
<td>0.10</td>
<td>1.04</td>
<td>0.55</td>
<td>0.08</td>
<td>0.06</td>
</tr>
<tr>
<td>Dryopteris sparsa</td>
<td>1.54</td>
<td>0.15</td>
<td>0.09</td>
<td>1.46</td>
<td>0.33</td>
<td>0.14</td>
<td>0.06</td>
</tr>
<tr>
<td>Dryopteris approximata</td>
<td>1.49</td>
<td>0.16</td>
<td>0.08</td>
<td>1.41</td>
<td>0.54</td>
<td>0.22</td>
<td>0.05</td>
</tr>
</tbody>
</table>

N - Total nitrogen    P - Total phosphorus    K - Total potassium    Ca - Total calcium
Mg - Total magnesium  Na - Total sodium      C - Total carbon       C/N - Carbon / Nitrogen ratio
### Table 4.11 Summary of soil analysis

<table>
<thead>
<tr>
<th>Parameters studied</th>
<th>Minimum value</th>
<th>Recorded in species</th>
<th>Maximum value</th>
<th>Recorded in species</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total nitrogen</td>
<td>1.16</td>
<td><em>Tectaria paradoxa</em></td>
<td>3.18</td>
<td><em>Lastreopsis tenera</em></td>
</tr>
<tr>
<td>Total phosphorus</td>
<td>0.17</td>
<td><em>Polystichum harpophyllum</em></td>
<td>0.80</td>
<td><em>Polystichum moluccense</em></td>
</tr>
<tr>
<td>Total potassium</td>
<td>1.10</td>
<td><em>Arachniodes tripinnata</em></td>
<td>1.90</td>
<td><em>Arachniodes amabilis</em></td>
</tr>
<tr>
<td>Total calcium</td>
<td>2.24</td>
<td><em>Dryopteris cochleata</em></td>
<td>4.81</td>
<td><em>Tectaria paradoxa</em></td>
</tr>
<tr>
<td>Total magnesium</td>
<td>1.95</td>
<td><em>Dryopteris madrasensis</em></td>
<td>2.91</td>
<td><em>Dryopteris approximata</em></td>
</tr>
<tr>
<td>Total sodium</td>
<td>0.35</td>
<td><em>Dryopteris sparsa</em></td>
<td>0.93</td>
<td><em>Tectaria wightii / Arachniodes amabilis</em></td>
</tr>
<tr>
<td>Total organic matter</td>
<td>17.05</td>
<td><em>Arachniodes aristata</em></td>
<td>46.22</td>
<td><em>Polystichum squarrosum</em></td>
</tr>
<tr>
<td>Total carbon</td>
<td>13.14</td>
<td><em>Tectaria coadunata</em></td>
<td>26.81</td>
<td><em>Polystichum squarrosum</em></td>
</tr>
<tr>
<td>C/N ratio</td>
<td>6.22</td>
<td><em>Lastreopsis tenera</em></td>
<td>11.52</td>
<td><em>Polystichum moluccense</em></td>
</tr>
<tr>
<td>Soil pH</td>
<td>5.89</td>
<td><em>Arachniodes amabilis</em></td>
<td>6.99</td>
<td><em>Dryopteris cochleata</em></td>
</tr>
<tr>
<td>Total alkalinity</td>
<td>0.02</td>
<td><em>Arachniodes amabilis</em></td>
<td>0.13</td>
<td><em>Tectaria coadunata</em></td>
</tr>
<tr>
<td>Lime status</td>
<td>2.01</td>
<td><em>Tectaria coadunata</em></td>
<td>4.60</td>
<td><em>Lastreopsis tenera</em></td>
</tr>
<tr>
<td>Water holding capacity</td>
<td>35.00</td>
<td><em>Lastreopsis tenera</em></td>
<td>60.58</td>
<td><em>Polystichum harpophyllum</em></td>
</tr>
<tr>
<td>Parameter studied</td>
<td>Minimum value</td>
<td>Recorded in species</td>
<td>Maximum value</td>
<td>Recorded in species</td>
</tr>
<tr>
<td>---------------------</td>
<td>---------------</td>
<td>------------------------------------------</td>
<td>---------------</td>
<td>------------------------------------------</td>
</tr>
<tr>
<td>Total Nitrogen</td>
<td>1.35</td>
<td><em>Tectaria wightii</em></td>
<td>2.43</td>
<td><em>Polystichum piceopaleaceum</em></td>
</tr>
<tr>
<td>Total Phosphorus</td>
<td>0.10</td>
<td><em>Tectaria wightii</em></td>
<td>0.19</td>
<td><em>Tectaria coadunata</em></td>
</tr>
<tr>
<td>Total Potassium</td>
<td>0.04</td>
<td><em>Tectaria paradoxa</em></td>
<td>0.17</td>
<td><em>Tectaria coadunata</em></td>
</tr>
<tr>
<td>Total Calcium</td>
<td>1.02</td>
<td><em>Lastropsis tenera</em></td>
<td>1.98</td>
<td><em>Tectaria paradoxa</em></td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>Polystichum squarrosum</em></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total Magnesium</td>
<td>0.12</td>
<td><em>Dryopteris hirtipes</em></td>
<td>0.69</td>
<td><em>Arachniodes amabilis</em></td>
</tr>
<tr>
<td>Total Sodium</td>
<td>0.04</td>
<td><em>Tectaria paradoxa</em></td>
<td>0.47</td>
<td><em>Lastropsis tenera</em></td>
</tr>
<tr>
<td>Total K/N ratio</td>
<td>0.02</td>
<td><em>Tectaria paradoxa</em></td>
<td>0.08</td>
<td><em>Tectaria coadunata</em></td>
</tr>
</tbody>
</table>
Table 4.13 Simple linear regression and correlation analysis

<table>
<thead>
<tr>
<th>Independent variable</th>
<th>Dependent variable</th>
<th>Regression equation ( y = a + bx )</th>
<th>Correlation coefficient ( \gamma )</th>
<th>Remarks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil nitrogen</td>
<td>Plant nitrogen</td>
<td>( y = 2.10 - 0.14x )</td>
<td>-0.30</td>
<td>significant</td>
</tr>
<tr>
<td>Soil phosphorus</td>
<td>Plant phosphorus</td>
<td>( y = 0.14 + 0.00x )</td>
<td>+0.05</td>
<td>significant</td>
</tr>
<tr>
<td>Soil potassium</td>
<td>Plant potassium</td>
<td>( y = 0.04 + 0.03x )</td>
<td>+0.26</td>
<td>significant</td>
</tr>
<tr>
<td>Soil calcium</td>
<td>Plant calcium</td>
<td>( y = 0.88 + 0.20x )</td>
<td>+0.51</td>
<td>non significant</td>
</tr>
<tr>
<td>Soil magnesium</td>
<td>Plant magnesium</td>
<td>( y = 0.65 - 0.08x )</td>
<td>-0.12</td>
<td>significant</td>
</tr>
<tr>
<td>Soil sodium</td>
<td>Plant sodium</td>
<td>( y = 0.20 - 0.09x )</td>
<td>-0.14</td>
<td>significant</td>
</tr>
<tr>
<td>Soil organic matter</td>
<td>Plant nitrogen</td>
<td>( y = 1.81 + 0.00x )</td>
<td>-0.03</td>
<td>significant</td>
</tr>
<tr>
<td>Soil organic matter</td>
<td>Soil nitrogen</td>
<td>( y = 0.11 + 0.06x )</td>
<td>+0.73</td>
<td>non significant</td>
</tr>
</tbody>
</table>

Number of pairs studied - 16

Critical value of correlation coefficient \( \gamma \) at 5% significance level : 0.482
plant nitrogen ($\gamma = -0.30$) and has a positive but nonsignificant correlation with soil organic matter ($\gamma = 0.73$). The negative correlation of soil nitrogen with plant nitrogen might be due to the rapid uptake of nitrogen by the ferns from the soil reserve and also because of the slow rate of the denitrification process in the forest humus due to low temperature.

In ferns, nitrogen is present not only in the structure of protein, but also in such important molecules as purines, pyrimidines, porphyrins and coenzymes. While purines and pyrimidines are found in the nucleic acids, RNA and DNA, essential for synthesis of proteins, the porphyrin structure is present in the chlorophylls and cytochrome enzymes. Since N is highly mobile within a plant, the deficiency of the element causes a drop in chlorophyll content. Older fronds become yellow-green and often completely yellow and leads to stunted growth (Jones, 1987).

**SOIL TOTAL PHOSPHORUS**

In ferns, ‘P’ occurs in the form of both organic and inorganic phosphates. It is a constituent of many compounds in ferns viz: nucleic acids, phospholipids, high energy phosphate bonds and in nucleotides. At neutral pH, phosphate exists in about equal parts of mono and divalent anions, contributing to the buffering capacity of the cell. This element is abundant in the meristematic regions of actively growing ferns and demanded at the time of sporophyll formation (Jones, 1987) ‘P’ deficiency cause premature fall of fronds, stunted growth and the fronds become dark to blue green colours.

The amount of phosphorus in soil ranges from 0.17 % (*Polystichum harpophyllum*) to 0.80% (*Polystichum moluccense*). It is interesting to note that soil phosphorus has significant positive correlation ($\gamma = 0.05$) with plant phosphorus. It reveals that inspite of the depletion of soil ‘P’ by ferns due to uptake, the uptake does not affect the soil reserve. More over the soil ‘P’ content is higher (0.17% to 0.80%) when compared to plant ‘P’ (0.10% to 0.19%). It is due to the fact that more phosphate solubulisation takes place in the forest soils.
SOIL TOTAL POTASSIUM

Potassium is a univalent cation, not a constituent of any compound in plants but occur in the cytoplasm of meristematic tissues of buds and roots. It functions in anion neutralisation, enzyme activation, membrane transport processes and osmotic potential. It is also important for the lengthing of tissues in the stipes and rhizomes. The symptoms of ‘K’ deficiency appear generally first on the mature leaves as a characteristic spotting of a colour other than green and followed by prominent shortening of the organs leading to stunted growth (Jones, 1987).

The value of soil potassium ranges from 1.10% (Arachniodes tripinnata) to 1.90% (Arachniodes amabilis). Soil ‘K’ has a significant positive correlation with plant ‘K’ ($\gamma = 0.26$).

Potassium status of soil depends greatly on the parent material and its degree of weathering. The common potassium bearing parent material in the study area is mica (which contains 5-8% of potassium (Konrad and Mengal, 1985).

SOIL TOTAL CALCIUM, MAGNESIUM AND SODIUM

Calcium is relatively a large divalent cation, immobile and usually not redistributed in plant tissues. It occurs in the ferns in a soluble form of crystalline form. There are four important roles attributed to Calcium viz: a) the cytoplasmic ionic activity b) low physiological mobility c) critical requirement outside the protoplast and a restricted role as a enzyme cofactor. ‘Ca’ is considered as a cell elongation factor required in the meristematic regions of roots, rhizomes and fronds. ‘Ca’ deficiency adversely affects the growth and leads to death especially in the limestone ferns.

The values of Ca in soils range from 2.24% (Dryopteris cochleata) to 4.81% (Tectaria paradoxa). No significant correlation exists between the soil ‘Ca’ and foliar ‘Ca’ levels inspite of its importance. This may be due to presence of more amount of calcium in the forest soils. It is also evident from the present study that the free calcium carbonate (soil lime status) is more than 2% in most of the soils under present study (upto 4%) and hence the soil is calcareous in nature.
Magnesium has the highest chemical activity of any divalent cation in the cytoplasm and its concentration varies highly in plant tissues. It is an important constituent of chlorophyll and plastids. ‘Mg’ deficiency usually results in the development of extensive interveinal chlorosis in the fronds. It is also an activator of many enzymes and often concentrated in the growing apices.

The values of soil magnesium ranges from 1.95% \((Dryopteris madrasensis)\) to 2.91% \((Dryopteris approximata)\). It has a significant negative correlation \((\gamma = -0.12)\) to foliar magnesium. Deficiency of ‘Mg’ is common in acid soils in regions of heavy rainfall and also occasionally in peats.

Though there is no convincing evidence that Sodium is essential for plant metabolism, it is present in considerable quantity. However, as a micro nutrient it has some promotive effect in osmotic adjustment and indirect enzyme activation.

The values of soil sodium range from 0.35% \((Dryopteris sparsa)\) to 0.93 \((Tectaria wightii\) and \(Arachniodes amabilis)\). It also shows a significant negative correlation \((\gamma = -0.14)\) with foliar sodium. Supply of enough amount of ‘Na’ prevents incipient wilting in ferns (Jones, 1987).

**SOIL ORGANIC MATTER AND C/N RATIO:**

It is derived from long and short-term addition of material from plants, animals and micro organisms growing above and below the ground. The forests soils contain a characteristic Mull humus which is a grey, brown grey or blackish material diffusely incorporated amongst the soil mineral particles by biological mixing. It is associated with soil pH values above 5.0 and abundant divalent cations.

The values of organic matter content range from 17.05% \((Arachniodes aristata)\) to 46.22% \((Polystichum squarrosum)\). Organic matter has positive but non significant correlation with soil nitrogen and significant correlation with plant ‘N’ \((\gamma = 0.03)\). Positive correlation with soil ‘N’ reveals that organic matter is the chief source of ‘N’ from which enrichment of soil nitrogen reserve has taken place by mineralization and hence for the ferns irrespective of species organic matter is required for its growth. The
C/N ratio in the present study ranges from 6.22 (*Lastreopsis tenera*) to 11.52 (*Polystichum moluccense*).

Climatic conditions, especially temperature and rainfall exert a dominant influence on the amounts of nitrogen and organic matter found in forest soils. The organic matter and nitrogen of the soil usually increase with rainfall and the C/N ratio widens somewhat. In general, the decomposition of organic matter and its complete mineralization is slow in the cool climate. Soil moisture also exerts a very positive control upon the accumulation of organic matter. In general the nitrogen and organic matter increase as the effective moisture becomes greater. At the same time, the C/N ratio becomes wider. So the organic situation of forest soil largely depends on both temperature and precipitation.

SOIL, pH, TOTAL ALKALINITY AND LIME STATUS

The pH values of forest soils show variation ranging from 5.89 (*Arachniodes amabilis*) to 6.99 (*Dryopteris cochleata*). Dryopteridaceous ferns can be regarded as calcicoles because they usually grow in soils with pH more than 5.5. These soils should be generally cation saturated and calcareous in nature. Even though the lime status is quite significant, the level of exchangeable Ca in the soil may be poor hence there is a slight acidic pH. The pH limits also reflects the mull humus nature of the soil. Another cause for acidity in the forest soil is due to the high rainfall which leachout the other exchangeable bases.

The values of total alkalinity ranges from 0.02% to 0.13% and lime status from 2.01% to 4.60%. Hence these soils can be inferred as calcareous soils tending towards neutrality. The acidic and alkaline problems are not found out.

WATER HOLDING CAPACITY:

It is the extent to which a soil can hold capillary water against gravity. The values range between 35% to 60.58%. The range indicates that these soils are having medium water holding capacity mainly due to the accumulation of organic mulch.
Analytical results of foliar mineral contents of ferns show that in general the ferns have more nitrogen followed by calcium and then magnesium and sodium followed by potassium and phosphorus. In the present study plant analytical values show significant correlations with their respective soil parameters except calcium. Among the minerals studied, in general, plant P, K, Ca and soil nitrogen to organic matter content of the soil have positive correlations with soil minerals, but calcium shows significance. However, plant ‘N’ and ‘Na’ have shown significant but negative correlation to their soil minerals. The reason could be that enormous amount of nitrogen compounds are recycled by humification. Plant nitrogen also shows significant negative correlation to soil organic matter. From the correlation studies it is concluded that the ferns under study in general absorb the nutrients more or less in the same quantity. It is very well expressed in case of nitrogen and phosphorus. As far as the forest soils are concerned they usually get their minerals from the parent rocks except nitrogen which is mostly enriched by denitrification process. Unlike metamorphic rocks the lime stone is the weakest one because of its solubility. Hence the soils in the present study area are mostly calcareous. Similarly, the acid igneous rocks contain considerable amount of ‘K’ and ‘Mg’. The phosphate content of igneous rocks is about 0.15% whereas lime stone contains only about 0.02% (Seth, 1977). Most of these minerals contained in rocks are usually leached away to deep layers during soil formation but a good quantity still remains in the surface because the plants tend to maintain the fertility of a soil by translocating minerals into their body and returning them to the surface. In general the chemical composition does not indicate any deficiency of an essential plant food, like N, P, K, Ca, Mg, Na and organic matter is also present in fair quantities. The water holding capacity of these soils is remarkably high. The pH of the soil is also tending towards neutrality. So the ferns well flourish in this type of habitat.
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