Plant life under extreme environments

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There is no habitat in the world where some plant or the other will not grow provided there is some moisture and light[1]. It is the energy provided by these plants that sustains the life of all heterotrophic organisms. Plants cannot tolerate excessively high temperatures like some of the bacteria and fungi, but do occur under extremely hostile surroundings such as mountain tops, hot and cold deserts, water-logged conditions, coastal habitats, metalliferous soils and spoil heaps of old mines. Plant life of the arctic is highly specialized with an antiquity dating back to at least 2 million years[2]. The knowledge of the survival strategies should assist humans to learn the secrets of balance, productivity and sustainability and as references against which we compare areas which we have developed[3]. Even for our own survival and that of the future generations, understanding of the nature of the stress-tolerant genes and their introduction into agricultural, horticultural and forestry species either through conventional breeding or genetic engineering would be important.

A vast amount of literature exists on the adaptation of plants to extreme environmental conditions. This pictorial article essentially deals with natural history. Certain leads in ecology and physiology have been indicated; aspects dealing with pollution and biotic stresses are not covered.

Plant life in deserts

Deserts are hot or cold, often sand-covered lands receiving below 125 mm annual rainfall. Their soils are dry with abundant soluble minerals and scanty vegetation. Humans have learnt to overcome the perils of desert existence by finding sources of water, food and shelter. Deserts also provide some of the world's most awe-inspiring scenery with a spectrum of moods and quiet mystery. Roughly one seventh of the globe's surface is occupied by deserts.

Water is necessary and convenient for all life and is a molecule of common occurrence. Plants have an extensive root system which absorbs both water and minerals. Ditmer (cited in ref. 4) of the Iowa State University has made the astounding finding that the total length of roots (minus root hairs) formed by a single rye plant in a period of four months is 387 miles, covering a total surface area of 2554 sq. ft.! Plants lose large amount of water in transpiration through minute openings in the shoot called stomata, sometimes in excess of the quantity absorbed. If the stomata close down to check water loss, the plants would starve as they are the gateways for entry of carbon dioxide, the important raw material for photosynthesis. In evolutionary terms, transpiration is an unavoidable evil of plant life. Thus conservation of water and its usage is one of the greatest challenges faced by desert plants. Plants inhabiting deserts are termed xerophytes (xerophiles) and are further categorized by Levitt[5] as evaders, avoiders and tolerant plants. Plants occurring in hot deserts are slow-growing and may suffer mechanical or metabolic form of drought injury[6]. The latter is manifested in the form of decreased photosynthesis, protein metabolism and membrane permeability.

As availability of water is restricted in most deserts, at times only to a few days, evaders have to complete seed germination, establishment of plant, flowering and seed set in a brief span. After one or two showers, the parched soil turns green and the splendour of flowering is spread over the entire desert. The evaders are thus ephemerals that pass the rest of the year as seed. The avoiders have special structural modifications to reduce water loss. These include a thick outer layer (the epidermis), sunken stomata, waxy coating, rolling of leaves during drought, reduction in size or absence of leaves or their early detachment. In plants such as *Euphorbia caducifolia* of the Thar desert, *Fouquieria splendens* and *Opuntia* sp. of the Sonoran desert, the stem turns green to carry on photosynthesis.

Table 1 shows the enormous extent of root development in a few desert plants. In plants such as *Aqave salmiana*, the root to shoot ratio is low. In older perennials and shrubs of the Great Basin, Turkestan and some other deserts, it ranges from 1 to 9 (refs 7, 8).

A common morphological feature of desert plants is succulence of the above ground parts. Succulents occur in several distant and unrelated families such as Aizoaceae, Chenopodiaceae, Cactaceae, Crassulaceae, Euphorbiaceae, Asclepiadaceae, Liliaceae and Amaryllidaceae. This leads to the confusion between succulents and cacti and strictly speaking the latter belong to the Cactaceae. All the cacti are of New World origin,

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This article is based on a lecture delivered by H.Y.M. at Jodhpur on 2 November 1996 during the 62nd Annual Meeting of the Indian Academy of Sciences. We pay homage to all the plant scientists of the Central Arid Zone Research Institute, University of Jodhpur, notably Professor M. M Bhandari and the Botanical Survey of India Arid Zone Circle, Jodhpur, who have enriched our understanding of plant life in the Thar Desert.

Table 1. Extent of root penetration of a few representative plants growing in different deserts

Genus	Location	Root penetration (m)		Source
Alhagi	Asian desert	Depth	25	Daubenmire (1959)
Glycyrrhiza	Asian desert	Depth	15	Daubenmire (1959)
Andina	Brazalian desert	Depth	19	Daubenmire (1959)
Prosopis	Arizonian desert	Depth	20	Daubenmire (1959)
Tamarix	Saharan desert	Radius	40	Ladover (1928)
Larrea	Saharan desert	Radius	27	Ladover (1938)

although they have been introduced to the other continents where some have run wild. Succulents are able to absorb huge amounts of water during a heavy rain and store it for a long time. The saguaro cactus (*Carnegia gigantea*) of the Sonoran desert reaches a height of 15 m, lives for 150–200 years and weighs 9–10 tons[9]. Its shallow, wide-ranging roots and the surface of the fluted stem can gather as much as one ton of water after one or two bouts of rain. Additionally in some succulents, the stomata close during the day to prevent evaporation and open only during the night. Carbon dioxide is fixed in the dark in the form of carboxylic acids, which are converted into carbohydrates during the day. Such plants are called CAM (Crassulacean Acid Metabolism) plants.

The truly drought-tolerant plants are those which have the capacity to stand dehydration for prolonged periods without succumbing to it. Lichens, mosses, ferns and a few seed plants are included under this category. They are collectively called resurrection plants. A common example is *Selaginella* sp. sold as a curiosity at holy places in North India. The dried and curled-up plants turn green after a few hours of soaking in water. Among the most dramatic examples of resurrection plants are creosote bush – *Larrea divaricata, Carex physoides, Ramonda nathaliae, Myrothamnus flabellifolia, Chamaegigas intrepidus*. These stay glued to the soil almost appearing dead and dry, turning green and reviving even after one rain. They start respiring within 48-60 hours and begin to photosynthesize thereafter. The rose of Jericho (*Anastatica hierochuntica*) is unusual, as the dry plant rolls up and is blown around by wind. When it starts raining the plants recover, become stabilized and continue to grow.

The creosote bush produces chemicals that smell like coal tar in its shoot to dissuade browsing animals. Its roots also secrete certain substances (allelopathic chemicals) that inhibit the roots of other plants in the vicinity. The plant collects moisture from the dew or in case of an exceptional rain by sending out underground stems with mats of tiny roots to absorb every drop of water percolated into the soil. Another bizarre plant that has an amazing capacity to survive for over 1000 years in perennially arid conditions of the Namib desert is the gymnosperm *Welwitschia*. It is also endowed with the ability to collect dew from the air.

Sand-dunes are by far the most common habitats of the arid deserts. The dunes are formed by strong winds that carry the sand particles and pile them into mounds. Some dunes are stabilized, others partially stabilized or unstabilized and barren. Several herbaceous grasses, amaranths, legumes, cucurbits and asclepiads cover the sand by striking roots at nodes. The most common shrubs of the dunes in the Thar desert are *Calligonum polygonoides* (an excellent source of charcoal), *Commiphora wightii* (guggul), *Clerodendrum phlomidis, Haloxylon salicornicum, Lycium barbatum* and trees such as *Prosopis cineraria, Salvadora oleoides* and *Acacia senegal*. These provide food, feed, shelter or other materials for animals and people[9a].

Some herbaceous plants surviving cold stress in the frozen arctic region have flowers which show solar tracking; for example *Dryas octopetela, Papaver radicatum* and *Ranunculus glacialis*. The petals reflect the warmth of the sun's rays towards the centre of the flower to increase the temperatures to attract the pollinating insects[1]. The cushion habit plants such as dwarf azalea (*Loiseleuria procumbens*) and dwarf campion (*Silene acaulis*) in the cold deserts increase the inner temperature by 15°C above the ambient temperature[10] and also humidity. These plants have the unusual capability of making a net carbon gain for the entire year in a brief growing season, complete development and reproductive cycle with minimal thermal input[1]. As they cannot invest sufficient material for sexual reproduction, they turn to vegetative propagation[11]. Shivaji and Ray[11a] have reviewed the survival strategies of microorganisms adapted to extreme cold conditions prevailing in Antarctica.

Salinity

Very often the aridity caused by low rainfall and extremely high or low temperatures are compounded by high salinity in the soil, resulting in severe problems in absorption of water and curtailing productivity. Plants that survive high salinity are called halophytes. Among these, members of family Chenopodiaceae, especially the species of *Atriplex* are notorious. Collectively called the saltbush, the species of *Atriplex* show accumulation of ions against concentration gradient. Plants such as *Suaeda, Salsola, Kochia, Haloxylon, Portulaca, Cressa, Sesuvium* and *Tamarix* commonly occur in the Thar desert. Some species have the ability to store and secrete salt through special glands on the leaf surface. Additionally, in the ice-plant *Mesembryanthemum crystallinum,* a native of the Namib desert, the presence of salt secreted on the surface enables absorption of moisture from the humid air.

Several useful species of *Atriplex* have been introduced to India for cultivation on saline soils for meeting fodder and fuel requirements and also for stabilizing mineral soils. As a result of heavy irrigation and poor drainage, many parts in India have been experiencing increased salinity. It is common to see large patches of white crust of salt on the surface of the clayey soils containing sodium chloride and other salts in Haryana, Punjab, Rajasthan and Western UP. Many crops are sensitive to salt whereas a few are moderately tolerant. The distribution of wild relatives of cultivated plants in the saline soils as well as varieties of rice that are salt tolerant and the mechanism of salt tolerance have lately become important aspects of agricultural research. An increase in root to shoot ratio has also been reported in response to salt stress[12,13].

Mangroves and plants of salt marshes

Plants that inhabit coastal regions and estuaries and have become adapted to survive under inundated salt water conditions constitute the mangrove vegetation. Some are viviparous and shed their germinated fruits in tidal waters to facilitate their establishment. Physiologically mangroves not only face the problem of absorption of water from highly saline conditions but suffer from insufficiency of oxygen in their roots. The angiospermous mangroves and swamp cypress (*Taxodium distichum*) produce characteristic vertical roots which grow in a negatively geotropic manner above the water level and serve the purpose of aeration (pneumatophores). Mangroves are ecologically important as they prevent coastal erosion. There has been a severe destruction of mangroves, on account of the valuable firewood and tannins they yield.

Coconut is among the most useful plants which is highly salt-tolerant. *Casuarina equisetifolia* and other species of *Casuarina* were introduced to India from Australia primarily for checking coastal erosion. They are presently grown even inland as fast-growing trees, capable of fixing atmospheric nitrogen with the association of *Frankia*. As the wood can be burnt even when still green, it is used as an important source of firewood. Herbaceous plants with excellent coastal sand-binding properties include *Ipomoea aquatica* and *Spinifex squarrosa*. The latter is being recommended for preventing coastal erosion in the Lakshadweep islands.

Aquatic plants

Water is essential for plant life but its over-abundance leads to several problems. This is particularly true of those plants in which photosynthetically active parts are submerged in water or float on the surface permanently or at least for several months each year[14]. About 2% of all the flowering plants known in the world live in water and more than 50% of these are represented in the Indian subcontinent[15]. Evolutionarily plants migrated from water to land. However, when the reverse process occurred, plants had to undergo a wide range of structural, physiological and biochemical changes. Notable modifications of aquatic plants include a poor root system, high reduction in mechanical tissues, development of large air spaces which interconnect the entire plant and a high propensity for vegetative propagation. Plants living in water and those subjected to flooding show different degrees of oxygen shortage[16]. Aquatic plants with floating leaves such as *Nymphaea* and the Indian lotus (*Nelumbo nucifera*) have rhizomes and roots buried in the anoxic sediments of shallow freshwater lakes. As oxygen supply by gaseous diffusion to the submerged parts is difficult, these plants have developed a pressurized diffusion system, also termed thermal transpiration (thermal osmosis). Addressing the French Academy in 1841, Raffeneau-Delile of the Faculty of Medicine at Montpellier, reported his curious observation of the escape of gases from partially submerged lotus leaves in Egypt. Since then, several other scientists have pursued the study of gas-flow through the air-space system in emergent water plants.

John Dacey, a doctoral student working at the Michigan State University on the flow-through ventilation system in the yellow water lily (*Nuphar advena* Ait = *N. lutea*) has been largely responsible for resurgence of interest in this study. Using sensitive GC analysis and by injecting ethane into the stalks of young leaves, Dacey[17] was able to demonstrate the downward movement of the gas into the rhizome and its escape through stomata in the older leaves. He noted that the heat absorbed by the young leaves (influx leaves) converts water into vapour, which is pushed downwards under pressure along with other gases through the intercellular spaces to their rhizome and their exit through the petioles and leaf blade of older leaves (efflux leaves) on the same rhizome branch (Figure 1). This process enables supply of oxygen to the roots, rhizomes and rhizosphere and the movement of respiratory carbon dioxide to the leaves for photosynthesis[17-19]. Dacey and Klug[20] also showed that these waterlily plants transferred methane gas formed by anaerobic methanogenic bacteria from lake sediments to the atmosphere. This mechanism has been shown to operate in other submerged plants for the supply of oxygen to parts below water[21,22] and has been aptly called the 'biological steam-engine'. In a recent review, Singh and Singh[23] have reviewed the role of plants such as *Typha* and rice in methane emission from the wetlands in India.

The Podostemaceae – A strange family of aquatic plants

A good deal of information is available on the stresses experienced by submerged, free-floating and emergent but rooted aquatic plants. There are gaps in our knowledge about a highly interesting family of flowering plants, the Podostemaceae. They occur almost exclusively under cataracts and fast-flowing rivers, submerged but firmly attached to rocks by means of rhizoids that secrete a gummy substance[24,25]. They have a thallus-like plant body that has no air spaces, unlike other water plants. Members of the sub-family Podostemoideae lack differentiation into root, stem and leaves and can be easily mistaken for algae, lichens or

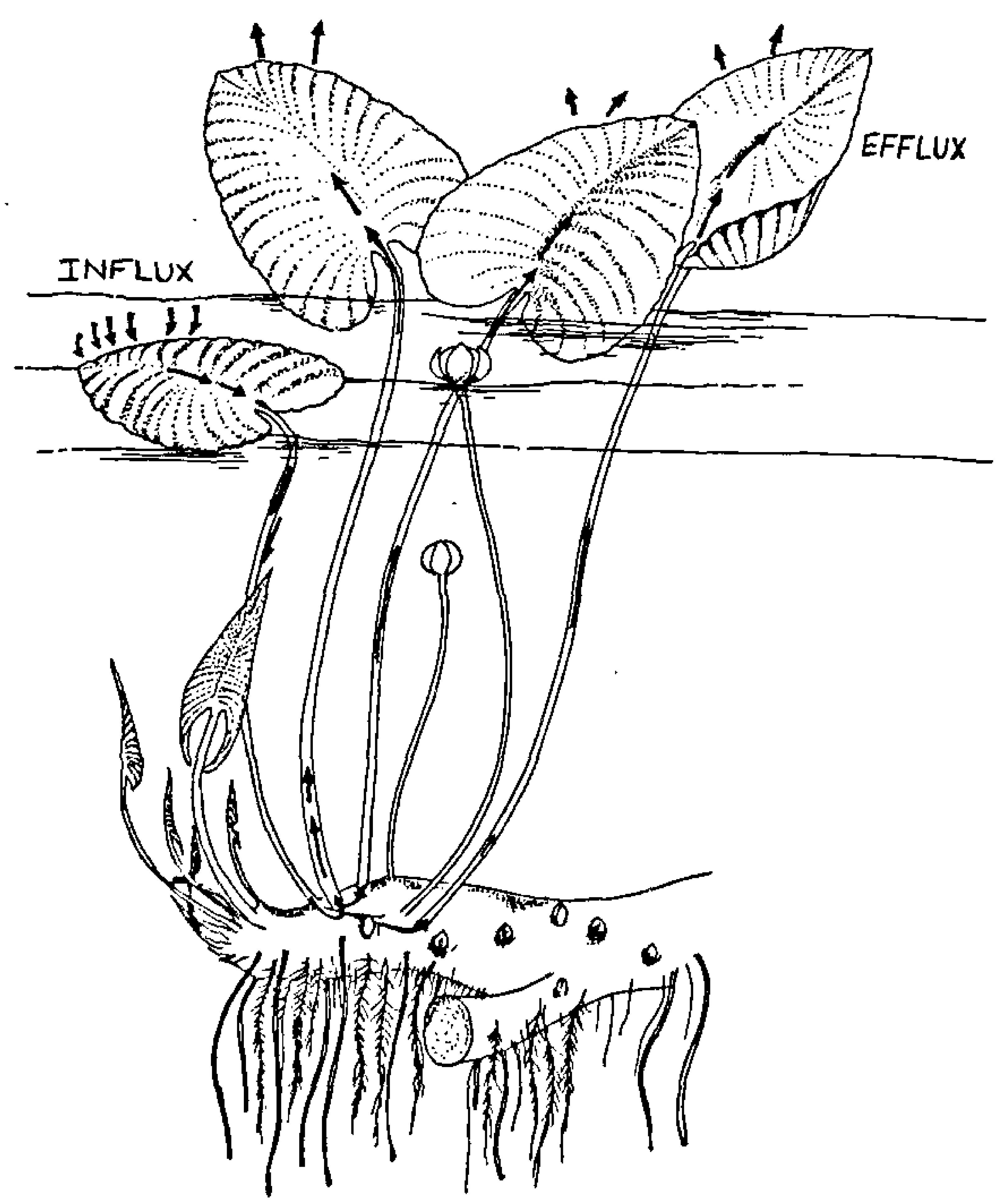


Figure 1. Ventilation in *Nuphar* advena, showing the path of the gas through flow (Drawn after Dacey).

liverworts. Generally so long as the plants lie 20–25 cm below water, they never enter the flowering phase. However, a drop in water level causes initiation of flower buds. Flower opening, fruit and seed development require exposure to air. Thus sexual reproduction in these plants appears to be regulated by water stress. These aspects have been substantiated by experimentally grown plants in our laboratory.

Water logging and flooding

Most trees are sensitive to water logging. However, there are many exceptions such as the massive trees of the Amazonian forests adapted to tolerate flooding for several months. The mechanisms that support life under anaerobic conditions of these plants are being studied[16].

Certain deepwater rices are known to respond to flooding in late monsoon. They branch at the higher nodes, show rapid internodal elongation when submerged due to rise in the level of water and produce adventitious roots at the upper nodes. Submergence stimulates the synthesis of ethylene gas which helps in cell lengthening response to the hormone gibberellic acid[26]. Both cell division and cell elongation are responsible for the rapid stretching of rice plants (often 25 cm in one day) under flooded conditions[27]

Metallophytes

Certain elements are essential for all organisms; some are needed in relatively large amounts (macro or major elements) and others in small amounts (micro elements). Unlike animals, the majority of plants do not need sodium and iodine. Curiously plants accumulate a wide spectrum of non-essential elements at concentrations several hundred-fold higher than that in the soil or water. Barring drinking water and pollutants, all the essential minerals needed by animals and humans are derived directly or indirectly from plants. Ecologists have studied the types of vegetation occurring on metalliferous soils, mine-tailings and abandoned mines and have identified plant communities and populations of individual species growing on them. It is possible to associate indicator species that reflect the concentration of a metal in the soil. This interesting branch of science termed geobotany, has been helpful in prospecting for minerals and also in bioremediation and recovery of contaminated soils to productive lands.

Baker and Walker[28] have classified plants that grow on metalliferous soils into three groups: (i) Metal-excluders – those that accumulate large amounts of metal(s) in their roots but prevent their translocation to the shoot. (ii) Indicators – which contain metals both in root and shoot but reflect the levels of metal present in the soil. (iii) Hyperaccumulators – species which con-

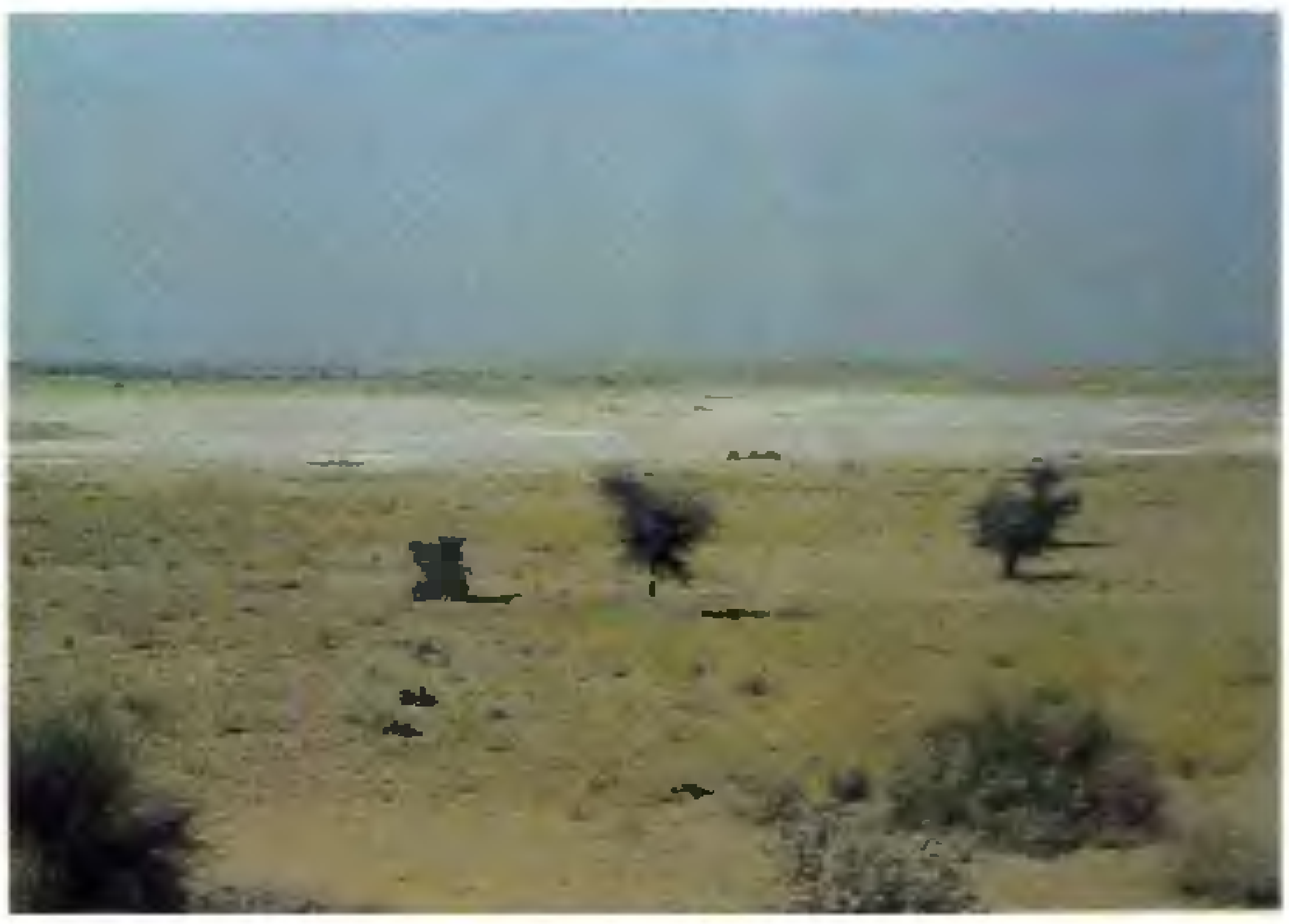
A close-up of the female inflorescence of the date palm *Phoenix dactylifera*. The palm is hardly and grows near oasis in the Central Asian deserts with 'feet in water and head in fire'.

A close-up of *Euphorbia caducifolia* of the Thar desert. The green stem is photosynthetic and contains a milky latex. Many succulents are erroneously called cacti. (H. Y. Mohan Ram).

Mature fruits of date, eaten fresh or dried. Before the oil boom, date was an important item of trade in Middle East. (H. Y. Mohan Ram).

Ferrocactus wislizerii, the fish hook barrel cactus from Arizona USA, with orange flowers. Browsing animals are kept away. (H. Y. Mohan Ram).

Opuntia or prickly pear of the Sonoran desert in N. America (this particular species has no barbed bristles). A leafless succulent, it stores water in the tissues and can tolerate 60°C for a few hours. (H. Y. Mohan Ram).



Suratgarh, Rajasthan. Salt deposition on the soil caused by rise in water table due to irrigation. (M. M. Bhandari).

Suade fructicosa a greyish-green, herbaceous halophyte of the Thar desert, it has an extensive root system. (M. M. Bhandari).

Pneumatophores of swamp cypress. Some of the roots grow vertically above water and assist in gaseous exchange. (H. Y. Mohan Ram).

Tamarix sp. A typical plant of the salt rich soils of Thar desert, it has an extensive root system. (M. M. Bhandari).

Nymphaea, a rooted aquatic plant with floating leaves and beautiful flowers has a 'steam engine' mechanism for aerating the buried rhizomes. (H. Y. Mohan Ram).

The ice plant, a native of the Namib desert in South Africa is now grown throughout the world as an ornamental. The surface of the plant has vesicles looking like ice crystals. The secreted salt helps in the absorption of moisture in the air. (Rajesh Tandon).

Astragalus graveolens, a leguminous weed established on a limestone quarry by scientists of the University of Delhi. Seeds embedded in sodium alginate along with the symbiotic nitrogen fixing bacterium *Rhizobium* are used for reclamation. (Anupam Joshi).

Spinifex squarrosa, a trailing grass, effective as a sand binder along the southern sea coasts of India. It is popularly called Ravana's whiskers on account of the stiff, sharp leaves. (Pratibha Pande).

The boojam tree (*Idira columnaris*) of Arizona, USA. It gives the impression of being upside down. (H. Y. Mohan Ram).

Kurrta. *Acacia senegal* is the source of gum arabic. The tree yields fodder, edible seeds and firewood. (Rajesh Tandon).

a. A rocky slope with thorny vegetation near Jodhpur. In the foreground is seen the innocuous, leafless shrub of guggul, amidst dry grass. ***b.*** A portion enlarged to show the tangled mass of branches of the shrub. The yellowish resin produced by incising the stem dries up into a brown mass. Guggul is an ancient Indian drug and its hypolipidaemic, hypocholestrolemic and antiarthritic effects have been reestablished by Indian scientists. 'Guglip' is presently sold in the market. The plant is threatened by over-exploitation.

centrate metals in the above ground parts, far in excess of that is present in the soil. Among the hyperaccumulators, those that take up heavy metals from soil are of tremendous importance. They have attracted attention for understanding the ecophysiological mechanisms and importantly the genetic basis of their endowment[29].

On a dry weight basis, hyperaccumulators may contain 0.1% of Ni, Co, Cu and Cr and Pb or 1% of Zn in their leaves. Tiagi and Aery[29a], working at the Udaipur University have studied the zinc deposits at the Zawar mines. They have noted that the balsam plant (*Impatiens balsamina*) and *Triumfetta pentandra* constitute an important vegetational unit. In the Rajpura–Dariba zinc bearing belt, *Kickxia ramosissima* and *Bidens biternata* show the highest constancy and fidelity on these soils.

The list of hyperaccumulating plants is growing steadily. Among these, species of the Brassicaceae (Cruciferae or the mustard family) are predominant in the temperate regions whereas the Euphorbiaceae represent their counterpart in the tropics[30]. Baker and co-workers[31] have reported that the Caledonian tree *Sebertia acuminata* has more than 11% of Ni in its latex on a dry-weight basis.

When hyperaccumulators enter the food chain through browsing wild animals or domestic livestock or poultry, there are chances of reaching acute toxicity levels in them as well as in humans. The classical examples of this condition are selenium-accumulating species of *Atriplex* and *Haplopappus*. Selenium replaces sulphur in the amino acids cysteine and methionine, resulting in various disorders in humans and livestock. 'Blind staggers' is a condition caused by excess selenium in livestock, consuming 100–1000 ppm in the forage. It results in impairment of vision, weakness of limbs and respiratory failure. Cattle and horses feeding on plants containing 25 ppm of selenium, suffer from 'alkali disease' with symptoms such as lack of vitality, loss of hair, sterility, atrophy of hooves, lameness and anaemia[32].

The copper flower (*Haumaniastrum katangense*), a common weed in the world's richest Zaire copper and cobalt belt in Central Africa, is a classical example which contains more than 0.1% of Co or Cu in the dried leaf-tissue.

Several scientists including botanists have a prejudiced view of the utility of a herbarium. Besides serving as a systematically arranged repository of dried plants, (authentic representatives of described and named species) a herbarium serves many other important functions. Recently pieces of leaves removed from herbarium specimens have indicated the amounts of heavy metals accumulated by plants 10–200 years ago from specific sites, thanks to sensitive methods of analysis. It is possible to judge the fluctuating levels of certain metals as well as levels of pollution over any given period of time by comparing the values in live plants with those in preserved plants of the past.

Mechanisms

The enormous biodiversity that exists in plants underlines their ability to adapt themselves to a wide spectrum of environmental conditions, as narrated above. Whether it is drought, cold, salt or metal stress or a combination of some or all of these, the end result is a dehydration stress. As early as 1958, Levitt[33] speculated that plants may have a general mechanism of resistance to every stress. At the morphological level wilting, leaf rolling and decrease in stomatal aperture, succulence, leaflessness, etc. constitute a general mechanism for conserving water[34]. At the physiological level, reduction in evapotranspiration and decrease in water potential are major manifestations.

How do plants sense stress signals?

There has been a revival in the study of signal communication in plants[35]. For example, how do roots perceive water stress and transmit the signal to the shoot to cause stomatal closure? The chemical communication with stress hormone abscisic acid (ABA) requires transcription and translation and hence is a slow process requiring at least two hours. The electrical signal (action potential) is rapid and acts in seconds. However, conduction of electrical signals has some limitations where long distances are concerned[35]. We are also in the dark regarding signals which transmit other stresses such as cold, salinity or high metal concentrations.

Stress- induced chemicals

Biochemical studies have revealed similarities in processes induced by various abiological stresses, leading to accumulation in plant tissues of compounds such as ascorbate, glutathione, α-tocopherol, betaine, proline and other amino acids, quaternary ammonium compounds, polyamines, sucrose, polyols (mannitol, sorbitol, pinitol) and oligosaccharides[36]. Additionally changes in the activity of certain key enzymes, gene expression and biosynthesis of ABA have also been noted.

Plants have developed mechanisms to prevent toxic effects of heavy metals on their metabolism. Many plants compartmentalize ions by storing them in their vacuoles. Inside the vacuoles, they may be chelated by citric or malic acid and rendered inactive. Recently certain polypeptides with the general formula γ(Glu–cys)*n*-Gly (where n = 2–11) have been identified in plants. These compounds termed phytochelatins or metallochelatins are believed to be induced by a specific metal. There is some evidence that as in animals, in plants also, there are genes that code for metallothionein-like proteins[37] but these are synthesized mainly in response to heavy metals[38–40].

Role of heat shock proteins in thermotolerance

Unlike certain archaea (such as *Methanococcus jannaschii*) and fungi which have the unusual propensity to survive and function normally under temperatures in the range of 80–100°C, most flowering plants are unable to stand temperatures above 50°C. The prickly pear (*Opuntia* sp.) occurring in the deserts of North America is shown to tolerate 60°C for a few hours. The role of heat shock proteins (HSPs) in thermotolerance of crop plants has been recently reviewed by Viswanathan and Khanna-Chopra[41]. These authors have also discussed the various heat-avoidance mechanisms which are significant in production of crops, specially those grown in the tropical and sub-tropical countries. That heat shock proteins are induced as a result of newly transcribed mRNA is universally accepted in a wide range of organisms[41–45]. This unique response was first reported in the fruit fly *Drosophila melanogaster*, where the heat-induced chromosome puffing was followed by a high-level expression of HSPs[42]. The synthesis of these proteins leads to acquired thermotolerance.

There is increasing interest in the identification of genes and their products that regulate tolerance to physical stresses in plants. This topic was discussed in depth at a workshop entitled 'Physical stresses in plants' held in Maratea, Italy[46].

Dehydrins

During the long course of evolution, several groups of plants have attempted to develop the seed habit but successful seed plants have been recorded from the upper Devonian, approximately 345 million years ago[47]. There is no structure equivalent to a seed in the entire animal world. Generally, seeds result from sexual reproduction in gymnosperms and flowering plants, capable of developing into a new individual. A seed that contains an embryo, stored food and protective coverings represents suspended animation as it is neither the beginning nor the end of plant growth. Unlike the vertebrate embryo which upon maturity develops into a young individual, in a seed all growth ceases for a brief or a prolonged period of time. A unique feature of most seeds is that they show a high degree of desiccation even though the surrounding parts may have abundant moisture as in watermelon, tomato or lotus. Seeds are known for their longevity and viability even under extremely severe environmental conditions. The most well-studied is the lotus seed, estimated to retain its germinability even after 1000 years[48]. Seeds of the arctic lupin (*Lupinus arcticus*) collected from a hemming burrough in the Yukon province of Alaska are estimated to retain viability even after 10,000 years, although some scientists are doubtful about this claim[48].

Understandably there has been a tremendous amount of interest in finding the mechanism by which mature embryos are protected from excessive dehydration to survive long periods of time and come back to life and establish plants when conditions become favourable for germination. In this context the discovery of dehydrins has been of special significance. The term dehydrin is synonymous with 'Late Embryogenesis Abundant' proteins designated as belonging to the LEA D–11 family. These were initially identified in investigations made on proteins and mRNA populations during the maturity of cotyledons of the cotton plant and subsequently in barley, rice, oil seed rape and wheat[49,50]. In mature embryos, they may reach levels in excess of 1% of total soluble proteins[51]. The LEA proteins can also be induced by ABA in zygotic as well as somatic embryos[52]. According to Close[34] dehydrins are the most conspicuous of soluble proteins which are formed in response to drought, cold, salinity stresses and also during normal seed maturation. They range in size from 9 kDa to 200 kDa without showing resemblance to any known enzyme sequence[53,54].

Xu *et al.*[55] have studied the expression of a LEA protein gene *HVA 1* from barley (*Hordeum vulgare*) and have observed that it confers tolerance to water deficit and salt stress in transgenic rice when this gene is introduced. Some LEA proteins when present alone are not sufficient to confer desiccation tolerance but require the presence of other solutes like sugars to be effective[56–58].

Phytoremediation

Phytoremediation is a new technology employed for removing excessive toxic metals and pollutants from soils or contaminated aqueous medium. Kaizer Jamil[59] has shown that water hyacinth can accumulate large amounts of Hg, Cd, Zn, Pb and Cr from solution containing salts of these elements. Ozimek[60] has demonstrated the ability of several aquatic plants to cycle heavy metals from sewage waste. Both algae and large flowering water plants such as water hyacinth and *Phragmites* are being used for removal of heavy metals from contaminated waters. It is believed that bioremediation with the use of specific plants is a relatively inexpensive operation. It is also possible to recover heavy metals by incineration.

Heavy industrialization, uncontrolled discharge of factory effluents from smelting, electroplating and leather industries, emission of organic lead in the atmosphere from automobile exhaust are causing accumulation of dangerous amounts of metals in our environment. The possibilities of a cleaner and greener planet by using plants and employing methods which are simple, safe and dependable, are keenly awaited.

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