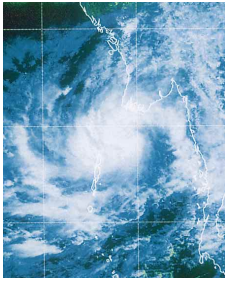

CHAPTER XV

PLANT SCIENCES

Botany is a mother science which has given birth to several branches, each being pursued as a speciality. The study of botany has undergone a tremendous change in the past 50 years and is presently called Plant Sciences to cover its wide scope. Early contributions to botanical knowledge were mainly made in colleges and universities by eminent individuals, who were fired by a spirit of nationalism. By talent and devotion they built schools of botanical learning. Undoubtedly, India has worldwide recognition in embryology, palaeobotany, taxonomy, cytology, cytogenetics, plant breeding, plant tissue culture and morphogenesis, and ecology. I.H. Burkill (1965) has compiled *Chapters on History of Botany in India*. B.M. Johri (1994) has edited two volumes on *Botany in India: History and Progress*, sponsored by the INSA. What proceeds is a summary of achievements in certain spheres of the subject.

Reproductive Biology

A discipline in which India holds leadership in the botanical world is embryology, nurtured by P. Maheshwari at Agra, Dacca and Delhi. *An Introduction to the Embryology of Angiosperms* authored by him in 1950 was, for many years, an authoritative textbook used the world over. Several important works such as *Embryology of Angiosperms* and *Comparative Embryology of Angiosperms*, by other authors have appeared since then. Besides investigating the embryology of seed plants of diverse families, and using the data generated for comparative and evolutionary purposes, outstanding contributions have been made in experimental embryology such as test-tube fertilization, pollen-pistil interaction, sexual-incompatibility, wide hybridization, nucellus and endosperm culture. In pollen biology the Indian endeavour covers morphology, aerobiology in relation to allergies, pollen viability, storage, germination and more recently biotechnology.

In plants that bear fruits with numerous seeds, there is intense competition among seeds for resources. It is only recently that studies have been initiated towards the understanding of concepts such as clutch-size, sibling-rivalry, parent-offspring conflict and neighbourhood effect by researchers at the University of Agricultural Sciences (UAS), Bangalore. These authors have provided recent evidence that only one out of 30 potential seeds develop in the *Jamun* tree (*Syzygium cumini*). The dominant seed draws the nutrients at the expense of the others. It also produces a chemical inhibitor (an indole compound) that suppresses the subordinate seeds.

It is regrettable that reproductive biology, especially breeding systems and gene flow in the identification of reproductive constraints, has not been studied in India in many economically important plants, including forest trees (except at a few centres such as Chandigarh, Jammu, Lucknow, Waltair and Delhi). For any tree-breeding programme, basic information on reproductive biology is essential. For instance a study made at Delhi on reproduction by seed in the ancient Indian medicinal plant guggul (*Commiphora wightii*) showed that the plant is a non-

pseudogamous apomict (not involving male participation) with nucellar polyembryony followed by autonomous endosperm development. Apomixis -- the formation of seeds without fertilization -- occurs in many grasses, dandelions and parthenium. Apomixis is now being studied at the molecular level with the hope that any gene(s) that regulate it might be introduced to fix hybrid vigour, to save time, labour and money. Genes which confer apomixis act at the stage of female meiosis. Therefore, it is essential to ultimately engineer apomixis in crop plants. Scientists at the CCMB have discovered a novel gene called *DYAD* in *Arabidopsis* which is involved in the control of female meiosis in plants.

Palaeobotany

Pioneering research work has been done at the Birbal Sahni Institute of Palaeobotany, Lucknow.

Four postage stamps released on the occasion of the Golden Jubilee of the Birbal Sahni Institute of Palaeobotany, depicting fossils and reconstructions.

Photo: BSIP, Lucknow

The creation of a new order Pentoxylales, a group of Jurassic fossil gymnosperms from Rajmahal hills in Bihar; verification of Wagner's theory of continental drift, providing scientific evidence for the Himalayan uplift, studies on stratigraphy relating to the classification of the Gondwanas; and origin, composition and reconstruction of the *Glossopteris* flora are some of the contributions which have received international recognition. Pollen with angiospermoid characters have been described from intertrappean sediments of Rajmahal basin (118 Ma). Besides reporting fossils of wild seeded banana and coconut, the Indian palaeobotanists have proved that the present Kutch region had luxuriant moist evergreen to deciduous vegetation. The earliest record of a mango fossil leaf from north-east India dates back to 55 Ma. Analysis of microfossils has enabled palaeobotanists to answer questions that have a bearing on coal, oil and natural gas. Other contributions of Indian palaeobotanists relate to changing palaeoclimates, migratory pathways of plants and causes of mass extinction. Coccoid and rod-shaped bacteria have been discovered in the sediments of Kudremukh iron formation, dating back to 2.6 billion years. The early photosynthetic, oxygen producing cyanobacteria isolated from stromatolites are also dated 2.6 billion years.

Biodiversity and Systematics

India is one of the 12 Megadiversity countries and has all the 13 biomes found in the world, with two major hotspots out of a total of 18. Importantly, India is one of the global centres for domesticated biodiversity (accounting for 160 domesticated species including rice, beans, sugarcane, citrus, mango, banana, eggplant, black pepper and cucumber). The approximate total number of plant species (including fungi and bacteria) recorded until now is between 45,000 and 49,000. These are distributed in the following groups: Angiosperms (flowering plants) 15,000-17,000; Gymnosperms 64; Pteridophytes 1,022; Bryophytes 3,700;Lichens 2,400; Fungi 23,000; Algae 2,500 and Bacteria 1,000. The exact numbers are not yet finally established. Among these there are 5,100

Photo: NBPGR, New Delhi

Variation in fruit shape, size and colour of egg plant or brinjal (Solanum melongena). Egg plant originated in India and was introduced to the other parts of the world.

endemics in angiosperms (1,600 in Western Ghats and 3,500 in Eastern Himalaya). These figures highlight the richness of our flora and the incompleteness of our knowledge of plants. About 2,000 species are threatened. Out of 120 endangered species, 60 are prioritized for conservation.

Non-Vascular Cryptogams: Indian botanists have carved a name for themselves in world botany for their studies on algae from soils, fresh water and marine environments. Whereas the school of Algae at Madras University led by M.O.P. Iyengar made extensive collections of marine brown and red algae, some of his students took up studies on the bluegreen algae or Cyanophyceae (now termed Cyanobacteria) and diatoms and wrote authoritative monographs. At the Banaras Hindu University (BHU) Y. Bharadwaja and R.N. Singh and their students specialized in the taxonomy, ecology and cytology of algae, physiology (notably nitrogen fixation), genetics and cytology. The first reports of the occurrence of viruses in the bluegreens and genetic recombination were from BHU using antibiotic-resistant mutants of *Anacystis nidulans*. The presence of plasmids and the role of UV radiation on growth, survival, adaptation and mutagenesis were also established for the first time at BHU. Other centres of algal research are at Allahabad, Lucknow, Jammu and Mysore. Applied aspects (such as extraction of biologically important compounds) from marine algae and use of bluegreen algae for scavenging toxic substances and heavy metals are being pursued at several centres.

More than 2,000 fungal genera accounting for 1/5 of the total global representation of fungi are reported from India. An enormous amount of work has been done on the taxonomy, morphology, reproduction, physiology, pathology (T.S. Sadasivan), genetics and industrial aspects of fungi (M.J. Thirumalachar). One hundred and eighty- five new genera of fungi have been described. The largest number belong to Deuteromycotina. Authoritative works have been published on Hyphomycetes, Myxomycetes and Clavariaceae (K. S. Thind). The physiology of parasitism and mechanism of resistance to fungal diseases have been pursued at the universitites of Madras, Calcutta and Allahabad (R.N. Tandon). The role of mycorrhizae (both ectotrophic and VAM) in the improvement of plant nutrition (especially phosphorus uptake), drought tolerance, suppression of soil-borne pathogens and reclamation of derelict lands are important current activities at UAS, Bangalore; Osmania University, Hyderabad; and University of Delhi (DU). The study of lichens was neglected until 1947. The pioneering efforts done at Lucknow, Pune and Kolkata have shown that over 2,000 species occur in India.

Bryophytes, the first plants to migrate from water to land are evolutionarily and ecologically significant. India accounts for nearly 18% of the world's bryophytes. The Lahore School of Bryophytes established by S.R. Kashyap was continued by his students, P. N. Mehra and R.S. Chopra at Chandigarh and by S.K. Pande at Lucknow. The evolutionary theories put forth by Mehra on the origin of thalloid forms from the

foliose habit and evolution of the marchantiaceous thallus have been highly valued in academic circles. Cytotaxonomic work on mosses (Chandigarh) and taxonomy and palynology of the bryophytes by Ram Udar at Lucknow have resulted in landmark publications.

At the Calcutta University, Gangulee took up the assiduous task of compiling the monumental work, *The Mosses of Eastern India and Adjacent Regions* (1969-80) in eight fasciles. The best known fossil liverworts (notably *Hepaticites nidpurensis*) were described from the Triassic beds of India by D.D. Pant.

Bryophytes have been used for ecological, geobotanical and geochemical studies in Kumaon Himalaya. They are also excellent materials for experimental studies on morphogenesis, physiology and molecular biology. Notable among the Indian contributions are studies on (i) control of spore germination, (ii) auxin regulation of protonemal differentiation from chloronema to caulonema and its regulation by cyclic AMP (at TIFR) Bombay, (iii) bud induction and formation of gemmae. Several other investigations include control of apogamy, apospory and sexuality by light, tempertaure and plant growth regulators (PGRs) and sugars included in the medium, and (iv) production of antibiotics.

Pteridophytes and Gymnosperms: Ferns and fern allies (Pteridophytes) ruled the dynasty of plant world during the carboniferous age (325 million years ago) as giant lycopods. They have now been relegated to a secondary position in botanical hierarchy. Over 82 species of Indian pteridophytes are vulnerable or extinct. Besides their important role in phytosociology, they are prized for their high ornamental value. The fascinating aspect that has attracted evolutionists to pteridophytes, both living and fossil, is incipient heterospory, leading to seed habit.

Azolla, the tiny aquatic fern harbours *Anabaena azollae*, a nitrogen fixing cyanobacterium in its pouches. Its role as a biofertilizer in tropical paddy fields has been studied at Varanasi and Cuttack. Plant scientists at Chandigarh and Patiala have carried out extensive work on the cytotaxonomy and ecology of pteridophytes. They have also started the *Indian Fern Journal*. Other active groups engaged in research which have added substantially to our knowledge of taxonomy, palynotaxonomy and reproductive biology of this group are from the National Botanical Research Institute (NBRI), Lucknow, and from universities of Lucknow, Allahabad, Panjab, Punjabi (at Patiala) and Calicut. Pteridophytes have also served as model systems for understanding morphogenesis. Several live collections of ferns and their allies have been conserved in botanical gardens in the above mentioned institutions. Owing to habitat destruction and over-collection by botanists and horticulturists, pteridophytes such as *Psilotum* and tree ferns have become rare and endangered at several original sites.

Gymnosperms are seed-bearing plants that lack fruits. They constitute a major component of the Himalayan forests as conifers. Cycads and gnetopsids are important groups in the study of plant evolution. B. Sahni's creation of a new group of fossil plants – the Pentoxylales – is a fundamental contribution to the field of gymnosperms. Befittingly *Pentoxylon sahnii* features in the emblem of the Birbal Sahni Institute of Palaeobotany (BSIP) and of the journal *The Palaeobotanist*.

Scientists of BSIP, D.D. Pant and his students at Allahabad, and U. Sen and his collaborators at Kolkata have enriched our knowledge of *Glossopteris* flora, Mesozoic gymnosperms and palynology. Structural, embryological, cytological aspects, and cytogenetical evolution, genetic architecture and taxonomic accounts of extant gymnosperms have been studied by researchers at Delhi, Lucknow, Chandigarh (P.N. Mehra), Allahabad, Chennai (B.G.L. Swamy) and Bangalore. Monographs and books have been prepared on *Abies, Cedrus, Picea, Pinus, Gnetum*, and *Ephedra*. Studies on population structure and reproductive

biology, with special reference to breeding system in pines have been carried out by P. D. Dogra. The cycads, often called living fossils, are disappearing from their natural habitats in India and need special efforts for conservation.

Angiosperms: The Botanical Survey of India (BSI) with its headquarters in Kolkata and nine circles was, has been, and will be the nucleus for preparing an inventory of plant resources of the country. This is a stupendous task and will have to be shared by teachers and scholars in colleges and universities and professionals in other institutions. The major achievements of BSI in the post-Independence era are the launching of a 35-volume *Flora of India* project, of which six have been published. Numerous local, district and state floras have appeared. The BSI has a chain of 11 herbaria, of which the Central National Herbarium, Howrah, is the largest. The total holdings in the BSI herbaria exceed 2.48 million, including 11,892 precious type specimens of the Indian Flora. Computerization of the herbarium sheets has been started by BSI. On the basis of floristic/taxonomic studies since 1964, over 1,500 taxa new to India and about 700 plants new to science, including over 26 genera have been added. After careful evaluation of the status and threat perceptions, Red Data Sheets on 1,182 species have been compiled. Data on 708 are available in print.

It is paradoxical that when there is serious global concern for the conservation of biodiversity, India should face an acute shortage of experts who can study, evaluate and explain the role of the wide variety of organisms in nature. The teaching of taxonomy is being neglected and taxonomists are undervalued not only in society but even in scientific circles. However, a few dedicated taxonomists have been relentlessly taking up floristic surveys and taxonomic studies. They have brought to light not only new species but have also uncovered several plants reported to be either extinct or extremely rare. Some of their

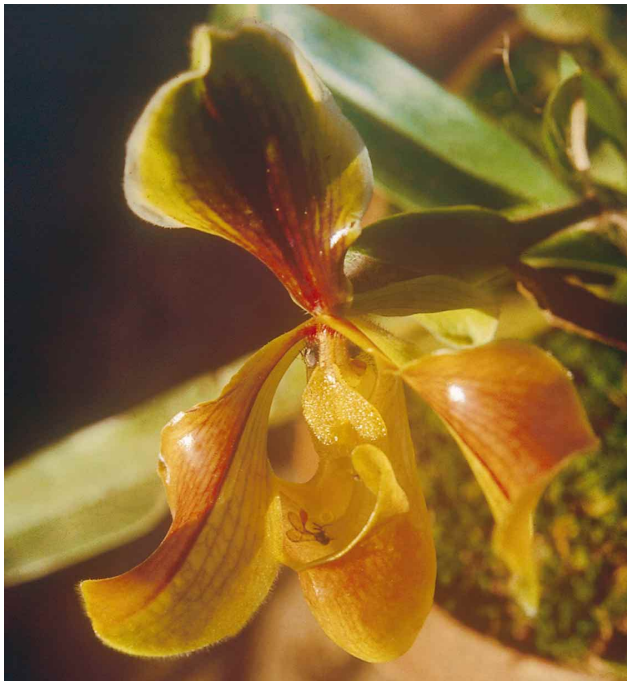

Photo: Pramod Tandon

Paphiopedilum villosum, the Lady's slipper orchid from Meghalaya.

contributions are: *Flora of Ladakh, Alpine Flora of Kashmir Himalaya, Flora of Indian Desert, Flora of Meghalaya, Flora of Tamil Nadu Carnatic and Excursion Flora (Tamil Nadu), The Flora of Karnataka* (two volumes), *Flora of Silent Valley, Flora of Udupi District, Flora of District Garhwal* and *Flora of Shimoga District.* The family Hydatellaceae (so far thought to be endemic to Australia) has been reported to occur in Maharashtra.

As a signatory to the Convention on Biological Diversity (CBD) held in Rio de Janerio in 1992, it was obligatory for India to commit itself to capacity building in taxonomy and take up exploration and preparation of an inventory of living organisms. Following the recommendations of a Workshop held in Jaipur for this purpose, the Ministry of Environment and Forests (MoEF) has set up an All India Co-ordinated Project on Taxonomy. The Project has organized specialist groups drawn from Universities, Botanical and Zoological Surveys of India to take up taxonomic work on animal viruses, bacteria and archaea, algae, fungi, lichens,

Photo: David Kothamasi

Many islands in the Andaman and Nicobar group are yet to be floristically explored.

bryophytes, pteriodophytes, gymnosperms, palms, grasses, bamboos, orchids, helminthes and nematodes, Microlepidoptera and Mollusca. Training in plant and animal biosystematics has also been recognized as an important component.

The taxonomic issues that need to be addressed in this century are mostly those that require interfacing of systematics and other disciplines. These include bioprospecting, conservation biology, ecosystem management and bioremediation. The other priority issues to be probed are inventorying and monitoring of plant diversity, particularly in areas which are unexplored, assessment of conservation status of species and roles of species in communities and ecosystems.

Cytology

Early efforts were addressed to the enumeration of chromosome number, size and karyotype of plants belonging to various groups at Chandigarh, Kolkata, Waltair, NBRI, BHU, Dharwar etc. Cytological information has been used as a criterion for evolution and genotoxicology. The book *Chromosome Techniques: Theory and Practice* is used the world over. Another most useful compilation is *Chromosome Atlas of Flowering Plants of the Indian Subcontinent* (1986), covering 6,973 species, 2,221 genera and 286 families. Banding techniques, chromosome painting, quantification of DNA, *in situ* nucleic acid hybridization and molecular aspects of genome organization are being pursued in India.

Plant Tissue Culture

Plant tissue culture, an off-shoot of human curiosity has presently become an essential component of plant biotechnology. Through the efforts of pioneers in France, USA, U.K. and Germany, plant tissue culture

Trichopus zeylanicus (locally called arogyapacha) is a wild plant that occurs in the Agasthyamalai hills of Kerala. It yields a drug that acts as an anti-fatigue and restorative agent. Scientists of Regional Research Laboratory (RRL), Jammu, and later of Tropical Botanical Garden and Research Institute (TBGRI), Kerala have carried our ethno-pharmacological studies on this plant and have prepared a formulation called Jeewani. The technology has been transferred to Arya Vaidya Pharmacy, Coimbatore. Fifty per cent of the monetary benefit from this transaction is being shared with the Kani tribe. This is the first example in which ethnobiological studies have resulted in tangible benefits to a tribal community. There are a large number of wild plants with potential use in agriculture, horticulture and medicine, requiring attention.

spread to various parts of the world. It was P. Maheshwari who started the first tissue culture Laboratory in India at DU in the 1950s as he foresaw the value of this technique in experimental embryology. Teachers trained abroad returned to Delhi, Baroda and Pune from where the interest spread to other universitites and CSIR laboratories such as NCL, NBRI, RRL(Jammu), and to BARC, Mumbai. The main benefits derived from tissue culture are: control of organogenesis, elimination of breeding barriers, micropropagation, disease detection and eradication, somatic embryogenesis, use of protoplasts, somatic hybridization, somaclonal variation, detection of genetic variability *in vitro* and production of transgenics. The discovery of androgenic haploidy at DU opened up an entirely new field of research in the production of pure lines of crop plants resulting in reduction of time and labour for exploiting hybrid vigour, especially for rice in China and later for other cereals. Very recently gynogenic haploids have been produced in mulberry.

Undeniably the most useful outcome of tissue culture has been in the micropropagation of ornamentals, agricultural and plantation crops, fruit and forest trees. Laboratory research on micropropagation of plants of economic importance (*Citrus*, *Eucalyptus*, bamboos, teak, poplar, banana, sugarcane, turmeric and cardamom) has been scaled up to near commercial level. The Asian bamboos have long flowering cycles and come to mast seeding once in 12-120 years. The first demonstration of micropropagation in bamboo using seed callus cultures was done in Delhi and over 10,000 plants were transferred to the field successfully. Several groups working in India and abroad have now demonstrated that micropropagation in bamboos can be accomplished, starting from vegetative parts. The pioneering work done at Delhi and NCL, Pune, led to the discovery that bamboo plantlets can come to flower *in vitro* precociously.

Tissue culture has been effectively used for multiplying and storing economically important, endangered (e.g. *Nepenthes khasiana*), threatened (Himalayan orchids) and biologically incompletely understood plants (Podostemaceae) and medicinal plants (*Dioscorea, Coptis teeta, Valeriana wallichi, Podophyllum hexandrum, Picrorhiza kurroa*) at North-Eastern Hill University (NEHU), DU, NBRI, NCL, BARC, CIMAP and Institute of Himalayan Bioresources and Technology (IHBT), Palampur.

The DBT has established six centres in India to provide hardening facilities for laboratory-raised plants and Micropropagation Technology Parks at TERI and NCL. The National Facility for Plant Tissue Culture Repository (also started by DBT) located at the NBPGR, has now been taken over by the ICAR. Collection, evaluation, introduction, exchange and conservation of germplasm, storage of elite plants, rare hybrids, and germplasm of vegetatively propagated plants and of plants bearing recalcitrant seeds in the form of tissues or embryonal axes in cryobanks are being practised at NBPGR.

Ecology and Environmental Studies

Plant ecological research in India can be traced to renowned ecologists— R. Misra of Banaras Hindu University (BHU), Varanasi, and F.R. Bharucha of the Institute of Science, Mumbai. Many of the other ecology centres in India owe their origin to persons directly or indirectly trained by Misra. The French Institute (Institüt Francais) at Pondicherry initiated studies on vegetation cartography in the 1950s.

In the beginning years attention was paid to the ecology of individual species in the ecosystem. Presently advances

Photo: Pramod Tandon

The only pitcher plant in India Nepenthes khasiana occurs in the north-eastern regions of India. Scientists of NEHU have propagated this plant in tissue culture and have introduced the plantlets to the natural habitat.

Photo: NBPGR, New Delhi

A corridor for modules in the National Seed Bank of NBPGR for storage of seeds at -20°C. Inset: Cryotanks for storing seeds and embryonal axes in liquid nitrogen.

have been made in the study of aquatic and wetland ecosystems, marine and mangrove ecosystems. In the study of forest ecosystems focus was shifted to nitrogen budget, mineral recycling, above ground and below ground (fine root) biomass production, functional analysis of effects of changes in land use, phenology of trees and vegetation analysis.

The BHU School has done commendable work on population differentiation, weed ecology, habitat conservation, productivity, energy flow, nutrient cycling and ecology of global change. The ecologists of this school have quantified biomass production and nutrient cycling of pine and oak forests in the Central Himalaya. They have shown that high C:N ratio of litter in pine leads to immobilization of available soil nitrogen, making the habitat inimical to species such as oaks that demand high amounts of nitrogen. This group has carried out detailed analysis of human and forest interactions in the Central Himalaya. The agro-systems in this part of the Himalaya are centres of massive energy consumption and their viability depends on the supply of energy from forests. A significant finding is that these forests are a source of CO_2 rather than a sink. The work on Ganga water was crucial in creating public awareness and inducing public and government participation in the form of Ganga Action Plan. The international journal *Tropical Ecology* was started at BHU and has maintained a high profile, acting as a vehicle to disseminate knowledge generated in and about the tropics.

The ecologists of the French Institute, Pondicherry, in collaboration with the ICAR and State Forest Departments prepared the first vegetation map of Peninsular India in 1956. With the availability of satellite imageries, another project was launched in 1973 for the cartography of the forests of the Western Ghats at a scale of 1:25,0000. These maps include details of flora and endemic species in addition to forests, grasslands, and wastelands. Analysis of the maps indicates the percentages of forest cover according to vegetation types. These data coupled with ecological studies in sensitive forest areas have been invaluable in strengthening conservation efforts. Other ecologic aspects studied at the Institute deal with bioclimatology and climate change with reference to deforestation.

Sustained plant ecological work at Rajkot and later at Agra has led to two significant discoveries: (i) 25 ecotypes of the desert grass *Cenchrus ciliaris* and nine of *C. setigerus* have been brought to successful cultivation in India and America, (ii) highest production, perhaps in the country, is in semi-arid areas like Agra Region with fresh or old alluvia, disproving the concept that semi-arid areas are next to arid and vulnerable to desertification (because native vegetation is dominated by C_4 plants with the highest water use efficiency).

Several investigators have studied the individual

effects of SO_2, fluoride and ozone and particulate matter on plants under controlled conditions at BHU, NBRI and JNU. The combined effects of pollutants with respect to injury symptoms have also been studied. The mechanism that prevents toxic effects of heavy metals on the metabolism of cyanobacteria and plants are being studied (BHU). The study of allelo-chemicals released by the weedy species to suppress other plants in the ecosystem has also received recent attention. Bioclimatic studies have been carried out to correlate vegetation distribution in the origin of tropical evergreen forests. That increasing emissions of greenhouse gases, such as CO_2, methane, CFCs, and nitrous oxide, are responsible for global warning is well-established. Among the sources of methane emission India, China and other Asian countries were considered as major contributors with huge areas of rice cultivation. Research carried out by IARI plant physiologists and ecologists at BHU has clearly indicated that methane emanating from the rice fields is not a major cause of global climate change as claimed by some western scientists.

A jhumed (slash and burn) area in Meghalaya.

Much of the ecological research had been carried out as if people did not matter. For the first time in India, a leading plant ecologist and his students began doing ground level research at the NEHU, and subsequently at JNU, in the interphase area of linking ecological and social processes. This group made an interdisciplinary case study of shifting cultivation (jhum cultivation) in north-east India, centred around sustainable management of natural resources. The information generated has been synthesized and published in 350 papers and a dozen books. Many traditional societies have accumulated a whole lot of empirical knowledge centred around the economic value of plant and animal species. The main contribution of this group has been to unravel the connection between Traditional Empirical Knowledge (TEK) and natural resource management and landscape management. This work has received international attention. Several strategies have been suggested by them for the improvement of landuse and resource management amongst mountain societies. The Nagaland Experiment of 1976-82 in rural management through Village Development Boards (VDBs) implemented by the government with support from India-Canada Environment Facility, has drawn largely from the research results of the NEHU ecologists..

The political economy of forest resource use has been studied by scientists at the Centre for Ecological Sciences, IISc. This group has brought to light the devastating long-term consequences for short-term gains by state governments. Bamboos were sold to paper mills at a throw-away price of just one rupee per tonne, whereas the basket-weavers had to levy in paying more than Rs. 5,000 per tonne in the Uttra Kannada district of Karnataka. Scientists at this Centre have also studied the ecological History of India and are compiling People's Biodiversity Register through participation of schools and colleges.

The restoration of degraded lands has been studied at BHU and Delhi. An important success story of DU scientists is the rehabilitation of a three-storeyed vegetation in the limestone-mined areas at Bhatta in Mussorie hills and morrum mined-out area of Bhatti wildlife sanctuary in Delhi and

extremely desertified land of Asola wildlife sanctuary, using a consortium of microbes belonging to different functional groups, associated with wild legumes and grasses.

Physiology

The rudiments of plant physiology can be traced to pioneers like J.C.Bose at Kolkata and Dastur in Mumbai. Parija (Cuttack), Sri Ranjan (Allahabad), R.S. Imamdar (BHU), T.Ekambaram (Chennai) and J.C.Sen Gupta (Kolkata) built active schools. The mechanism of regulation of stomatal movements and the various morphological, physiological and biochemical strategies to withstand drought, salinity, alkalinity and cold stress are being investigated (Tirupati, Hyderabad, IARI). Availability of water is a crucial factor that limits crop growth and productivity. With predictions about acute shortage of water in the near future and changing rainfall pattern, plant physiologists are giving serious attention to crop-water relations. Water Use Efficiency (WUE) is the ratio of the amount of biomass produced over a period of growth to the total amount of water transpired. Scientists at UAS, Bangalore have developed a method of estimating WUE by weighing a large number of plants in containers (mini lysimeters) on a daily basis. There is genotypic variability in WUE. Plants descriminate against heavy isotope of carbon (^{13}C) during photosynthesis. Since intercellular CO_2 concentration determines both carbon isotope descrimination and WUE, a strong inverse correlation exists between these paramters. In genotypes with high WUE, despite high transpiration, mesophyll efficiency for carbon reduction is also high. For rapid screening of genotypes with superior mesophyll efficiency, the Bangalore scientists are using the Isotope Ratio Mass Spectrometer (IRMO, a National facility set up by DST and DBT), which can monitor $^{13}C/^{12}C$, $^{18}O/^{16}O$, $^{15}N/^{14}N$ ratios on a continuous flow basis. This set up further facilitates analysis of these traits using molecular markers.

Basic and applied aspects of photosynthesis have been studied by several groups with emphasis on photochemistry, biochemistry and biomass production (JNU, NBRI, MKU, University of Hyderabad). In the mid 1960s the C_4 pathway was discovered in tropical plants which had high productivity. Plant physiologists at IARI noted that in *Sorghum* and *Pennisetum* a change from C_4 to C_3 pathway occurred after flowering. This was the first explanation that C_3 pathway is basic whereas C_4 can change with environment and phenology. Research done at Tirupati showed that certain plants are intermediate between C_3 and C_4 in leaf anatomy and biochemistry and also that the same plant may bear leaves with C_3 and C_4 photosynthetic pathway. IARI workers explained that heterosis in yield increment is the culmination of complementary relation between the 'source' (foliage) and 'sink' (grains). The heterosis in height and leaf area are the result of multiplicative effect of their component characters which show dominance/partial dominance.

Yet another area that has been in the forefront is the understanding of root-shoot signalling as a drought resistance strategy. Signals have been characterized involving the stress hormone abscisic acid (ABA) as a predominant positive signal and ions (calcium, nitrite) and cytokinins as negative signals. Electrical signals are indeed rapid and they can cause closure of stomata in the leaves instantaneously preventing transpiration (UAS, Bangalore).

A school of mineral nutrition was established at the Lucknow University by S. C. Agarwala to investigate the adequate dosage of micronutrients for important Indian crops and to establish critical limits of deficiency and toxicity. Of special significance is the metabolic and developmental role of micronutrients, especially zinc.

Several groups in India have studied nitrogen metabolism and the regulation of nitrate and nitrite reductase enzymes. Nitrogen fixation by free-living bluegreen algae and other bacteria, and symbiotic prokaryotes has been studied extensively. Pioneers in the area of biological nitrogen fixation are R. N. Singh and G.S. Venkataraman and their students and

scientists at Kalyani. The attention of scientists at JNU has been focussed on the regulatory aspects of nitrate reductase (NR) in response to light (NR is synthesized in response to phytochrome), hormones, nitrate, ammonium, amino acids and so on. These workers have also shown the phytochrome regulation of Ca^{+} fluxes and its effects on the turnover of phosphoinositide cycle.

S. M. Sircar and his students at Kolkata were pioneers in India in the physiology of flowering. In later period his group isolated gibberellins from mangroves and water hyacinth. Cytokinins were extracted by other workers from several plants. According to plant hormone researchers of IISc, Bangalore, cytokinins and auxin are involved in the production of haustoria in the parasitic plant *Cuscuta* even without organic contact with the host. An entirely new group of antigibberellins-- the cucurbitacins -- which are widespread in the family Cucurbitaceae were reported from Kolkata. Indian scientists have also provided extensive evidence for the growth regulating properties of polyamines. An impressive amount of work has been done on the physiologial effects and agricultural applications of plant growth regulators (PGRs) and their antagonists, especially on the rooting of cuttings, induction of flowering, parthenocarpy, biennial bearing in mango, sex expression, induction of male sterility, defoliation, fruit ripening, and retardation of senescence in flowers. Special mention is made of the work of K.K. Nanda on the induction of flowering in the short day plant (SDP) *Impatiens balsamina* by gibberellins under non-inductive conditions and in duckweeds by phenolics, especially salicyclic acid and also by chelating agents at DU.

A brief account of Plant Molecular Biology is covered in Chapter XIV.

Ethnobotany

An aspect of botany which has received recent attention and recognition as an organized discipline in India is ethnobotany, defined as the total direct relationship between humans and plant kingdom. Detailed surveys have been carried out to record the knowledge systems used by tribals and other ethnic communities in the use of plants and other products. Publications such as *Contributions to Indian Ethnobotany, Dictionary of Indian Folk Medicine, Ethnobotany and Notable Plants in Ethnomedicine* of India provide enormously rich information.

Botanical Journals and Wealth of India

A few prestigious periodicals that publish the major papers from Indian scientists are: *Journal of the Indian Botanical Society*, *Phytomorphology*, *Palaeobotanist*, *Nucleus*, *Tropical Ecology*, I*ndian Phytopathology*, *Indian Journal of Genetics and Plant Breeding* and *Rheedea*. The *Wealth of India* is a unique encyclopaedic publication consolidating all available information in Indian economic raw materials (plants, animals and minerals) and industrial products. This work is published by the National Institute of Science Communication (NISCOM, formerly PID), CSIR, and has gained respect in the world of learning. The number of entries on plants alone exceed 5,000 species.

Conclusion

The above account, by no means exhaustive, brings to the fore certain aspects of plant science research in India. From individual efforts with meagre facilities, botanists have proceeded to group activities involving persons from other disciplines. As a humanistic science, botany has begun to embark on areas with deep social concerns. There is still a vast scope for generating new knowledge through basic science to maximize crop yields per unit area, minimize stresses, secure assured water supply, conserve plant germplasm, cultivate plants that yield products of high economic returns and ensure sustained availability of non-timber forest products to raise the incomes of tribals and the rural poor. What the country needs is a proper blend of inputs from Botany, Microbiology, Agriculture, Chemistry, Forestry, Economics, Sociology and Management.