suitable trees along ridges and for a little way down the slope facing the rain bearing and damp winds, will produce the maximum of certain desired effects, in proportion to the area occupied. Suitable tree and bush growths in swampy areas and around their margins will increase their effect in checking flood discharge, and may prevent these areas from contributing large quantities of silt to the streams during very heavy rains. Areas of soft, cultivable soil liable to denudation may similarly be protected. Generally, a country which is, in the ordinary English sense of the words, 'well timbered' is, from the point of view of the hydraulic engineer, a favourable country; and in the development of new lands the future effects of a poposed agricultural policy should be considered from this point of view, and in consultation with hydraulic engineers.

(R.A. Ryves, *Engineering Handbook*, 1936)

6.1 INTRODUCTION

This chapter deals with the complex interactions between trees and the incoming energies of radiation, precipitation, and the winds or gaseous envelope of earth. The energy transactions between trees and their physical environment defy precise measurement as they vary from hour to hour, and according to the composition and age of forests, but we can study the broad effects.

What I hope to show is the immense value of trees to the biosphere. We must deplore the rapacity of those who, for an ephemeral profit in dollars, would cut trees for newsprint, packaging, and other temporary uses. When we cut forests, we must pay for the end cost in drought, water loss, nutrient loss, and salted soils. Such costs are *not* charged by uncaring or corrupted governments, and deforestation has therefore impoverished whole nations. The process continues with acid rain as a more modern problem, not charged against the cost of electricity or motor vehicles, but with the inevitable account building up so that no nation can pay, in the end, for rehabilitation.

The "capitalist", "communist", and "developing" worlds will all be equally brought down by forest loss. Those barren political or religious ideologies which fail to care for forests carry their own destruction as lethal seeds within their fabric.

We should not be deceived by the propaganda that promises "for every tree cut down, a tree planted". The exchange of a 50 g seedling for a forest giant of 50–100 tonnes is like the offer of a mouse for an elephant. No new reafforestation can replace an old forest in energy value, and even this lip service is omitted in the "cut-and-run" forestry practised in Brazil and the tropics of Oceania.

The planting of trees can assuredly increase local precipitation, and can help reverse the effects of dryland soil salting. There is evidence everywhere, in literature and in the field, that the great body of the forest is in very active energy transaction with the whole environment. To even begin to understand, we must deal with themes within themes, and try to follow a single rainstorm or airstream through its interaction with the forest.

A young forest or tree doesn't behave like the same entity in age; it may be more or less frost-hardy, wind-fast, salt-tolerant, drought-resistant or shade tolerant at different ages and seasons. But let us at least try to see just how the forest works, by taking one theme at a time. While this segmented approach leads to further understanding, we must keep in mind that everything is connected, and any one factor affects all other parts of the system. I can never see the forest as an assembly of plant and animal species, but rather as a single body with differing cells, organs, and functions. Can the orchid exist without the tree that supports it, or the wasp that fertilises it? Can the forest extend its borders and occupy grasslands without the pigeon that carries its berries away to germinate elsewhere?

Trees are, for the earth, the ultimate translators and moderators of incoming energy. At the crown of the forest, and within its canopy, the vast energies of sunlight, wind, and precipitation are being modified for life and growth. Trees not only build but conserve the soils, shielding them from the impact of raindrops and the desiccation of wind and sun. If we could only understand what a tree does for us, how beneficial it is to life on earth, we would (as many tribes have done) revere all trees as brothers and sisters.

In this chapter, I hope to show that the little we do know has this ultimate meaning: *without trees, we cannot inhabit the earth*. Without trees we rapidly create deserts and drought, and the evidence for this is before our eyes. Without trees, the atmosphere will alter its composition, and life support systems will fail.

6.2 THE BIOMASS OF THE TREE

A tree is, broadly speaking, many biomass zones. These are the stem and crown (the visible tree), the detritus and humus (the tree at the soil surface boundary) and the roots and root associates (the underground tree).

Like all living things, a tree has shed its weight many times over to earth and air, and has built much of the soil it stands in. Not only the crown, but also the roots, die and shed their wastes to earth. The living tree stands in a zone of decomposition, much of it transferred, reborn, transported, or reincarnated into grasses, bacteria, fungus, insect life, birds, and mammals.

Many of these tree-lives "belong with" the tree, and still function as part of it. When a blue jay, currawong, or squirrel buries an acorn (and usually recovers only

80% as a result of divine forgetfulness), it acts as the agent of the oak. When the squirrel or wallaby digs up the columella of the fungal tree root associates, guided to these by a garlic-like smell, they swallow the spores, activate them enzymatically, and deposit them again to invest the roots of another tree or sapling with its energy translator.

The root fungi intercede with water, soil, and atmosphere to manufacture cell nutrients for the tree, while myriad insects carry out summer pruning, decompose the surplus leaves, and activate essential soil bacteria for the tree to use for nutrient flow. The rain of insect faeces may be crucial to forest and prairie health.

What part of this assembly is the tree? Which is the body or entity of the system, and which the part? An Australian Aborigine might give them all the same "skin name", so that a certain shrub, the fire that germinates the shrub, and the wallaby that feeds off it are all called *wuru*, although each part also has *its* name. The Hawaiians name each part of the taro plant differently, from its child or shoot, to its nodes and "umbilicus".

It is a clever person indeed who can separate the total body of the tree into mineral, plant, animal, detritus, and life! This separation is for simple minds; the tree can be understood only as its total entity which, like ours, reaches out into all things. Animals are the messengers of the tree, and trees the gardens of animals. Life depends upon life. All forces, all elements, all life forms are the biomass of the tree.

A large tree has from 10,000 to 100,000 growing points or MERISTEMS, and each is capable of individual mutation. Unlike mammals, trees produce their seed from multitudinous flowers. Evidence is accumulating that any one main branch can therefore be an "individual" genetically. Some deciduous poplars may produce a single evergreen branch. "Seedlessness" in fruit, or a specific ripening time, may belong only to one branch. Grafts and cuttings perpetuate these isolated characteristics, so we must look upon the tree itself as a collection of compatible genetic individuals, each with a set of persistent characteristics which may differ from place to place on the tree, and each of which may respond differently to energy and other stimuli. Like ourselves, trees are a cooperative amalgam of many individuals; some of these are of the tree body, but most are free-living agents. As little as we now know about trees, they stand as a witness to the complex totality of all life forms.

6.3
WIND EFFECTS

Vogel (1981) notes that as wind speed increases, the tree's leaves and branches deform so that the tree steadily reduces its exposed leaf area. At times of very high winds (in excess of 32 m/sec) the interception of light, efficient water use, and convective heat dissipation by the tree becomes secondary to its survival.

Vogel also notes that very heavy and rigid trees spread wide root mats, and may rely more totally on their weight, withstanding considerable wind force with no more attachment than that necessary to prevent slide, while other trees insert gnarled roots deep in rock crevices, and are literally anchored to the ground.

The forest bends and sways, each species with its own amplitude. Special wood cells are created to bear the tension and compression, and the trees on the edge of a copse or forest are thick and sturdy. If we tether a tree halfway up, it stops thickening below the tether, and grows in diameter only above the fixed point. Some leaves twist and reverse, showing a white underside to the wind, thus reflecting light energy and replacing it with kinetic or wind energy. In most cases, these strikingly light-coloured leaves are found only in forest edge species, and are absent or uncommon within the forest.

As streamlines converge over trees or hills, air speed increases. Density and heat may also increase, resulting in fast low-pressure air. To leeward of the obstruction, such streamlines diverge, and an area of slower flow, higher pressure, and cooler air may result. If rain has fallen due to the compression of streamlines, however, the latent heat of evaporation is released in the air, and this drier air can be warmer than the air mass rising over the obstruction. The pressure differentials caused by uplift and descent may affect evaporation as much as wind drying or heat.

Apart from moisture, the wind may carry heavy loads of ice, dust, or sand. Strand trees (palms, pines, and *Casuarinas*) have tough stems or thick bark to withstand wind particle blast. Even tussock grasses slow the wind and cause dust loads to settle out. In the edges of forests and behind beaches, tree lines may accumulate a mound of driven particles just within their canopy. The forest removes very fine dusts and industrial aerosols from the airstream within a few hundred metres.

Forests provide a nutrient net for materials blown by wind, or gathered by birds that forage from its edges. Migrating salmon in rivers die in the headwaters after spawning, and many thousands of tons of fish remains are deposited by birds and other predators in the forests surrounding these rivers. In addition to these nutrient sources, trees actively mine the base rock and soils for minerals.

The effect of the wind on trees is assessed as the Griggs and Putnam index (**Table 6.1**), and the accompanying deformations in both crown shapes and growth (as revealed in stems) is given a value which is matched to wind speeds with an average 17% accuracy.

Such scales and field indicators are of great use in design. When we go to any site, we can look at the condition of older trees, which are the best guide to gauge wind effect. Trees indicate the local wind direction and intensity, and from these indicators we

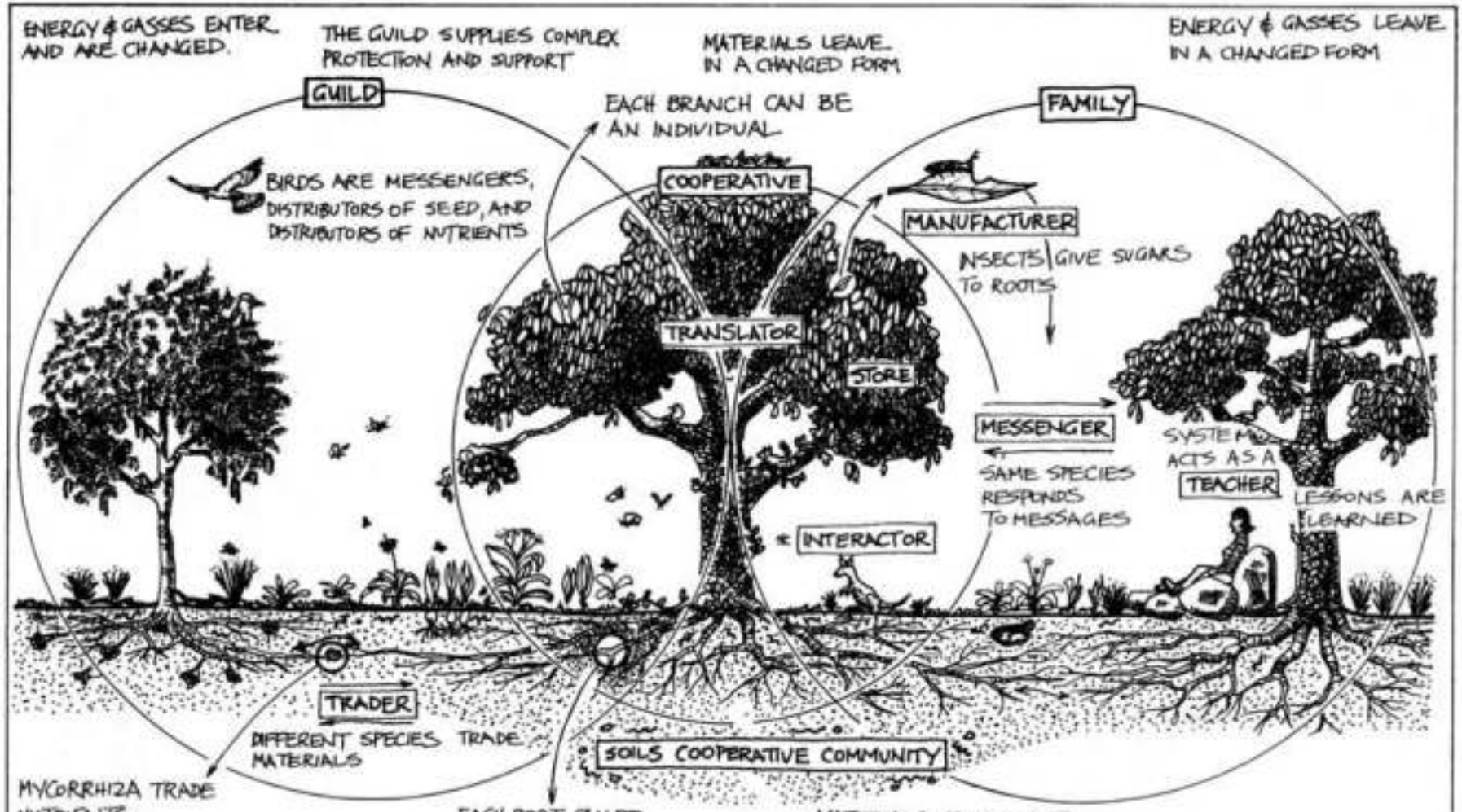


FIGURE 6.1
TREES IN A WHOLE SYSTEM
The tree itself is a cooperative, depends on a guild, is a member of a family of like species, and is involved in the creation of complex molecules from inorganic and organic elements – a transformer, or translator, of gases, liquids, and solids.

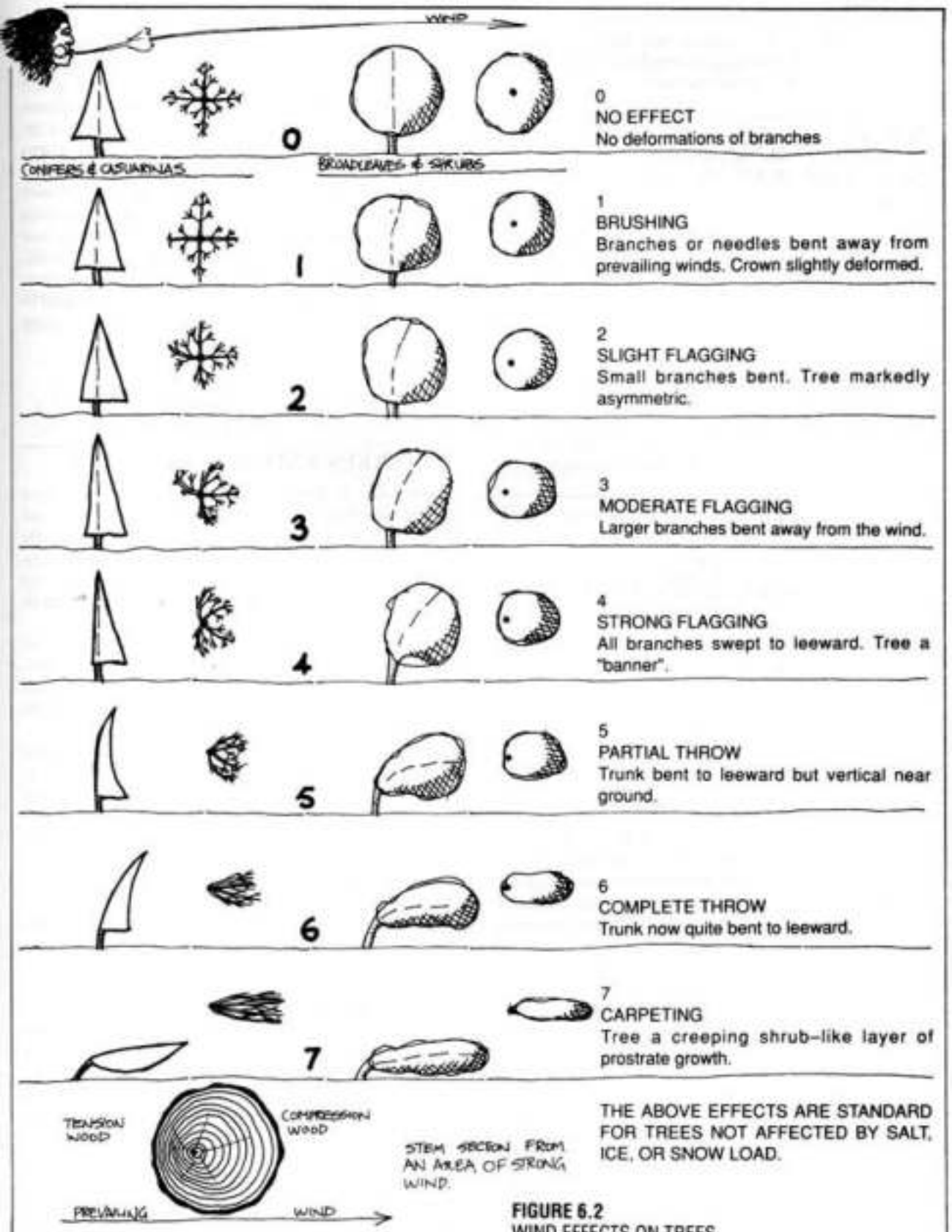


FIGURE 6.2
WIND EFFECTS ON TREES
As winds cross tree lines they are deflected in a new direction. Trees deform or 'flag' permanently in prevailing strong winds and can be used to assess the effects of such winds; they form a site-record of wind history.

can place windbreak to reduce heat loss in homes, to avoid damage in catastrophic winds, and to steer the winds to well-placed wind machines.

TABLE 6.1
RELATIONSHIP BETWEEN GRIGGS AND PUTNAM INDEX (G) AND ANNUAL MEAN WIND SPEED (V) IN m/sec.

G	V (m/sec.)	mph
0	<3.3	<7.5
1	3.3 - 4.2	7.5 - 9.5
2	4.3 - 5.1	9.6 - 11.5
3	5.2 - 6.2	11.6 - 14
4	6.3 - 7.5	14 - 17
5	7.6 - 8.5	17 - 19
6	8.6 - 11	19 - 24
7	>11	> 24

[From Wade, John E., and Wendell Hewson, 1979, *Trees as indicators of wind power potential*, Dept. of Atmospheric Sciences, Oregon State University.]

6.4
TEMPERATURE EFFECTS

EVAPORATION causes heat *loss* locally and CONDENSATION causes heat *gain* locally. Both effects may be used to heat or cool air or surfaces. The USDA's Yearbook of Agriculture on Trees (1949) has this to say about the evaporative effects of trees: "An ordinary elm, of medium size, will get rid of 15,000 pounds of water on a clear dry hot day" and "Evapotranspiration (in a 40 inch rainfall) is generally not less than 15 inches per year."

Thus, the evaporation by day off trees cools air in hot weather, while the night condensation of atmospheric water warms the surrounding air. Moisture will not condense unless it finds a surface to condense *on*. Leaves provide this surface, as well as contact cooling. Leaf surfaces are likely to be cooler than other objects at evening due to the evaporation from leaf stomata by day. As air is also rising over trees, some vertical lift cooling occurs, the two combining to condense moisture on the forest. We find that leaves are 86% water, thus having twice the specific heat of soil, remaining cooler than the soil by day and warmer at night. Plants generally may be 15°C or so warmer than the surrounding air temperature.

Small open water storages or tree clumps upwind of a house have a pleasant moderating effect. Air passing over open water is cooled in summer. It is warmed and has moisture added even in winter. Only water captured by trees, however, has a DEHUMIDIFYING effect in hot and humid tropical areas, as trees are capable of reducing humidity by direct absorption except in the most extreme conditions.

Reddish-coloured leaves, such as are developed in some vines and shrubs, reflect chiefly red light rays. Sharp decreases in temperature may result by interposing reddish foliage between a thermometer and the sun, up to 20°C (36°F) lower than with green pigmented plants (Daubenmire, 1974). Whitish plants such as wormwood and birch may reflect 85% of incoming light, whereas the dark leaves of shade plants may reflect as little as 2%. It follows that white or red-coloured roof vines over tiles may effectively lower summer temperatures within buildings or in trellis systems. Additional cooling is effected by fitting fine water sprays and damp mulch systems under trellis, thus creating a cool area of dense air by evaporation. This effect is of great use in moderating summer heat in buildings, and for providing cool air sources to draw from by induced cross-ventifilation.

6.5
TREES AND PRECIPITATION

Trees have helped to create both our soils and atmosphere. The first by mechanical (root pressure) and chemical (humic acid) breakdown of rock, adding life processes as humus and myriad decomposers. The second by gaseous exchange, establishing and maintaining an oxygenated atmosphere and an active water-vapour cycle essential to life.

The composition of the atmosphere is the result of reactive processes, and forests may be doing about 80% of the work, with the rest due to oceanic or aquatic exchange. Many cities, and most deforested areas such as Greece, no longer produce the oxygen they use.

The basic effects of trees on water vapour and windstreams are:

- Compression of streamlines, and induced turbulence in air flows;
- Condensation phenomena, especially at night; Rehumidification by the cycling of water to air;
- Snow and meltwater effects; and
- Provison of nucleii for rain.

We can deal with each of these in turn (realizing that they also interact).

COMPRESSION AND TURBULENCE EFFECTS

Windstreams flow across a forest. The streamlines that impinge on the forest edge are partly deflected over the forest (almost 60% of the air) and partly absorbed into the trees (about 40% of the air). Within 1000 m (3,300 feet) the air entering the forest, with its tonnages of water and dust, is brought to a standstill. The forest has swallowed these great energies, and the result is an almost imperceptible warming of the air within the forest, a generally increased humidity in the trees (averaging 15-18% higher than the ambient air), and air in which no dust is detectable.

Under the forest canopy, negative ions produced by life processes cause dust particles (++) to clump or adhere each to the other, and a fall-out of dispersed

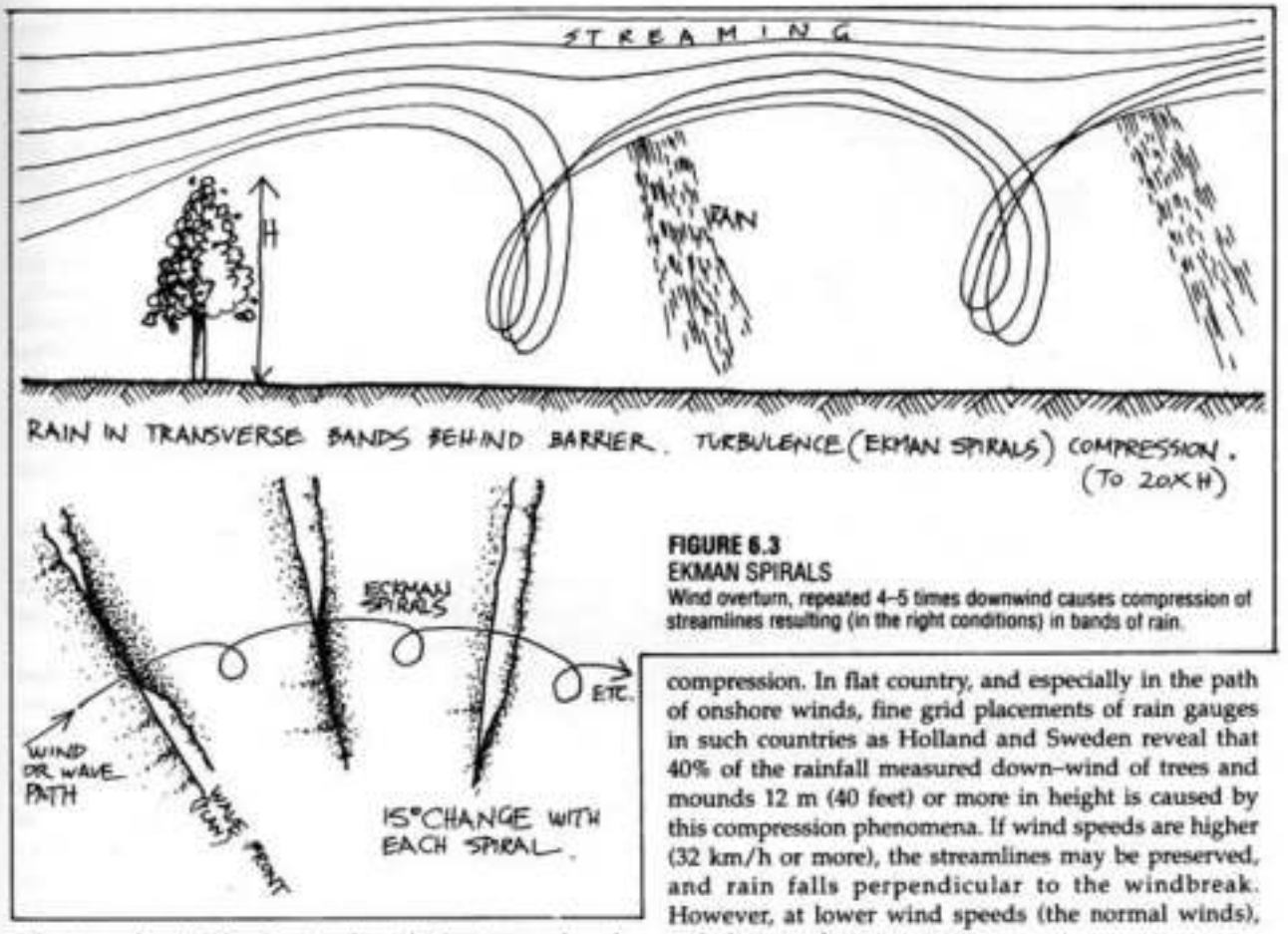


FIGURE 6.3
EKMAN SPIRALS
Wind overturn, repeated 4–5 times downwind causes compression of streamlines resulting (in the right conditions) in bands of rain.

dust results. At the forest edge, thick-stemmed and specially wind-adapted trees buffer the front-line attack of the wind. If we cut a windward forest edge, and remove these defences, windburn by salt, dust abrasion, or just plain windforce may well kill or throw down the inner forest of weaker stems and less resistant species. This is a commonly observed phenomenon, which I have called "edge break". Conversely, we can set up a forest by planting tough, resistant trees as windbreak, and so protect subsequent downwind plantings. Forest edges are therefore to be regarded as essential and *permanent* protection and should never be cut or removed.

If dry hot air enters the forest, it is shaded, cooled, and humidified. If cold humid air enters the forest, it is warmed, dehumidified, and slowly released via the crown of the trees. We may see this warm humid air as misty spirals ascending from the forest. The trees modify extremes of heat and humidity to a life-enhancing and tolerable level.

The winds deflected over the forest cause compression in the streamlines of the wind, an effect extending to twenty times the tree height, so that a 12 m (40foot) high line of trees compresses the air to 244 m (800 feet) above, thus creating more water vapour per unit volume, and also cooling the ascending air stream. Both conditions are conducive to rain.

As these effects occur at the forest EDGE, a single hedgerow of 40% permeability will cause similar compression. In flat country, and especially in the path of onshore winds, fine grid placements of rain gauges in such countries as Holland and Sweden reveal that 40% of the rainfall measured down-wind of trees and mounds 12 m (40 feet) or more in height is caused by this compression phenomena. If wind speeds are higher (32 km/h or more), the streamlines may be preserved, and rain falls perpendicular to the windbreak. However, at lower wind speeds (the normal winds), turbulence and overturn occurs.

Wind streaming over the hedgerow or forest edge describes a spiral section, repeated 58 times downwind, so that a series of compression fronts, this time parallel to the windbreak, are created in the atmosphere. This phenomena was first described by Ekman for the compression fronts created over waves at sea.

The Ekman spirals over trees or bluffs may result in a ranked series of clouds, often very regular in their rows. They are not perfectly in line ahead, but are deflected by drag and the Coriolus force to change the wind direction, so that the wind after the hedgerow may blow 5–15 degrees off the previous course. (One can imagine that ranks of hedgerows placed to take advantage of this effect would eventually bring the wind around in a great ground spiral.)

Winds at sea do in fact form great circuses, and bring cyclonic rains to the westerly oceanic coasts of all continents. These cyclones themselves create warm and cold fronts which ridge up air masses to create rain. In total, hedgerows across wind systems have a profound effect on the airstreams passing over them, and a subsequent effect on local climate and rainfall.

CONDENSATION PHENOMENA

On the sea-facing coasts of islands and continents, the relatively warmer land surface creates quiet inshore airflows towards evening, and in many areas cooler

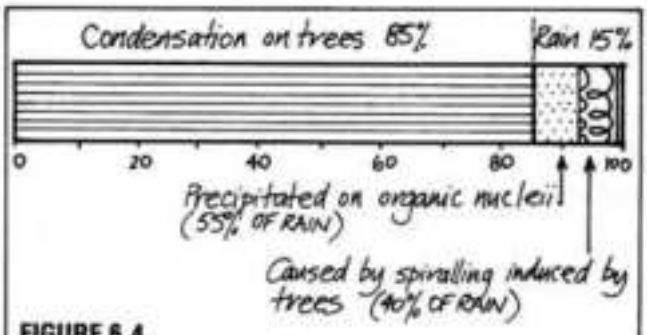


FIGURE 6.4
PERCENTAGES OF TOTAL PRECIPITATION
On a sea-facing hillside, trees as condensers, providers of bacterial ice nuclei, inducers of stream line compression, and re-humidifiers of the airstream create most of the conditions that create precipitation.

water-laden air flows inland. Where this humid air flows over the rapidly cooling surfaces of glass, metal, rocks, or the thin laminae of leaves, condensation occurs, and droplets of water form. On leaves, this may be greatly aided by the colonies of bacteria (*Pseudomonas*) which also serve as nucleii for frost crystals to settle on leaves.

These saturated airstreams produce seaward-facing mosses and lichens on the rocks of fresh basalt flows, but more importantly condense in trees to create a copious soft condensation which, in such conditions, may far exceed the precipitation caused by rainfall. Condensation drip can be as high as 80–86% of total precipitation of the upland slopes of islands or sea coasts, and eventually produces the dense rainforests of Tasmania, Chile, Hawaii, Washington/Oregon, and Scandinavia. It produced the redwood forests of California and the giant laurel forests of pre-conquest Canary Islands (now an arid area due to almost complete deforestation by the Spanish).

A single tree such as a giant Til (*Ocotea foetens*) may present 16 ha of laminate leaf surface to the sea air, and there can be 100 or so such trees per surface hectare, so that trees enormously magnify the available condensation surface. The taller the trees, as for example the giant redwoods and white pines, the larger the volume of moist air intercepted, and the greater the precipitation that follows.

All types of trees act as condensers; examples are Canary Island pines, laurels, holm oaks, redwoods, eucalypts, and Oregon pines. Evergreens work all year, but even deciduous trees catch moisture in winter. Who has not stood under a great tree which "rains" softly and continuously at night, on a clear and cloudless evening? Some gardens, created in these conditions, quietly catch their own water while neighbours suffer drought.

The effects of condensation of trees can be quickly destroyed. Felling of the forests causes rivers to dry up, swamps to evaporate, shallow water to dry out, and drought to grip the land. All this can occur in the lifetime of a person.

Precipitation from clear air is much less than that from fog, from which the precipitation by condensation often exceeds the local rainfall. Advection fogs are most noticeable where cold currents such as the Oya Shio off East Asia and the Labrador current off northeast America cause humid inland airstreams in spring and summer. Southfacing coasts near Newfound-land get 158 days of fog per year. Wherever mountains or their foothills face onshore night winds, fog condensation will probably exceed rainfall. On Table Mountain (South Africa) and on Lanai (Hawaii), fog drip has been measured at 130–330 cm, and in both cases condensation exceeds rainfall. Redwoods in California were once restricted to the fog belt, but will grow well in areas of higher rainfall without fogs

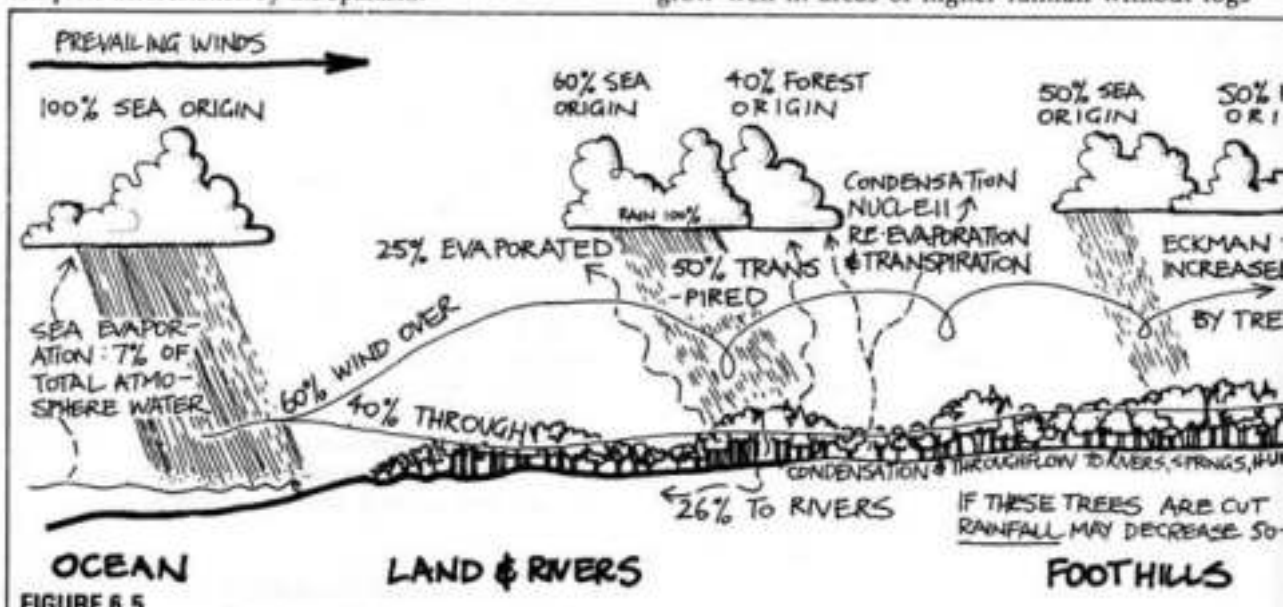
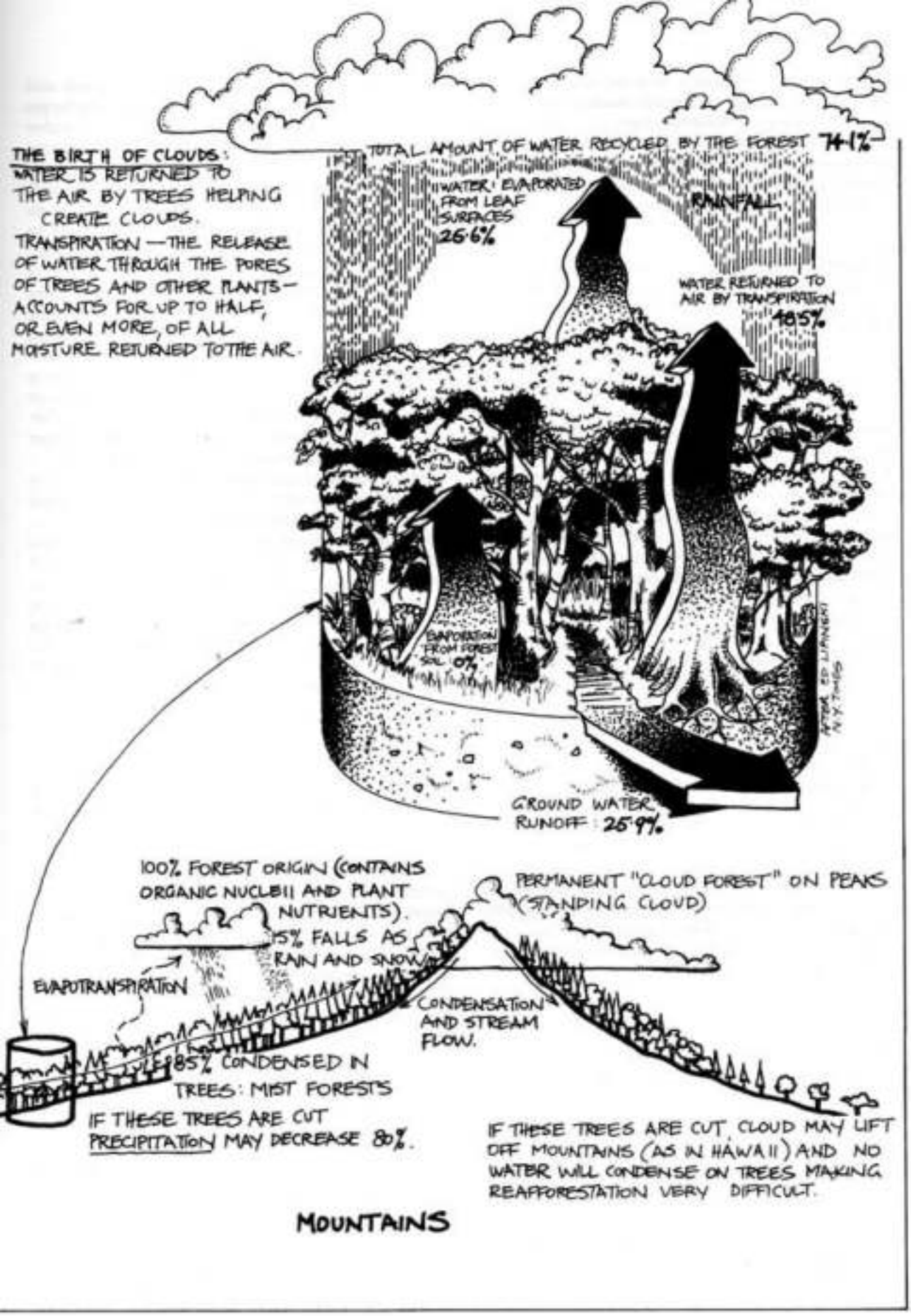


FIGURE 6.5
FOREST INTERACTIONS WITH CLIMATE. (Based on work in Brazil).
Forests inland produce most of the water for subsequent rainfall; recycled water is repeatedly transpired to the airstream.


THE BIRTH OF CLOUDS:
WATER IS RETURNED TO THE AIR BY TREES HELPING CREATE CLOUDS.
TRANSPIRATION — THE RELEASE OF WATER THROUGH THE PORES OF TREES AND OTHER PLANTS — ACCOUNTS FOR UP TO HALF, OR EVEN MORE, OF ALL MOISTURE RETURNED TO THE AIR.
TOTAL AMOUNT OF WATER RECYCLED BY THE FOREST 74.1%
WATER EVAPORATED FROM LEAF SURFACES 26.6%
RAINFALL
WATER RETURNED TO AIR BY TRANSPIRATION 48.5%
EVAPORATION FROM FOREST SOIL 0%
GROUND WATER RUNOFF: 25.9%
AFTER ED LIANGAI N.Y. TIMES
100% FOREST ORIGIN (CONTAINS ORGANIC NUCLEI AND PLANT NUTRIENTS).
15% FALLS AS RAIN AND SNOW.
PERMANENT "CLOUD FOREST" ON PEAKS (STANDING CLOUD)
EVAPOTRANSPIRATION
CONDENSATION AND STREAM FLOW.
85% CONDENSED IN TREES: MIST FORESTS
IF THESE TREES ARE CUT PRECIPITATION MAY DECREASE 80%.
IF THESE TREES ARE CUT, CLOUD MAY LIFT OFF MOUNTAINS (AS IN HAWAII) AND NO WATER WILL CONDENSE ON TREES MAKING REAFFORESTATION VERY DIFFICULT.
MOUNTAINS

(Chang, 1968). In Sweden "... wooded hills rising only 3050 m (9,500 feet) above the surrounding plains may cause precipitation [rain only] during cyclonic spells [fronts] to be increased by 50–80% compared with average falls over the lowland." In most countries, however, the rain gauge net is too coarse to detect such small variations (Chorley and Berry, 1971).

REHUMIDIFICATION OF AIRSTREAMS

If it rains again, and again, the clouds that move inland carry water mostly evaporated from forests, and less and less water evaporated from the sea. Forests are cloud-makers both from water vapour evaporated from the leaves by day, and water transpired as part of life processes. On high islands, standing clouds cap the forested peaks, but disappear if the forests are cut. The great bridging cloud that reached from the forests of Maui to the island of Kahoolawe, remembered by the fathers of the present Hawaiian settlers, has disappeared as cutting and cattle destroyed the upper forests on Maui and so lifted the cloud cap from Kahoolawe, leaving this lower island naked to the sun. With the cloud forests gone, and the rivers dry, Kahoolawe is a true desert island, now used as a bombing range for the U.S. Air Force.

A large evergreen tree such as *Eucalyptus globulus* may pump out 3,600–4,500 l of water a day, which is how Mussolini pumped dry the Pontine marshes of Italy. With sixty or so of these trees to the hectare, many tens of thousands of litres of water are returned to the air to become clouds.

A forest can return (unlike the sea) 75% of its water to air, "in large enough amounts to form new rain clouds." [Bayard Webster, "Forests' Role in Weather Documented in Amazon", *New York Times* (Science Section), 5 July '83]. Forested areas return ten times as much moisture as bare ground, and twice as much as grasslands. In fact, as far as the atmosphere itself is concerned, "the release of water from trees and other plants accounts for half, or even more, of all moisture returned to air." (Webster, *ibid.*) This is a critical finding that adds even more data to the relationship of desertification by deforestation.

It is data that no government can ignore. Drought in one area may relate *directly* to deforestation in an upwind direction. This study "clearly shows that natural vegetation must play an important role in the forming of weather patterns" (quote from Thomas E. Lovejoy, Vice-president of Science, World Wildlife Fund).

Clouds form above forests, and such clouds are now mixtures of oceanic and forest water vapour, clearly distinguishable by careful isotope analysis. The water vapour from forests contain more organic nucleii and plant nutrients than does the "pure" oceanic water. Oxygen isotopes are measured to determine the forests' contribution, which can be done for any cloud system.

Of the 75% of water returned by trees to air, 25% is evaporated from leaf surfaces, and 50% transpired. The remaining 25% of rainfall infiltrates the soil and eventually reaches the streams. The Amazon discharges 44% of all rain falling, thus the remainder is either locked into the forest tissue or returns to air. Moreover, over the forests, *twice as much rain falls than is available from the incoming air*, so that the forest is continually recycling water to air and rain, producing 50% of its own rain (Webster, *ibid.*). These findings forever put an end to the fallacy that trees and weather are unrelated.

Vogel (1981), applying the "principle of continuity" of fluids to a tree, calculates that sap may rise, in a young oak, fifty times as fast as the leaves transpire (needing only 7% of the total trunk area as conductive tissue, with an actual sap speed of 1 cm/sec). It is thus certain that only perhaps one-fiftieth of the xylem is conducting sap upwards at any one time, and that most xylem cells contain either air or sap at standstill. Perhaps too, the tree moves water up in pulsed stages rather than as a universal or continuous streamflow.

With such rapid sap flows, however, we can easily imagine the water recycled to atmosphere by a large tree, or a clump of smaller trees.

It is a wonder to me that we have any water available after we cut the forests, or any soil. There are dozens of case histories in modern and ancient times of such desiccation as we find on the Canary Islands following deforestation, where rivers once ran and springs flowed. Design strategies are obvious and urgent—save all forest that remains, and plant trees for increased condensation on the hills that face the sea.

EFFECTS ON SNOW AND MELTWATER

Although trees intercept some snow, the effect of shrubs and trees is to entrap snow at the edges of clumps, and hold 75–95% of snowfall in shade. Melting is delayed for 210 days compared with bare ground, so that release of snowmelt is a more gradual process. Of the trapped snow within trees, most is melted, while on open ground snow may sublime directly to air. Thus, the beneficial effects of trees on high slopes is not confined to humid coasts. On high cold uplands such as we find in the continental interiors of the U.S.A. or Turkey near Mt. Ararat, the thin skeins of winter snow either blow off the bald uplands, to disappear in warmer air, or else they sublime directly to water vapour in the bright sun of winter. In neither case does the snow melt to groundwater, but is gone without productive effect, and no streams result on the lower slopes.

Even a thin belt of trees entraps large quantities of driven snow in drifts. The result is a protracted release of meltwater to river sources in the highlands, and stream-flow at lower altitudes. When the forests were cleared for mine timber in 1846 at Pyramid Lake, Nevada, the streams ceased to flow, and the lake levels fell. Add to this effect that of river diversion and irrigation, and whole lakes rich with fish and waterfowl have become dustbowls, as has Lake Winnemucca. The Cuiuidika'a Indians (Paiute) who live there lost their fish, waterfowl, and freshwater in less than 100 years.

The cowboys have won the day, but ruined the future to do so.

PROVISION OF NUCLEII FOR RAIN

The upward spirals of humid air coming up from the forest carry insects, pollen, and bacteria aloft. This is best seen as flights of gulls, swifts and ibis spiralling up with the warm air and actively catching insects lifted from the forest; their gastric pellets consist of insect remains. It is these organic aerial particles (pollen, leaf dust, and bacteria mainly) that create the nucleii for rain.

The violent hailstorms that plague Kenya tea plantings may well be caused by tea dust stirred up by the local winds and the feet of pickers, and "once above the ground the particles are easily drawn up into thunderheads to help form the hailstorms that bombard the tea-growing areas in astounding numbers... Kenyan organic tea leaf litter caused water to freeze in a test chamber at only -5°C, in comparison with freezing points of -11°C for eucalyptus grove leaf litter, and -8°C for the litter from the local indigenous forests" (of Colorado). That is, tea litter "is a much better seeding-agent than silver iodide, which requires -8°C to -10°C to seed clouds." (*New Scientist*, 22 Mar '79). Thus, the materials given up by vegetation may be a critical factor in the rainfall inland from forests.

All of these factors are clear enough for any person to understand. To doubt the connection between forests and the water cycle is to doubt that milk flows from the breast of the mother, which is just the analogy given to water by tribal peoples. Trees were "the hair of the earth" which caught the mists and made the rivers flow. Such metaphors are clear allegorical guides to sensible conduct, and caused the Hawaiians (who had themselves brought on earlier environmental catastrophes) to "tabu" forest cutting or even to make tracks on high slopes, and to place mountain trees in a sacred or protected category. Now that we begin to understand the reasons for these beliefs, we could ourselves look on trees as our essential companions, giving us all the needs of life, and deserving of our care and respect.

It is our strategies on-site that make water a scarce or plentiful resource. To start with, we must examine ways to increase local precipitation. Unless there is absolutely no free water in the air and earth about us (and there always is some), we can usually increase it on-site. Here are some basic strategies of water capture from air:

- We can cool the air by shade or by providing cold surfaces for it to flow over, using trees and shrubs, or metals, including glass.
- We can cool air by forcing it to higher altitudes, by providing windbreaks, or providing updraughts from heated or bare surfaces (large concreted areas), or by mechanical means (big industrial fans).
- We can provide condensation nucleii for raindrops to form on, from pollen, bacteria, and organic particles.
- We can compress air to make water more plentiful per unit volume of air, by forcing streamlines to converge over trees and objects, or forcing turbulent flow in airstreams (Ekman spirals).

If by any strategy we can cool air, and provide suitable condensation surfaces or nucleii, we can increase precipitation locally. Trees, especially crosswind belts of tall trees, *meet all of these criteria in one integrated system*. They also store water for local climatic modification. Thus we can clearly see trees as a strategy for creating more water for local use.

In summary, we do not need to accept "rainfall" as having everything to do with total local precipitation, especially if we live within 30–100 km of coasts (as much of the world does), and we do not need to accept that total precipitation cannot be changed (in either direction) by our action and designs on site.

6.6
HOW A TREE INTERACTS WITH RAIN

Rain falls, and many tons of rain may impact on earth in an hour or so. On bare soils and thinly spaced or cultivated crop, the impact of droplets carries away soil, and may typically remove 80 t/ha, or up to 1,000 tonnes in extreme downpours. When we bare the soil, we lose the earth.

Water run-off and pan evaporation, estimated as 80–90% of all rain falling on Australia, carries off nutrients and silt to the sea or to inland basins. As we clear the land, run-off increases and for a while this pleases people, who see their dams fill quickly. But the dams will silt up and the river eventually cease to flow, and the clearing of forests will result in flood and drought, not a long-regulated and steady supply of clean water.

When rain falls on a forest, a complex process begins. Firstly, the tree canopy shelters and nullifies the impact effect of raindrops, reducing the rain to a thin mist below the canopy, even in the most torrential showers. There is slight measurable silt loss from mature forests, exceeded by the creation of soils by forests.

If the rain is light, little of it penetrates beyond the canopy, but a film of water spreads across the leaves and stems, and is trapped there by surface tension. The cells of the tree absorb what is needed, and the remainder evaporates to air. Where no rain penetrates through the canopy, this effect is termed "total interception". INTERCEPTION is the amount of rainfall caught in the crown. It is the most important primary effect of trees or forests on rain. The degree of interception is most influenced by these factors:

- Crown thickness;
- Crown density;
- Season;
- Intensity of rain; and
- Evaporation after rain.

Broadly speaking, interception commonly falls between 10–15% of total rainfall. *Least* interception occurs in thinned and deciduous forests, winter rain, heavy showers, and cloudy weather conditions, when it is as little as 10% of rain. *Most* interception occurs with dense, evergreen trees, light summer rain, and sunny conditions, when it may reach 100% of the total.

However, if more rain falls, or heavy rains impact on the trees, water commences to drift as mists or droplets to earth. This water is called THROUGHFALL. Throughfall depends on the intensity of rain, and there is little interception effect in heavy downpours. As an average figure, the throughfall is 85% of rain in humid climates.

At this point, throughfall is no longer just rainwater, any more than your bathwater is rainwater; throughfall contains many plant cells and nutrients, and is in fact a much richer brew than rainwater. Dissolved salts, organic content, dust, and plant exudates are included in the water of throughfall (**Table 6.2**). "The results show that rain washes large amounts of potassium and smaller amounts of nitrogen, phosphorus, calcium, and magnesium from the canopies to the surface soil. Litter adds organic matter, and is a rich source of calcium and nitrogen and a moderately rich source of magnesium and potassium." (Murray, J. S. and Mitchell, A., *Red Gum and the Nutrient Balance*, Soil Conservation Authority, Victoria, Australia, undated).

Nor can throughfall be measured in rain gauges, for the trees often provide special receptors, conduits, and storages for such water. The random fall of rain is converted into well-directed patterns of flow that serve the needs and growth in the forest. In the stem bases of palms, plantains, and many ephiphytes, or the flanged roots of *Terminalia* trees and figs, water is held as aerial ponds, often rich in algae and mosquitoes. Stem mosses and epiphytes absorb many times their bulk of water, and the tree itself directs water via insloping branches and fissured bark to its tap roots, with spiders catching their share on webs, and fungi soaking up what they need. Some trees trail weeping branches to direct throughfall to their fibrous peripheral roots.

With the aerial resevoirs filled, the throughfall now enters the humus layer of the forest, which can itself (like a great blotter) absorb 1 cm of rain for every 3 cm of depth. In old beech forests, this humus blanket is at least 40 cm deep, and the earth below is a mass of fungal hyphae. In unisturbed rainforest, deep mosses may carpet the forest floor. So, for 40-60 cm depth, the throughfall is absorbed by the decomposers and living systems of the humus layer. Again, the composition of the water changes, picking up humic exudates, and water from deep forests and bogs may then take on a clear golden colour, rather like tea.

TABLE 6.2

Nutrient content of litter, canopy drip, and rain in the open of a naturally regenerating stand of red gum (*Eucalyptus camaldulensis*), Gringegalgona, VIC, Australia. [Source: Murray, J.S., and A. Mitchell, Red Gum and the Nutrient Balance, Soil Conservation Authority, Australia (undated)].

SOURCE	PERIOD*	TOTAL RAIN (in.)	NUTRIENT RETURN (LB/A.)							TOTAL LITTER (lb.)
			N	P	K	Ca	Mg	Na	Cl	
Old trees: (5% of Total) LITTER	1*	-	19.0	1.2	6.0	25.0	6.0	4.0	ND	2,800
CANOPY DRIP	1	30.67	6.0	1.1	28.0	13.0	11.0	71.0	143.0	-
TOTAL	1	30.67	25.0	2.3	34.0	38.0	17.0	75.0	-	
Regrowth: (95% of Total) LITTER	1		38.0	1.9	10.0	49.0	15.0	5.0	ND	5,400
CANOPY DRIP	1	30.67	3.0	0.7	16.0	6.0	5.0	29.0	51.0	
TOTAL	1	30.67	41.0	2.6	26.0	55.0	20.0	34.0	-	
Rain:										
Nearby	2*	9.25	0.5	0.1	0.7	0.8	0.7	4.2	7.0	
Coleraine§	3*	33.61	0.5	ND	1.5	3.0	3.0	21.0	38.0	
Cavendish §	4*	21.75	ND	ND	1.0	3.0	2.0	14.0	20.0	

*1: 5/5/60 - 4/5/61. *2: 22/11/60 - 4/5/61. *3: 1/9/55 - 1/9/56. *4: 1/9/54 - 1/9/55.
§ From Hutton and Leslie (1958). ND = Not Determined.

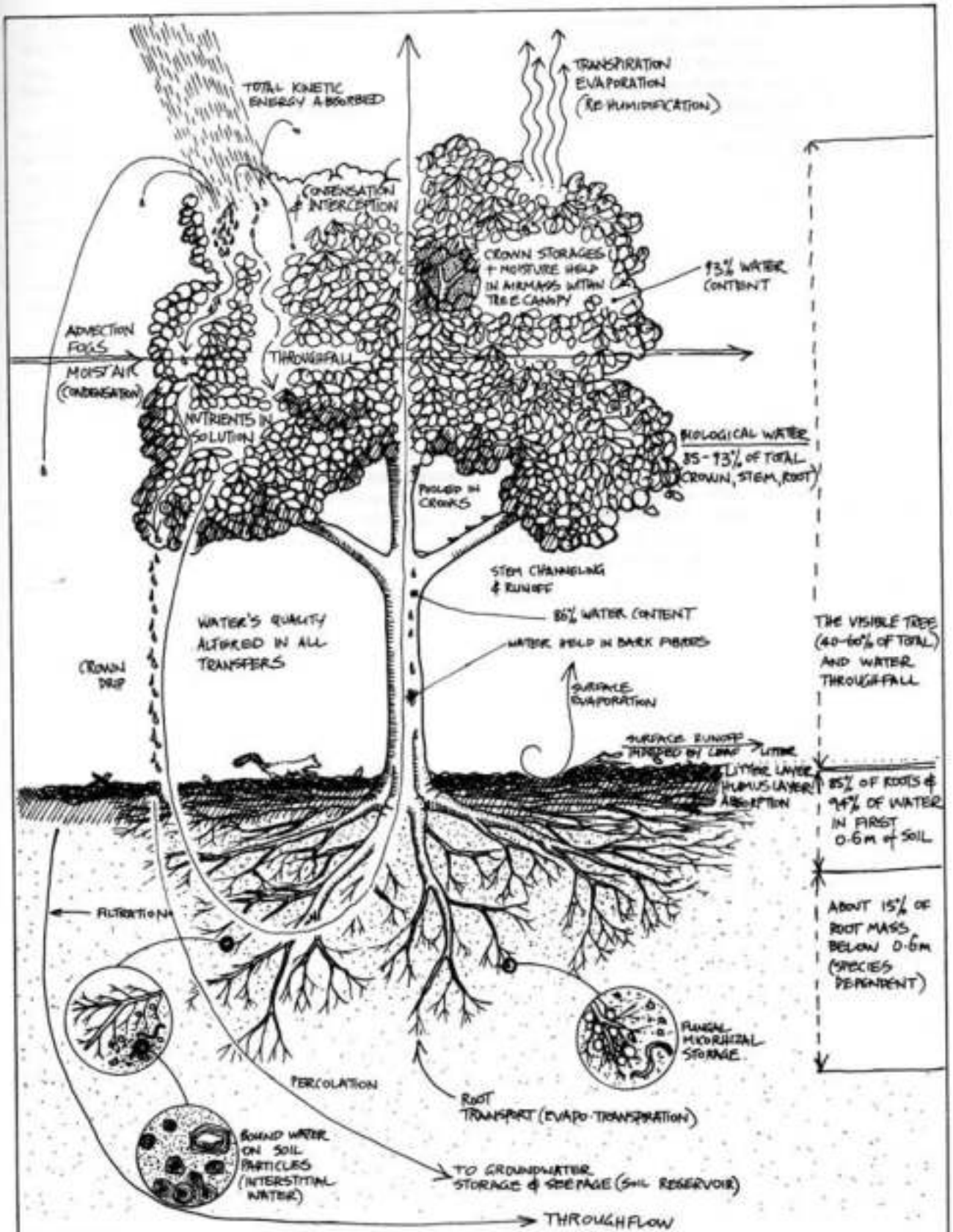


FIGURE 6.6
HOW A TREE INTERACTS WITH RAIN
Every tree, every plant species, intercedes in rain to change the composition, energy, and distribution of water; the overall effect of trees is to *moderate and conserve* incoming energy.

pH can reach as low as 3.5 or 4.0 from natural humic layers, and rivers run like clear coffee to sea. Below the humus lies the tree roots, each clothed in fungal hyphae and the gels secreted by bacterial colonies. 30–40% of the bulk of the tree itself lies in the soil; most of this extends over many acres, with thousands of kilometres of root hairs lying mat-like in the upper 60 cm of soil (only 10–12% of the root mass lies below this depth but the remaining roots penetrate as much as 40 m deep in the rocks below).

The root mat actively absorbs the solution that water has become, transporting it up the tree again to transpire to air. Some dryland plant roots build up a damp soil surround, and may be storing surplus water in the earth for daytime use; this water is held in the root associates as gels. *Centrosema* and *Gleditsia* both are dryland woody legumes which have "wet" root zones, and other plants are also reported to do the same in desert soils (*Prosopis* spp.)

The soil particles around the tree are now wetted with a surface film of water, as were the leaves and root hairs. This bound water forms a film available to roots, which can remove the water down to 15 atmospheres of pressure, when the soil retains the last thin film. Once soil is fully charged (at "field capacity"), free water at last percolates through the **interstitial** spaces of the soil and commences a slow progression to the streams, and thence to sea.

At any time, trees may intercept and draw on these underground reserves for growth, and pump the water again to air. If we imagine the visible (above-ground) forest as water (and all but about 5–10% of this mass *is* water), and then imagine the water contained in soil, humus, and root material, the forests represent great lakes of actively managed and actively recycled water. No other storage system is so beneficial, or results in so much useful growth, although fairly shallow ponds are also valuable productive landscape.

At the crown, forceful raindrops are broken up and scattered, often to mist or coalesced into small bark-fissured streams, and so descend to earth robbed of the kinetic energy that destroys the soil mantle outside forests. Further impedence takes place on the forest floor, where roots, litter, logs, and leaves redirect, slow down, and pool the water.

Thus, in the forest, the soil mantle has every opportunity to act as a major storage. As even poor soils store water, the soil itself is an immense potential water storage. INFILTRATION to this storage along roots and through litter is maximised in forests. The soil has several storages:

- RETENTION STORAGE: as a film of water bound to the soil particles, held by surface tension.
- INTERSTITIAL STORAGE: as water-filled cavities between soil particles.
- HUMUS STORAGE: as swollen mycorrhizal and spongy detritus in the humic content of soils.

A lesser storage is as chemically-bound water in combination with minerals in the soil.

As a generalisation, 2.5–7 cm (1–3 inches) of rain is stored per 30 cm (12 inches) depth of soil mantle in retention storage, although soils of fine texture and high organic content may store 10–30 cm (4–12 inches) of rain per 30 cm depth. In addition, 0–5 cm (0–2 inches) may be stored as interstitial storage.

Thus the soil becomes an impediment to water movement, and the free (interstitial) water can take as long as 1–40 years to percolate through to streams. Greatly alleviating droughts, it also recharges the retention storages on the way. Thus, it almost seems as though the purpose of the forests is to give soil time and means to hold fresh water on land. This is, of course, good for the forests themselves, and enables them to draw on water reserves between periods of rain. (Odum, 1974).

6.7
SUMMARY

Let us now be clear about how trees affect total precipitation. The case taken is where winds blow inland from an ocean or large lake:

1. The water in the air is that evaporated from the surface of the sea or lake. It contains a few salt particles but is "clean". A small proportion may fall as *rain* (15–20%), but most of this water is CONDENSED out of clear night air or fogs by the cool surfaces of leaves (80–85%). Of this condensate, 15% evaporates by day and 50% is transpired. The rest enters the groundwater. Thus, *trees are responsible for more water in streams than the rainfall alone provides.*

2. Of the rain that falls, 25% again re-evaporates from crown leaves, and 50% is transpired. This moisture is added to clouds, which are now at least 50% *"tree water"*. These clouds travel on inland to rain again. Thus trees may double or multiply *rainfall* itself by this process, which can be repeated many times over extensive forested plains or foothills.

3. As the air rises inland, the precipitation and condensation increases, and moss forests plus standing clouds may form in mountains, adding considerably to total precipitation and infiltration to the lower slopes and streams.

4. Whenever winds pass over tree lines or forest edges of 12 m (40 feet) or more in height, Ekman spirals develop, adding 40% or so to rainfall in bands which roughly parallel the tree lines.

5. Within the forest, 40% of the incident air mass may enter and either lose water or be rehumidified.

6. And, in every case, rain is more likely to fall as a result or organic particles forming nucleii for condensation, whereas industrial aerosols are too small to cause rain and instead produce dry, cloudy conditions.

Thus, if we clear the forest, what is left but dust?

6.8

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Chapter 7

WATER

Water is the driving force of all nature.
(Leonardo da Vinci)

In an animal or a plant, 99 molecules in 100 are water... An organism is a pool in a stream of water along which metabolites and energy move through ecosystems.
(W.V. Macfarlane)

The sustained flow of rivers is truly remarkable, considering that precipitation is an unusual event in most areas of the earth. Localisation of precipitation in space or time is striking (e.g. at Paris, it rains for 577 hours a year, or only 7% of the time. *B.Mollison*). Few storms last more than a few hours, so that even storm days are mainly rainless. Yet rivers flow throughout the year. The sustaining source of flow is effluent groundwater... The amount of soil water is about fifteen times the amount in channel storage in rivers.
(Nace *in* Chorley, 1969)

7.1 INTRODUCTION

Very little of the world's total water reserves are actually available for present human needs. Many areas of earth, particularly dryland areas, over-developed cities, and towns or cities surrounded by polluting industry and agriculture, face an absolute shortage of useable water. Millions of city-dwellers now purchase water, at prices (from 1984 on) equivalent to or greater than that of refined petroleum. This is why the value of land must, in future, be assessed on its yield of potable water. Those property-owners with a constant source of pure water already have an economically-valuable "product" from their land, and need look no further for a source of income. Water as a commodity is already being transported by sea on a global scale.

The PRIMARY SELECTION FACTOR, when choosing a cropland property to develop, should be an adequate, preferably well-distributed, and above all reliable rainfall. "Adequate" here is about a minimum of 80 cm (31 inches) and upwards. An equally important factor is the ability of the area to hold water as dams in clay or clay-loam storages; any stream flow within the boundaries is a bonus. All other factors (soil type, present uses, number of titles, market potential, access, and forested areas) are secondary to water availability.

Little of the lands now used for crop agriculture have such fortunate characteristics. Few farmers have invested in "drought-proofing" their land by creating gravity-fed irrigation systems of **Keyline systems**[5]. Specific strategies of water conservation and control are given in this book under their appropriate climatic and landform sections.

While there are no economically-feasible strategies or technologies for freshwater creation from the sea or from polluted sources, there are several currently neglected strategies for recycling, purification, conservation, and increased storages of rainwater. In particular, the construction of tanks and dams have been neglected in built-up areas, as have earth storages on farms and in rural areas. Waste usage ranging from over-irrigation, non-recycling in industry, inappropriate domestic appliances, and unnecessary uses (on lawns and car washes) have not as yet been adequately costed by legislators or by householders.

Tables 7.1 and **7.2** show abstract figures of the global and local water cycles. These should not be regarded as fixed or even sufficient representations of water in relation to actively designed or rehabilitated landscapes. There are ways in which we can constructively reverse past trends in water deficits,

waste, pollution, and misuse. There is plenty of water for the world if we define the ways in which we store and use it carefully.

7.2

REGIONAL INTERVENTION IN THE WATER CYCLE

CLOUD SEEDING

Silver iodide, and no doubt other ice nucleii such as tea dust can be "seeded" into cumulus, cumulonimbus, or nimbostratus clouds (by plane, ground burners, or rocket) in order to initiate local precipitation.

Until recently these attempts to make rain were assessed as ineffective because no one had, at the time, realised how far and for how long the seeding effects spread and persisted. More recent analysis show that rain in fact increases over a very wide area, and that secondary effects last for months, so that varying wind directions and speeds carry the induced rain effects for hundreds or thousands of square kilometres (*Ecos*, 45, Spring 1985). It also seems probable that ground burners or ground release of ice nucleii could have a similar effect. On the ground, silver iodide is absorbed into coal dust, and this is then burnt when clouds form on hill crests. Strategic downwind hills can generate clouds and rain over large areas of land.

Once initiated, however, such effects cannot quickly be stopped, and even in places like India or Ethiopia may create a little too much rain if ground storage systems are not previously developed to cope with the extra water. In arid or semi-arid areas, flood retardation basins, oversized swales, large sand dams, water spreading systems, pelleted seed of fast-growing plants, and in fact any sensible civil strategy to preserve soil and people from any effect of increased precipitation is a necessary prelude to cloud-seeding.

Initial precipitation (due to increased bacterial or ice nucleii stimulus) increases can be as much as 30%, and subsequently averaged in Australia at 19% (17% in Israel) over weeks, falling to 8% in months. The cloud-seeding system promises to help increase monsoon or frontal rains in areas where suitable clouds occur without sufficient precipitation. This system can be very cheap for large land areas. For more data or references, contact the Cloud Physics Laboratory,

TABLE 7.2
FRESHWATER LOCATION.
Freshwater is only 3% of all water on earth, and very little is in circulation, most being locked up in storages.

STORAGE	% OF FRESHWATER
Ice and glaciers*	75.0
Groundwater more than 800 m deep	13.5
Groudwater less than 800 m deep	11.0
Lakes	0.3
Soils	0.06
Atmosphere (in circulation at any one time)	0.035
Rivers	0.03

*Frozen ground or permafrost is not assessed in this table. It represents a considerable storage (about 40% of the landmasses of Canada and the Soviet Union.

TABLE 7.1
RENEWAL TIMES OF ALL WATER IN BASIC STORAGES (seawater and freshwater)[From: Southwick, C.H., *Ecology and the Quality of our Environment*, Van Nostrand Reinhold, NY, 1976.]

LOCATION IN STORAGES	DISTRIBUTION (% of total water)	RENEWAL TIME (Turnover rates, cycles)
Ocean	93.8	37,000 years
Glaciers and permanent snow	1.986	16,000 years
Groundwater (to 5 km depth)	4.1	4,600 years
(Actively exchanged)	0.274	300 years
Lakes	0.0051	13 years
Atmosphere	0.000959	9 days
Rivers	0.00008	13 days
Biological water	0.000005	3.4 days

Division of Atmospheric Research, CSIRO, Canberra, Australia.

As similar effects (thunderstorms, rain) have been noted for tea leaf dust downwind of Kenya plantations, more homely strategies may also be developed if the underlying nucleation causes can be established. It may even be that the fires and dances of the old "rain makers" on a high hill were, in truth, effective. Certainly, fires of specific vegetation and dances with the "right" dust plume could help seed ice nucleii in clouds; quite local rain falls near some factory smoke emissions.

Windward slope forests, cross-wind tree lines, and even slight earth rises of a modest 4–6 m have been observed to induce air humidity, cloud formation, and even rain, by orographic (uplift) effects on windstreams. Thus, we are not powerless in the matter of increasing local moisture by a series of sensible ground strategies based on providing trees, mounds, and cloud ice nucleii, and perhaps a serious attempt to induce these changes will in the near future bring relief to areas such as the Indian Deccan, the Sahel, and large areas of Australia and the USA subject to rainless cloud masses.

OROGRAPHIC AND FOREST EFFECTS

Strategically-selected cross-wind ridges of even modest height [3–20 m (10–65 feet)] are ideal sites for the planting of known tree "condensers" and cross-wind tree-lines. These ridges are most useful when lying in the path of the summer afternoon sea breezes that flow inland, or located where the air drifts in at night, such as on the Californian and sub-tropical trade-wind coasts. The clearing of trees from such sites may well induce long-term drought and create a drying effect for hundreds of kilometres inland.

It is long past time that we also assessed vegetation for some of the following effects:

- Ability to provide rain nucleii, as bacteria and natural sulphur particles, and also to effectively condense water from air at night.
- The rainfall effects from forested ridges, where forests exceed 6–10 m (19–32 feet) in height, on rainfall induced by streamline compression effects. This effect is credited with up to 40% of rainfall where now assessed in Sweden and Australia (Tasmania and Victoria).
- The total effect of forested catchment area. Historical and recent evidence suggests that rainfall, streamflow, and cloud may all be seriously depleted by upland deforestation. Such effects are never assessed or costed against deforestation or wood-chipping. The soil erosion and salted land effects are, however, well known in deforested areas.

Any conservationist policies of future effective and informed regional governments would first research

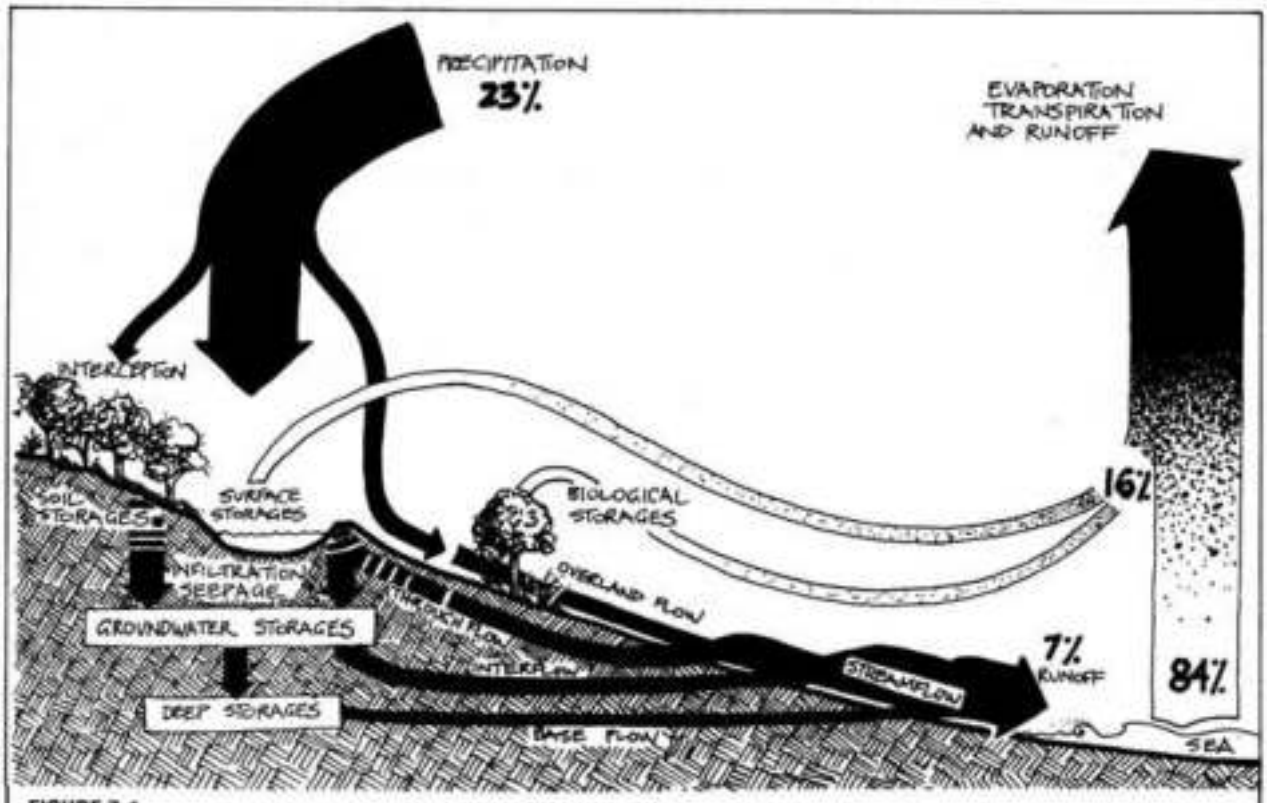


FIGURE 7.1
THE GLOBAL WATER CYCLE (Land and sea)
Omits most of the biological effects but gives the broad schematic of the water cycle. We can affect all parts of this cycle in adverse or beneficial ways.

such effects, then quickly establish national forest and watershed management or restoration policies based on such research. For ourselves, as designers, the proper approach to land planning infers that we recommend permanent forests and the preservation of older forests on cross-wind ridges, and on steep (18° slope or more) sea-facing slopes. The preservation of alpine or upland absorption areas is also essential.

SOIL STORAGES

Soil conditioning or "ripping" (see Chapter 8), providing it is followed by tree plantation, trace element additions, and a non-destructive agriculture of well-managed natural yields, sparse grazing, and conservation farming certainly increases (by factors of up to 70-85%) the ability of soils to hold and infiltrate water. Areas of up to 85% run-off can be converted to zero overland flow by a combination of soil conditioning, swales, and water spreading to forests.

As soils can contain many times the water of open storages or streams, then both the throughflow, baseflow, and water available for plants also increases. It follows that the CYCLING of water via evapotranspiration and rainfall also increases. Soil treatments now need to precede tree planting over almost every area that has been used by contemporary agriculture. In particular the barren areas used for constant cropping in dryland areas need soil treatment to initiate water absorption. Trees are essential to prevent water-logging of soils and soil salting in the long term.

INFILTRATION VIA EARTHWORKS

Cheap broadscale earthwork systems, and many minor forms of earthworks can aid the infiltration of overland water flow. PITTING, SWALES and WATER SPREADING are the main aids to getting fresh water to deeper storages for long-term use, and also to increase base flow. Diversion of surface flow to sand basins, dune fields, swamps, and soakage beds in earth-bermed fields all ensure resident water reserves for crop and trees, and longer-term storages for use in dry seasons.

Diversion drains and their associated valves, slides, cross-walls, intakes, and irrigation systems enable effective water harvesting, dependable storage, and fast emergency use in normal rolling lowlands, hill country, and drylands. They can also recharge sand basins and swales from otherwise wasted overland flow, and damp our wildfires.

POND AND FARM DAM STORAGES

Wherever precipitation exceeds the demands of transpiration and evaporation, small dams, wetlands, and swamps can proliferate. All of these act as long-term water and wildlife reserves in the total landscape, and many Australian farms are now "drought-proof" due to sensible investment in Keyline or similar water conservation systems by the owners. Excellent technical manuals exist (see references at the end of this chapter).

Dams and ponds are potential aquaculture sites, and the production of a diverse plant and fish or waterfowl protein product should also be considered during their construction. In humid areas, therefore, these water storages can occupy up to 20% of the landscape with great benefit in providing fish and a great variety of aquatic product, while at the same time moderating the effects of drought and flood.

BIOLOGICAL STORAGES

The great forests and the biological water storages in the form of fruits and nuts (such as the coconut) are the basis for the proliferation of life forms where no "free" water otherwise exists. In particular, browsers, insects and fungi draw on these biological tree reserves year-round, and perform a host of useful functions in any ecosystem. On atolls and arid islands of free-draining sands, the biological reserves are the main water reserves. This is often overlooked, except by those inhabitants dependent on the waters contained in fruits or nuts. Many plants such as cactus, palms, and agaves have specific tissues or organs to store water.

In the local microclimate, the water in vegetation greatly moderates heat and cold excesses, and both releases to, and absorbs water from passing air streams. Essential crops such as cassava will produce crop as a result of the humidity provided by surrounding vegetation, so that even this side effect of vegetation is of productive use (*New Scientist* 29 May '86).

TANK STORAGES

Water can be captured off roof areas, roads, and other paved areas, and used for both drinking water and shower or garden water, providing it can be stored. Roof water is least polluted, or most easily treated for drinking and cooking in houses, while absorption beds are sufficient for the muddy or polluted run-off from roads and parking areas.

7.3

EARTHWORKS FOR WATER CONSERVATION AND STORAGE

For the serious small dam and earth tank builder, there is no substitute for such comprehensive texts as that recently compiled by Kenneth D. Nelson (1985). This small classic deals with catchment treatments, run-off calculations, soils, construction, outlets, volume and cost estimates, and includes detailed drawings for most adjunct structures.

However, like most engineers, Nelson concentrates mostly on valley dams (barrier or embankment dams), and less on the placement of dams in the total designed

landscape. Few dam builders consider the biological uses of dams, and the necessary modifications that create biological productivity in water systems.

A second essential book for water planning in landscape is P. A. Yeomans' *Water for Every Farm/The Keyline Plan* (1981)[5]. This very important book, written in 1954, is without doubt the pioneering modern text on landscape design for water conservation and gravity-fed flow irrigation. As it also involves patterning, tree planting, soil treatment, and fencing alignment, it is the first book on functional landscape design in modern times.

There are two basic strategies of water conservation in run-off areas: the diversion of surface water to impoundments (dams, tanks) for later use, and the storage of water in soils. Both result in a recharge of groundwater. As with all technologies, earthworks have quite specifically appropriate and inappropriate uses. Some of the main productive earthwork features we create are as follows:

- Dams and tanks (storages);
- Swales (absorption beds);
- Diversion systems or channels; and
- Irrigation layouts, and in particular those for flood or sheet irrigation.

SMALL DAMS AND EARTH TANKS

Small dams and earth tanks have two primary uses. The minor use is to provide watering points for rangelands, wildlife, and domestic stock; such tanks or waterholes can therefore be modest systems, widely dispersed and static. The second and major use is to contain or store surplus run-off water for use over dry

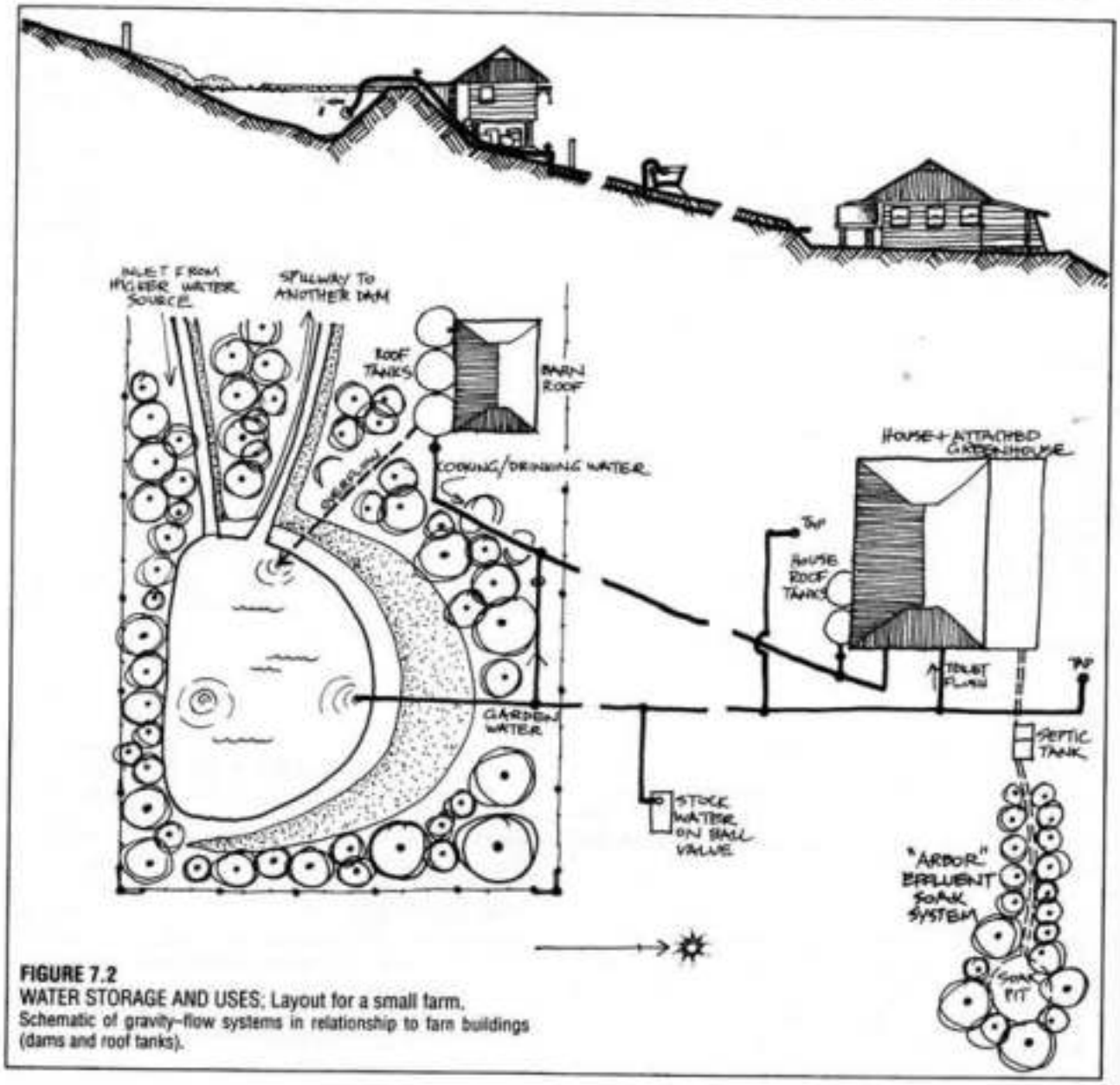


FIGURE 7.2
WATER STORAGE AND USES; Layout for a small farm.
Schematic of gravity-flow systems in relationship to farm buildings (dams and roof tanks).

periods for domestic use or irrigation. The latter storages, therefore, need to be carefully designed with respect to such factors as safety, water harvesting, total landscape layout, outlet systems, draw-down, and placement relative to the usage area (preferably providing gravity flow).

A separate category of water storages, akin to fields for crop or browse production, are those ponds or wet terraces created specifically for *water crop* (vegetation or mixed polycultural systems of aquatic animal species).

Open-water (free water surface area) storages are *most appropriate in humid climates*, where the potential for evaporation is exceeded by average annual rainfall. There is a very real danger that similar storages created in arid to subhumid areas will have adverse effects, as evaporation from open water storages inevitably concentrates dissolved salts. Firstly, such salty water can affect animal health. Secondly, the inevitable seepage from earth dams can and does create areas of salted or collapsed soils downhill from such storages. And in the case of large barrier dams, so little water may be allowed to bypass them in flood time that agricultural soils, productive lakes, and estuaries may lose more productive capacity by deprivation of flush-water and silt deposits than can be made up (at greater cost) by irrigation derived from such lakes.

Dryland storage strategies are discussed in Chapter 11. What I have to say here is *specifically addressed to humid areas and small dams* unless otherwise noted.

Earth dams or weirs where retaining walls are 6 m (19 feet) high or less, and which have a large or over-sized stable spillway, are no threat to life or property if well-made. They need not displace populations, stop flow in streams, create health problems, fill with silt, or block fish migrations. In fact, dams or storages made anywhere *but* as barriers on streams effectively add to stream flow in the long term.

Low barrier dams of 1–4 m (3–13 feet) high can assist stream oxygenation, provide permanent pools, be "stepped" to allow fish ladders or bypasses, and also provide local sites for modest power generation. While almost all modern assessments would condemn or ban large-scale dams (and large-scale power schemes) on the record of past and continuing fiascos, a sober assessment of small water storages shows multiple benefits.

Given the range of excellent texts on small dams (often available from local water authorities, and by mail order from good bookstores), I have therefore avoided specific and well-published construction details, and have here elaborated more on the types, placement, links to and from, and function of small dams in the total landscape. Yeomans (*pers. comm.*, 1978) has stated that he believes that if from 10–15% of a normal, humid, lowland or foothill landscape were fitted with small earth storages, floods and drought or fire threat could be eliminated.

Not all landscapes can cost-effectively store this

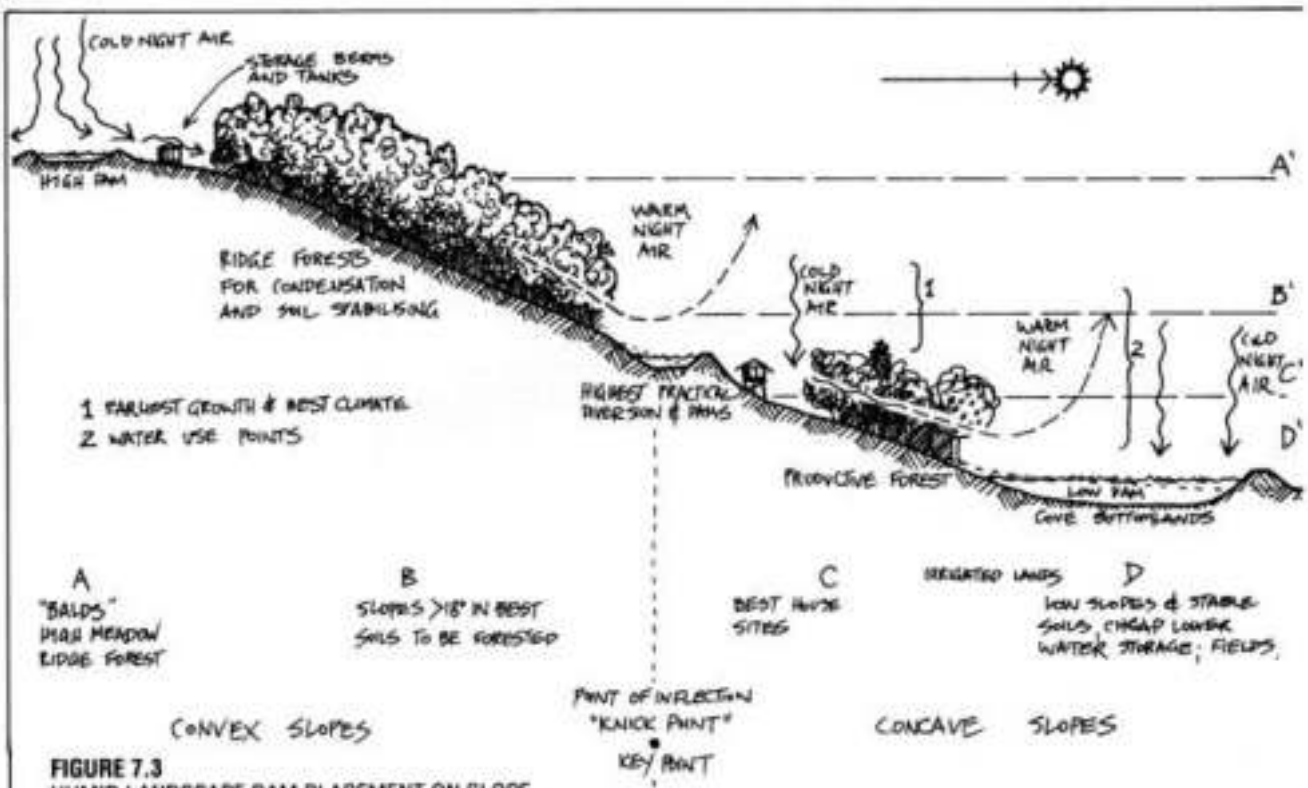


FIGURE 7.3
HUMID LANDSCAPE DAM PLACEMENT ON SLOPE
Schematic of water storages with respect to slope, forests, and dwellings.

proportion of free surface water; some because of free-draining soils or deep or coarse sands. Other areas are too rocky, or of fissured limestone, and yet others are too steep or unstable. But a great many productive areas of clay-fraction subsoils (40% or more clay fraction) will hold water behind earth dams, below grade levels as earth tanks, or perched above grade as "turkey's nest" or ring dams. There are very few landscapes, however, that will not store more soil water if humus, soil treatment, or swales are tried; the soil itself is our largest water storage system in landscape if we allow it to absorb.

Almost every type of dam is cost-effective if it is located to pen water in an area of 5% or less slope. However, many essential dams, if well-made and durable, can be built at higher slopes or grades, made of concrete, rock-walled, or excavated if water for a house or small settlement is the limiting factor. Each and every dam needs careful soil and level surveys and planning for local construction methods.

DAM TYPES AND LOCATIONS

There are at least these common dam sites in every extensive landscape:

SADDLE DAMS are usually *the highest available storages*, on saddles or hollows in the skyline profile of hills. Saddle dams can be fully excavated below ground (grade) or walled on either side of, or both sides of, the saddle. They can be circular, oblong, or "shark egg" shaped with horns or extensions at either end (**Figure 7.4**).

Uses: wildlife, stock, high storage.

RIDGEPOINT DAMS or "horseshoe" dams are built on the sub-plateaus of flattened ridges, usually on a descending ridgeline, and below saddle dams. The shape is typically that of a horse's hoof. It can be made below grade, or walled by earth banks (**Figure 7.5**).

Uses: As for saddle dams. Only of limited irrigation use, but very useful for run-off and pumped storages. Note that both saddle and ridge dams can act as storages for *pumped* water used for energy generation.

KEYPOINT DAMS are located in the valleys of secondary streams, humid landscapes, at the highest practical construction point in the hill profile, usually where the *stream* profile changes from convex to concave; this place can be judged by eye, and a descending contour will then pick up all other keypoints on the main valley (**Figure 7.6**).

Uses: Primarily to store irrigation water. Note that a second or third series can be run below this primary series of dams, and that the spillway of the last dam in a series can be returned "upstream" to meet the main valley, effectively spilling surplus to streams.

CONTOUR DAM walls can be built on contour wherever the slope is 8% or less, or sufficiently flat. Contours (and dam walls) can be concave or convex to the fall line across the slope (**Figure 7.7**).

Uses: Irrigation, aquaculture, or flood-flow basins in

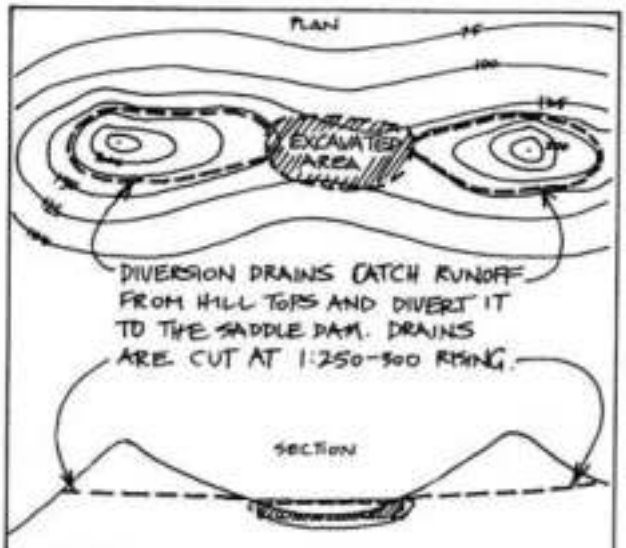


FIGURE 7.4
SADDLE DAM
Very useful for fire control, wildlife, limited irrigation. The "highest" type of dam in the landscape that fills from hill runoff.

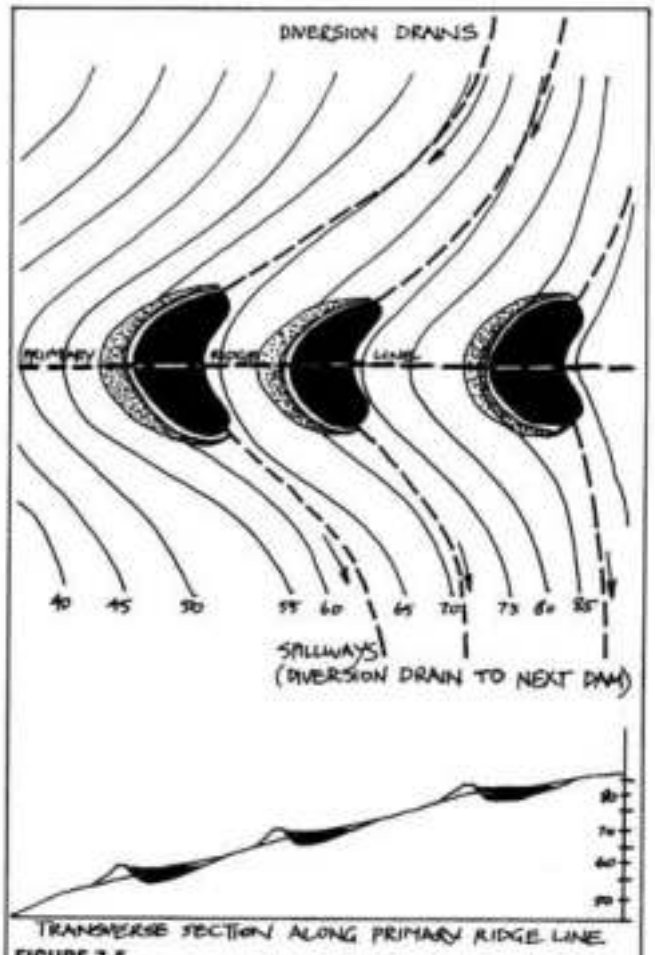


FIGURE 7.5
RIDGEPOINT DAM
or "horseshoe" dam, built on plateau areas of ridges. Uses as for saddle dams.

semi-arid areas.

BARRIER DAMS are always constructed across a flowing or intermittent stream bed. These dams therefore need ample spillways, careful construction, fish ladders on biologically important streams, and are made most frequently as energy systems, but are also used for irrigation if they are constructed well above the main valley floors where crops are grown (**Figure 7.8**).

TURKEY'S NEST DAMS or above-grade tanks; water has to be pumped in to these, often by windmill or solar pump. They are common in flatlands as stock water tanks or for low-head irrigation (**Figure 7.9**).

CHECK DAMS. There are many forms of barrier dams not intended to create water storages, but to

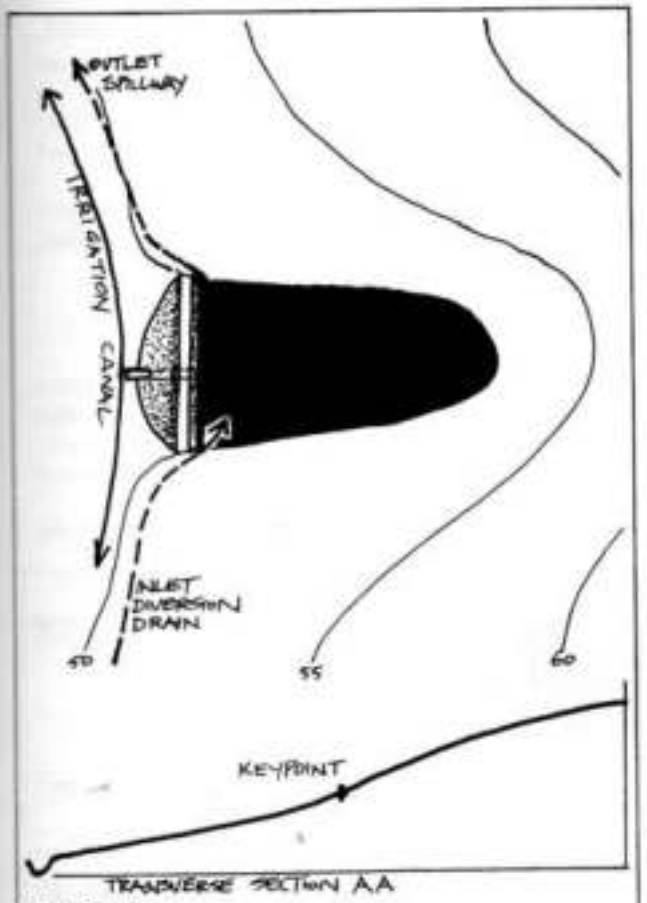


FIGURE 7.6
KEYPOINT DAM
A. If used in series, no spillway is built and the overflow goes to the next dam, and eventually to a stream. Fitted for irrigation on lower slopes.
B. The keyline (heavy dashes) links keypoints in primary valleys.

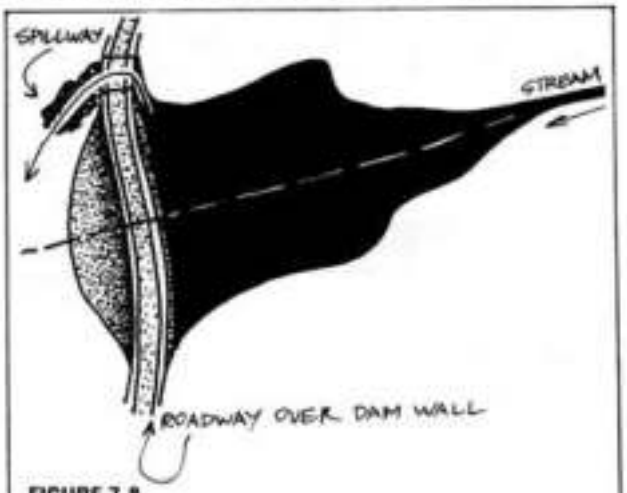


FIGURE 7.8
BARRIER DAM
'The engineer's dam.' Can affect fish, migration, and be difficult to spill; works well as part of a keyline series only.

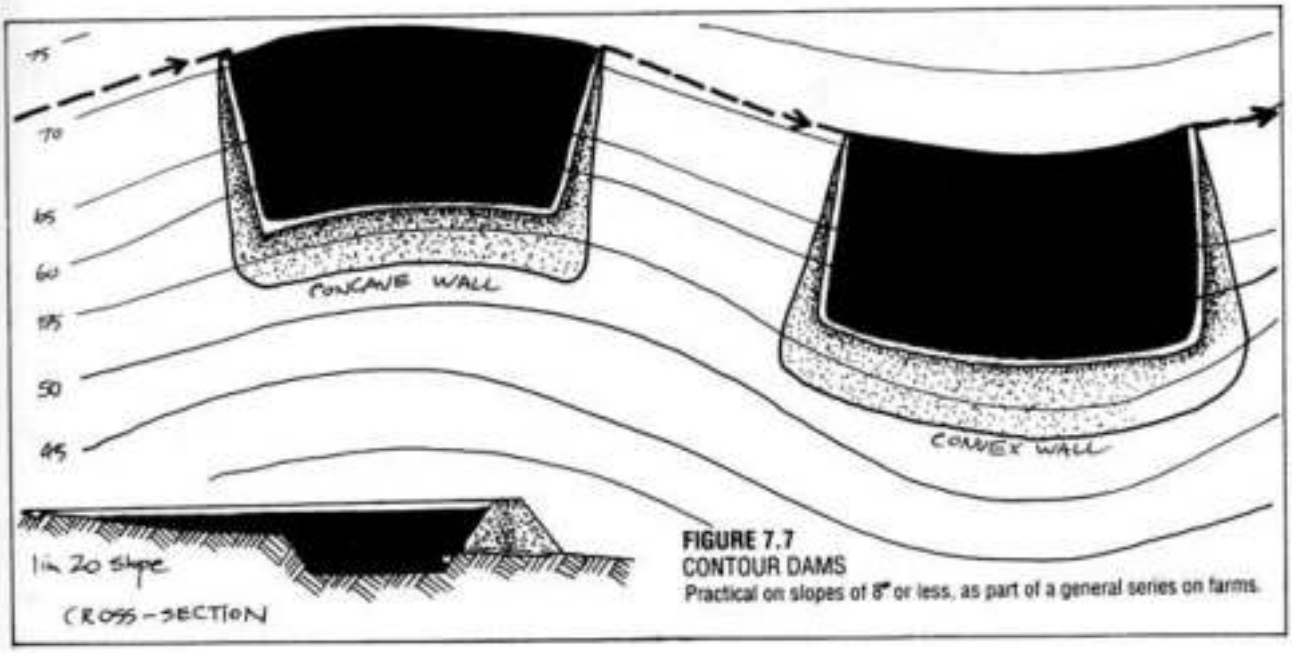


FIGURE 7.7
CONTOUR DAMS
Practical on slopes of 8° or less, as part of a general series on farms.

regulate or direct stream flow. Even a 1–3 m (3–10 foot) wall across a small stream gives enough head to drive an hydraulic ram, to fit a waterwheel, to divert the stream itself to a contoured canal for irrigation, or to buffer sudden floods. Dams intended to regulate flood crests may have a base pipe or fixed opening in the streambed which allows a manageable flow of water downstream while banking up the flood crest behind the dam itself, so spreading the rush of water over time. The base opening allows silt scour and so keeps the dam free of siltation (**Figure 7.10–13**).

GABION DAMS. In drylands, permeable barriers of rock-filled mesh "baskets" (**gabions**) will create silt fields and water-spreading across eroding valleys. The scale of these dams varies, but for farm construction, walls 0.5–2 m (2–6.5 feet) high are usual. As with **Figure 7.12**, the purpose is not to store free surface water, but to create a flat area where silt loads can usefully deposit, and so form absorption beds in flood conditions.

We can see the landscape (as though sliced into layers through contours) as a set of catchment, storage, usage, and revitalisation zones. (**Figure 7.15**)

BUILDING DAMS

Although we can build dams or tanks on *any* site, given enough material resources, commonsense dictates that storage dams be carefully located with respect to:

- Earth type (core out a sample pit for assessing clay fractions);
- Grade behind wall (lower slopes give greatest

FIGURE 7.9
RING AND TURKEY'S NEST DAM.
Hold water pumped in by a windmill and provides a low head in flat landscapes; can be pipe-filled from a large roof or from parking areas.

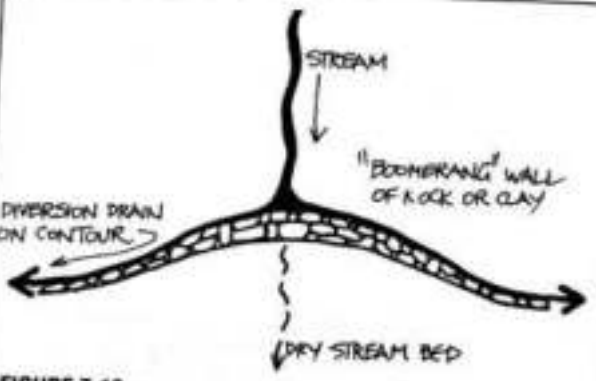


FIGURE 7.10
DIVERSION CHECK DAM
Diverts intermittent flow to ridges, storages , or canals on contour.

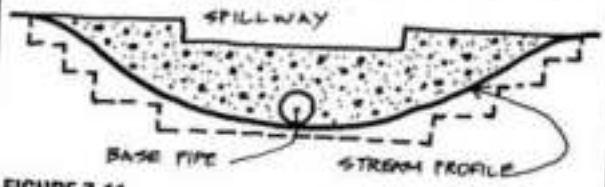


FIGURE 7.11
CONCRETE FLOOD CHECK DAM
Allows normal flow to pass, retards floods, and prevents rapid flood discharge.

FIGURE 7.12
SILT CHECK DAM
Earth or concrete walls or gabions hold silt fields, spread water, reduce silt load in streams.

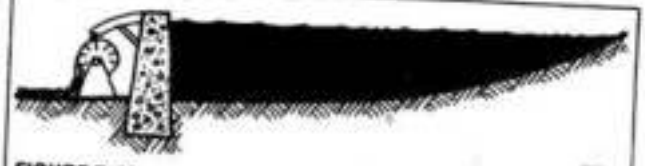


FIGURE 7.13
CHECK DAM FOR RAM PUMP OR WATER WHEEL
Only 1–3 m of head enables modest energy use for mechanical power, lift pumps, or diversion to canals.

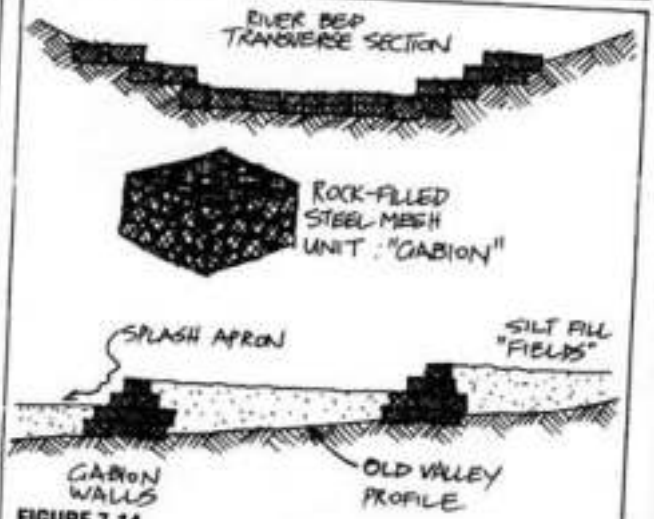


FIGURE 7.14
Eroding gullies are best stabilised using strong wire baskets to contain stones or shingle; these resist floods well.

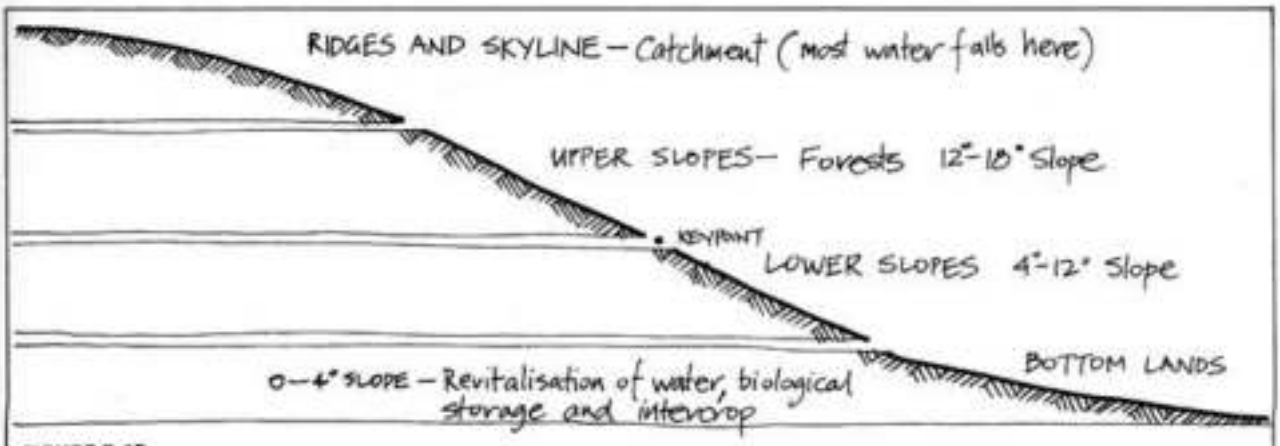


FIGURE 7.15

capacity);

- Downstream safety of structures and houses (a key factor in large dams);
- Height above use points (gravity flow is desirable); and
- Available catchment or diversion.

Tamped earth with some clay fractions of better than 50% is a waterproof barrier up to heights of 3.6 m (12 feet), not counting the holes behind such walls caused by their excavation. Therefore we speak of depths of 4.5–6 m (15–20 feet) for small earth dams. Few of us will want to build farm dams higher, and we must get good advice if we wish to do so.

Slopes to crest should be concave, and every 25 cm (10 inches) a machine such as a roller, or the bulldozer tracks themselves, should ride along and tamp down

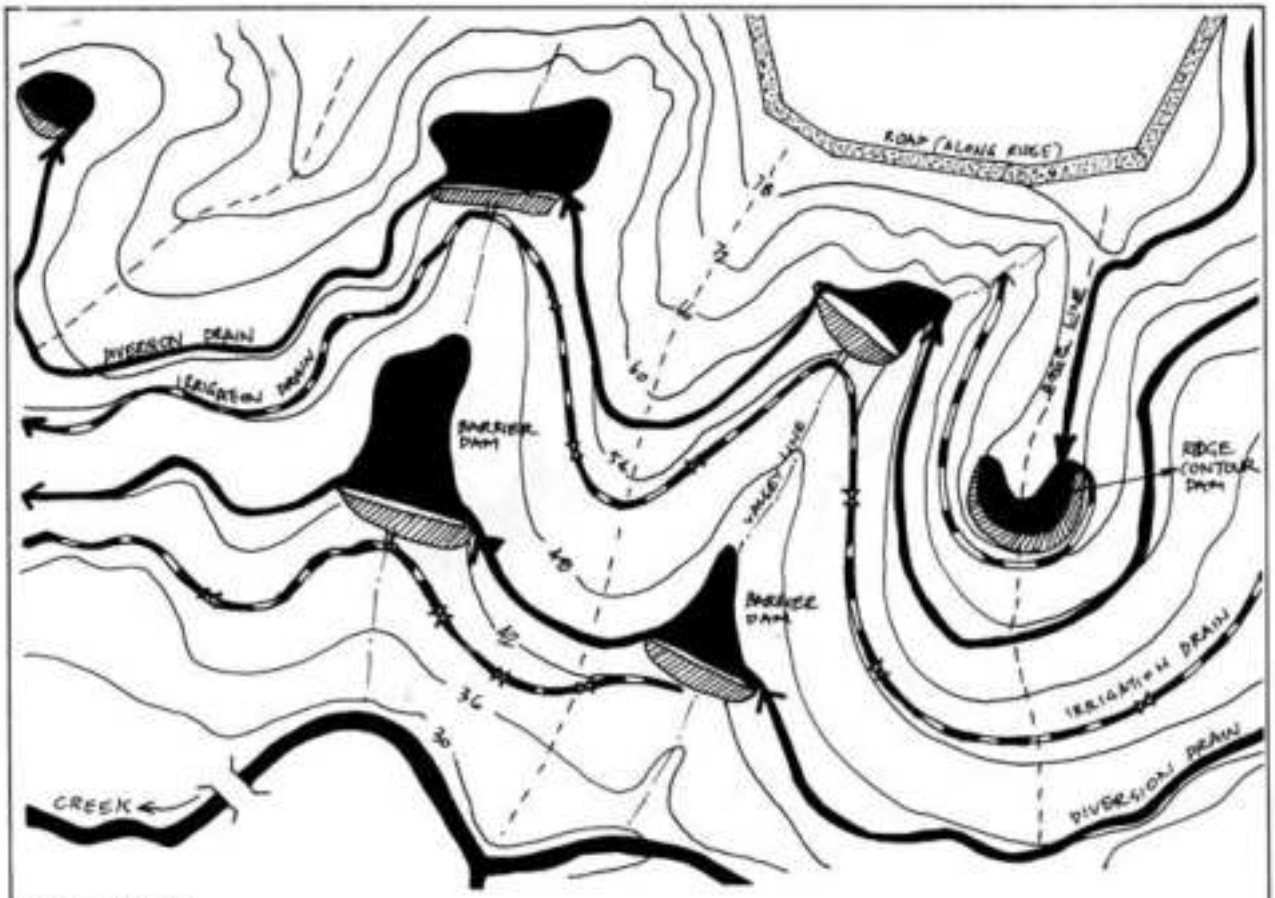


FIGURE 7.16.A
P. A. Yeomans' 'Keyline' system provides drought-proofing for farms with very low maintenance and operating costs; his was the first book in English on total water design for foothill farms, access, tree belts, soil creation, low tillage, and creative water storage.

DAM	m³ 1000's	Imp. gall. 1000's	US gall. 1000's
1	25	5.5	6.6
2	37	8.1	9.8
3	31	6.8	8.2
4	20	4.4	5.3
5	15	3.3	4.0
6	74	16.3	19.5
7	31	6.8	8.2
8	39	8.6	10.3
9	15	3.3	4.0
10	22	4.8	5.8
11	49	10.8	13.0
12	55	12.1	14.5
13	136	30.0	35.9
14	61	13.4	16.1
15	25	5.5	6.6
16	80	17.6	21.1
Tot.	715	157.3	188.9

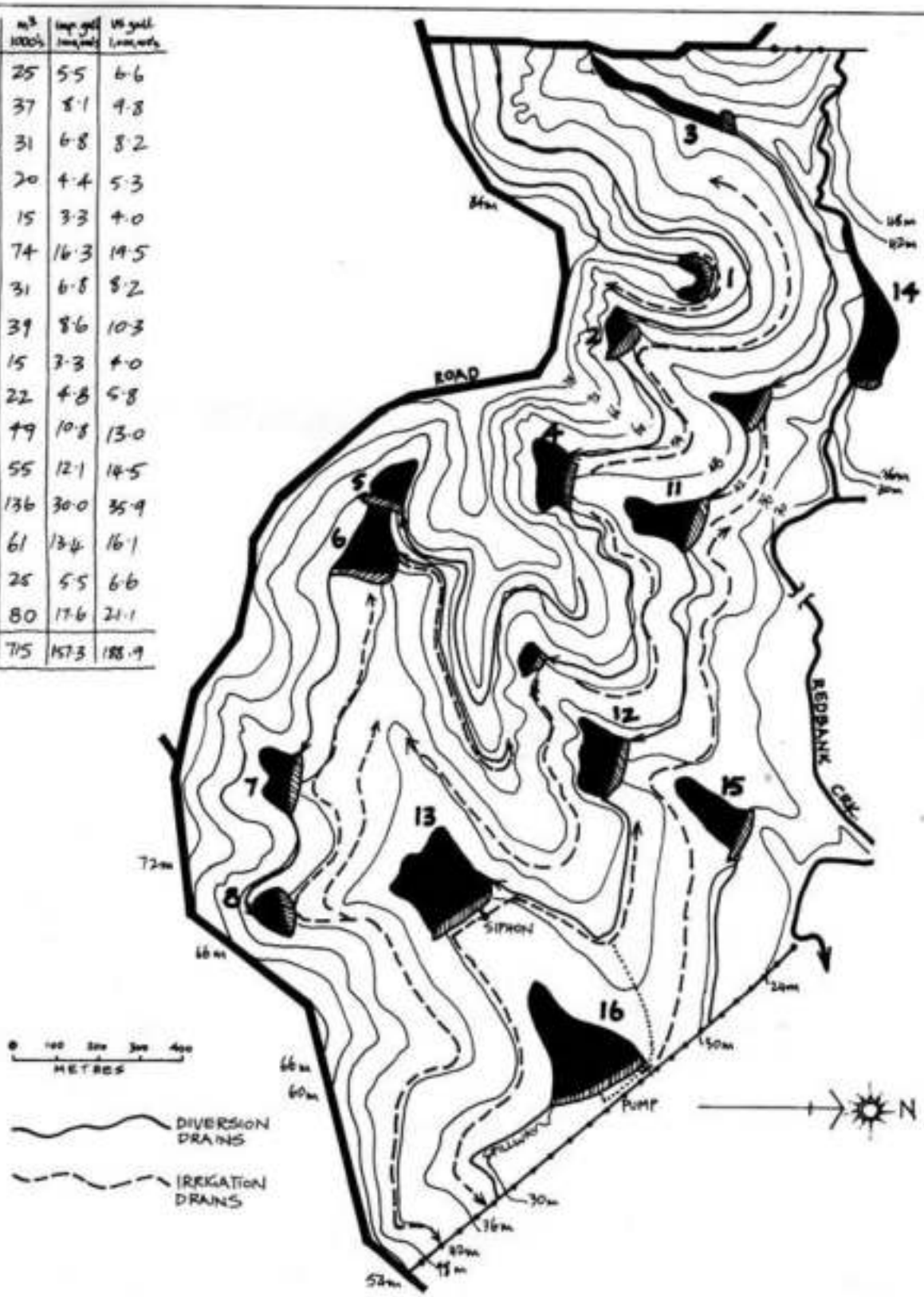


FIGURE 7.16.B
A MAP OF ONE OF P.A. YEOMANS' PROPERTIES.
P. A. Yeomans' former property "Yobarnie", after 17 years of keyline irrigation development, covering about 307 ha (758a.). The road on the southern edge of Yobarnie is located along a main ridge. Note the primary valleys and primary ridges falling to Redbank Creek to the North. For further information and photographs see Yeomans[illegible].

the earth. This, like the exclusion of boulders and logs, grass clumps and topsoil, is critical to earth stability (shrinkage of well-compacted dams is less than 1%). Earth so rolled should be neither so dry as to crumble nor so wet as to slump or squash out under the roller.

A key should be cut to prevent shear and cut off any base seepage. This is needed on all walls 1.8 m (6 feet) or more high, otherwise the base should be on a shallow clay-filled ditch. Slopes are safe at a ratio of 3:1 (inner) and 2 or 2.5:1 (outer), freeboard at 0.9 m (3 feet), key at 0.6–0.9 m (2–3 feet) deep. In suspect soils, the whole core can be of carted clay (**Figure 7.17**).

The wall can curve (out or in), but if carefully made as diagrammed and provided with a broad spillway, should be stable and safe forever, barring explosions or severe earthquakes.

The SPILLWAY base should be carefully surveyed at 1 m below crest and away from the wall or fill itself (don't try to judge this, measure it), and a SIPHON or BASE OUTLET pipe fitted with baffle plates placed to draw off water (**Figure 7.18**).

The efficiency in capacity of dams depends on the flatness of the area behind the wall. A "V" valley or "U" valley, plateau, or field should be as level as can be chosen for greatest efficiency. The key to efficiency is the length of the dam wall, compared with the "length" of water dammed. If the back-up is greater than wall length, then this is a measure of increasing efficiency of energy used or earth moved for water obtained. A careful survey of grade plus dam length gives this data before starting the wall. Some dam sites are very cost-effective, especially those short dams at constricted sites where the valley behind them is flattish.

Small dams of this nature are a jewel in the landscape. Fenced and planted to 30–60 m of forest and fruit surround, they will provide biologicially clean, if sometimes muddy, water, and if the topsoil is returned,

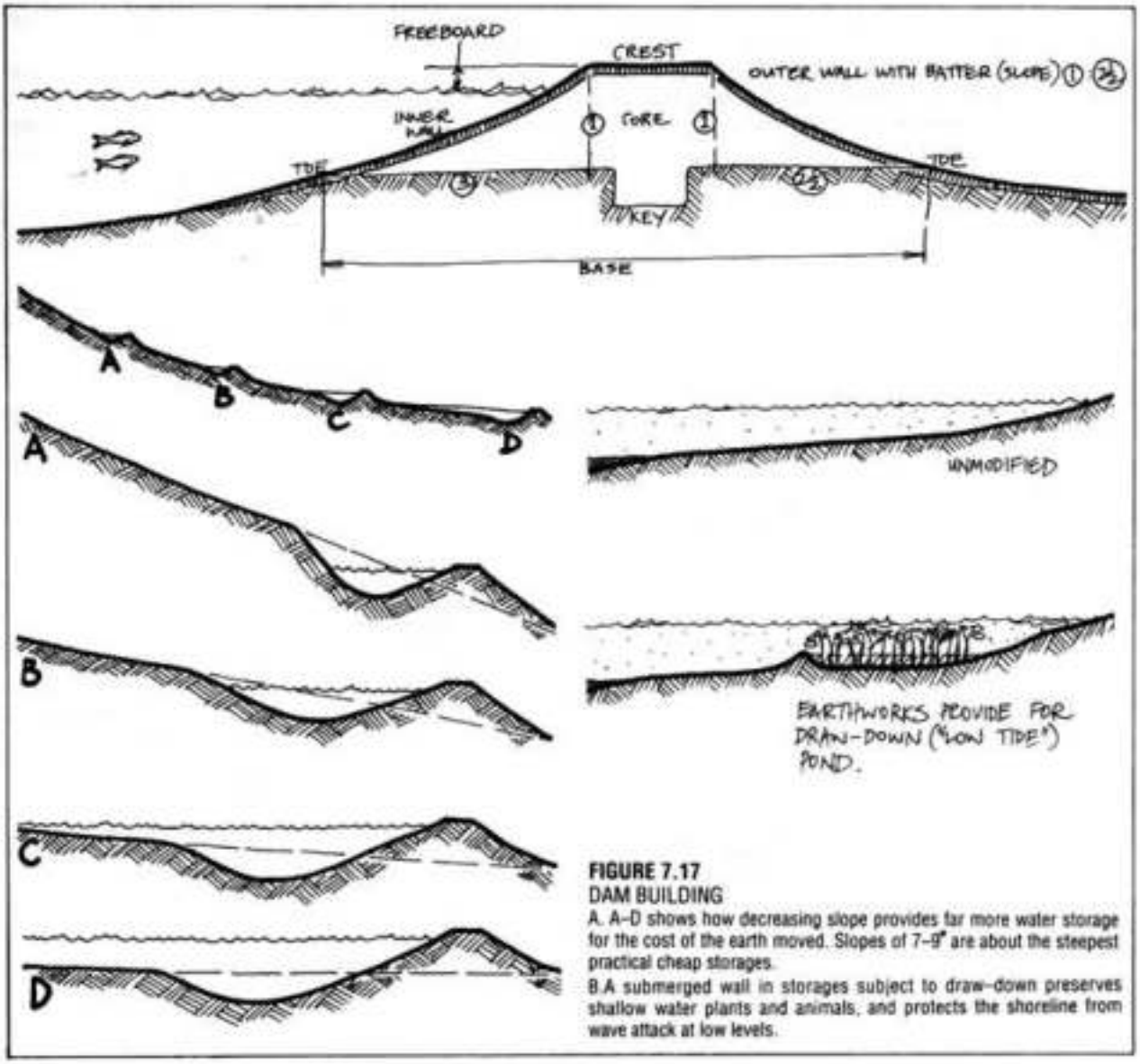


FIGURE 7.17
DAM BUILDING
A. A–D shows how decreasing slope provides far more water storage for the cost of the earth moved. Slopes of 7–9° are about the steepest practical cheap storages.
B.A submerged wall in storages subject to draw-down preserves shallow water plants and animals, and protects the shoreline from wave attack at low levels.

lime used, and edges planted, mud will decrease and eventually clear. For water cleanliness and parasite control, cattle, sheep, and other animals should be watered at spigots or troughs, not directly at the dam. Troughs are easily treated with a few crystals of copper sulphate to kill snails and parasitic hosts; dams stocked with fish will do the same job.

Crests can be gravelled and safely used as roads to cross valleys or bogs, and special deep areas, islands, peninsulas, and shelves or benches made inside the dam for birds, plants, and wild-fire-immune houses.

SEALING LEAKY DAMS

There are several ways to seal leaking dams:

- Gley;
- Bentonite;
- Explosives;
- Clay; and
- Impermeable membranes.

GLEY is a layer of mashed, wet, green, sappy plant material sealed off from air. Although the very green manure of cattle is preferred, shredded, sappy vegetation will also work. It is carefully laid as a continuous 15–23 cm (6–9 inch) layer over the base and *gently* sloping sides (ratio of 1:4) of a pond, and is covered *completely* with earth, cardboard, thick wet paper, plastic sheets, or rolled clay, and allowed to ferment anaerobically. This produces a bacterial slime which permanently seals soil, sand, or small gravels. Once ferment occurs, the pond is pumped or hosed full of water, and the paper or plastic can be later removed. I have used carpets and odd pieces of plastic sheets overlapped with good results. In cold areas, ferment can take a week or two, in tropics a day or so. Lawn or second-cut grasses, papaya and banana leaves, vegetable tops or green manure all serve as the base layer. I believe that in very good soils, especially in the tropics, it may be possible to grow the gley as a mass of *Dolichos* bean and just roll it flat before sealing it (**Figure 7.19**).

Modifications are:

- To pen and feed a herd of cattle in the dry dam until the bottom is a manurial pug; occasional watering assists this process.
- To strew bales of green hay and manure on ponds that leak slightly, producing algae which seal minor cracks.
- To sow down green crop in the dry dam, spray irrigate and feed it off regularly with cattle.

BENTONITE is a slippery clay-powder derived from volcanic ash. It swells when watered and will seal

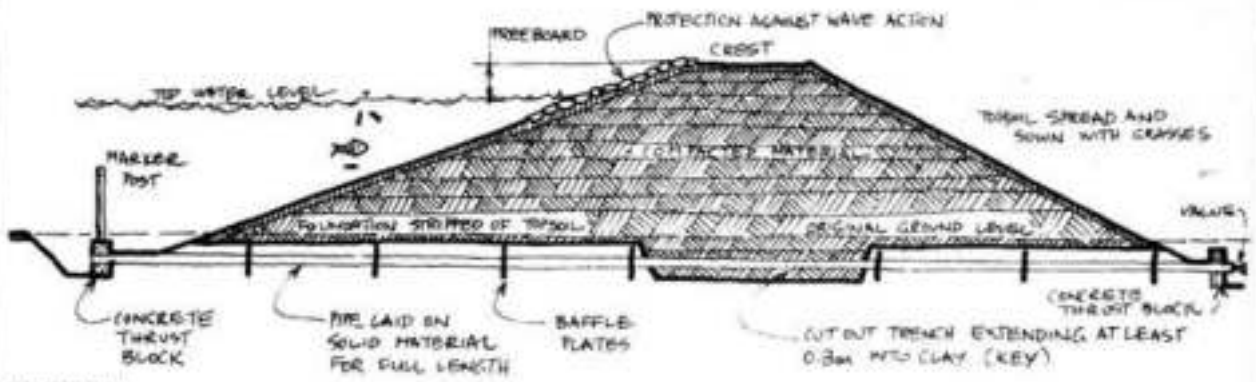


FIGURE 7.18
DAM WITH LOCK PIPES.
A large earth dam feeding irrigation canals in the Keyline system can be fitted with a base pipe. Smaller dams use siphon over the dam wall to gardens and houses.

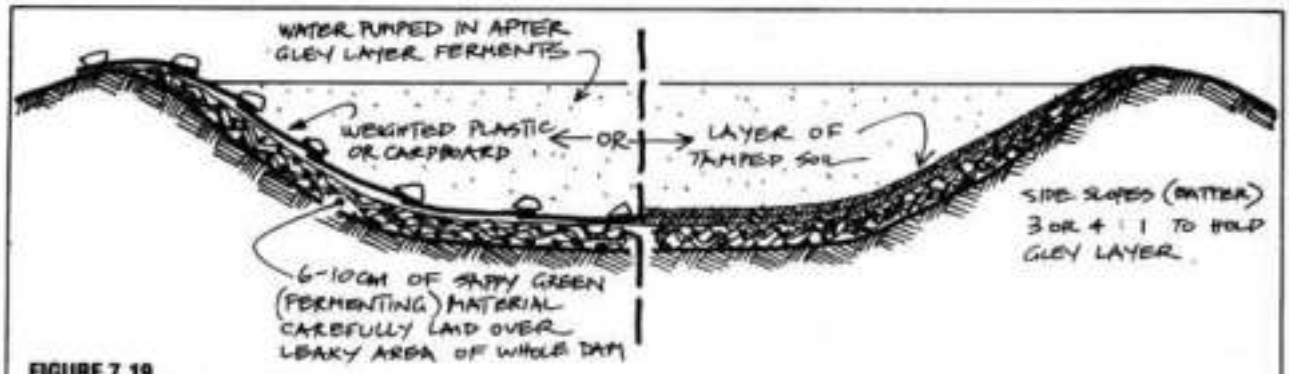


FIGURE 7.19
GLEYING A POND
With great care taken to slope side and place ferment material, this technique will seal ponds in sands, gravels, shales, or leaking substrates.

clay-loams if rototilled in at 5–7 cm (2–3 inches) deep and rolled down. However, it is expensive and doesn't always work. Cement and tamping plus sprinkling might be preferable, or a bituminous spray can be rolled in after tilling. In clay soils, salt or sodium carbonate can have the same effect.

EXPLOSIVES are sometimes used to compact the sides of full dams, and consists of throwing in a 3–5 stick charge of dynamite. This works well at times, but is dangerous if you own a retriever, or if the dam wall is poorly compacted to start with.

CLAY is expensive if it has to be carted in, but it is often used to seal dams near a clay pocket. The clay is spread and rolled 23–30 cm (9–12 inches) thick over suspect areas.

IMPERMEABLE MEMBRANES can be of welded plastic, neoprene, or even poured concrete. Impermeable membranes are too expensive to use on any but critical dams, which may mean a guaranteed water supply to a house or garden in very porous areas. Using membranes enables banks to be steeper than in any other earth-compaction or gley system, so that more water can be fitted into smaller space. It is not "biological" unless a sand or topsoil floor is also added over the sealing layer, when fish or plants can be added.

Earth storage is now the cheapest, easiest, and most locally self-reliant method of water conservation. Unless both cities and farms use such methods, clean water will deservedly become known as the world's rarest mineral, ill-health will be perpetuated, and droughts and floods alike become commonplace. None of these are necessary.

Costs vary greatly; as a rough guide, water stored in soil and humus is the cheapest and of greatest volume, surface dams next cheapest, and tanks dear, but still much less expensive than piped water from mains supply. I can only urge all people of goodwill to promote, fund, and investigate water and water storage, water energy and water cleanliness, as the chlorinated, metallic, asbestos-fibred, poisonous water of modern centralised systems is producing such epidemic disease and illness as cancer, bone marrow failure, and gastrointestinal disorder.

If a 22,500 l tank costs 20 units of money, the same units in a sensible eath storage pays for 2,500,00 l, or about 100 times as much water. Up to 135,000–2,500,000 l tanks get cheaper, as less concrete is used for more water. That is, a large tank is relatively cheaper than a small tank. Above 22,500 l, such tanks are usually poured on site; below this, they are carted from a central manufacturing site.

Dams, in contrast, begin to cost more as the height of the wall rises. About 3 m (10 feet) of retaining wall is the limit of cheap dams. Above this, costs rise rapidly as greater skills, more expensive and massive materials, more complex controls of levels, and much greater environmental risks take their toll.

As noted, "cheap" water in dams depends on the choice of site, so that very low dams on well-selected sites impound 20–100 times more water than the same earth used on steeper sites, where every unit of earth moved equals a unit of water. However, even earth tanks excavated below grade are at one-tenth the price of concrete tanks above grade.

Where are tanks, modest dams, and massive dams appropriate? Tanks are appropriate on isolated dwellings, in flatlands, and everywhere in cities and urbanised areas. Dams of from 22,500 to 4.5 Ml are best built on any good site in country and parkland areas. Massive dams are appropriate hardly anywhere but the the rock-bermed or glaciated uplands of solid and forested hills, subject to low earthquake risk and then only for modest domestic (not dirty industrial) power generation.

TANKS

Cultural and historical precedent may determine how earth is moved and used, or even if it can be moved at all. Thus, an Australian, accustomed to a great variety of surface storage, is astounded that there are no

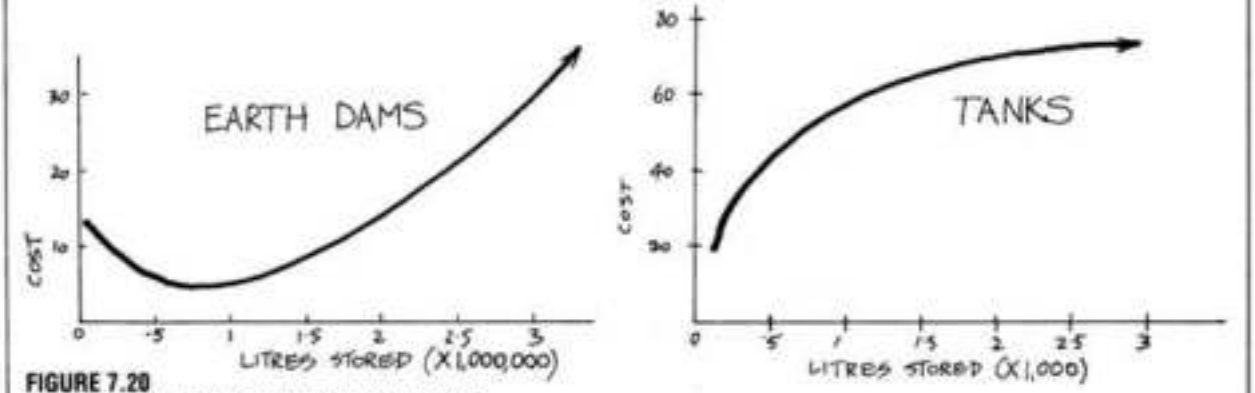


FIGURE 7.20
SCHEMATIC OF COSTS FOR DAMS AND TANKS
Storage tanks cost about 100 times the cost of dams for the same amount of water stored; cost-size schematics for both are given.

significant domestic rainwater tanks in Europe, the USA, or India (where clean drinking water is rare), that British, American, and Brazilian farmers rarely use multiple earth storages of water, and that expensive pipelines and bores are the preferred "alternative", even where local rainfall often exceeds local needs.

The simple forms for making concrete tanks cost a few hundred dollars, and may be used hundreds of times. About 22,500 l provides a family with all needed water (drinking, showers, cooking, modest garden water on trickle) for a year; tank water is renewed by rain at any time of year. Every roof, whether domestic or industrial, would fill many such tanks, and simple calculations (roof area x average rainfall in millimetres or inches) and conversion to litres or gallons gives the expected yield.

Granted that roof areas themselves can be contaminated by birds, dust, or industry, the first precaution is to reject the first flow-off of water, and use it on gardens or in swales. Two methods for doing this are shown in **Figure 7.21**.

As for the entry of insects, birds, or rodents to tanks (and this includes mosquitoes), a "U" pipe entry and exit, a sealed tank roof, and an overflow pipe emptying to a gravel-filled swale all effectively exclude these potential nuisances. If birds persistently perch on roof ridges, a few very fine wires or thread stretched along the ridge as a 10 cm (4 inch) high "fence" will discourage them.

Gutters on roofing can be cleaned out regularly, or "leaf-free" gutters or downpipes fitted (about 3 or 4 types are commercially manufactured; some systems are illustrated in **Figure 7.22**).

Given that most dust and leaves are removed, residual organics are usually harmless. These "fix" as an active biological velvety film on tank walls and bases. Taps or outlet pipes are normally fitted 15–20 cm (6–8 inches) above any tank floor to allow such a film to remain.

Finally, a net or bag of limestone, shell, or marble chips is suspended in the tank. This creates hard (alkaline) water, preventing heavy metal uptake from the water and decreasing the incidence of heart attacks in those using the tank. Washing and shower water can be soft (acid) but the water we drink is best made alkaline for the sake of health.

It makes far more sense to legislate for such tanks on every roof than to bring exotic water for miles to towns; it will also ensure that clean air regulations are better observed locally, that every house has a strategic water reserve, and that householders are conservative in their use of water.

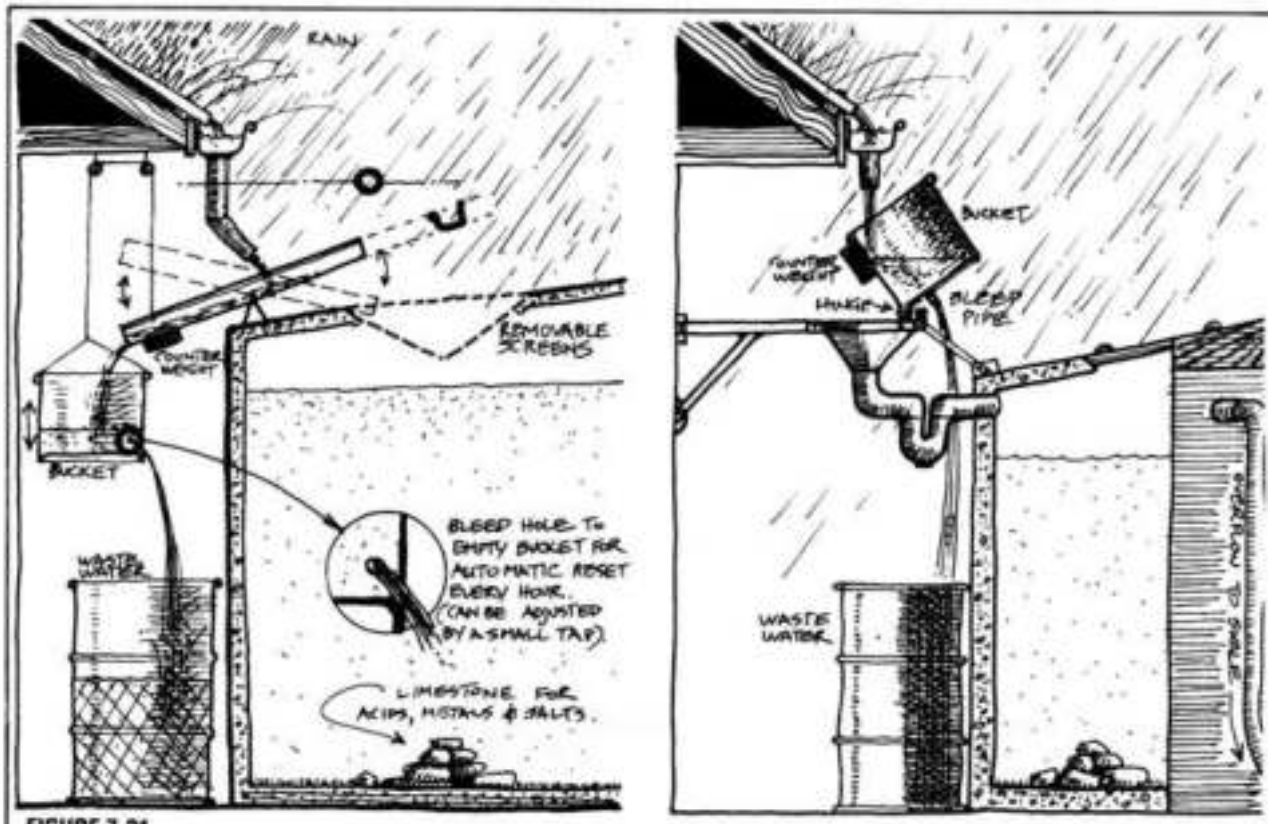


FIGURE 7.21
METHODS OF REJECTION OF FIRST WATER FLOW OFF A ROOF.
The first rains wash the roof, and are rejected; these systems automatically reset when empty.

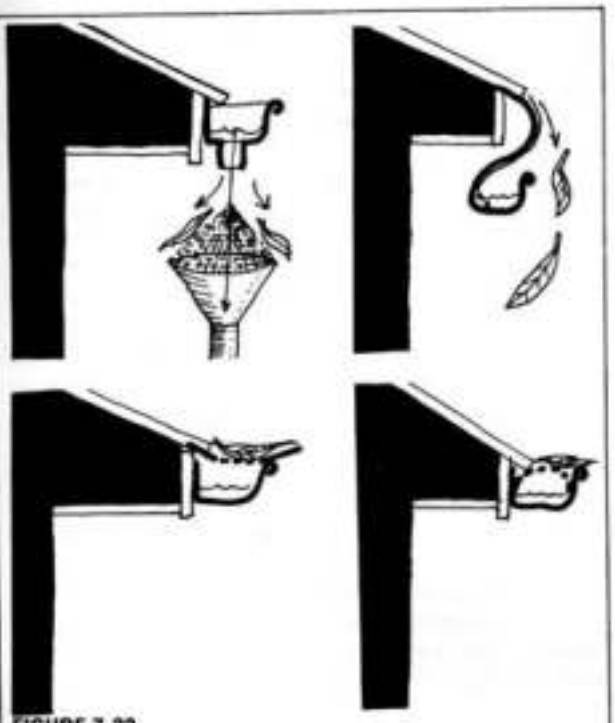


FIGURE 7.22
TYPES OF GUTTERS
Self-cleaning and leaf-free gutters or downpipes are useful where trees overhang a house; cone to pipe is also useful to collect water from rock domes.

SWALES

Swales are long, level excavations, which can vary greatly in width and treatment from small ridges in gardens, rock-piles across slope, or deliberately-excavated hollows in flatlands and low-slope landscapes (**Figure 7.23**).

Like soil conditioning or soil loosening systems, swales are intended to store water in the underlying soils or sediments. They are, simply, cross-flow dry channels or basins intended to totally intercept overland flow, to hold it for a few hours or days, and to let it infiltrate as GROUNDWATER RECHARGE into soils and tree root systems. *Trees* are the essential components of swale planting systems, or we risk soil waterlogging and a subsequent local rainfall deficit caused by lack of evapotranspiration of the stored water. Thus, tree planting *must* accompany swaling in arid areas.

Swales should ideally not exceed in width the total crown spread of the fringing trees planted to use the stored water absorbed into the swale sediments. Trees overshade and cool the soils of swales, further reducing the risk of evaporation and dissolved salt concnetration, or water loss. Although swales can also be grazed, few grasses can effectively remove the absorbed water to re-humidify airstreams.

Swales are therefore widely used in arid to sub-humid, even humid areas, on both fairly steep slopes and flatlands, and in both urban and rural areas. They are appropriate to road and other silty or contaminated run-off harvest (where the dust or tar oils washed off have no adverse effect on tree growth).

The essentials of swale construction are simple: they are all built on contour or dead level survey lines, and are neither intended nor permitted for water flow. Their function is just to *hold* water. Unlike dams, swale banks and bases are never compacted or sealed (although small tanks can be sunk in swale bases for watering livestock or trees). Conversely, the swale soils can be gravelled, ripped, or loosened to assist water infiltration. The swale depth and width can be varied to cope with the speed of infiltration locally, so that wider and shallower swales are made in sands, narrower and deeper swales in clay-fraction soils.

After an initial series of rains that soak in a metre or more of water, trees are seeded or planted on either bank or side slopes of the swales. This can take two wet periods. Thereafter, it takes about 3-5 years for tree belts to overshade the swale base, and to start humus accumulation from leaf tissue. (Humus will accumulate, however, by wash-down and wind movement from bare or uphill areas.)

Early in the life of an unplanted swale, water absorption can be slow, but the efficiency of absorption increases with age due to tree root and humus effects. As this happens, it is possible to admit water to swales from other areas, leading it in via DIVERSION DRAINS DRAINS. This "exotic" water from unused road or rock surfaces or overland flow can enable the planting of high-value trees of higher water demand or a new set of swales to be constructed.

Every sub-humid and arid townscape can, with great energy gain and much reduced cost for roading and water use, fit all roads and paved areas with swales, along which tree lines shade pavement and reduce heat oases while they produce fuel, mulch, and food products. Every roof tank overflow, and some greywater wastes can be led to swales (if boron detergents are not used).

Swales interpenetrating the suburban development of Village Homes in Davis, California (Michael Corbett, designer) accept all road and excess roof run-off, and

FIGURE 7.23
Swales on contour do not flow; they first stop and then infiltrate overland flow. Swales on hillsides are part of access or production systems.

support hundreds of productive trees in settlement. Water penetrated soils to 6 m (19 feet) deep after a few years of operation, and swales were self-shaded after 3–4 years of tree growth. In Hawaii and in central Australia, swales I have designed produced fast growth in trees in volcanic cinder and sandy soils.

Swales in Australian drylands have consistently grown larger and healthier water run-off fed trees than have open plantings. In arid areas, it is imperative to plant trees on swales, or we risk salt concentration and soil collapse downhill. All swales are therefore temporary events, as trees supplant their function; they are precursors to rehabilitation of normal forests in their region. Natural swales in humid forests (Tasmania) not only generate much larger trees and provide level access ways, but support a thick humus and specialised plants on the swale floors. Orchids, fungi, and ginseng do better in swales.

Most swales should be adjusted (by widening, gravelling, or ripping) to absorb or infiltrate all water caught in from 3 hours to 3 days. Fast absorption will not harm most tree species, although trees such as chestnuts and citrus may need to be planted on nearby spoil banks for adequate root drainage. I believe swales to be a valuable and greatly under-used earth form in most climates, including upland and plains areas of snow-drift in winter.

In summary, a swale is a large hollow or broad drain intended to first pool, then absorb all surplus water flow. Thus, the base is ripped, gravelled, sanded, loosened, or dressed with gypsum to allow water INFILTRATION. Trees ideally overshade the swale. The base can be uneven, vary in width, and treated differently depending on the soil type. The spoil is normally mounded downhill or (in flat areas) spread. Water enters from roads, roof areas, tank overflows, greywater systems, or diversion drains.

The distance between swales (the run-off or mulch-planted surface) can be from three to twenty times the average swale width (depending on rainfall). Given a useful swale base of 1–2 m (4–6 feet), the interswale space should be 3–18 m (12–60 feet). In the former case, rainfall would exceed 127 cm (50 inches), and in the latter it would be 25 cm (10 inches) or less. In humid areas, the interswale is fully planted with hardy or mulch-producing species. In very dry areas, it may be fairly bare and exist mainly to run water into swales.

Mulch blows into, can be carried to, or is grown and mown in swales. Fine dust and silts build up in swale bases, and domestic wastes can be buried here as a mulch-pit for hungry plants. The swale and its spoil-bank make a very sheltered starting place for plants on windy sites, and the lower slope swales can be planted mainly to *Casuarina* or leguminous trees to prevent upslope winds. Ridges should always have windbreak and condensation plants of hardy and useful species (*Casuarina*, *Acacia*, *Leucaena*, silky oak, pine, cypress). Windbreaks can occupy every sixth to tenth swale on sites where wind is a limiting factor. It is better to plant on the downslope side to allow mulch collection in the swale base for use elsewhere.

Swale sections can be over-deepened, so that although the swale lip is surveyed level, its floor may rise and fall. Deepening is most effective in clay-fraction soils, and may result in shallow ponds for water-needy crop. Widening is most effective in sand or volcanic-fraction soils, and readily admits water to the ground table.

Two other pit systems are useful in swales: one mulch and manure-filled for heavy nutrient feeders (yams, bananas, etc.) and the other to hold oil drums, plastic liners, or tyre ponds as a sealed water reserve for watering young plants. These can be planted with lotus, kangkong, watercress, Chinese water chestnut, or like crop.

Keeping the swale width to the tractor, donkey cart, foot track or wheelbarrow access width that one has planned, sections can be widened at regular intervals to take assemblies of plants, to dig ponds or mulch pits, and to plant trees of higher water need. This leaves access open and enables many assemblies, species, and constructs to be built along the swale as need dictates.

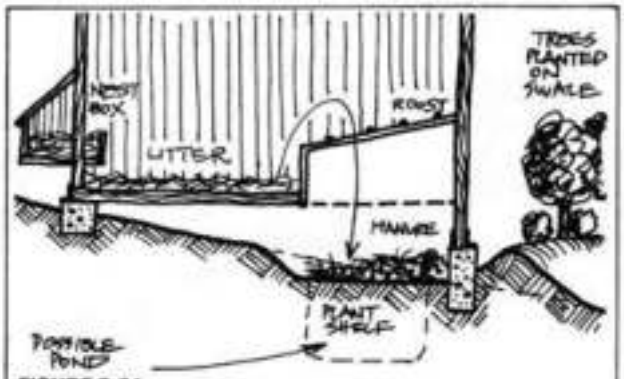


FIGURE 7.24
CHICKEN HOUSE OVER SWALE
Manures from animals placed in swales, or canals feeding wet terraces, provide nutrients via water transport for swale crops, and associated trees.

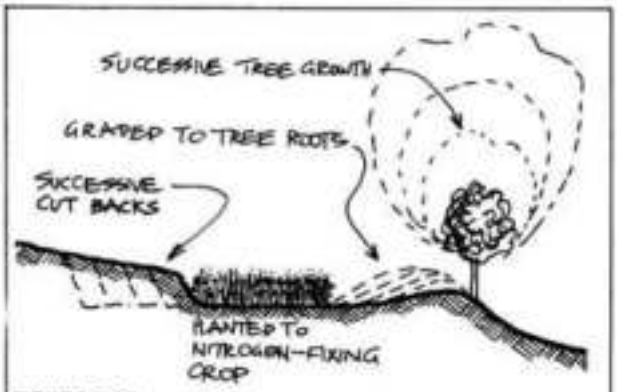


FIGURE 7.25
REGRADING SWALES TO REMOVE SILT
Silt from swales is graded out or shovelled up to tree lines on downslope side. Swales can be widened over time to create a terrace.

DIVERSON BANKS AND DRAINS

Diversion drains are gently sloping drains used to lead water away from valleys and streams and into storages and irrigation systems, or into sand beds or swales for absorption. If low earth-walls are raised across the flow channels of larger diversion drains, these then act as a series of mini-swales for specific tree sites, while surplus water flows on to storages. Diversion drains differ from swales in that they are built to *flow* after rain (from overland flow or from feeder streams). They are the normal and essential connectors of dam series built on the Keyline systems, so that the overflow of one dam enters the feeder channel of the next.

Such diversion systems need careful planning and survey, with drain bases sloping as little as 1:6000 in fine sands. Dam crests and irrigation drains need equally careful placement. Even without a stream intake, diversion drains will gather water from overland flow in as little as 1-1.5 cm (1/2 inch) of rain over 24 hours, so that isolated dams are normally fitted with diversion drains even in quite dry country. Diversion drains can be led to broad level swales in drylands, or made of simple concrete or stone walls across solid rock faces. In the Canary Islands, these gather rock run-off which is led to underground cave storages or large open tanks. Simple sliding gates across or in the downhill banks of such drains allow controlled flow, controlled irrigation, and (in floods) by-passing of dams.

Spill gates can be FIXED (concrete slide holders and aprons) or MOVEABLE (plastic sheets weighted with a chain sewn into the foot, and supported across the drain by a light pipe sleeved into the top). These latter are called "flags" (**Figure 7.27**).

Slide gates can open on to ridge lines, and water then spreads downhill, while plastic flags can be placed and taken up at any point along a drain. This enables one or two people to water 200-240 ha (400-600 acres) in a morning. It is also an effective wildfire control system in forested areas. For sophisticated wildfire or irrigation control, both slide gates and dam-base gate valves can be remotely operated, by radio signal and storage batteries or buried electrical conduits, to power small motors or hydraulic slides. A complete wildfire control can be achieved by dams and sheet irrigation, and using infrared sensers and automatic spill-gates. Such systems remove the risk for fire-fighters, and allow forests to regenerate in semi-arid areas.

Interceptor drains. These drains-or rather, sealed interceptors—act in the opposite tense to diversion drains. These earthworks are specifically designed (by Harry Whittington of West Australia) to prevent overland waterflow and waterlogging, which has the effect of collapsing the dryland valley or downslope soils of a desert soil catena. Thus, they ideally totally intercept overland flow, and direct it to streams or valley run-offs. They can be cross-slope as are swales, but they differ from diversion drains and swales in that their construction always involves the ramming (by bulldozer blade) of subsoil layers hard against the downhill bank. This effectively prevents or impedes water seepage through the downhill wall of the interceptor bank. Moreover, they are always 1.5-2.5 m (5-8') deep, carefully spaced, and effectively stop not only overland flow but also salt water seepages in shallow sand seams. In effect, they isolate large blocks of soil from waterlogging and salt seepage.

After this preparation, trees can be planted in previously desertified soils.

Where deeper sand seams carrying salty water are located, these can be trenched out and stopped with a vertical plastic barrier, backed by compacted clay on the uphill side.

Made to flow at 1:600 to 1:1500 cross-slope interceptors effectively cut up incipient or degraded croplands subject to desertification into blocks of 100 m (330 feet) to a maximum of 300 m (985 feet) wide, isolating each block from flooding and the salty "cascade" flow from uphill. Surplus water is carried off in streams. Interceptor banks also cut off seepage from salt lakes, and can divert early (salted) overland flow around saltpans, letting later fresh floodwater fill the pans or shallow lakes.

Spreader drains or banks are intended to spill a thin sheet of surplus (overflow) water down a broad grassy slope, either for irrigation or (in deserts) to prevent channel scour and gullying. They are normally made to

FIGURE 7.26
DIVERSION DRAINS
Unlike swales, these run from streams to dams, or collect overland flow and convey it to storages. They are part of any rainwater harvesting system.

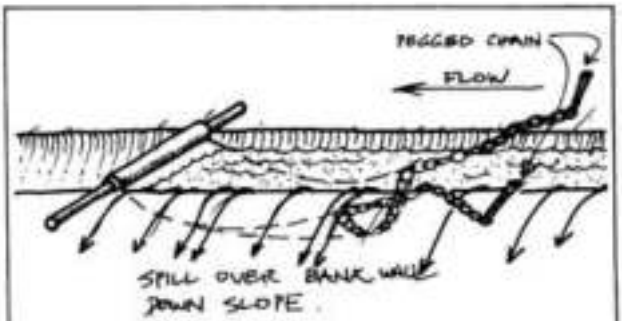


FIGURE 7.27
FLAG
A plastic sheet, one end supported by the channel banks, the other wighted by a chain, forms a temporary dam, causing the channel to flood out and irrigate land downhill.

take any overflow from swales and dams, and may be tens or hundreds of metres long. Spreader banks have the lower side dead level, and compacted or even concreted. Water enters from a dam, swale, or minor stream and leaves as a thin sheet flow downslope. Spoil is piled *uphill*, preferably in mounds, or removed to allow downhill sheet flow to enter the spreader ditch (**Figure 7.28**).

For irrigation areas of flatlands, the bank is often pierced by a series of dead-level pipe outlets, each feeding an irrigation bay (itself planed flat), to which water is confined by low side walls (STEERING BANKS). At the lower end of that bay, a TAIL DRAIN—a surplus water drain—leads off excess water to a stream or secondary storage dam. In such cases, the uphill or primary feeder drain is called the HEAD RACE, and has cross-slides that block flow; this causes the levelled pipes to flood out into the bays. Sometimes the pipes are replaced with level concrete sills and in old-established spreader banks, the whole of the lower lip may be concreted to give a permanent level spill immune to breakage by cattle or vehicles.

Spoil lines uphill from spreader banks are best piled or at least broken by frequent openings to allow downhill overland flow to enter the drain without carrying silt loads.

In *any* landscape, a subtle and well-planned combination of dams, drains, spreader banks, swales, and appropriate pipes, gate-valves, spill gates, flags, or culverts will harvest, store, and use surplus flood or overland flow waters. These are used to flush out salts from soils, spread water evenly over crop, put out wildfires, and modestly irrigate land. It is a matter of first deciding on, then surveying any or all these systems, and above all of considering the long-term effects on the immediate landscape and the soils.

All earthworks can be regarded as REHABILITIVE and remedial if they replace salted and eroded lands with perennial browse or forests. They can be seen as DAMAGING and exploitative if used to irrigate high water-demand crop (like lucerne/alfalfa) in drylands, to cut off flow to dry areas, or to run water for unessential uses to large urban centres devoted to lawns and car washes.

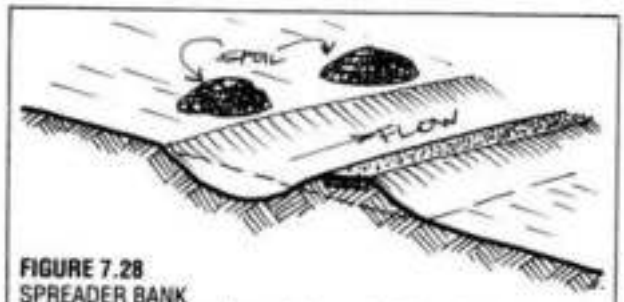
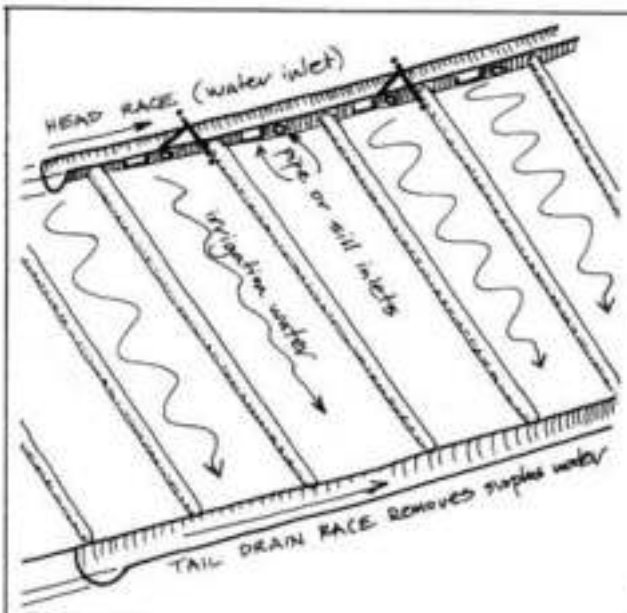


FIGURE 7.28
SPREADER BANK
Water overflow is evenly spread by carefully levelling the downhill bank as a sill.

7.4
REDUCTION OF WATER USED IN SEWAGE SYSTEMS

In cities, water is chlorinated and fed back into the system, sometimes mixed with seawater or "treated" waste water to give it that city taste so typical of, e.g. Las Palmas in the Canary Islands. Surplus sewage,



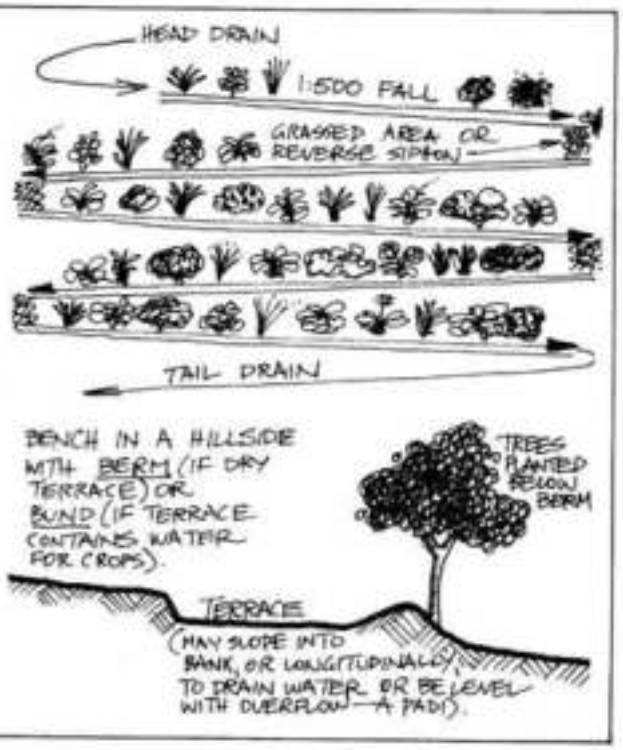


FIGURE 7.29
SCHEMATIC OF IRRIGATION BAYS
Layout for channel irrigation; bays should not exceed 100 m long or water can be wasted to evaporation. See also Figure 7.30.

untreated, is often passed to sea, with bacteria, viruses, and parasites intact for bathers to wallow in.

All of this arises from the frequent, wasteful, and unneccessary flushing of toilets by those of us living in the effluent society. In Sweden, it is compulsory to use dry toilets in remote, unsewered, or unsuitable areas. In the USA, UK, and Australia, one has to fight hard to get permission to use these, as it is the vested interest of industry and town clerks to supply and charge for sewerage systems.

However, *no* clean water need be used to flush toilets if there is a diversion from a hand-basin to the toilet tank. In Australia at least, hand-basins moulded in to toilet flush tanks are available (**Figure 7.31**). It is essential to use low-flush toilet bowls with such systems, as they otherwise flush incompletely, and build up heavy pathogenic bacteria populations.

This is a simple solution to 40% of domestic water misuse, and encourages hand cleanliness rather than the false cleanliness/tidiness of toilet flushing for its own sake.

Dry toilets are not always appropriate, except in cities and other water-critical areas. They are unnecessary on farms or in well-drained soils, or wherever sewage is used to produce methane by anaerobic digestion in tanks. In fact, dry toilets reduce the potential uses of sewage, just as compost is a reduction in the potential use of mulch. Dry toilets are quite specifically useful where:

- No methane system is used;
- Sewage is not used in the production of plants;
- Soils do not suit septic tanks; and
- Cities have critical water supply problems.

In using wastewater from kitchen, bathroom, and laundry, it is wise to establish just what chemicals, and at what concentration, are being released to gardens and soils (or waterways). A typical analysis of a powdered detergent or a soap could include: sodium or potassium salts or polysulphates, silicates, sulphates or bicarbonates, borates, residual biocides (concentrated in animal fats) e.g. DDT, Dieldren, Hexachlor from dairy cattle, additives such as resins (hardeners), scents, dyes, and brighteners, faecal bacteria and viral or worm pathogens from washing (in showers or via clothes). This data is from Kevin Handreck, CSIRO Division of Soils, (*pers. comm.* 1979).

Of these, most can be dealt with by soil organisms, but if the basic water supply is already saline, sodium and potassium salts can add to this and deflocculate soil clays or damage leaves (at >1,000 ppm), while

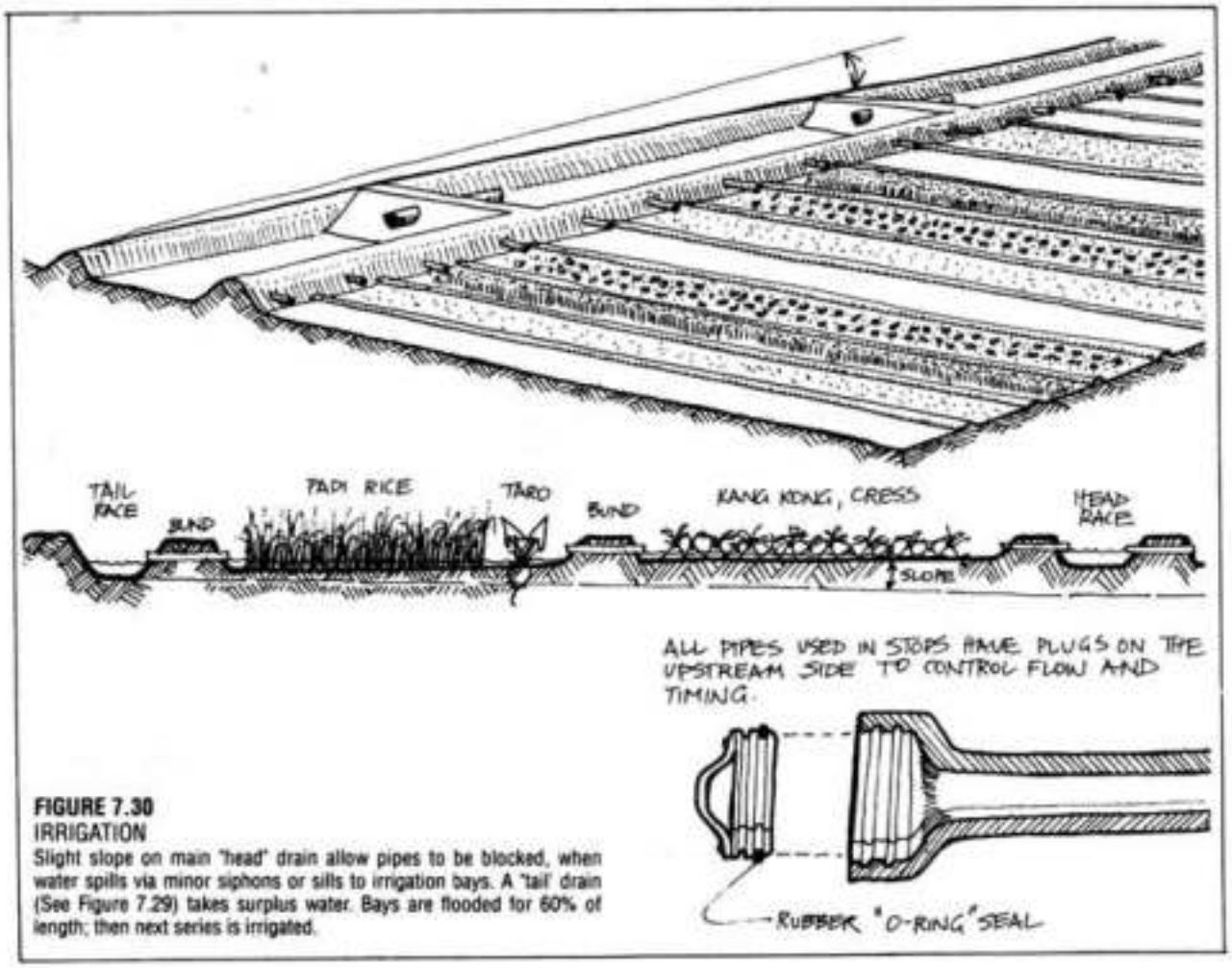


FIGURE 7.30
IRRIGATION
Slight slope on main "head" drain allow pipes to be blocked, when water spills via minor siphons or sills to irrigation bays. A "tail" drain (See Figure 7.29) takes surplus water. Bays are flooded for 60% of length; then next series is irrigated.

borates at >0.5 ppm can create excessive boron concentration in soils, and above 1.0 ppm is harmful to soil life and plants. Thus, we need to use plain soaps on crop if possible, and route more complex pollutants to tree systems (well-monitored), as woody perennials can cope better than garden vegetables, and allow more time for decomposition of long-term pollutants.

In critical areas, and especially in arid or delicate environments, we may need to create both special soaps (unpolluted oils, potash or sodium) and plant special crops which remove excesses (many water plants) before passing on greywater to the soils and streams. There is no blanket policy, only specific cases where we can expect to gain yield and also clean up water *if* we know the composition of soils and soaps.

7.5
THE PURIFICATION OF POLLUTED WATERS

The only long-term insurance of good water supply to a settlement is by rigorous control of a forested catchment, including a total ban on biocides and metallic processing. As there are few such clean areas left in the world, house roof tanks must do for the foreseeable future. The 30–40 additives commonly introduced into water supplies are often pollutants in themselves to that increasingly sensitive sector of society developing allergies to any type of modern pollutant. These additives represent the end point of the technological fix: pollution is "fixed" by further pollution.

Herein, I will stress the *biological* treatment of common contaminants; the only water safe for us is also safe for other living things. For millenia we have existed on water supplies containing healthy plants and fish, and if we keep natural waters free of faecal and industrial contaminants, we can continue to do so. This is not so much a matter of water treatment, as the prevention of polluting activities.

However, for many existing cities and towns, sewage and stormwater supplies must continue to represent a "disposal problem". As the wastewaters of upstream settlements are the drinking waters of downstream areas, our duty is to release from any settlement only water of sufficiently good quality to be safely useable by others.

The problem contaminants most likely to affect drinking water are:

- TURBIDITY: silt and fine particles suspended in the water.
- BACTERIAL or ORGANIC pollution from sewage, and as decay products, e. g. *E. coli*, disease organisms and viral or protozoan pathogens, parasitic worm eggs and so on.
- METALLIC POLLUTANTS such as chromium, cadmium, lead, mercury.
- BIOCIDES, e.g. Aldrin; Dieldrin; 2, 4-D; 2, 4, 5-T; dioxin; PCB, etc (organophosphates, halogenated hydrocarbons).
- EXCESSIVE FERTILISER, especially nitrogenous compounds, phosphates, sodium and potassium salts.
- ACIDS or acid-forming compounds (a pH less than 5.5 increases metallic pollution).

Many of these factors interact. Acid rain dissolves out of rocks and soil poisonous forms of aluminium, mercury, lead, cadmium, and selenium, or other metals such as copper, nickel, and lead from drinking tanks, tea urns, and hot water tanks. Organisms may convert inorganic mercury to organic forms (as happened in Minamata, Japan) which are readily absorbed by the body. Sewage in water aids such conversion to biologically active metals.

Mercuric fungicide dressing on seeds has not only caused direct poisoning of people who have eaten the seed, but also poisons the soil. Excessive artificial fertiliser increases aquatic biological activity, which results in further uptake of metals in acidic waters, and so on. In biocides, Aldrin prevents DDT being excreted; the combination is deadly (one can buy this mix in Australia and the third world, or farmers will achieve it by successive sprays. DDT is a stable residual poison co-distilling with water, so that distillation will not help). An additional threat to public health comes from

FIGURE 7.31
HANDBASIN FLUSH TOILETS
Water use in handbasins about equals that for toilets, so in effect no extra, or clean, water is used in toilets; holding tank can contain several flushes and excess drains to toilet.

the many miles of asbestos pipe used in public water supply systems; there is a definite threat of both stomach and bladder cancer from asbestos particles in water supplies.

Ferric and aluminium sulphate, salt, and lime are all added to water to cause fine particles to flocculate and settle out as clay. In England, as pH increases due to acid rain, and in fact wherever acid rain occurs, aluminium goes into solution, and with lead and cadmium may bind to protein in vegetables and meat, especially those boiled or steamed. Even if salt is added to cooking water to decrease these effects, levels far exceeding the 30 ug/l allowable for those with kidney problems are experienced. Cooking may increase the water content of metals by a factor of 5 due to this protein binding, and as well make the metals so bound easy to assimilate in the body. Cooking acidic substances in aluminium pots simply worsens the problem. Aluminium from *acidic* rain leaching is now thought to be a major cause of tree and lake death. Ferric sulphate may be safer to use, especially if water is initially or reasonably alkaline. Obviously, these effects need more study and any inorganic salt or metallic salt deserves very cautious use.

WATER TREATMENTS COMMONLY USED

- AERATION (oxygenation) by wind, mechanical aeration, or by increasing turbulence in flow. Aeration is also achieved by trickle columns and vegetation, phytoplankton, or injected air.
- SETTLING: spreading flow in still-water ponds or rush beds to allow particles to fall out, filter out, or flocculate.
- SKIMMING and SIEVING to remove large organic particles.
- FILTRATION via sand beds or charcoal-fibre columns, soils, the roots of aquatic plants.
- COAGULATION or FLOCCULATION by using chemical additives (lime, salt, ferric sulphates) or organic (bacterial) gels.
- BIOLOGICAL REMOVAL by bacteria, phytoplankton, and higher plants.
- pH ADJUSTMENT by adding calcium (as lime) or sulphur compounds as needed.

Filtration

A classical and widely-used filter is sand. Britain and many cities use sand filters followed by chlorination to clean settled and treated raw sewage water sedimentation. Filtration by slow drip through 1.2 m (4 feet) of sand (top half fine, bottom half coarse) is used even in temporary rural camps for water filtration. For cities, fixed sand beds with brick bases are used, the top 1 cm (0.5 inch) or so of sand periodically swept, removed, and dried or roasted to remove organic particles before the sand is returned.

Activated charcoal, often from bones or plants such as willow or coconut husks, is also used as a fine filter in homes and where purity is of the essence. Fine dripstone (fine-pored stone) is used in water cleaners and coolers to supply cool water in homes.

Trickle filters through sand and gravel columns actually feed resident bacteria which remove the surplus nutrient. In less polluted environments, a similar task is carried out by freshwater mussels.

Carbon is essential for the removal of nitrogen or for its conversion by bacteria to the gross composition $C_5H_7NO_2$, and it is generally added as carbohydrate, which can be liquids such as methanol, ethanol, or acetic acids, many or all of them derived from plant residues. This is a bit like "adding a little wine to the water" to encourage the bacteria to work. Surplus nitrogen is released by bacteria to air. Unless bacteria are encouraged and allowed to work, nitrates move easily through sub-soils in which no plants or bacteria can live, and can emerge in wells and streams.

In ponds intended for drinking, light exclusion and surface water stabilisation reduce both turbidity, and thus algae, to a minimal quantity. The stabilisation of banks by grasses and clump plants helps considerably. Pond surface stabilisers are water lilies, *Azolla*, and water hyacinth. Bank stabilisers are *Juncus*, *Scirpus*, various grasses and clovers, *Phyla nodosa (Lippia)*, and bamboo and pampas grass clumps.

With turbidity much reduced, filtration loads are likewise reduced. Liming will further reduce turbidity if pH is 6.0 or less. This is as simple as placing crushed marble or limestone as a layer in a tank, or casting burnt lime over a pond before filling and (if necessary) after filling. Crushed shells or even whole shells in water tanks and ponds have the same effect. Lime flocculates particles, causing them to settle out of the water.

There are several techniques for filtration, some or all of which can be used in series. First, trickle filters of

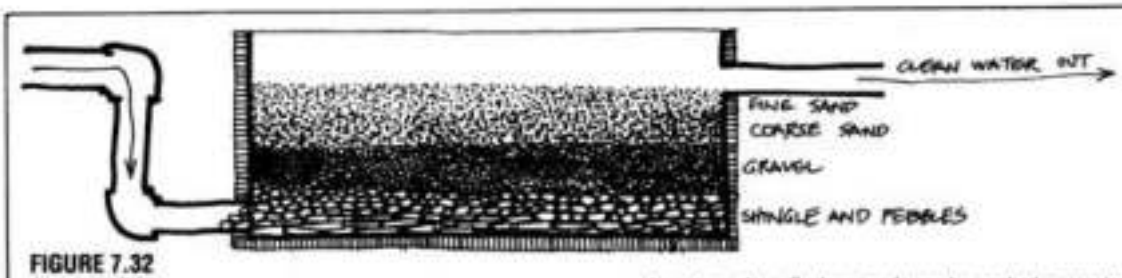


FIGURE 7.32
SAND FILTER
A basic cleanser for microbiological pollution; flow is upwards from base to surface. Surface sands can be washed or roasted for cleaning as needed usually every 12-18 months.

loose pebbles (2.5–10 cm) can be used to form an active bacterial surface layer to absorb nutrients, then a sand filter can be used to absorb bacterial pollution. Water rising through a sand column is fairly clear.

The shells of water mussels can be substituted for pebbles, and the living mussels in the pond or tank not only monitor acidity (dying at pH 5.5 or thereabouts) but filter, individually, up to 100 l/day, digesting bacteria and depositing wastes in the mud base. Mussels and crayfish are not only susceptible to low pH but are also very sensitive to biocides such as Dieldrin, so that their living presence is a constant monitor on life-threatening pollution.

Water, now fairly clean, can be passed through a bed of watercress to remove dyes and nitrates, and the cress cut and fed to animals or dried and burnt to ash. As a final process, the water can be trickled through a column (a concrete pipe on end) of active carbon (10%) and silicon dioxide (90%), otherwise known as burnt rice, oat, or wheat husks.

The results should be clear, sparkling, safe water to drink. No machinery is involved if the system is laid out downslope to permit gravity flow

Lime (freshly burnt) is often used to remove phosphorus and sludges in a primary settling lagoon, and then water is passed to a trickle tower for ammonia removal by bacteria. In towers, of course, the bacteria are not further consumed, but in open lagoons a normal food cycle takes place, with myriad insect larvae and filter-feeders removing bacteria, and frogs, fish, and waterfowl eating the insects. In small towns, the water can be passed from filter towers to sewage lagoons, which in fact may become rich waterfowl and forest sanctuaries. It can then be routed to field crop such as forest, pasture, and to crops to be distilled or burnt, which does not directly re-enter the food chain.

Sewage Treatment Using Natural Processes

Raw sewage is a mixture of nutrients, elements, heavy metals, and carbon compounds; it also contains quite dangerous levels of bacteria, viruses, and intestinal worm eggs. A typical analysis is given in **Table 7.3**. Units are as mg/l; samples are of 30% industrial, 60% domestic wastes at Werribee, Victoria, Australia (Hussainey, Melbourne Metropolitan Water Board Pubs., 1978).

Melbourne is a city of 2,700,000 people and its sewage lagoons cover 1,500 ha (3,700 a.) Thus, there is one hectare of pond (in total) to 1,800 inhabitants (or about 1 a. for 820 people). In the ponds, raw sewage is run into about 724 ha (1,790 a.), where it settles out. Each of these primary settling ponds rarely exceed 7 ha (17 a.) in area, so about 100 ponds receive and settle all raw sewage. Scaled down, this means 1 ha (2.5 a.) of settling pond to 3,800 people.

All these settling ponds are anaerobic, and give off biogas, a mixture of methane (CH_4), carbon dioxide (CO_2) and ammonia gas (NH_3), with traces of nitrous sulphide or marsh gas (NO_2). Biogas is, of course, a useful fuel gas for engines, or a cooking gas for homes. However, it is also a gaseous component of the atmosphere that is creating the "greenhouse effect" and thus should be used, not released to air.

The next set of ponds is faculative (as described below) and the last set aerobic. These, in total, slightly exceed the area of the anaerobic or settling ponds. Most

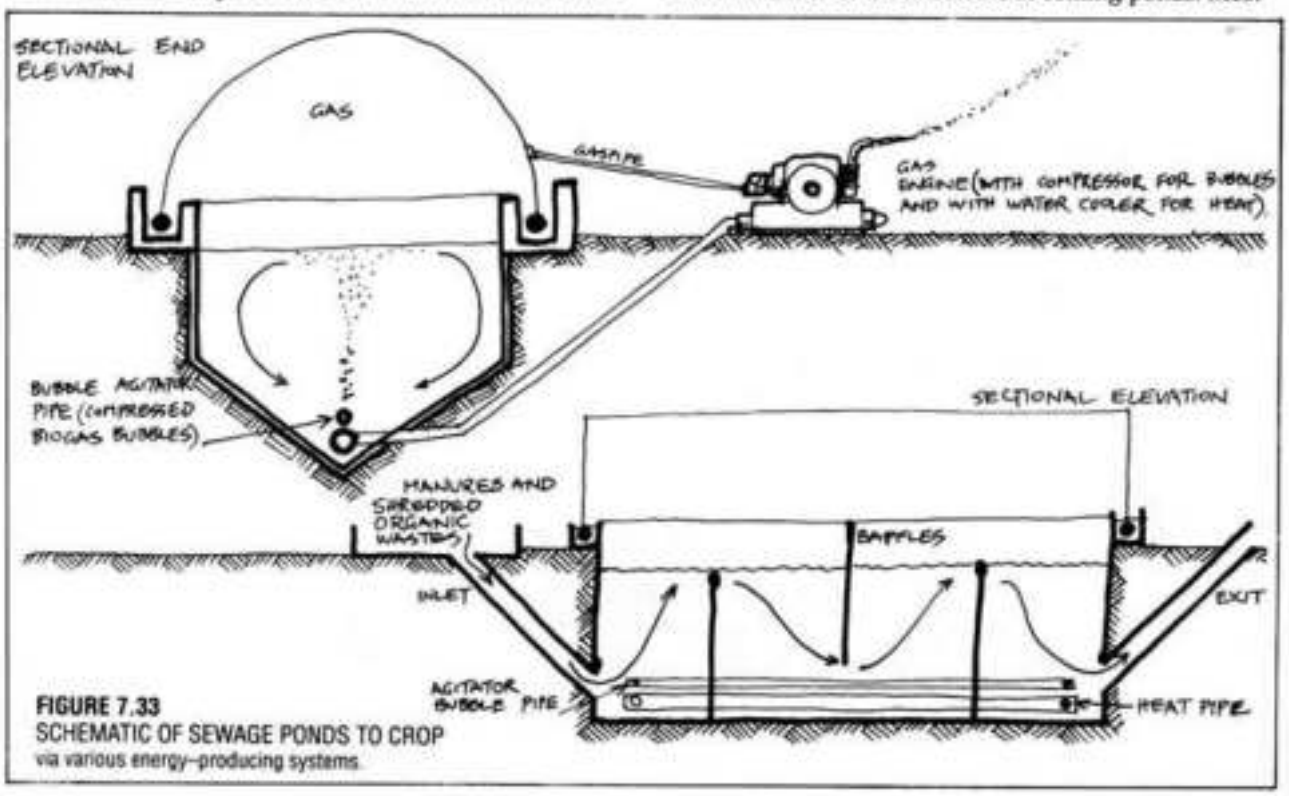


FIGURE 7.33
SCHEMATIC OF SEWAGE PONDS TO CROP
via various energy-producing systems.

are 7–10 ha (17–25 a.) in size.

Ponds can be built (as they are at Werribee) to fall by gravity flow from one to the other. In the first series of (settling) ponds, the sludge creates an ANAEROBIC condition. In the next series of ponds, some sludge passes over and becomes anaerobic at the pond base, while the surface water in the pond (due to wind or algae) is AEROBIC (oxygen–producing). The final series of ponds is totally aerobic. Thus, from intake to outlet, we have the terms:

- ANAEROBIC, or methane–producing (digester ponds).
- FACULATIVE, or part methane, part oxygen–producing.
- AEROBIC, or oxygen–producing ponds.

Ponds at Werribee are only an average of 1 m (3 feet) deep. Deeper, and the sludge breakdown and wind aeration effects are less.

One thousand townspeople and their associated industries therefore need as little as 270 metres square of settling pond 1 m deep. We could, in fact, achieve this as a "long" pond (or series of ponds) 3 m wide x 90 m long, or 3 side–by–side ponds 30 m long and 3 m wide, or any such combination. We can halve the length by doubling the depth to 2 m, and get a pond 3 m x 45 m long; or treble the depth and condense the pond area to a 3 m deep x 3 m wide x 30 m long "digester" pond.

Such a long and narrow pond is easily made *totally* anaerobic by fitting water seals and a weighted cover over the top (which can be of plastic, metal, butyl rubber, or fibreglass). Note that for these deeper digester ponds we would need to *artificially agitate* the sludge (using pumped biogas to stir it), otherwise it settles and becomes inactive (**Figure 7.33**).

Sludge is "active" only in contact with the semi–liquid inputs of the sewer; thus when we stir up the sludge, the better we break down the sewage to biogas. Another (critical) benefit in sealed and agitated digesters is that no scum forms on the pond surface, which can slow the breakdown process further and cause an acid condition.

Of the total dissolved solids (or influent) entering such a digester, over a period of 20 days and with a temperature of 25–30°C (77–86°F), a very high percentage of the mass is transferred into methane; a small proportion is also passed on to other ponds, some as living cells (bacteria or algae). As methane forms, so the oxygen demand of the effluent falls; about a cubic metre of methane generated removes about 2.89 kg of solids, reducing biological oxygen demand (B.O.D.) to that extent.

In the digester, 90–94% of worm eggs are destroyed, as are many harmful bacteria. Useful energy is generated, and can be used at that location to run a motor for electricity, or to compress gas for cooking or machinery (or both, as power demands vary). This motor both supplies the heat for the digester process, and also compresses the gas for digester agitation, and for energy supply.

What happens in the digester? The marsh gas produced, hydrogen sulphide (H_2S), combines with any soluble forms of heavy metals to produce sulphides, which are insoluble in water above pH 7. A little lime can also achieve or assist this result.

TABLE 7.3
ANALYSIS OF RAW SEWAGE

ANALYSIS	MG/L
SOLIDS	
Total dissolved solids	1,200 (TDS)
Bilogical oxygen demand	170 – 570 (BOD)
Suspended solids	160 – 620
Volatile liquids	180 – 510
Total organic carbon	110 – 360
Anionic surfactants	1.0 – 3.6
NUTRIENTS	
Nitrite as **N**	0.05
Nitrate as **N**	0.1 – 0.3
Ammonia as **N**	5 – 32
Organic **N**	7 - 24
Total N	9 – 56.2
Orthophosphate as **P**	1.5 – 6.0
Total phosphorus	1.5 – 9.0
METALS	
Copper	0.09 – 0.35
Chromium	0.25 – 0.4
Cadmium	0.015
Iron	1.6 – 3.3
Lead	0.3 – 0.4
Mercury	0.003
Nickel	0.15
Zinc	0.4 – 0.8
COLOUR	
(as Pt/Cp Units)	100 – 300
pH	6.9 ± 2.0 (near neutral)

Of the total sewage input, from 45 – 60 % of the volume builds up as sludge in settling ponds.

Hussainy found that the following result occurred in anaerobic ponds (see original metal content, **Table 7.3**):

- Copper is removed 97%, of which 78% was removed anaerobically.
- Cadmium is removed 70%, all anaerobically.
- Zinc is removed 97%, 83% removed anaerobically.
- Nickel is removed 65%, 47% aerobically.
- Lead is removed 95%, 90% anaerobically.
- Chromium is removed 87%, 47% anaerobically.
- Iron is removed 85%, 47% anaerobically. (Up to 92% of iron was removed by the faculative pond process, but some iron was partly dissolved in the aerobic pond again, to give the 85% quoted.)

The results are that solids, metals, and disease organisms are very greatly reduced by the first (anaerobic) treatment of sewage. What, in fact, happens to the sludge? It becomes methane. In an anaerobic shallow pond, or a deeper agitated pond, the more sludge, the more active the pond. Thus, *a self–regulated equilibrium condition soon establishes* where input balances gas output. If we remove the sludge, the process slows down or stops. This is a clear case of

leaving well alone, of active sludge becoming its own solution; rather than being a problem, it generates a resource (methane).

In the anaerobic pond, there are few algae, but there are some specialised sulphur-loving bacteria of the genera *Thiosporallum*, *Chromatium*, and *Rhodopseudomonas*. These (in open ponds) may appear pink and give this colour to the ponds. They use hydrogen sulphide as a hydrogen source for carbon assimilation; their by-product is therefore elemental sulphur (S), which binds to the metals present. About 1.8–2.0 mg/l of heavy metals are precipitated as sulphides at 1.0 mg/l of elemental sulphur. The bacteria help in this process.

Passing now to the faculative ponds, we see both the life forms and the biochemical processes change. Here, algae blooms; four almost universal sewage lagoon algae are forms of *Euglena*, *Chlamydomonas*, *Chlorella*, and *Scenedesmus*. The total algal and bacterial flora (of many species) are called PHYTOPLANKTON (plant plankton).

Bacteria are also phytoplankton, the bacteria benefiting from the oxygen produced by the algae. Typical bacteria in the open ponds are *Cyclotella*, *Pinnularia*, *Hypnodinium*, and *Rhodomonas*. The sulphur-loving bacteria may linger on in the sludge base of faculative ponds, but are absent or rare in aerobic ponds. The algae fix carbon, releasing oxygen to the bacteria.

With such a rich algal food available, ZOOPLANKTON now thrive: most are rotifers (*Brachionus*, *Trichocerca*, *Haxarthra*, *Filinia*); cladocerans (*Daphnia*, *Moina*, *Chydorus*, *Pleuroxus*); copepods (*Mesocyclops*); and ostracods (*Candanocypris*, *Cypridopsis*). Among these are protozoan flagellates, ciliates, and some nematodes. On this rich fauna, waterfowl and fish can flourish.

Some of the remaining metals are gathered by the zooplankton. In mg/l (dry weight) they contain 1,200 of iron, 152 of zinc, 37 parts of copper, 28 of chromium, 12.2 of nickel, 10.3 of lead, 1.7 of cadmium—almost a mine in themselves. Harvested, both zooplankton and algae can be added to foodstuffs for poultry. Pumped into forests or fields, they provide manures and trace elements for growth. In rich algal growth, blooms of such forms as *Daphnia* can be as dense as 100 mg/l.

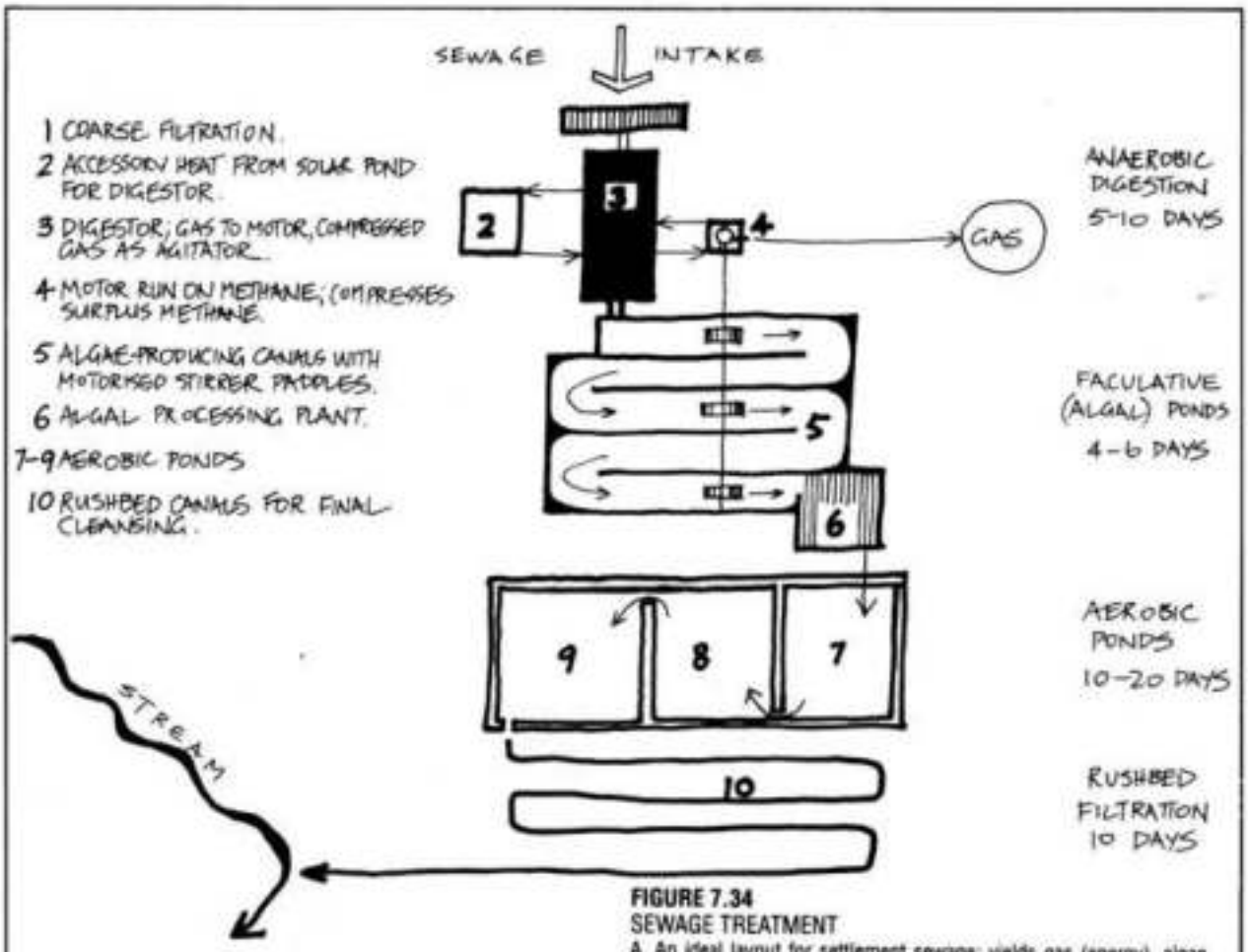


FIGURE 7.34
SEWAGE TREATMENT
A. An ideal layout for settlement sewage; yields gas (energy), algae, fish, wildlife, crop, and thoroughly cleanses water for release to streams. See notes 1–10 on illustration.

These zooplankton masses are self-controlled by eating out their algal foods, and can in their turn be eaten by fish in subsequent pond systems.

Of the pH, which varies both long-term and in 24-hour cycles, it too increases from stage to stage: anaerobic pH 6.2–7.8; faculative pH 7.5–8.2; and aerobic pH 7.5–8.5. In clogged algal waters at night, it may climb higher.

At the aerobic stage, the B.O.D. is only 3–57 mg/l, due mainly to nitrogenous compounds, the suspended solids 32–50 mg/l (now mainly algae and zooplankton). About 80% of these have been removed and incorporated into life forms, and the metal levels are now down to World Health Organisation standards. The water can be used for irrigation, or filtered via rush beds to streams.

Seasonal changes are noticeable. In winter, more hydrogen sulphide is given off by anaerobic ponds (8–15 mg/l compared with summer's 2–5 mg/l), and winds may contribute more to oxygen levels in open ponds than do algae; in winter too, more ammonia (NH_3) is released to the atmosphere.

Summer sees residues oxidised to nitrates. The oxygen being provided more by algae than by wind, less hydrogen sulphide is given off, and there are greater ranges of temperature. In winter (10–15°C), decomposition slows and sludge levels build up, only to be more actively converted in the summer warmth of 18–22°C (64–72°F). B.O.D. is 495 kg/ha/day in winter, 1034 kg/ha/day in summer (at optimum pond conditions), showing that activity almost doubles as temperature increases. Consequently, almost twice as much gas as methane is given off in summer (or in *heated* digesters). In winter, the cooling water of methane-powered engines can provide the essential heat to digesters via a closed loop pipe.

In all, this simple lagoon series produces a very beneficial effluent from heavily-polluted influent. However, there are even more sophisticated biological treatments omitted—those effected by the higher plants. As outlined below, some genera of rushes, sedges, and floating plants can greatly assist with removal of heavy metals and human pathogens, but perhaps more importantly, some plants can also break down halogenated (chlorine, bromine) hydrocarbons synthesised as herbicides and pesticides.

Israel (*New Scientist*, 22 Feb '79) leads sewage waters to long canalised ponds, agitated by slowly-revolving paddle-wheel aerators. Ponds are 0.5 m or less deep. Under bright sunlight (or under glasshouse covers) dense algal mats form, and these are broken up by the addition of aluminium sulphate (a pollutant!), skimmed off, drained, centrifuged, steam-dried, and fed to either carp or chickens (although I imagine that carp could self-feed on aquatic algae). Algal protein replaces 50% of soya bean protein in feed rations to poultry. Total treatment by these methods takes about 4 days. The water is alkaline and somewhat anaerobic, needing more agitation in winter or on cool days. Holland runs sewage to similar canals, and reaps reeds or plants as green crop or for craft supplies.

It has been found (*Ecos* 44, Winter '85) that the artificial aeration of faculative ponds is most efficient if run at intervals of two hours in six (30% of the time). The faculative bacteria follow two digestive modes, and operate best if a rush of air is supplied after a four-hour anaerobic period, excreting carbon dioxide and thus reducing the bulk of sludge. There are corresponding reductions in energy costs for aeration. Nitrogen was reduced from 20 mg/l to less than 5 mg/l, phosphorus from 8.5 mg/l to less than 1 mg/l when ferric chloride was supplied. The process has been dubbed A.A.A. (alternating aerobic and anaerobic) digestion.

Thus, *agitation* of anaerobic systems by bubbling with compressed methane, and A.A.A. of faculative ponds can be used to obtain useful yields of methane and high-protein alage from sewage. As for the aerobic ponds, such higher plants as water hyacinth removed residual metals, surplus nutrients, and the *coli* group of bacilli (*New Scientist*, 4 Oct '79, p. 29). Microwave radiation can also be effective at breaking up algal mats, and sterilising algal products, eliminating toxic aluminium salts.

As for temperatures, solar ponds used in conjunction with compact anaerobic ponds can supply the low grade heat necessary for efficient sludge digestion, and methane will drive any motors needed for both aeration and the gas compression used for the agitation of sludge. The whole processing system can be made very compact, and at the aerobic pond level, throughflow can be led to firewood or fuel forest systems, to irrigated grasslands (as at Werribee), or via trickle irrigation to crops in arid areas.

Final treatment, now in use in Holland and recommended by scientists at the Max Planck Institute in Switzerland, can be released via a sinuous, sealed canal of a variety of rushes and floating water plants.

Waters polluted with metals, biocides, or sewage can be cleaned by travelling through reed beds of *Scirpus*, *Typha*, and *Juncus*; or by harvesting off floating plants such as water hyacinth. The rushes and sedges can be mown and removed periodically for mulch or cellulose. For *untreated* sewage, a holding time of 10–12 days is necessary, or travel through a series of maze-like gravel-filter canals with floating weeds and sedges. For swimming pools and less polluted systems, a pumped "cycle" of water through ferns, rushes, and watercress suffices to remove urine and leaves. Such pools need a 23–30 cm (9–12 inch) coarse river gravel base, with intake pipes below, and a skimming notch for leaves.

Species recommended are:

- *Phragmites communis* and spp., *Typha* spp.: Flocculate colloids, dry out sludges, eliminate pathogens.
- *Schoenoplectus* spp.: Takes up copper, cobalt, nickel, manganese; exudes mould antibiotics.
- *Scirpus* spp.: Breaks down phenols, including toxic pentachlorophenol.

Low to zero populations of *E. coli*, coliform bacteria, *Salmonella*, and *Enterococci* are found after water is

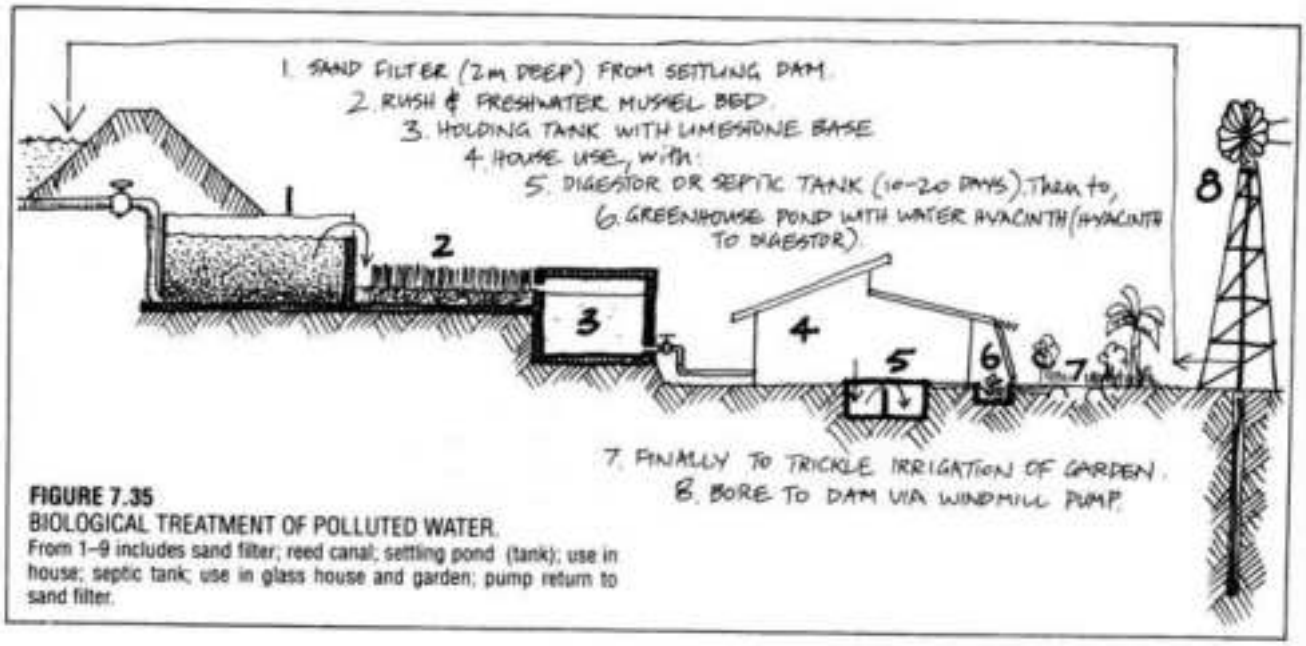


FIGURE 7.35
BIOLOGICAL TREATMENT OF POLLUTED WATER.
From 1–9 includes sand filter; reed canal; settling pond (tank); use in house; septic tank; use in glass house and garden; pump return to sand filter.

treated via the above species. Virus and worm eggs are also eliminated.

Also active in pathogen removal are (although these species must be tested and selected for specific problems): *Alisma plantago-aquatica, Mentha aquatica, Juncus effusus, Schoenoplectus lacustris, Spartina* spp., *Iris pseudocorus.*

For chlorinated hydrocarbons, use rush types with large pith cells (*Aerenchyma*), e.g. *Juncus* spp., especially *Juncus effusus; Schoenoplectus* spp.

Cyanide compounds, thiocyanates, and phenols were treated in fairly short flow times (7+ hours) with *Juncus.*

Systems must be carefully tended and monitored in field conditions. Water can flow through a gravel base planted to purifying species, or for longer rest times, passed through lagoons and ditches.

Domestically, a comfrey bed is one way to absorb the faecal products of animals, where wash-water from yards or pens is available. Comfrey can stand heavy inputs of raw faeces in solution, and the crop may then be used for fodder or trenched for "instant compost" under other species of plants such as potatoes. Flowthrough systems for methane production take little plant nutrient from faecal matter, and comfrey or algae ponds deal with the residues, while producing useful by-products for compost and stock feed.

The water from sewage lagoons has been safely used to rear beef cattle at Werribee for 35 years, and at Hegerstown (Maryland, USA), sewage waters supplied

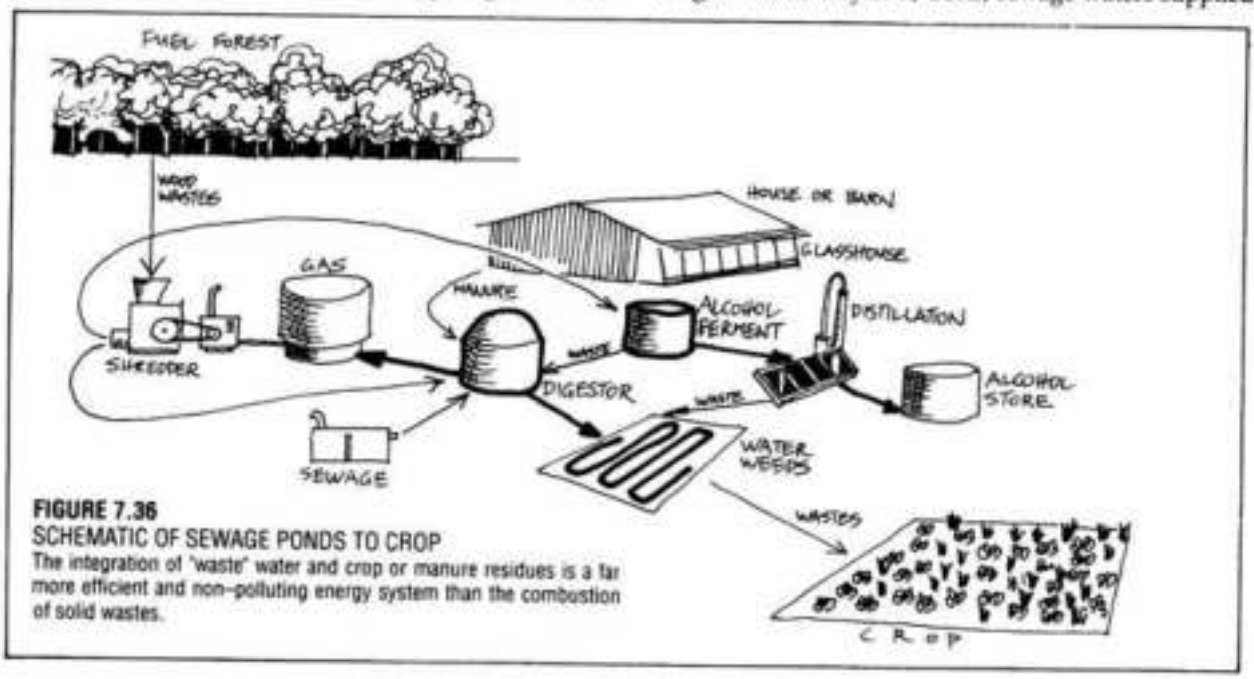


FIGURE 7.36
SCHEMATIC OF SEWAGE PONDS TO CROP
The integration of "waste" water and crop or manure residues is a far more efficient and non-polluting energy system than the combustion of solid wastes.

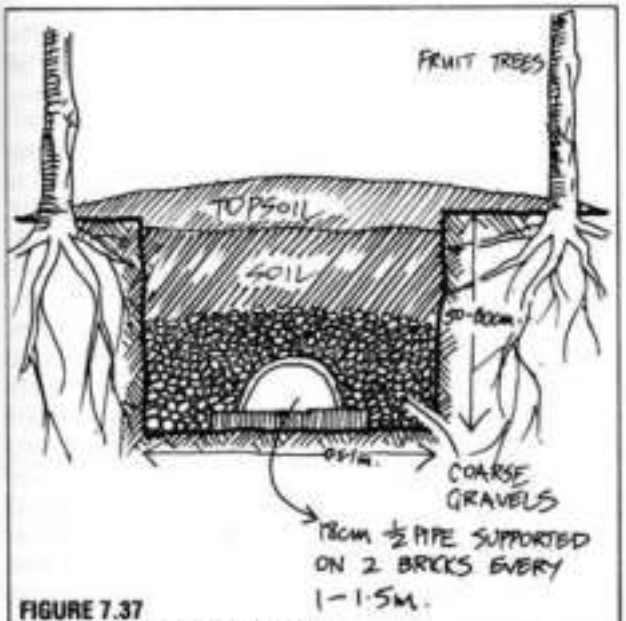


FIGURE 7.37
PITS FOR SEPTIC TANK DISPOSAL
Developed in South Australia as the "Arbor" system. Supported half-pipe never clogs with tree roots, enables trees to remove waste water from trench which has cross-supports every 1.2 m to create "pools".

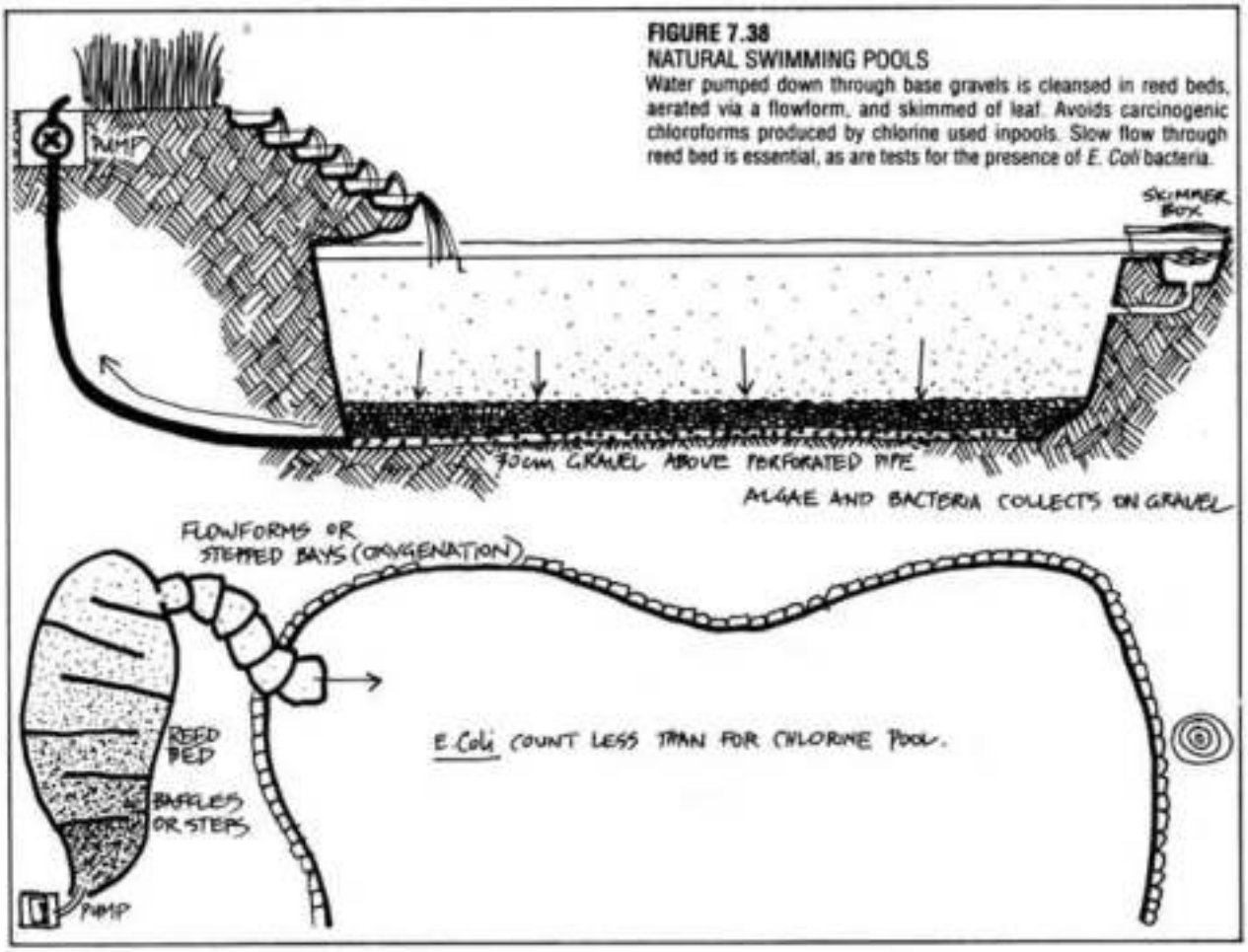
to selected coppiced poplar plots can produce (as wood chips) some 60% of town energy use. Obviously, water saved from reducing the extent of urban lawn systems can supply the remaining deficit *plus* food crop for any town.

As waters pass through towns, it may gain from 300–400 ppm in salinity—a grave factor in usage in any dryland area (*New Scientist*, 13 Oct. 77). Saline waters can cause problems in irrigated systems, but algae and plant production and removal will reduce this surplus salinity. Discharge of sewage to subsoils does not remove nitrogen compounds from sewage or farm run-off. Again, it is necessary to use productive pond production of algae to reduce nitrates to safe levels for discharge to soils, or we risk pollution of wells and bores, as has occurred in Israel and the USA.

As with garbage, separation of sewage into solids and liquids at the domestic level has productive advantages; 2% urea sprayed on the foliage of rice plants in padi has increased grain protein yields to 40% (11% protein by weight; *New Scientist*, 1 Sept. 77). Such separation can also be used to recover alcohol and chemicals from urine wastes. Urine diluted with water to a 5% solution controls moulds on cucurbits, and aids garden growth or compost activity generally.

In summary, it has long been apparent that modestly-designed sewage treatment systems based on

FIGURE 7.38
NATURAL SWIMMING POOLS
Water pumped down through base gravels is cleansed in reed beds, aerated via a flowform, and skimmed of leaf. Avoids carcinogenic chloroforms produced by chlorine used inpools. Slow flow through reed bed is essential, as are tests for the presence of *E. Coli* bacteria.



sealed (not leaky) lagoons and their associated biological systems not only function to recycle water efficiently, but to create a variety of yields from the 'wastes' of society. There are simply no modern excuses for continuing with the dangerous disposal of such wastes to seas and subsoils, where they inevitably turn up as pollutants in wells, streams, and on beaches, or add considerably to the greenhouse effect of atmospheric carbon dioxide. It is possible to design small and large systems of water treatment systems which are both biologically safe and productive.

Creative Disposal of Septic Tank Effluent

There are two basic productive disposal systems for septic tank effluent:

- Underground and surface leach fields around which trees are grown.
- Biogas conversion, followed by a pond growing aquatic crop for biogas feed stock, then a leach field.

A leach field is a trench or open gravelled soakage pit through which sewage wastes from a septic tank flows. In clays and clay–loams, tank water from a family home will stimulate fruit tree growth (without other irrigation) for 20 metres or more. The system follows normal procedures in that a long trench with a 1:12 ratio base slope is dug away from the septic tank outlet pipe. Topsoil is put to one side, and the trench is fitted with an 18 cm or larger half–pipe as per **Figure 7.37**. Coarse gravels or stones are placed in the trench, and over all this a strip of plastic or tarpaper is placed. The trench is then back–filled and trees planted 1–2 m off both sides as 2–6 m spacing. All fruit and nut trees benefit.

Square or round pits about 25 m square can be dug out and filled with graded stone (coarse 6 cm at base to 2 cm at top). Over this, a layer of cardboard and a thick layer of straw is spread, and the latter sown to oats or green crop. Around the pit, trees can be planted.

For biogas applications, septic tank effluent, weeds, and manures are loaded into a tank 2 to 1.5 m deep and 3–4 m in diameter. A loading chute for weeds and wastes about 20 cm and 30 cm slants to the base. Septic tank effluent also enters at the base. Overflow goes to a pond with baffles, and *Pista*, watercress, or any rampant soft water weed is grown there. These are returned to the tank every week. A perforated pipe at the tank base is worked by a small gas compressor to "bubble" gas back into the tank for 1–3 hours daily on a timer. This breaks up the scum on top of the ferment. Gas caught in an inverted tank is fed to the house cooking range, lights, refrigerators. Surplus from the pond is fed to a leach field.

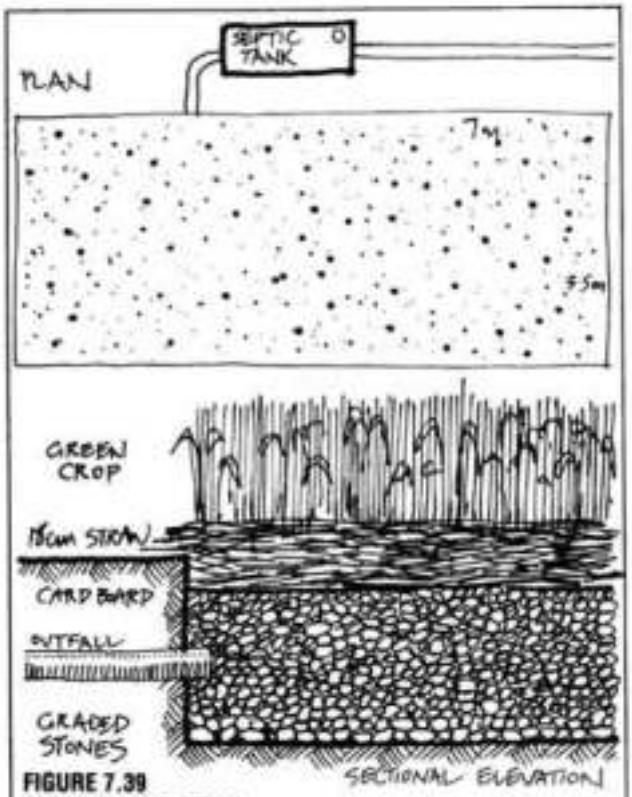


FIGURE 7.39
SEPTIC TANK OUTFALL
For semi–arid areas goes to a 8 x 8 m disposal pit with 0.5 m of gravel, straw mulch, trees around pit. Widely used in rural Australia.

7.6
NATURAL SWIMMING POOLS

When thou wilt swimme in that live bath
Each fish, which every channel hath
Will amorously to thee swimme
Gladder to catch thee than thou him...
(John Donne)

Swimming pools have crept across the affluent suburbs so that, from the air, these ponds now resemble a virulent aquamarine rash on the urban fringe. The colour is artificial, like that blue dye that imitates an ocean wave obediently crashing down the toilet bowls of the overly–fastidious. Chemicals used to purify the water are biocides, and we are biological organisms; if fish can't live in our pools, we should also keep our bodies out of the water. When chlorine isn't being used as a war gas, it is being dumped into our drinking, bathing, and swimming water, where it forms carcinogenic chloroform.

Innovative pool designers now filter natural pools below a base pebble bed, using the pebbles as algal/bacterial cleaners, then cycle it through a reed–bed to remove excess nutrients before cascading it back, freshly oxygenated, into the pool. Such pools can be delightful systems with tame fish, crayfish, rock ledges, over–arching ferns, and great good health (**Figure 7.38**).

They are also reserves for fire–fighting, potential heat sources for heat pumps, barriers to fire, and emergency water supplies rechargeable from the roof, and can be recycled by photovoltaic pumps. Goodbye to the endless servicing, and perhaps hello to an occasional lobster or overgrown trout!

7.7

DESIGNER'S CHECKLIST

On any property, identify sources of water, analyse for quality and quantity, and reserve sites for tanks, swales, or dams. Wherever possible, use slope benefits (or raise tanks) to give gravity flow to use points, and detail plant lists that will grow (as mature plants or trees) unirrigated.

In the general landscape, soil samples (for 40% or more clay content) will reveal sites suited to earth-dam construction; such sites need to be reserved for future storages. A sequence of primary valleys may enable a Keyline system to be established for downhill fire control and irrigation.

Where evaporation exceeds precipitation (arid areas), make sure all water run-off is infiltrated to soil storages via soil conditioning (rip-lines), swales, pits, or sandfield soakages. In humid areas, open-surface dams dams can be used.

Define water "pathways" in use, so that water use is economical in houses, and that greywater is used in gardens (via filtration beds), forests, or (for villages) design for clean-up on site through a common effluent scheme based on maximum use (methane, plant production, irrigation).

Get good advice on (and supervise construction of) all dams. Wherever possible do not impede normal stream flow or fish migration, and site houses out of the way in case of dam failure. In particular, allow adequate stable spillway flow for "worst case" rain intensity.

Make sure that all earth storages, and in particular swales, are planted with trees, to remove infiltrated water and (in arid areas) to prevent salting problems.

Before recommending cloud-seeding, make sure that the area to be affected is warned, and that dams and swales are designed to cope with any increase (up to 30%) in rains.

Design for forested ridges, and maximise forest on strategic uplands; do not lend your skills to high-country deforestation (or any deforestation).

Windbreaks and in-crop trees are essential to reduce water loss in croplands.

7.8

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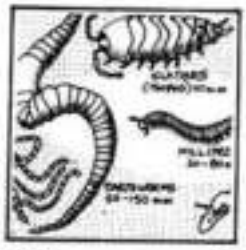


Chapter 8

SOILS

The best fertiliser is the footsteps of the gardener.
(Chinese Proverb)

8.1 INTRODUCTION

The properties and treatments of common soil types in specific climatic areas are summarised in later chapters, so that in this chapter we deal more with soil as a material, including some of the ways to stabilise and assist soils in retaining their productivity (soil conservation and soil conditioning).

Soils defy precise treatment, as their structure (and permeability), organic content, gaseous components (some derived from the atmosphere, some from processes within the soil, and some exhaled from the sediments below), minerals, pH, and water (or rather solute status) changes from hour to hour with soil depth and treatment, and in response to micro-elevations. Added to this is the fact that many soils are originally complex mixtures derived from a variety of rock types and that they may have had a very long and varied history.

A final factor is that despite all our knowledge, in spite of soil services and soil analysis, and despite the best attempts of people to care for land, we are losing topsoil at an ever-increasing rate. Australia, where I live and write, has perhaps 30% of its original soils in fair condition. The rest are washed or blown away, or sadly depleted in structure and yield; this is true of most countries of the world where extractive agriculture and forestry occurs.

The closer soils are defined, it seems, the less likely we are to know them. Notwithstanding this specific uncertainty, there are some sustainable approaches to soil maintenance and to soil rehabilitation. It is in these areas that we will outline strategies. Keep in mind, however, that we are always dealing with a matrix or mosaic that is in constant variation in place and time. Nobody can be dogmatic about any natural system.

Soil science concentrates very much on *what is there* (classifications), but not on *how to evolve soil*. Often it is left to amateurs—gardeners and farmers—to create good soil by water control, modest aeration, and plant and animal management. Farmers and gardeners seem to be so often the practical, innovative, experimental, successful group (while often ignored by academics) that I despair of esoteric knowledge ever preceding effective action. Very few farmers can persuade a group of scientists to assess their apparently successful soil trials. It is past time that we assessed whether more "science" is not being done by outdoor people than by scientists who (like myself) more often collect the results of others than generate them by example. Science is good at explaining why things work, and thus making skills teachable. It is not so good at initiating field work, or in training people already in the field to work effectively.

It is hard to say if scientists lack the means to get into the real work, or if they choose science to escape from field problems. It *is* hard out in the field of erosion, landlords, foreclosures, poverty, greed, malnutrition, and exploitation, but that's where all the action is. A field approach means choosing values, getting involved with people, and inspiring broad scale change. Farmers' field days advance knowledge far more effectively than scientific papers, and local educational sessions more than either of these. However, both scientists and farmers have much to "give and take". This sort of coalition is slowly starting to happen as a result of joint concern on a private level.

Soils can be RESIDUAL (resting in place over their present rock) or TRANSPORTED by water, ice, gravity, and wind. In their formation the key factors are rock type, climate, and topography (or landform). Water has a key role in rock breakdown, combining with such

common minerals as felspars in rock to swell and fracture the rock, then to hydrate the felspars to kaolin, clay, and potassium carbonate. The carbonates released make of soil water a stronger carbonic acid than it is as rain.

Atmospheric oxygen dissolves in rain to oxidise iron minerals (pyrites) and forms both haematite and a quantity of sulphuric acid, which again dissolves metals, so that water makes an effective rock decomposer, even without invoking the expansion of water as ice, or the power of ice (as glaciers) to grind rocks to flour. Plants too are wedging open rocks and mineral particles, recreating acids, and transporting minerals in their sap to other locations. All of this work creates a mantle of topsoil, which is estimated to build at about 2–4 t/ha per year as uncompacted topsoil, but which we remove at a rate of from 40–500 t/year in cropping and soil tillage. Even the most ideal tillage just keeps pace with the most ideal conditions of soil formation, and in the worst cases we can remove 2000 years of soil in a single erosion season, or one sequence of flood or strong wind over cultivated soils.

The *only* places where soils are conserved or increased are:

- In uncut forests;
- Under the quiet water of lakes and ponds;
- In prairies and meadows of permanent plants; and
- Where we grow plants with mulched or non-tillage systems.

These then are the core subjects of sustainable societies of any conceivable future. They are not, you might notice, the subjects most taught in the agricultural colleges or forestry courses of the recent past, nor do they occupy the minds of politicians, investment bankers, or TV stars.

Before starting on the complex subject of soils (and I am *not* a soil scientist), it is wise to draw back a little and consider the question of soils from some very different viewpoints, or sets of values. They are broadly these:

- Health (both human and plant). We must be careful and conservative in approach, *especially* in the area of biocides and high levels of artificial fertilisers. After all, our ancestors lived to a ripe old age on home-grown produce without the benefit of herbicides, pesticides, or artificial fertilisers. We must therefore improve on, not lessen, that factor of long-tested vitality that was, and is, integral to good gardeners.

Not that I believe that their health was purely due to diet. Several other factors associated with gardening may be one day better assessed, including:

— *mild but regular exercise*: gardening is a sort of steady and non-stressing *tai chi*.

— *meditation*: we can sit and look as much as work, and banish all cares. I found my grandfather as often just looking as working (and he fed about 20 families from his market garden).

— *meaning* in gardening, there is a very conscious sense of doing a job that is worthwhile, and of *direct* value to others. Gardening, especially food gardening, is "right livelihood".

— *life interest*, perhaps derived from the above. Every day, every season there is change, something new to observe, and constant learning. Permaculture greatly adds to this interest, and has the dimensions of a life-oriented chess game, involving the elements, energy, and the dimensions of both life-forms and building structures (also with political, social, financial, and global implications).

- Yield. Here, we come to a grave impasse. There is no doubt that the once-off yield of a ploughed and fertilised monoculture, supported by chemicals and large energy inputs, can out-yield that of almost every other production system. *But*: at what public cost? for how long maintained? with what improvement in nutrition? with what guarantee of sustainability? with what effect on world hunger? on soils? and on our health? There is now abundant proof that such forced yields are temporary, and that plough cultures destroy soils and societies.

These are some very awkward questions to ask of the agricultural establishment, for very few, if any, modern agricultural systems do not carry the seeds of our own destruction. These systems are those that receive public financial support, yet they destroy the countryside in a multitude of ways, from clearing the land of forest, hedgerow, and animal species to long-term soil degradation and poisoning. We are thus obliged, by entrenched bureaucracies, to pay for the destruction of our world, regardless of the long-term costs to be borne by our children and our societies.

- Life in soil. Soil organisms are a major soil factor, and have myriad perceptible and profound effects on pH, mineral content and availability, soil structure, and erosion.

- Ethics. It is *not* the purpose of people on earth to reduce all soils to perfectly balanced, well-drained, irrigated, and mulched market gardens, although this is achievable and necessary on the 4% of the earth we need for our food production. Thus, what I have to say of soils *refers to that 4%*, with wider implications only for those soils (60% of all agricultural soils) that we have ruined by the plough or polluted by emissions from cars, sprays, radioactives and industry.

Our largest job is the restoration of soils and forests for the sake of a healthy earth itself. It is most definitely not to clear, deforest, or ruin any more land, but first to put in order what we have destroyed, at the same time attending to the modest area that we need for our survival and full nutrition.

Without poorly drained, naturally deficient, leached, acidic or alkaline sites, many of the plant species on earth would disappear. They have evolved in response to just such difficult conditions, and have specialised to occupy less than perfect soil sites.

Colin Tudge (*New Scientist* '86) muses on the proportion of the British Isles that could be given back to nature. He comes down with a very conservative estimate of perhaps 60%. And at that, without letting

go of the misconception that it is agriculture (not individual and market gardening) that will actually provide the future food we eat (a common fallacy). John Jeavons estimates (on the basis of *gardens*) that we could return perhaps 94% of land to its own purposes. Not that I think that we will get there this next decade, but we can start, and our children can continue the process, and so develop new forests and wilderness to explore. A reduction of the ecological deserts that we have called agriculture is well overdue, as is a concomitant reduction in the twin disasters of newspapers and packaging derived from ancient forests.

8.2
SOIL AND HEALTH

As long as we live, we will be discovering new things about the soil-plant-animal relationship. Soils harbour and transfer both diseases and antibiotics; plants will take up from the soil many modern antibiotics (penicillin, sulfa drugs), and we might then ingest them at concentrated levels. Animals will retain residual antibiotics (therefore new and resistant strains of disease organisms), and will contain residual hormones and biocides. Plants and animals may concentrate, or nullify, environmental pollutants. Most of these pollutants are in fact concentrated by both plants and animals, but the degree to which this happens varies between species.

Both dangers and benefits arise from our food. Natural levels of soil antibiotics may sustain us, and natural resistance to disease is in great part transmitted to us via food. It is certainly the case with vitamins and trace elements that they maintain the function of many metabolic processes, in minute but necessitous amounts.

When people lived as inhabitants of regions (as many still do) they adapted to local soils, plants, and nutritional levels or they died out. Today, we bring in global food to global markets, and so risk the global spread of "agricologenic" (farm-caused) diseases. Like the home water-tank, the house garden represents a limited and localised risk *under our control*, and of little risk to society generally. Public water supplies and commercial foods are a different matter, distributed as they are throughout many modern societies.

In soil rehabilitation, we are forced to start with what is now there. Only rarely have we a soil containing all the nutrients a plant may need to grow. Most gardeners and farmers who have developed sustainable soil systems allow 3–4 years for building a garden, and 5–15 years to restore a devastated soil landscape. This applies only to the physical restoration of soils and to the development of appropriate plant systems. There are far more lengthy processes to be undertaken where past chemical pollution has occurred.

THE POLLUTION OF SOILS AND WATERS

Orchards, sugarcane areas, pineapple, cotton, tobacco crop, and banana plantations (to name just a few well-known cases) have had such an orgy of mineral additives, arsenicals, Aldrin, DDT, copper salts, and dioxins applied that even after 18–20 years of no chemical use, a set of apple orchards in West Australia produces unsafe levels of Aldrin and Dieldrin in the eggs of free-range chickens. Attempts to grow prawns in ponds on such lands have failed on the basis of residual Dieldrin levels in soils.

When we come to assess the total environmental damage caused by persistent misuse of chemicals, we will find many farms (as well as bores and rivers) that will need to be put into for non-food production (as fuel forests or structural timber) for decades to come. The same may already hold true for soils within 100 m of roadways where leaded petrol is used (and where 800–1000 cars pass daily).

We face lock-up periods of tens or at times thousands of years for the radioactives blowing off, or leaking from, waste dumps and strategic stockpiles of yellowcake Uranium (Iowa, Kentucky, Russia and the UK or France), or from "accidents" such as those occurring at atomic power plants, or from their wastes. Cadmium and uranium-polluted soils of chemically-based and heavily-fertilised market gardens, waste dumps of industry, and the long-term effects of nitrate-polluted soil waters can be added to those lists of already-dangerous areas. Even now, *applied* health levels would close down many farms and factories, and (as awareness rises) this will be done in the near future by public demand.

The costs of rehabilitation (as for acid rain) already far outstrip the profits of degradation, and may in fact be prohibitive for areas that were developed for farming from 1950 to the present (the age of agricultural pollution).

Large quantities of lead, arsenic, copper, and persistent biocides are applied on most apple orchards. Data is available for some metals (*ECOS* 40, Winter '84). Copper and lead stay at or near the surface of soils in high concentrations. Arsenic may also stay at this level in clay soils, or wash down to subsoil (50–60 cm deep) in acid sands. Leaching from clays or organic profiles (10–20 cm) is unlikely, although phosphate application *may* dislodge arsenic to deeper levels. In pasture plants under such orchards, copper can reach 50 ppm (poisonous to sheep). Excess copper in the diet causes toxaemic jaundice (liver poisoning) and blood in the urine. (People in Australian deserts often show high copper blood levels and blood in urine.)

Molybdenum, zinc and sulphur may buffer copper uptake in sheep at least; uptake by plants increases with temperature and acidity (for lead and copper), as for vegetables. Arsenic uptake is not related to acidity; silver beet (Swiss chard) fed with nitrogen lose high arsenic concentrations, but may then be unsuitable for children due to high nitrate levels.

Several substances have now polluted soils. There

are no easy remedies for polluted soils, but the following strategies may help:

• LEAD (from car exhausts and lead paint, pipes, battery burning). Worst cases are in urban areas of older buildings. Lead at 1,100 ppm can be present, and is both taken up by and dusted on the surface of vegetables. However, it is possible to garden by:

— Cracked bricks or gravel as a base.

— Building up beds to 30 cm deep, and making up a rich composted soil of over 40% organic content.

— Growing vegetables and having leaf analyses done; washing in dilute vinegar if lead is still used locally in petrol.

• PERSISTENT BIOCIDES, especially DDT, Aldrin, Dieldrin, BHC, etc. If you buy or inherit an old orchard, canefield, or plantation (banana, pineapple, cotton, tobacco) it is unlikely that any animal product (milk, eggs, meat) will be free of high levels of biocides. There is no choice but to go into forestry, and to produce non-food crop until other methods are developed. Also, test your own vegetables for residual toxic materials.

• GROUNDWATER can contain 80–90 biocidal substances below farms, including those derived from fertilisers, sprays, and fuels. Near industrial waste dumps, dioxins, radioactives, and heavy metal wastes (cadmium, chromium, mercury) can be added. Do not use untested wells or bore waters for *any* purpose. Drink tankwater and try to harvest surface run-off for gardens. It is estimated that several decades may be needed to clear most aquifers of pollutants. Almost every state of the USA has serious problems. Rainwater harvest and strict water conservation is indicated for the long-term future. Several substances are added to town water supplies—and these may include chlorine, fluorine, alum (aluminium sulphate) and other metabolic poisons.

We must not add to this mess. Avoid all biocides, high levels of nitrates, and watch on-farm disposal of oils and fuels.

HUMAN HEALTH AND NUTRITION

The subject of human nutrition is complex, and under fairly constant assessment by scientists from many disciplines. Four very broad statements can be made:

1. A normally-mixed diet (omnivorous) has been exhibited by most human groups. Excessive dietary simplicity, reliance on too few foods, or a restricted dietary range has its dangers, while a mixed diet of local foods, plus an active life, has usually proved healthy, providing good hygiene is also observed (public, personal, and domestic).

2. In the developed countries, refined and processed foods, too much inclusion of animal fats, and a plethora of food additives has certainly resulted in malnutrition and in degenerative diseases (obesity, high blood pressure, heart disease). There is now a general move away from smoking, heavy drinking, and many fatty or processed foods, and a rising demand for lean meats, fish, and clean vegetables, fruits, and nuts.

3. In areas subject to famine, semi-starvation, or where very low levels of critical vitamins (commonly C, A, B-complex) or minerals (iron, zinc) exist, it is necessary to take great care with human and soil health, and to have a very sound knowledge of the possible results of any new dietary change (whole grains and pulses may strip out the little zinc the body retains where there are starving people in alkaline desert areas; zinc tablets may then been needed if such foods are commonly used). Traditional diets, long maintained, are a guide to local food tolerances.

4. There is a complex and constant interaction between food, soil, trace elements, pH, biocides, and fertilisers. Too often, product yield, weight, or processing suitability is the only reason given for using biocides and fertilisers; nutrition is rarely mentioned in plant breeding programmes. Heavy use of fertilisers—the macronutrients—can cause a deficiency of micronutrients [*ApTech* 6(1), 1984].

We are *individually different* in our ability to metabolise and tolerate foods. For some of us, specific food allergies are very real, and at least in part (e. g. lactic acid intolerance) arise from little exposure to certain food groups in our racial history. Individuals can test for ill effects by becoming conscious of headaches or other symptoms, and experimentally eliminating some foods or beverages from their diet, or even a class of food (e.g. dairy products, grains), still leaving a very wide range of foods from gardens, farms, ponds, and nature.

Another basic individual variable (apart from metabolic efficiency) is bodyweight itself. Dosages of any substance vary with body build, fats, and dosage per kilogram weight, so that alcohol and anaesthetics (for instance) may have a very different metabolic effect on two people of equal weight, one of whom is fat and one lean. So it is with specific foods.

The sane procedure in health is to maintain basic hygiene, grow and eat healthy plants and animals, avoid biocides and pollutants, take easy exercise, drink clean water or beverages, and stay as cheerful as this world permits (or adopt a positivistic lifestyle). The rest is up to chance, traffic accidents, or megalomaniacs and wars, and these demand commonsense changes to the social systems, plus a little good luck.

8.3

TRIBAL AND TRADITONAL SOIL CLASSIFICATIONS

From *The Ecologist 14* (4) 1984:

Tribal and traditional people classify their soils on a great variety of characteristics based on:

- Colour (indicates humus content).
- Taste (agrees with our pH measures).
- Moisture capacity and water retention.

- Sand content.
- General texture.
- Firmness.
- Structure (dry soils).
- Wet-season structure.
- Vegetative indicators ("health" of a specific crop).
- Drainage.
- Slope.
- Elevation.
- Animal indicators (e.g. termites: the shape and size of their mounds).
- Plant indicators (for acidity, drainage, fertility).
- Catena (types of soils based on slope relationships).
- "Hot" and "cold" soils — relative fertility (*not* temperature); can also indicate water retention.
- Usage, e.g. pigments, pottery, salt extraction from reeds.
- Work needed for crop (an *energy input* classification).
- Suitability for specific crop (e. g. yam soil, taro soil). Soils can be ranked for up to twelve crop types, giving a complex classification.
- Organic content (apart from colour).

Thus, sophisticated assessments of soils are available from most agricultural societies. However, modern classifications are more complex in terms of nomenclature and physical categories, and use standard colour charts (Munsell and others), standard comparisons, standard sieves and so on.

8.4
THE STRUCTURE OF SOILS

Soil is a complex material, and if it has enough plasticity (usually clay), or glue or fibre from organic sources, it can be pressed or compacted into mudbricks, hard pise, or baked to clay or stoneware. In any of these forms, it is of little use to plants.

Uncompacted soils are open, crumbly, or soft unless concreted by chemical solutes or compacted by ploughs, hooves, or traffic. Crumbly soils have nevertheless a definite structure. The soil particles are in nodules or clumps held together by roots, clay minerals, and chemical bonds. If we speed a plough or drag harrows through these fragile assemblies, they may powder up as they do in a potter's ballmill, or on outback roads. ("Bulldust" is the term used in the Australian outback. A soil scientist might speak of "snuff".) Dryland soils with a high salt content are particularly susceptible to loss of crumb structure, only partly relieved by application of gypsum.

The mantle of soil and subsoil that covers the earth is as thin as the shine on the skin of an orange, and this mantle extends as living mud below the waters of earth as well as on land. It is composed of these elements:

- MINERALS, mainly silica, oxides of iron and aluminium, and complex minerals.
- SOIL WATERS, fresh, saline, with differing pH, and dissolved minerals and gases.
- GASES, some from the atmosphere, others emitted by the breakdown of rocks and the earth's interior.
- LIFE FORMS, from fungal spores and bacteria to wombats and ground squirrels, from massive roots to minute motile algae.
- ONCE-LIVING REMAINS; the humus of the earth; decayed, compressed, and fossil organic material.

Soils rarely extend much below 1–2 m, and are more often a living system 6–12 cm deep. Subsoils, lacking the life components, and buried soils or deep washed silts are rare and confined to valley floors and deltas, or glacial mounds.

To estimate the proportion of clay, silt, sand, and coarse particles in soil, a sufficient first test (for judging the suitability of soil for dam building, mud brick construction, and crop types), mix a sample of soil from a few typical sites, and pour a cup of soil in a tall jar, filled almost with water. Shake vigorously and let the soil fractions settle out over a day or a week (clay can remain in suspension for up to a week). 40% or so clay is needed for dam walls, and less than that for good mud bricks (without lime or cement added).

Of these fractions, the coarse particles are inert, although useful in fine soils as a wind-erosion deterrent. Sands are 0.05–2 mm, silt 0.05–0.02 mm, clay particles less than 0.002 mm (1 g of clay has a surface area of up to 1000 times that of 1 g of sand).

Soil crumb structure, aided by lime (calcium) aids the bonding together of these fractions and creates 20–60% pore space. The organic materials and gels hold the structure open in rain, and where plant nutrients can become soluble for absorption by roots.

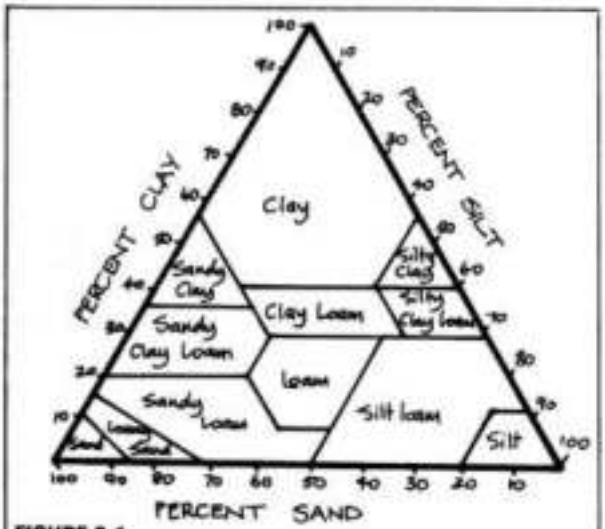


FIGURE 8.1
SOIL PROCESSES.
The USDA classification of soil types by particle size.

8.5
SOIL AND WATER ELEMENTS

Of the 103 known elements, only some are commonly dealt with in the literature on soils and water. Soil itself is predominantly composed of aluminium, silica, iron, and (in certain shell, sand, or limestone areas) calcium. Only mineral ore deposits have large quantities of other elements.

The modified form of the periodic table is given in the centrefold of the colour section and a more extensive annotation on specific elements is given in **Table 8.1**. It is essential that designers in any field have a basic knowledge of nutrients, poisons, and tolerable or essential levels of trace elements in food, water, and the built environment.

The health of plants, animals, and the environment of soils and buildings are all dependent on the balance of elements, radioactive substances, radiation generally, and water quality. Of particular concern in recent times is the level of radioactives in clays, bricks, paints, and stone, and both the emissions from domestic appliances (TV, microwave ovens) and microwave radiation from TV transmission and power lines.

Thus, the annotations in **Table 8.1** cover a range of topics, including short comments on human health. In this case we are using the periodic table not as an aid to chemistry but as a guide to understanding the role of the elements in soil, water, plants and animal tissue, and nutrition.

The colour-coding and the dots on the periodic table (**see centrefold**), plus the following annotations of elements give some of their known effects on soil, plant, and animal health, or their special uses.

FIGURE 8.2
JAR METHOD
of assessing crude soil composition; useful for classification, uses for mud brick or pisé work. Soil sample is shaken in water and allowed to stand until layers form (1–20 days). The volume of each fraction determines uses and a texture classification (see **FIGURE 8.1**).

8.6
PRIMARY NUTRIENTS FOR PLANTS

Soils are often analysed as deficient in both PHOSPHATES and POTASH in heavily leached areas. Phosphates are supplied either by guano (bird manures) from dry islands, or from older deposits found in sedimentary rock. Potash occurs in the mineral kainite, formed in areas of evaporated waters. Desert salts usually contains 20–25% potash. Phosphatic rock is restricted in distribution, and contains 8–15% phosphorus in various combinations with oxygen or water (hydrated). There are large reserves of potash in common minerals like orthoclase (a major constituent of granite).

NITROGEN can be supplied by water or land plants inoculated with rhizobia, or fixed by algae and water plants such as *Scirpus* or *Azolla*. We can create the conditions for fixing nitrogen by growing these nitrogen-fixing plants, inoculated with the appropriate rhizobia. Much higher levels of nitrogen than were previously thought to be available are fixed by land plants, in a series of zones extending from the roots. Even after nitrogenous plants such as *Acacia*, *Albizzia*, and *Eleagnus* are cut, the root zone will continue to release nitrogen for up to 6 years, so that pioneer legumes or nitrogenous trees serve as cover crop for trees, and release nitrogen during their lifetimes and for some years after. Legumes may not be needed in older forests, and typically die out under canopy. Only a few larger leguminous trees (*Samanea*, *Acacia melanoxylon*) persist as forest trees in a mixed forest.

Both phosphate (concentrated by seed-eating birds) and potash (from burnt and rotted plants or compost) can be locally produced if birds are plentiful and their manures are used. The phosphates mined from marine guano, however, may contain concentrated levels of cadmium and uranium, either or both of which (and other heavy metals) can be taken up by the oceanic fish and shellfish used by marine bird colonies. Continual heavy use of such resources is likely to become polluting to soils. Our only ethical strategy is to use just enough of these resources, and to conserve them locally.

SOURCES OF MINERALS IN SOILS

The Sea

It makes sense to assume that as soils are leached, and so made mineral-poor, these minerals later become more concentrated in the sea, in marine organisms, or in inland saltpans. Seaweeds, seagrasses, and fish residues have always been part of agricultural fertilisers, and have maintained their place even in

modern times. As seawater evaporates, first calcite and dolomite, then gypsum and anhydrite separate out; all are used for soil conditioning, pH adjustment, or to restore soil crumb structure.

Next, rock salts crystallize out, but only wet tropical uplands may actually lack this common nutrient, although even there specific plants (often aquatic) concentrate salt which can be gathered or leached from their ashes.

Lastly, potash, magnesium salts, and a host of minor elements remain; the evaporites (those already deposited) being the most soluble and therefore earliest deposited. The liquid that remains after the common salt content deposition is a rich source of minor minerals and trace elements. It is, in fact, sold as "bitterns" (bitter oily fluids) for dilution and incorporation in crop soils, or in low concentrations (diluted 100–500:1) used directly as foliar sprays in strengths varying from 1–20 l/ha. Very corrosive, bitterns (which include bromine and many of the early elements of the periodic table, plus some rare minerals), are safely held and distributed only via non-corrosive vessels and pipes (today, polyethylene pipes and drums).

Bitterns are cheap, and easily transported to leached areas, but their effects must be established by local trials on specific crop. As these evaporites are so easily dissolved, they are also those most likely to be carried to sea in rains.

Rocks and rock dusts

Granites contain felspars yielding potash or sodium salts. Limestone and dolomite yield calcium and magnesium, and mineral deposits or their ores give traces of the basic minor elements. Of these, calcium (in all but highly calcareous areas) is most needed, dolomite (except where magnesium is already in high ratio) is next; phosphates and felspars follow, along with trace elements in small quantities (as low as 5–7 kg/100 ha for zinc, copper, cobalt, and molybdenum).

Field trials have established that cheap ores, finely ground, are as effective as more refined sulphates or oxides (Leeper 1982). Sometimes such minerals are given to animals as salt licks, in molasses, in water, or as injections or "bullets" of slow-release elements (cobalt) in a pellet which lodges in the rumen. Some mineral elements also reach plants via urine, but foliar sprays are more rapid-acting and effective.

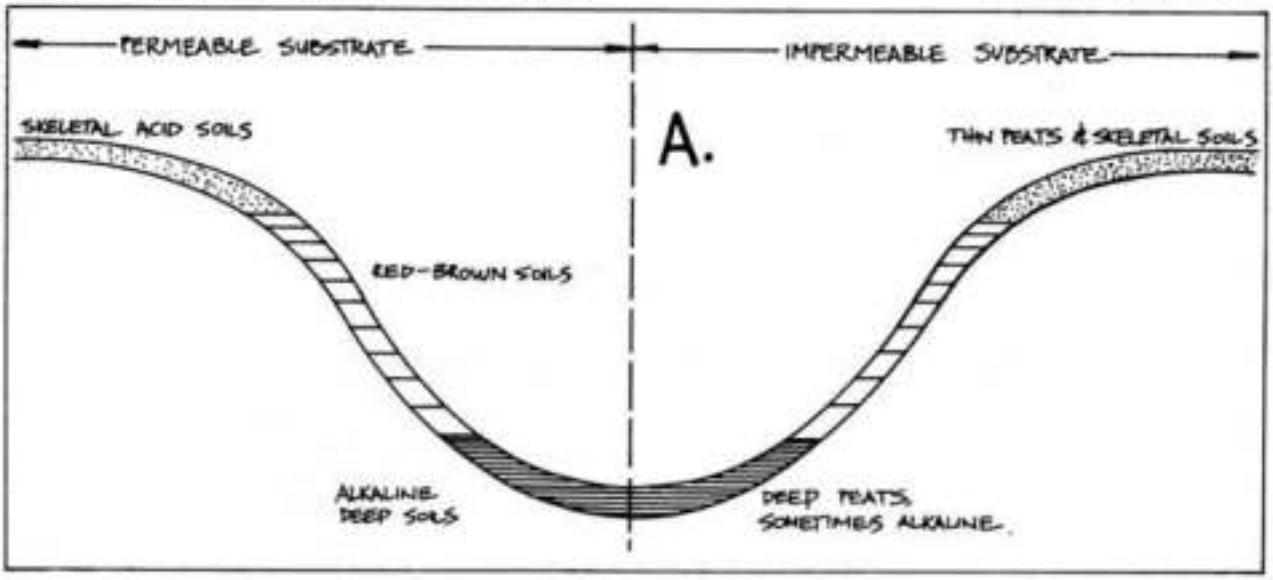
Fine rock dusts of a specific rock suited to local needs are often cheaply available from quarries or gravel pits. Basalt dusts are helpful, for example, on leached tropical soils. Rock phosphate contains 8–15% phosphorus, but is very slow to release nutrient, and may in fact be absorbed completely on to leached clays and clay-loams. Super-acid phosphate added to compost, or to plants used in compost, may be necessary under such conditions. Rock dust as an unselective category can do as much harm as good on soils, adding excessive or poisonous nutrients in some cases, or excessive micronutrients.

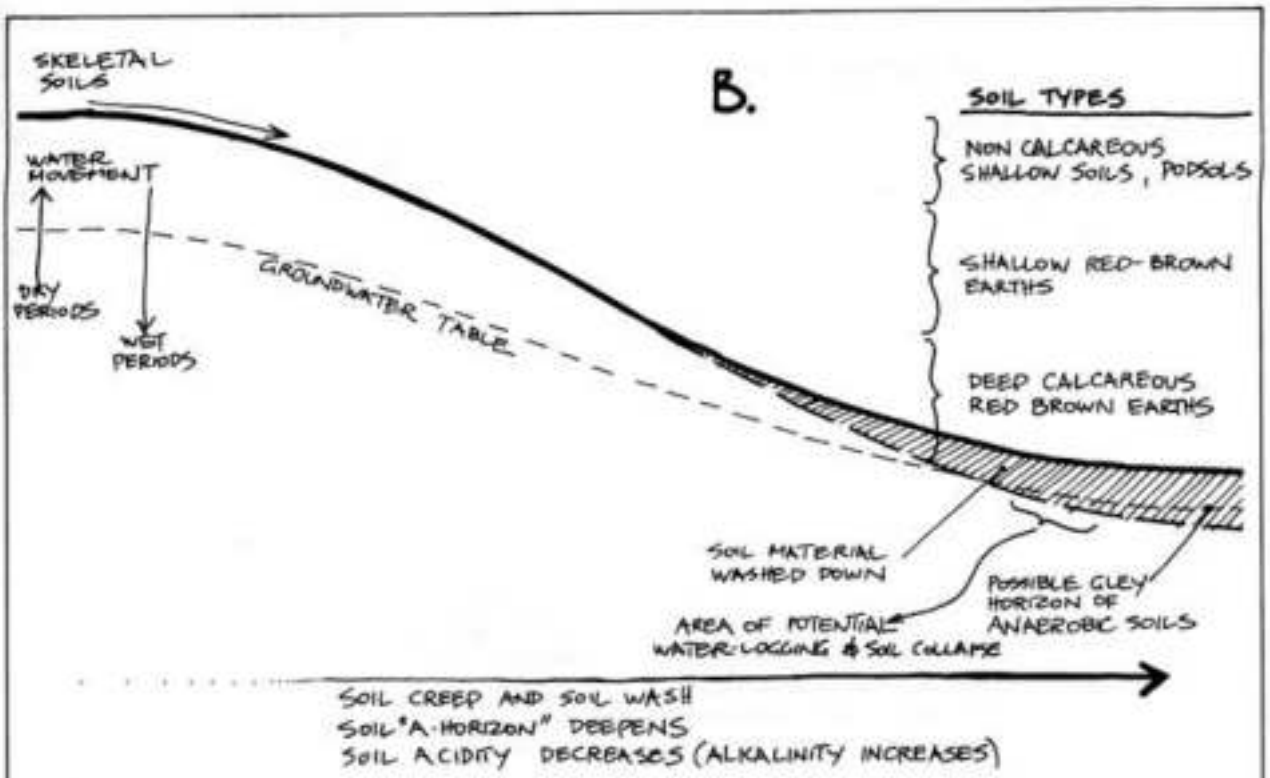
8.7 THE DISTRIBUTION OF ELEMENTS IN THE SOIL PROFILE

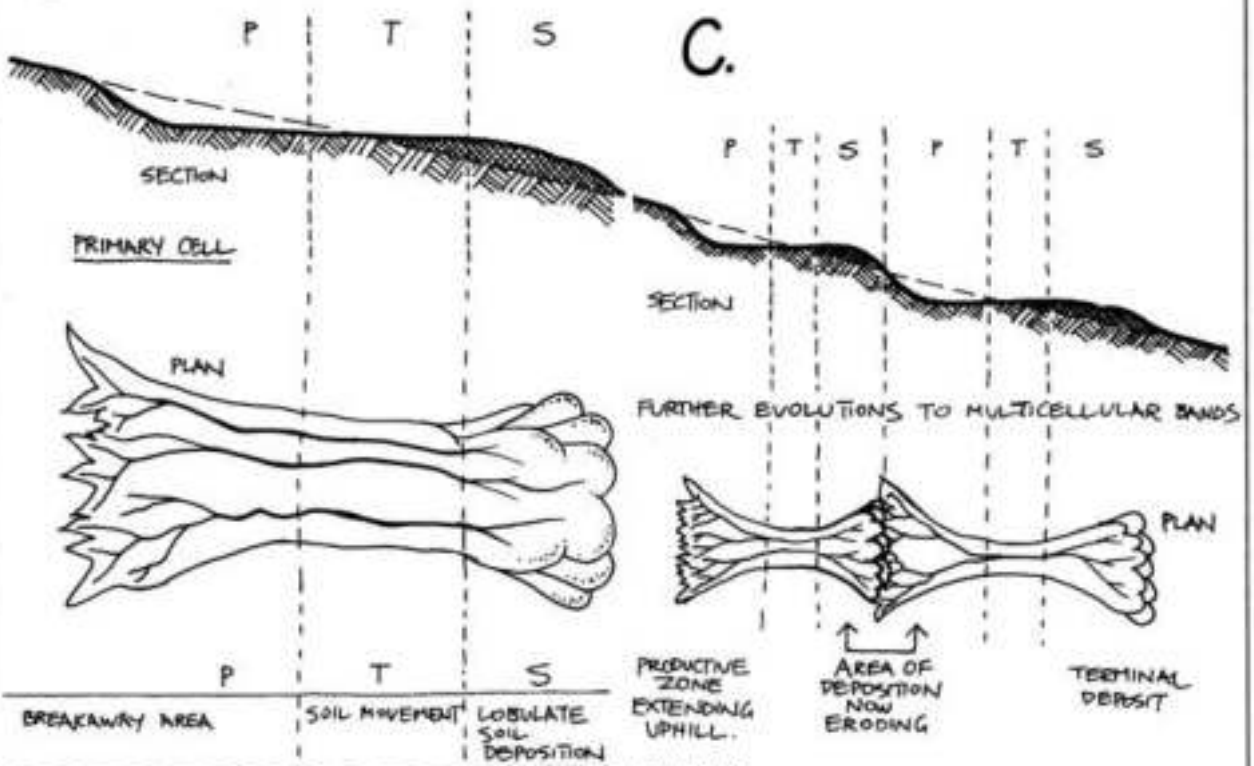
There seem to be two important determinants of the concentration of elements or nutrients through the soil profile (that vertical column of soil from the surface to 2 m or so deep). The first is the penetration of water. Water is a universal solvent, enabling compounds to dissociate into ions, and transporting them, firstly, to various deposits at microsites in the soil. This effect works in three dimensions:

- Water travels by infiltration to varying depths, soaking in from the surface down.
- Water can also rise from the soil water table upwards, either by flooding, by capillary action

(continued on page 195...)







	P	T	S
BREAKAWAY AREA		SOIL MOVEMENT	LOBULATE SOIL DEPOSITION
FEW TREES		SCATTERED TREES	DENSE TREES
TRIBUTARIES		SAND CLOGGED STREAMS	DISTRIBUTARIES (WATER ABSORPTION)

FIGURE 8.3
A SOIL CATENA
A A typical profile across a valley; rainfall, erosion, and leaching create fairly predictable soil sequences.
B Detailed section shows procession in arid areas.
C Soil erosion cells; degree of erosion and extent of erosion processes can be analysed from aerial photographs.

TABLE 8.1
KEY TO PLATES 12 AND 13: THE PERIODIC TABLE

1. **Hydrogen** (H) is an extremely mobile and reactive gaseous element; the number of free ions of this element determine the pH of soils, together with the hydroxyl (OH^{2-}) radical in alkaline areas. Hydrogen combines with several other elements and organic substances to form acids. It is a potentially inflammable light gas, now replaced by helium in balloons and airships. Some plants, especially algae and rushes, can transpire hydrogen, and in so doing break down the halogenated hydrocarbons that are used in pesticides and herbicides.

Hydrogen combines with oxygen as hydroxyl (OH^{2-}) or water (H_2O), the basic gaseous and liquid elements. It is the concentration of H^+ or OH^{2-} ions in solutions that decides the pH of soils and water. Hydrogen combined with carbon as methane (CH_4) is emitted by decaying humus in anaerobic (airless) environments such as under water or in compacted or boggy soils. Such soils usually have a mottled profile, and are often bluish, yellow, or contain iron stains and nodules. Methane is a component of marsh gas, or biogas from digesters, usually associated with carbon dioxide and sulphur dioxide (the gases of decomposition). A sulphurous smell in subsoils is a guide to wet-season water-logging, and should be noted for plants intolerant of stagnant waters.

3. **Lithium** (Li), the lightest metal, is prescribed medically as tablets in cases of hyperactive and disturbed people; it may moderate nerve impulse transmission across synapses. Lithium is found in plant and animal tissue.

5. **Boron** (B) is a trace element, necessary to (e.g.) the brassicas and beets. As many detergents also contain boron, boron pollution or poisoning can build up in gardens and affect plant health adversely. Use soap, especially in drylands, where citrus and grains in particular can be boron-poisoned in dry seasons. Borax at 160 g/ha is used on beet and *Brassica* (cauliflower, turnip) crops where soil levels are low in boron. Boron seems to be essential to the transport of sugars in the plant, to pollen formation (hence, fertility), and to cell wall structure (like calcium).

Borax is poisonous to seed and to insects, and is used with dilute honey as an ant and cockroach poison. Sea sediments (and the sea) contain high boron levels. Surplus boron can cause anaemia in people. In soils, 0.75 ppm is ideal, but 1.0 ppm can be toxic to plants. It is likely to be at toxic levels in dry years, where soils have been derived from marine sediments (*Rural Research*, CSIRO, Autumn '86).

6. **Carbon** (C) is the basic building block (with hydrogen, oxygen, as hydrocarbons) of life forms. It is added to soils as humus, compost, and mulch. Pitted or buried wastes need nitrogen or oxygen, therefore *air*, for decomposition. 10–20% humus ensures good structure in both clays and sands. More than 50% humus inhibits uptake of polluting heavy metals (lead) cities; less than 7% may not improve soil structure *unless* calcium is added.

Carbon combines with oxygen to form carbon dioxide gas, which is released from agriculture, forest felling, and industry to create the greenhouse effect and subsequent earth heating; this may be a critical adverse factor for human survival on earth. Plant trees, do not use bare fallow, and add humus to soil. Carbon in soils is about 58% of organic matter (combustible), existing mostly as colloids (assess nitrogen and multiply times 20 to obtain the carbon content of soils).

7. **Nitrogen** (N) is a major plant nutrient, 80% of the air itself. Legumes and many non-legumes (alder, *Casuarina*) that have root associates (fungi, bacteria) will fix nitrogen from air if molybdenum is present as a catalyst to convert nitrogen to ammonia. Nitrogen as a foliar spray of urea can, however, increase the protein content of grains such as rice by 40%.

Nitrogen is part of all amino acids (hence proteins), of chlorophyll, and of enzymes. It is very mobile in plants, and has dominant effect on other nutrient use, or uptake. Plants absorb nitrogen in the form of nitrates or ammonium, and the plant coverts this to ammonia to create proteins.

In water or with bacteria, nitrogen forms NITRATES which at low levels are benefical, but at high levels (more than 80 ppl) are lethal to young animals and children. Also, mouth bacteria and sewage bacteria turns nitrates into NITRITES, hence NITROSAMINES which are cancer-associated. Nitrates are building up in all soil waters below agricultural land, and occur naturally in many desert bore waters. Thus, fertilise plants in the garden at *minimum* nitrogen levels; do *not* use heavy doses of nitrogen fertilizer, but rather a modest legume interplant. Check water levels for human health, especially in deserts.

Too much animal manure also releases surplus nitrogen. Thus, *reduce* cattle and run them on pastures, *not* on feedlots. Dispose of sewage in forests to aid in tree growth. Constantly measure nitrate levels in leaves, water, soil. In particular, do not inflict high nitrate levels on people with malnutrition; they can be killed by an excess of nitrate in their food. Accepted levels in Europe (E.E.C. standard) are 50 mg/l in water (50–80 ppm). These levels are being exceeded where nitrate fertilisers and even natural manures are spread on soils; ammonia from cow dung is now 115,000 t/year in Holland, accounting for 30% of the acid in rain from Dutch sources (*N.S.* 6 Feb '86). In humid areas, 70% of human intake is from vegetables, and 21% from water.

SOME NITRITE (OR NITRATE) LEVELS (ppm):

0–50	Safe for human consumption
500	Spinach grown from compost
2,000–3,000	Chemical fertiliser-grown spinach

8. **Oxygen** is a necessary for respiration (energy release in blood). Soils also need oxygen (air) and thus good open structure and soil pores as 12–30% of the soil bulk. Aeration in soils is achieved by using calcium, trees, worms, ripping, humus, or sometimes by blowing air through sub-surface irrigation pipes. WATER-LOGGING reduces pore space and thus root oxygen. Crops such as walnuts, oranges, chestnuts, and potatoes require deep loose soil and plenty of oxygen. Pear trees and marsh grasses (Yorkshire fog, Imperata grass) require much less oxygen and can grow in more compacted or wet soils. Soil loosening and draining (conditioning) improves oxygen supplies to soils. Soils need to have good open pore spaces to 1–2 m (3–6 feet) deep. Large soil pore spaces are only achieved by soil life and perennial crop.

9. **Fluorine**. Although beneficial in small amounts, as in seaweed fertiliser, it is a serious poison at high levels. It is commonly found in bore water, or in downwind pollution plumes from metal processing works (zinc, aluminium, copper), causing bone deformation in animals, stunted growth, and serious metabolic disturbance. Check water, especially bore water, for high levels and use tanks for drinking water. Fluorine is useful at very low trace levels **only**. Surplus can cause anaemia; high levels are found in (e.g.) marine phosphate deposits, hence fluorine can be high in fertilisers derived from these.

The fluorine level sufficient for normal growth and bone develoment is about 1 mg/day. Tea drinkers ingest this from tea leaves; as the chief source is in water, 1 mg/l (1 ppm) is sufficient. Seafoods (fish, oysters) can contain 5–10 ppm fluorides.

Problems of excess flourine occur where dusts from mineral processing fall out on vegetation, where "hard" waters (common in deserts) contain more than 1 ppm fluorine (actual levels can reach 14 ppm) and where diet is mainly seafood. The bones, spine and ligaments can become calcified in areas where excessive flourine is present in the diet. Teeth may be "case-hardened" by flourine, and show little outer sign of decay while the tooth itself rots.

11. **Sodium** (Na). With chlorine, it makes up common salt. At low levels, it is necessary to plants and animals, cell health, and function of the nervous system. At high levels, sodium causes collapse of soils and loss of pore space, displaces calcium and disperses colloids. Beets and some other crops need adequate levels, likely to be absent or low in wet tropical uplands only. Elsewhere, enough sodium comes in with rain as salt crystals in raindrop nucleii. Real problems occur when soil salts are mobilised by irrigation, potash fertiliser, or soil flooding in dryland areas. Excessive salt causes circulatory and kidney problems in people, especially those in sedentary occupations. Salt in vegetable cooking water blocks uptake of some heavy metals on plant proteins, so if lead pollution is suspected, add salt to cooking waters.

12. **Magnesium** (Mg) With calcium it is found in DOLOMITE. It is needed by plants, and common in most subsoils. It forms the central atom of the chlorophyll molecule, activates enzymes, and concentrates in seeds. Like nitrogen, it is very mobile in the plant. Magnesium is likely to be deficient only in sands and sandy soils; it is present in the clay fraction of soils, and is released by soil acids and humus. It is supplied by dolomite application on farmlands, as tablets of dolomite for animals, and mixed in animal foodstuff. Magnesium carbonate from dolomite buffers plant and soil acids, as does lime, but it can cause plant poisoning if not balanced by high lime (calcium) levels.

Magnesium is essential for chlorophyll and in the mitochondria of human cells, hence energy metabolism. It is present in all green plants. Deficiencies do not normally occur where people are healthy and are not subject to diarrhoea; when required by people it is given as an intravenous fluid at 10 minimoles per kgm bodyweight.

13. **Aluminium** (Al). A "Jekyll and Hyde" element, it forms a large part of soils and red clays (with iron), or as poorer bauxitic dryland deposits. It is poisonous as aluminium sulphate, formed in acid rain or sulphur-polluted soils, e.g. in industrial areas, and is also released when cooking onions in aluminium cookware! Heavy aluminium silica uptake in humans may assist the development of senile dementia, thus *calcium* in the soil and as tablets is a partial defence. Some areas are naturally high in acid-aluminium soils. An adequate level of calcium is needed in all gardens, and even in rainwater tanks (as marble or limestone chips, whole sea shells, gravels of lime).

Avoid aluminium utensils (use iron, enamel, stone, steel) if cooking salty, acid or sulphurous substances (vinegar, onions). Soluble aluminium in concentrations of 0.1 to 1.0 ppm is tolerable, but above this level susceptible plants start to die. At 15 ppm or higher, many plants die.

14. **Silicon** (Si) is an important part of cell walls in many grasses, bamboo, and is essential in soil cation exchange capacity of deep, red, heavily-leached tropic soils (an application of cement dust can assist this exchange). Pine trees and conifers generally are poor nutrient recyclers, and can produce nutrient-deficient silica soils under their litter, thus losing calcium and other elements to leaching. Therefore, use grasses and broadleaf, leguminous, or soil-building trees with conifers. Many trees deposit salt, phosphorus, manganese, zinc, potash, etc. at high topsoil levels due to good nutrient recycling *via* leaf fall. Silica is normally at 20–40 ppm in soil waters, and in highly alkaline, wet, warm areas can be leached away altogether, hence the use of cement (calcium silicate) to restore some silica to plants; in such areas, **tree crops** are the only sustainable solution.

Silicates make up much of the bulk of normal soils, but very high silica in rock may produce acid soils in high rainfall areas (silicic acid). Bamboos are good sources of calcium and silica as a garden mulch in the tropics. In ponds, diatoms need silica to proliferate; these are an excellent fish food.

15. **Phosphorus** (P) (as phosphate) is an essential, common plant element, recycled by many trees and fixed by the root associates of several trees (*Casuarina, Pultenea, Banksia*), by algae, in the mud of ponds, in bones, and in freshwater mussels. High phosphate levels in bird manures are derived from fish bones and seeds. Phosphorus is essential to the energy metabolism of plants, hence photosynthesis and respiration. Cell divison, root development, and protein formation are regulated by phosphorus. It is highly mobile in plant tissue.

In some oceanic guano deposits, phosphates can be contaminated by cadmium, mercury, uranium (40 ppm) and fluorides. All heavy cropping demands phosphate for production, and there is a general world soil phosphate deficiency, especially in poorer countries. Most western soils are now over-supplied, with a very large unused soil bank of phosphorus, hence with the pollutants of phosphatic rock. Cadmium levels in inorganic market garden crop may commonly exceed health limits.

Bird islands, areas of recent volcanic ash, and some soils over phosphatic rocks are not phosphate-deficient. Sandy, bare-cropped, wet, and water-logged soils, old soils, and alkaline soils may show deficiencies. On the latter, try sulphur to adjust availability. Super-acid phosphates are used to make phosphate available to plants, albeit expensively. Most soils (superphosphated since the early 1950's) may have 750 ppm in the top 4 cm, and most of the rest of the applied phosphate is bound up and unavailable in the top 20 cm. Only on deep, coarse, leached treeless sands with heavy rains or in bare-soil fallows is a lot of phosphate lost. Drainage water contains 0.2 ppm in clay or loam soils, a minute loss. In natural systems, phosphates are supplied by fish and bird manures.

Calcium, iron and aluminium immobilise phosphate; a pH of 6–7.5 releases it. Basic superphosphate (phosphate and lime) finely ground is available (soluble) to plants. The home gardener can use bone dust, phosphate and lime, and mulches, which are all effective. About 45 ppm phosphate in soil is needed for grains (optimum pH 6.0–6.5). Pelleting seeds with basic superphosphate provides phosphorus. In soils, phosphorus combines with iron, aluminium and calcium as insoluble compounds, and with living materials or humic compounds as "available phosphorus". Despite folk stories to the contrary, superphosphate has not been found to acidify soils (unlike ammonium sulphate).

Phosphate levels ("native phosphate") fall with depth, and are low in most subsoils. Generally, to increase phosphate availability, try humus in warm wet areas, sulphur in drylands, and adjust pH elsewhere with calcium (lime or dolomite). For trees, apply light phosphate dressings regularly in sands. Phosphorus deficiency reduces growth in animals by depressing their appetite for herbage.

Of all the elements of critical importance to plants, phosphorus is the least commonly found, and sources are rarely available locally. Of all the phosphatic fertilisers used, Europe and North America consume 75% (and get least return from this input because of overuse, over-irrigation, and poor soil economy). If we really wanted to reduce world famine, the redirection of these surplus phosphates to the poor soils of Africa and India (or any other food-deficient area), would do it. Forget about miracle plants; we need global ethics for all such essential soil resources. As long as we clear-cultivate, most of this essential and rare resource will end up in the sea. Seabirds and salmon do try to recycle it back to us, but we tend to reduce their numbers by denying them breeding grounds.

Unpolluted phosphate deposits are found only in limited areas, in sedimentary rock. Trees do mine the rare phosphorus released by igneous rocks, and they are responsible for bringing up phosphorus to the topsoil wherever it is rare in more shallow-rooted plants.

About 15–20% of the inessential use of phosphorus is in detergents. The older potash soaps are the answer to that sort of misuse, or the recovery of phosphorus from greywater rather than a one-way trip via a sewer to the sea. Uncut forests may lose 0.1 kg/ha/year, while clear-cropping can lose 100 kg/ha/year or more, a 1000 times increase in lost minerals, never accounted for in logging and clearing, or added to the cost of woodchipping and newspapers.

Phosphorus is found concentrated in seeds and in the bones of vertebrates, especially fish, in mussels (freshwater) and the mud they live in, and in the manures of animals eating fish, seeds, and shellfish. Bone meal from land animals is a traditional source, and most farms (up to 1940) kept a flock of pigeons as their phosphate factory, while in aquatic cultures, phosphorus was recovered from the mud of ponds stocked with mussels and from fish and waterfowl wastes. Bat guano is also a favoured source of phosphate in Holland. Even a modest perch in a bare field will attract a few perching birds to leave their phosphates at a tree or along a crop line.

Conservation farming (Cox and Atkins, 1979, p. 323) loses about one-half to one-third the phosphorus of contemporary agriculture, even without non-tillage. Non-tillage farming would lose even less, but is rarely assessed except in dollar yield terms. Bioregional farming, and home gardening with wastes returned to soils would lose even less; and finally, regional food supply, waste recycling, and a serious consideration of devoting 30% of land surface to trees might just be a sustainable system. Next to clean water, phosphorus will be one of the inexorable limits to human occupancy on this planet. We must not defer solving these problems or conserving our resources any longer, or we betray our own children.

16. **Sulphur** (S). Many anaerobic bacteria (thiobacilli) fix sulphur, which is why anaerobic ferment of plant and animal materials is rich in the sulphur-based amino acids, and of high nutritional value. The sulphur oxidised by anaerobic bacilli also removes, as

insoluble sulphates, most heavy metals from such flow–through systems as sewage digesters. Some thiobacilli occur in all warm wet soils, and many can operate down to pH 1.0! With ammonium sulphate, soils tend to become acidic and so reduce plant yields. Sulphur is used in drylands to reduce pH and so make iron, zinc, and trace elements available. Clover, in particular, may show sulphur deficiency in the sub–tropics (wet summers).

Sulphur is part of all proteins, and is present in the body as the two amino acids methionine and cystein. The vitamins thiamin and biotin contain sulphur. Food intake by people is from the amino acids, and deficiencies do not occur if meat protein is sufficient, or if anaerobic ferment of leaf materials is part of food preparation. Many vegetarians get their animo acids from yeasts or bacteria rather than from fresh plant material.

17. **Chlorine** (Cl) was used as a war gas, and today to "sterilise" waters; it is a dangerous gas to inhale. Chlorine is used by plants, and is normally available as salt. It is a trace element, and used only in minute amounts. It concentrates in crop, e.g. 350 ppm in soil gives 1000 ppm in crop. In water, and in contact with organic materials, it releases chloroform, a carcinogenic gas. Avoid chlorinated water if possible!

19. **Potassium** (K) is used in large quantities by plants. It is usually plentiful in arid areas. Potassium is deficient on sandy, free–draining coast soils. Not much is removed by livestock, but potatoes, beans, flax, and the export of hay may remove soil reserves to below plant needs. It is readily absorbed on colloids, and is usually plentiful in clays, especially illites, **not** in kaolin. Gardeners add ashes, bone, natural urines and manures or green crops for supply to heavily cropped ground.

Earthworm castings commonly concentrate potash (at 11 times soil levels). Excess potash fertiliser can greatly increase soil sodium, and so block calcium uptake; beware of this in alkaline or dryland soils.

20. **Calcium** (Ca) is needed in all soils, and is removed by sodium in drylands. Even where calcium exists in an alkaline area, sodium may suppress its uptake by plants. Sometimes, gypsum is applied (30 tonnes/ha) and the excess sodium then removed by flushing out as sodium sulphate. Plants need large amounts of calcium. It is an essential part of cell walls, enzymes, and in chromosome structure.

The proportion of the four major ions in ideal agricultural soils should be about: Calcium: Magnesium: Potassium: Sodium (50:35:6:5)

Note that adding potassium can increase sodium, that sodium is antagonistic to (displaces) calcium, and that magnesium ions should always be less than calcium ions. Do not add too much dolomite if soils (as clays) already contain adequate reserves of magnesium.

Many peoples have lactose intolerance and cannot get calcium on a milk diet, so lime or dolomite on gardens or as tablets may be needed. Calcium is lost (excreted) in stress, and needs replacement after periods of prolonged stress. Low calcium areas produce predominantly male farm animals and humans (as a primary sex ratio), and lack of calcium produces skeletal and metabolic malfunction.

Calcium phosphate is the chief mineral constituent of bones. Bony tissue is always losing and gaining calcium, but older women, in particular, suffer bone fractures from loss of calcium in the ageing process; immobilised limbs also lose calcium. Gross calcium and vitamin D deficiency results in rickets.

22. **Titanium** (Ti) is not a nutrient, but in sands and the presence of sunlight it acts as a catalyst to produce ammonia for plants, often combined with iron (TiFe) (*N.S.* 8 Feb 79, 8 Sep '83). Ammonia is provided at 50–100 kg/ ha/year. Rain and moist soils make this available to plants—a useful desert strategy.

24. **Chromium** (Cr) is a poison to plants and animals, occurring in serpentine rock. It is used in the preservation of timber, and is to be guarded against from electrolytic and leather works as it poisons active biological agents in sewage works. It is easily removed or recycled at the source.

As some chromium occurs in all organic matter, it is in fact a trace element, related to glucose tolerance in humans, and necessitating insulin if absent or in very low quantities. Very little firm knowledge of the metabolic function of chromium is available.

25. **Manganese** (Mn) is a readily available trace element on acid soils, except in sands. It may cause manganese poisoning below pH 6.5. On alkaline soils, or when pH exceeds 7.5, it may be deficient in grain crop or vegetables, but seed soakage, seed pelleting, or foliar sprays supply this nutrient. Even flooding at periods will mobilise manganese. A typical deficiency situation occurs on poor sands heavily dressed with lime.

Bacteria fix insoluble manganese, and can create problems in pipes and in concrete water raceways even at 2–3 ppm manganese. Aluminium sulphate (from acid rain on soil) may mobilise manganese, mercury, cadmium to lethal levels. Manganese leaches out of acid soils, deposits in alkaline horizons as manganese–iron concretions, and on sea floors as larger nodules.

26. **Iron** (Fe) is normally plentiful in soils, and is a critical element for plants and animals. Plants can show iron deficiency symptoms in alkaline drylands or on heavily limed garden soils. Sulphur in gardens, or iron chelates, remedies this situation; iron can also be added as small amounts of ferric sulphate. Deficiency causes interveinal leaf yellowing in plants, and low blood iron in people (anaemia). Ferrous iron spicules in soil assist the formation of ethylene. Ferric iron (oxides) are "unavailable" (F_2O_3). Iron concretions and iron staining in sands are often associated with microbial action along plant root traces. Iron–deficiency anaemia in people is a common problem in deserts, or after blood losses in menses or dysentery.

In humans, blood iron is as important in energy

transfers as is copper in invertebrates. Deficiencies are normally rare but must be watched in women of reproductive age, when lack of iron is widespread and causes ill-health and lassiitude; anaemia also occurs in infants and children. Meats such as veal, liver, and fish eaten with soya beans, lettuce, parsley, maize, etc. can provide dietary iron. Meat and ascorbic acid (vitamin C) increase iron absorption from food. Iron in bone marrow is needed for new blood cells. Clinically, ferrous salts ingested can be used in cases of excessive blood loss.

People brewing beer and wine or cooking cereals in iron pots often ingest excess iron. Alcholism and diabetes exacerbate iron excess, although excessive iron is an unusual condition.

27. **Cobalt** (Co) Copper and cobalt can be deficient on poor coastal sands. Cobalt is necessary to many legumes, and especially needed by livestock, who are "unthrifty" if it is deficient, as it can be in highly alkaline areas. Only an ounce or two per acre is needed, and this can be supplied as a cobalt "bullet" in the rumen of sheep.

Cobalt is necessary for synthesis of vitamin B_{12} in ruminants; if deficient, further metabolic problems then occur. Often diagnosed via B_{12} tests on blood levels. Deficiency can cause anaemia. Toxicity can occur if excess is ingested. Radioactive cobalt is a serious poison.

28. **Nickel** (Ni) is not noted as a plant nutrient or poison, but with copper can intensify poisoning in people, e.g. in office rooms using urns, or in mining areas. Many people demonstrate skin reaction (rash) if nickel is used as bracelets.

29. **Copper** (Cu) is a necessary micronutrient which can become a poison at higher concentrations. Copper in plants is an enzyme activator, and is concentrated in the chloroplasts of leaves. Copper is deficient on shell-grit dunes, acid peaty soils, coastal heaths over poor quartzite sands, and in deeply weathered basalts. Black sheep are good indicators, and if deficient develop whitish or brown wool, or white-coloured sheep will grow "steely" wool. Copper sulphate at 1 kg/ha every 5 years is a cure. Old stockmen put a few crystals into water-holes. Deficiency (with iodine) can lead to goitre (thyroid inbalance) and anaemia in animals. Levels above 12 micromoles/l are excessive in drinking water. High blood copper levels in deserts are often as a result of zinc deficiency.

While copper deficiency is rare or absent in adults, copper toxicity is of more concern especially where copper sulphate is used to clear algae from drinking water, and also from foods or water standing in or boiled in copper utensils and pipes. Copper poisoning is serious, with liver deterioration (cirrhosis) and brain effects (tremors, personality changes). Once hopeless, such cases can now be somewhat alleviated by chelating agents.

30. **Zinc** (Zn) is deficient on leached sands, dunes, alkaline sands, and supplied by zinc sulphate spray on plants or zinc salts in seed pellets. It should be tested for in all desert gardens. Zinc is critical for both tree establishment in many deserts or dunes, and to human health, and is cheap to supply. In plants, zinc is essential to the growth control hormones.

Zinc deficiency causes gross metabolic imbalances and stunting of growth. People with malnutrition often have low zinc blood levels and poor wound healing. Diabetes is often linked with zinc deficiency. Excessive zinc acts as an emetic, causes vomiting and weakness.

Zinc is necessary to several enzymes in the body; prostate (hence seminal) fluids are high in zinc. Diets of coarse grains, unleavened bread, and low meat intake contribute to zinc deficiency in poor people, especially in high-calcium soils. Oral zinc sulphate can be given clinically. Alcoholism and diabetes, feverish sweating and stress all lower zinc levels. Severe deficiency causes hair loss, moist eczema of the mouth area, impotence, apathy, diarrhoea.

33. **Arsenic** (As) sometimes seems to be needed by horses, and is included also in chicken pellets, but is a poison to animals even at slight concentrations. Polluting sources come often from gold processing areas, or from chickens fed on pelleted foods containing high arsenic levels.

34. **Selenium** (Se) deficiency in lambs causes "white muscle" or "still lamb" disease which is cured by selenium and vitamin E injection. It also causes "ill-thrift" in animals in many countries where a severe dietary deficiency occurs. Five mg/year is sufficient for sheep; more can cause toxicity. Seaweeds may supply sufficient selenium to gardens.

38. **Strontium** (Sr) is becoming, as a long-term and very poisonous radioactive element (Sr90), a widespread danger from atomic plants. It now pollutes many areas, milk, and is being used as a "blackmail", e.g. in New York water supply in 1985. One of the great pollutants of the future, it causes cancer at absorption site, leucaemia in children, and is a "hidden cost" (very hidden) of the atomic age. It is excreted in urine of breast-fed babies, and concentrates 4–8 times in cows' milk, thus levels in cows' milk must be monitored after atomic fallout. There are no safe levels. Ordinary strontium is a trace element.

42. **Molybdenum** (Mo) is a trace element for clover establishment, and needed by all plants, rhizobia. A few ounces per acre is used on many acid soils, and rarely again needed. It is locked up not by alkali or lime but by sulphuric acid, and may therefore be deficient in plants subject to acid rain. Legumes need molydenum for nodulation, but non-legumes deficient in molybdenum can concentrate dangerous levels of nitrates, causing "leaf burn".

48. **Cadmium** (Cd) is a poison that is concentrated by green leafy plants and shellfish. It is derived from traffic (tyres) and superphosphate. It may already be in very high levels in acid soils of market gardens using artificials (as it is in Canberra). Cadmium causes painful human disease *itai-itai* (Japan) and permanent deformations.

50. **Tin** (Sn). Ores and wastes create plant

establishment problems. It is not noted as toxic at low levels in diets, but can become toxic at high levels in canned food.

51. **Antimony** (Sb) As for arsenic.

53. **Iodine** (I). Deficiencies occur in weathered basalts, causing growth problems and goitre; these are remedied by fish and shellfish, seaweed diet. I131 now a common radioactive fall-out from atomic plants and tests; it poisons milk over wide areas, and affects thyroid function. Iodine can cause cancer, death of children from hyperthyroidosis; a real risk from atomic establishment and tests.

80. **Mercury** (Hg) is a common poison released by mines, metal processes, acid rain, and is more active in organically polluted areas. It creates very serious coordination and sanity problems, central nervous system malfunction, bone deformity, insanity.

81. **Thallium** (Tl) is a toxin, causing birth deformities, thus very dangerous.

82. **Lead** (Pb) is a common poison from petrol, old paints, battery burning. It is a serious urban soil pollutant, needing heavy organic soils to block uptake, or removal of lead-concentrating vegetation for disposal. Earthworms may concentrate lead to lethal levels in polluted soils.

86. **Radon** (Rn) is a gas from the decay of uranium. Seeps up in most soils, especially over volcanic areas, igneous rock, and can pollute super-insulated buildings if the air is not exchanged. Several million homes in the UK and USA have high levels of radon. Avoid building poorly ventilated homes in areas of radioactive ores, granites, and basalts, or the use of such rocks or crushed metals in buildings. If houses are to be super-insulated or draught-proofed, then adequate heat exchangers must be fitted to bring in clean air.

[...from page 188]

(soaking), or by being pressured upwards by an aquifer flow in permeable sediments.

• Water travels by throughflow, traveling by the effects of gravity downslope in the profile.

This latter effect produces soil types called *catenas* specific to slope, drainage, rock type, and landscape (**Figure 8.3**).

INFILTRATION effects are most marked in soils where, for very long periods, a succession of light intensity rains have alternately wetted and then dried out in the soil. At the wet-dry boundary we find concentrations of easily soluble salts and deposits of minerals and nutrients (sometimes in over-supply).

The second set of effects on element transport are biological. Elements are actively sought out or selected, and either concentrated or dispersed by living organisms. These effects are myriad in total, but some of the ways this is known to happen are:

• CONCENTRATION BY SELECTIVE SPECIES of fungi, bacteria, and invertebrates which can seek out, assemble, and change specific compounds to stable new forms as concretions or nodules. Iron, iron-manganese, calcium, phosphate, zinc, nickel, copper, selenium, cadmium, phosphate and nitrogen are all so selected and concentrated by one or other form of mycorrhiza (root fungi), bacteria, molluscs, or algae.

• CONCENTRATION BY ACCUMULATION OF DETRITUS. Diatoms, swamp peats, whole forests, sponges (and their spicules of silica), molluscs, and vertebrates are at times buried by vulcanism, sedimentation, or deposition in oceanic deeps to form specifically concentrated sediments, and eventually ore bodies or rock types (coal, rare earths, or manganese deposits).

• DISPERSAL BY TRANSPIRATION. Many water plants seem to be able to dissociate and transpire a great variety of substances to atmosphere. Reeds do this with mercury, hydrogen, and other elements from phosphates to chlorine. Not all of these are vapourised to drift off in the winds; many are deposited in special leaf repositories, or evaporated to a wax, dust, or efflorescence on the leaves and stems of trees, from where they are washed down again to earth by rain throughfall. In this way, both major plant nutrients and minor elements are concentrated in the top 4 cm (1-2 inches) of soil below trees. Metals, oxides, halogens, acids, alkalis and salts are also concentrated.

• CONCENTRATION BY METABOLIC PROCESSES. We build our bodies up by ingesting a large range of complex foods, as do all living things. From these ingested bodies, materials are selected to build our bones, flesh, blood, and brain tissue or organs, nails and hair, fats and milk. Thus, our own bodies and those of other animals are complex storages of elements; even our faeces package very different concentrations of potash, nitrates, and pollutants from the different concentrations of foods that we eat. And, by our behaviours, these are variously disposed of in a personalised, culturally-determined, or species-specific way in the environment. Plants and animals ceaselessly ingest and defecate, refect and exude over their whole lifetimes, thus altering the concentration of nutrients in their immediate environment.

8.8

pH AND SOILS

Of the parent rocks of soils, we speak of ACID rocks as containing 64% or more of silica (SiO_2), INTERMEDIATE rocks at 50-64%, BASIC at 40-50%, and ULTRABASIC at less than 40% silica. Of soils themselves, we speak of acidity and alkalinity in terms of a logarithmic scale, in which each point is 10 times the concentration of hydrogen ions less than the scale point below it, so that pH 8 (alkaline) is 10 x 10 x 10 x 10 or 10,000 times *less* acidic than pH 4, and pH 3 ten

times *more* acidic than pH 4.

Table 8.3 serves to portray the availability to plants of some important elements with respect to pH value.

ACID AND ALKALINE WATERS AND SOILS

We commonly speak of "hard" (alkaline) or "soft" (acid) waters. The latter used with soap lathers easily, and is desirable for washing; the former (including seawater or other alkaline waters) is difficult to use for washing, as soaps and detergents are themselves alkaline and so do not easily dissolve in other alkalis. Soaps, based on sodium or potassium (ash) and fats will lather in soft acidic waters, and detergents based on phosphates or sulphur, lather in hard waters. Hard waters contain calcium (Ca^+) or magnesium (Mg^+) ions. Soft water contains hydrogen (H^+) ions.

The properties of alkali (soaps or carbonates) and acids (vinegar, citrus juice) have long been recognised and used medicinally or in village chemistry. The word for deserts in Arabic is *al khali* ("the salt").

Acids and alkalis arise from the solution of oxides, hydroxides, sulphates, or carbonates of metals and non-metals. In water and soil water, the common rock

TABLE 8.2
NUTRIENTS IN SOIL AS MINERAL CONTENT.

PRIMARY		SOURCES (Compost generally, rock dusts)	COMMENTS by crop	Removed in Soil (Kg/ha)	Available in soil (kg/ha)	Insoluble (Kg/ha)
N	Nitrogen	Legumes, water plants, urine,	Basic to crop growth.	100	20-200	1,000-10,000
P	Potassium	Ash, leafy materials, kainite, bone meal.	Basic to crop growth.	100	40-200	5,000-50,000
K	Phosphorous	Bones, bird manures. Found in super-phosphate (acid-treated bone or rock phosphate.	Basic to crop growth.	20	20-100	1,000-10,000
S	Sulphur	Elemental Sulphur, Volcanic mineral deposits, swamps.	Adjusts pH towards acid.	30	50-100	100-10,000
Ca	Calcium	Limestone, some crops (e.g. buckwheat), dolomite.	Adjusts pH toward alkaline.	40	100-5,000	10,000-100,000
Mg	Magnesium	Dolomite		20	100-1,000	2,000-100,000
MINOR (TRACE) ELEMENTS		(Seaweed concentrate generally, sea algae)				
Fe	Iron	(All of these are needed in minute amounts, and either	Likely to be deficient (with Mg) at high pH.	0.5	10-200	2,000-100,000
Zn	Zinc	made available by adjusting pH or by adding oxides, sul-	Likely to be deficient in dunes.	0.2	2-200	100-10,000
Cu	Copper	phates, or sodium salts of the element itself. Most are	Likely to be deficient in coastal plain pastures.	0.1	1-20	2-200
Se	Selenium	present im seaweeds, or	Frequently deficient.	0.01	0.002-1.0	0.5-5.0
Bo	Boron	seaweed concentrate.)	Frequently deficient.	0.2	1-5	4-100
Mb	Molybdenum	Deficient in deep, volcanics.		0.01	0.002-1.0	0.5-10
Co	Cobalt			0.001		

MULCH OR COMPOST OF MIXED MATERIALS SUPPLY ALL NUTRIENTS, plus if available, 200g dry pulverized poultry manure per square metre. Gross deficiencies are likely to occur in the primary nutrients; calcium and phosphates are usually low in old or leached or overworked soils. Rock dusts add potash, limestone adds calcium, dolomite for magnesium, and tree or clover legumes for nitrogen. Manures add most of these except calcium.
N:P:K is ideally added in a 5:8:4 ratio, for sandy loams with 5 parts of lime to balance acidity. In a 5:6:6 ratio for clays.
Fertilizer can be added as manure teas sprayed on leaves, with seaweed concentrate, and in humid weather this is absorbed in from 24-56 hours.

and soil constituents are:

• Metals: Sodium, potassium, magnesium, calcium, and minerals (iron, zinc, aluminium, copper).

• Non-metals: Silicon, sulphur, traces of phosphorus, boron, fluorine, chlorides. Carbon is also found in organic soils.

In solution, metals release positive (H) ions. Nonmetals release negative (OH) ions. Chalk, limestone, calcite, dolomite, magnesite, and gypsum are rocks and minerals giving rise to hard water (from air and water which gives carbonic acid). All of these are carbonates, sulphates, or oxides of calcium or magnesium, or both, e.g. dolomite.

All these below are used to raise pH values in soils:

• CHALK and LIMESTONE are calcium carbonates.

• GYPSUM – calcium sulphate.

• MAGNESITE – magnesium carbonate

• DOLOMITE – calcium magnesium carbonate

In the table of elements (Centrefold), groups I and II

TABLE 8.4
SOIL AMELIORATION: A BASIS FOR TRIAL PLOTS

SOIL	LOCATION CLIMATE	pH 11<---------- ALKALINE	7 ----------> 4 ACID
SANDS	General	Add magnesium sulphate as spray at 10 g/L, or at 45 g/m^2.	Add Dolomite (for Ca, Mg) at 100-300 g/m^2 (Neutralise with lime 20g/m^2)
	Humid	Add ammonium sulphate or fine dolomite (for Ca). Add zinc every 7 years at 1 g/m^2. Add water-retaining polmers.	Add water-retaining polymers, add gypsum, sulphur. Use copper-based sprays sparingly. Add neutralised superphosphate (for P).
	Non-wetting	Add 10 g/m2 bentonite or monmorillinite clays, polymers,	Add bentonite, polymers.
	Deserts	Add ferrous sulphate (for Fe) at 23 g/L as a foliar spray. Add polymers.	Add dolomite, gypsum, polymers.
	Coarse	Trial Cobalt sulphate at 0.11 g/m2 or foliar sprays of cobalt.	Add potash . Trial neutralised cobalt.
	Wet areas	Use rock phosphate, dolomite.	
	Coastal	Add copper sulphate (for Cu) every 7-14 years, if cropped, at 1 g/m2. Add zinc sulphate (for Zn) every 7-14 years at 1 g/m2. every 7-14 years.	Add neutralised copper sulphate (for Cu) every 7-14 years, if cropped, at 1 g/m2. Do not add sulphur unless absent. Add Zinc sulphate 2:1 with lime at 1 g/m2
LOAMS	Tropics	Add Silicate or spray silica solutions. (Calcium silicate) at 100-400 g/m^2.	Coarse textures in tropics. Add cement.
	Deserts	Add dolomite, gypsum.	
	Loams	Add potash if cropped. Add zinc sulphate	Addpotash if cropped.
	Coasts	Add copper sulphate 1 g/m2 every 7-14 years.	Add neutralised copper sulphate every 7-14 years at 1 g/m^2.
CLAYS		Acidify with sulphur , add manganese sulphate, at 2-3-g/L as spray. Molybdenum needs trials at 350 g/ha.	Add gypsum to improve drainage, reduce salinity in dry areas.
GRAVELS	Iron oxides present	Add copper sulphate at 1 g/m2. Immobilize phosphates.	Molybdenum at 350 g/ha every 10-15 years.
ALL SOILS		Blood and bone, manures, compost, acidic phosphate, urine for potash. Foliar sprays of seaweed concentrate.	Blood and bone, manures, compost, dolomite, seaweed, pebble dust from cement works.

contain the non-metals of which lithium, sodium, potassium, magnesium, calcium, strontium, and barium compounds give up alkaline (OH) ions to soils.

The usual soluble (solid) bases for alkalis are magnesium, calcium, potassium, barium, sodium, and selenium. The usual soluble (liquid or gaseous) compounds for acids are silica and sulphur based, or derived from humus.

The measurement of acidity–alkalinity (pH or hydrogen ion concentration) is basic to soil and water science, as it affects the availability (solubility) of other key or trace nutrients, and (at its extremes) the ability of life forms to obtain nutrition, or even to live.

The pH scale ranges from 0 (acid) to 14 (alkaline), although in nature we rarely find readings below 1.9 (lime juice) or above 11.0 (alkali flats). In the presence of air, and in ploughed and aerated soils, both metals and non-metals form oxides, and these dissolve in water or soil water.

The METALLIC OXIDES (bases) form alkaline solutions. The litmus reaction is *blue*. There is an excess of hydroxide ions (OH^-) present in solution.

The NON-METALLIC OXIDES form acidic solutions. The litmus reaction is *red*. Excess hydrogen ions (H^+) are present in solution.

Common acidic substances are citrus juices and battery acid. Common alkaline substances are sodium bicarbonate (baking soda) and washing soda.

As rain falls, carbon dioxide in the air combines with water to form weak carbonic acid (as in soft drinks); this helps to dissolve metallic oxides in soils, and to bring the minerals of rocks and soils into solution. Sulphur from industrial processing, or from pyrites in rocks or soil can form sulphuric acids, and these also aid the solubility of metallic oxides. Phosphorus and nitrogen can form phosphoric and nitric acids with water. Silica in soils dissolves to silicic acids, and chlorine to hydrochloric acid. Weak nitric acid is a plant growth stimulant (*New Scientist* 22 May 86). All of these acids, in *moderation*, are helpful in nutrient supply to plants.

pH is not a constant for soil or water. Not only does it exhibit diurnal or seasonal changes due to rain, growth, and temperature changes, but it is essentially a *mosaic* in soil crumb structure, on the surface of colloids, and at microsites. Further, pH exhibits vertical soil gradients, being more acid in surface mulches and more basic or alkaline where evaporation, wormcasts, and capillary action draw up bases to the surface of the soils (dry or wet-dry areas). Mosaics on a larger scale are imposed by slope, and both rock and vegetative types. As long as people are aware of this, and realise that root hairs can both create and seek out ideal pH environments if there are no gross imbalances, then gardens are likely to contain every sort of pH level *somewhere* in the soil.

Only by grinding mixed samples of soils to damp pastes, or measuring conductivity, can we "average" pH and obtain some idea of net balance, but (as usual) our measuring methods alter the thing we measure. If

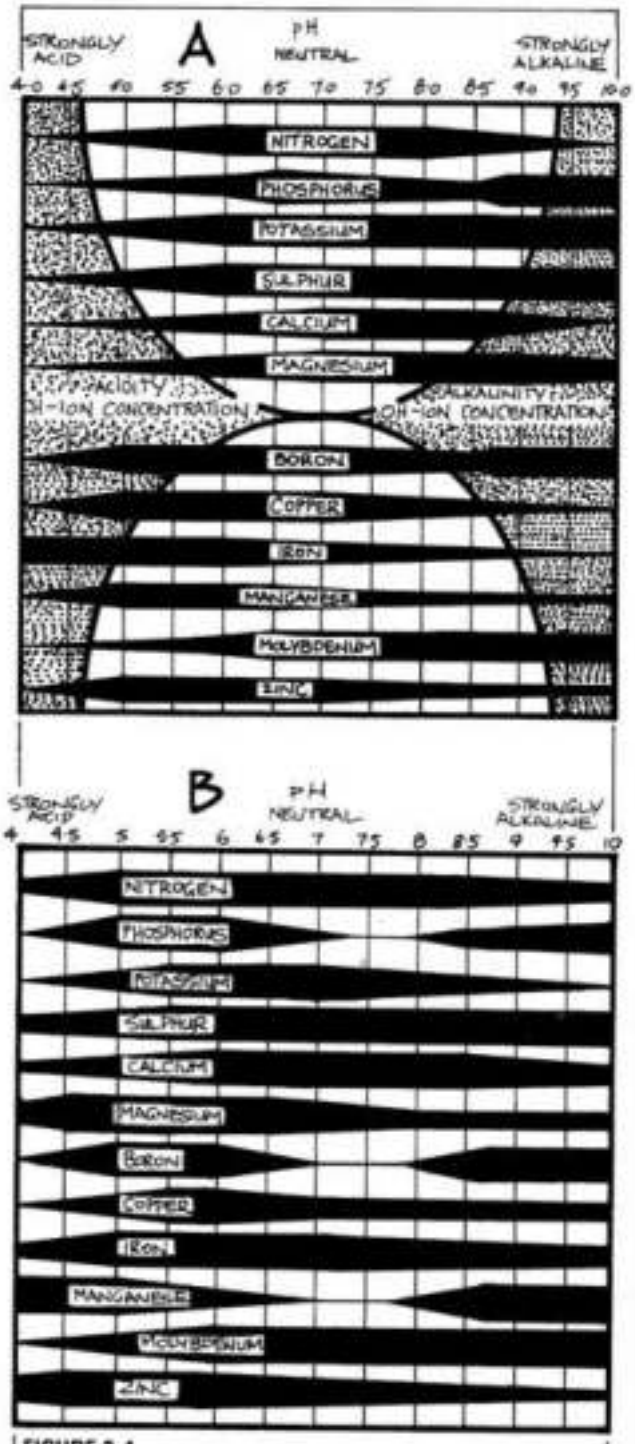


FIGURE 8.4
INFLUENCE OF pH ON AVAILABILITY OF PLANT NUTRIENTS
A In inorganic (mineral) soils. The widest parts of the black areas indicate maximum availability of each element. The curves represent pH values.
[After Nelson, L. B., (Ed.), *Changing patterns of fertiliser use*. Soil Science America, Madison, WI (1968)].

B In organic soils. The widest parts of the black areas indicate maximum availability of each element.
[After Lucas, R. E., amd J. F. Davis, 'Relationships between pH values of organic soils and availability of 12 plant nutrients', *Soil Science*, 92:17-182 (1961)]

we keep the average pH value to between 4.5 and 10, we can grow a wide range of plants and rear aquatic organisms *if* calcium is present. If we narrow the range to pH 6.0–7.5, most vegetables grow well in gardens. Outside these ranges (less than pH 4.0 or more than pH10.0), only specialised bacteria or higher organisms can cope. Moreover, soil humus is itself a buffer as is calcium (lime); humus will grow plants at satisfactory levels even if the pH changes, so that limed and mulched gardens rarely show plant deficiency symptoms.

8.9
SOIL COMPOSITION

We think of soils as mineral compounds, but the pie diagram in **Table 8.4** will alter that impression; it does not, of course, represent any one soil, but is an average sort of figure for a good loam with adequate humus. Outside the pie, I have noted some of the possible ranges of variation from peats to sands in old dunes.

THE HUMUS CONTENT OF SOILS

Soils in nature can vary from a humus content of 2% to close to 100% (as peats). In gardens, 40% or more humus helps block heavy metal uptake by plants, holding heavy metals bound in colloids. Many compost-fed or mulched garden soils contain 10–30% humus (some much more). The effect of adequate soil humus is both physical, in effecting good water retention and in preventing erosion, and chemical via colloid formation. The breakdown products of humus, including the mineral content of the donor plants, form the readily-available and biologically active components of soil that are of value to newly-established plants. If these plants are perennial or (in part) mulch-producing, and if we return food wastes to the garden (including urine and well-composted faeces) then very little humus loss occurs.

On the broad scale, humus can only be provided by the root and the above-ground mass of grasses, trees, and plants. Prairie grasses and broadleaf trees are particularly effective at this job. When we aerate (plough) soils we turn up humus and oxidise it to carbon dioxide, thence to atmosphere. It is lost. Burning the vegetation is worse, with a host of additional pollutants (terpenes, creosotes, nitrogen, and dust particles), and a rapid loss of soil humus. Where soils are not tilled or burned, soil humus lasts a long time (hundreds or even thousands of years) and provides for a complex soil life.

ORGANIC SOIL ADDITIVES

Mulching is here defined as covering the soil surface with 15 cm or more of organic material, as a loose (uncompacted) mulch; 8 cm of tight-rolled sawdust does not qualify! Mulching is more generally applied to loose dust "mulches", plastic sheet mulches, and so on, and these may have specific local value in soil amendment, heating, sterilisation, weed suppression, or pest reduction, but as here considered, the *object* of mulching is to add plant nutrients, buffer soil temperatures, prevent erosion, promote soil life, and restore soil structure.

Plastic mulches, soil gels (polyacrylamides), herbicide-treated soils, and organic or natural mulches may all achieve the result of preventing erosion and helping soil crumb structure develop. Only long periods of natural mulches stabilise nutrient supply, and complex the soil life. None can be judged over one or two seasons, as it can take 3–5 years to create a balanced soil under mulch from a compacted or mined-out soil. Even longer periods are necessary to develop humus in permanent crops assessed for yield on the broad scale, where added mulch is not carried to the site, but derived from tree wastes and specially-sown crop (green manures) produced on the site itself.

Used in areas such as wet tropics and arid lands, or on dry coarse sands, mulches may prove to be ephemeral (even if their effects continue), as ants, termites, and leaching reduce the mulch to humic acids or underground storages in fungi and bacteria. In particular, water absorption is improved under mulch, both as field crop mulch and imported garden mulch, thus water needs are reduced. Jeanette Conacher, in Western Australia's *Organic Gardening*, 1979, reporting on extension trials in Nigeria, records 11% better water infiltration on low- to no-tillage and mulched plots. Under mulch, excessive soil temperature ranges are buffered, being cooler by day and warmer at night or in winter. Seed germination is enhanced, and *over the long term*, major nutrients (N, P, K) remain at satisfactory levels. Only under mulch does the population of important soil organisms, such as earthworms, increase.

Mulches need some selection for minimal weed seed, minimal residual biocides, and for best effect on specific crops (tested as row-by-row comparisons).

Plastic mulches (black for heat and weed control, silver for aphid repellancy) have a more limited role, important in the short-term, but often expensive or impractical in poor countries, or rejected by growers who suspect that many plastics release persistent chemical polymers of unknown effect on the soil life.

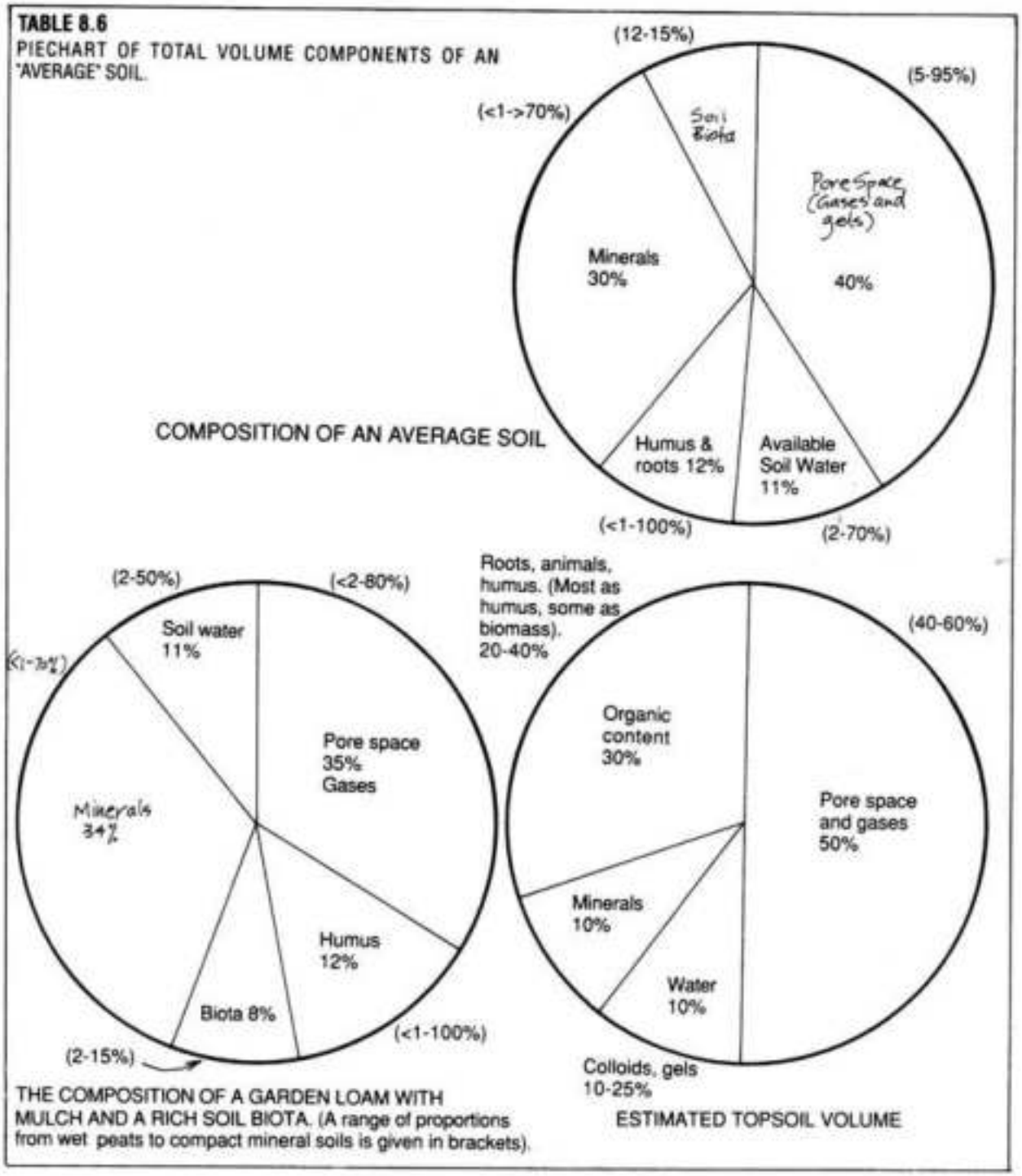
Mulch is an excellent way to add nutrients to soils; the "cool" decay loses little nitrogen, while stimulating soil life generally. There are some problems with compost, where "hot" (aerobic) heaps heat up and nitrogen (ammonia) losses are severe. Cold heaps (pitted or silage) do not lose nitrogen, but neither do they kill weed seeds. One percent of superphosphate added to a hot compost heap prevents ammonia escape. Chinese scientists get the best of both worlds by first building an aerated heap with bamboo poles as holes to create air tunnels. This is then covered with

mud and the heap heats up to 55–60°C (130–140°F) for a few days. Then all holes are sealed, and the rest of the decay is anaerobic. With sealed boxes, either hot or cold processes can take place.

Compost or mulch is critical to preserving soil crumb structure, buffering pH, and (in taste tests) improving sugar content and the flavour of vegetable product. The gums and gels produced by soil organisms create crumb structure, aerate the soil, and darken it so that it heats up faster in spring. The humic acids assist root development dramatically even at levels of 60 ppm carbon. Inorganic (chemical) and mechanical farming can as easily destroy soil structure.

In the U. K. (*New Scientist* 3 Nov. '79), liquid manures sprinkled on straw in silos or tanks, together with a forced air draught, produce compost in about a week (efficient open piles encased in straw need 10 days). The liquid effluent system plus straw is suited to treatment of a manurial sludge (still full of seeds) such as that we get from biogas digesters. It is best to use

TABLE 8.6
PIECHART OF TOTAL VOLUME COMPONENTS OF AN "AVERAGE" SOIL.



THE COMPOSITION OF A GARDEN LOAM WITH MULCH AND A RICH SOIL BIOTA. (A range of proportions from wet peats to compact mineral soils is given in brackets).

ESTIMATED TOPSOIL VOLUME

this with dry twiggy or straw material as hot compost to both kill weed seeds and to produce useful heat, after the compost pile has been made. However, in severe winter areas, such "efficiency" is counter-productive as a slower heat release from large compost piles of 10–50 cubic metres (12–59 cubic yards) can provide heat over a long period in winter and greatly reduce glasshouse and house heating costs, while the compost itself is best applied to soil in spring.

CARE IN SELECTION OF COMPOST MATERIALS

Even using organic residues, or "natural" wastes, soil problems can arise from a concentration of nitrates in manures, or toxic mineral residues. Leaf material cut and mulched (or composted) green will contain more nutrients than fallen leaves, although the latter are still useful for humus production. Kevin Handreck (*Organic Growing*, Autumn '87, Australia) has identified potential mineral contamination from these sources:

- Galvanized, copper, or brass containers containing wet residues of manures, or manurial teas; clay, stainless steel, glass, or iron are preferable. Zinc and copper are produced in excess from galvanized or copper/brass containers.
- Manures from pigs, poultry, cattle, or sewage sludges can add excessive copper, zinc, nickel, boron, lead, or cadmium to soils (and especially acid sandy soils).

Where such elements are naturally deficient, such manures may initially help, but heavy or constant application will build up a toxic soil condition. Excess zinc can be built up by using earthworm casts from contaminated pig, sheep, or domestic wastes. Animals penned in galvanized areas can produce excess zinc in pen wastes.

It is in poultry mixes that such contaminants show up, with excess zinc inhibiting plant growth and health, so that the urban gardener should test and use safe mixes, or proceed via plant trials. Handreck recommends a limit of 10% worm casts in a potting mix. In such cases, nitrogen and potash can be supplied by dilute urine.

Note that copper, arsenic, and other minerals are commonly added to stock feeds, and therefore try to buy clean natural feeds from organic sources. After initial soil treatment, and a continuing watch for foliage deficiency symptoms (see Deficiency Key, this chapter), the safest course is to grow our own green manures as the foliage of leguminous hedgerow, windbreak, or intercrop, and to use these as mulch and compost materials.

8.10

SOIL PORES AND CRUMB STRUCTURE

The structure of soil (whether compact or open) depends on the soil composition itself, the way we use it, and the presence or absence of key flocculating or ionic substances (synthetic or natural). Crumb structure in well-structured soils permit good gaseous exchange and free root water penetration without the creation of excessive anaerobic conditions by waterlogging. In free sands, and in the kraznozems developed over deeply-weathered basalts, crumb structure is either not a factor, or else is so well developed that it permits leaching (to immobile clay sites) of almost all applied fertilisers.

However, in most other soils, we would like to see a good crumb structure develop as in our gardens or crop soils. Where crumb structure is poor, we can use a great variety of coulter and rip-tine machines, soil additives, and deep-rooting plants such as trees or lucerne to re-open and keep open the soil structure, which in turn allows adequate water penetration and drainage, and eventually develops the oxygen-ethylene processes that make bound nutrients available.

Soil crumbs of 0.2–2 mm diameter can form as little as 10% of the total soil volume, and still produce crop; below this, crop is greatly reduced and impoverished. The same soils can, when not ploughed lifeless, contain 92–95% of such crumbs (Leeper, 1982). We destroy crumb structure by destroying permanent vegetation, flooding soils for long periods, using high-speed or heavy vehicle cultivation, stocking with sheep or cattle in especially wet periods, using fertilisers that deflocculate the soils (e.g. too much potassium where soil sodium levels are already high), or by burning in hot periods.

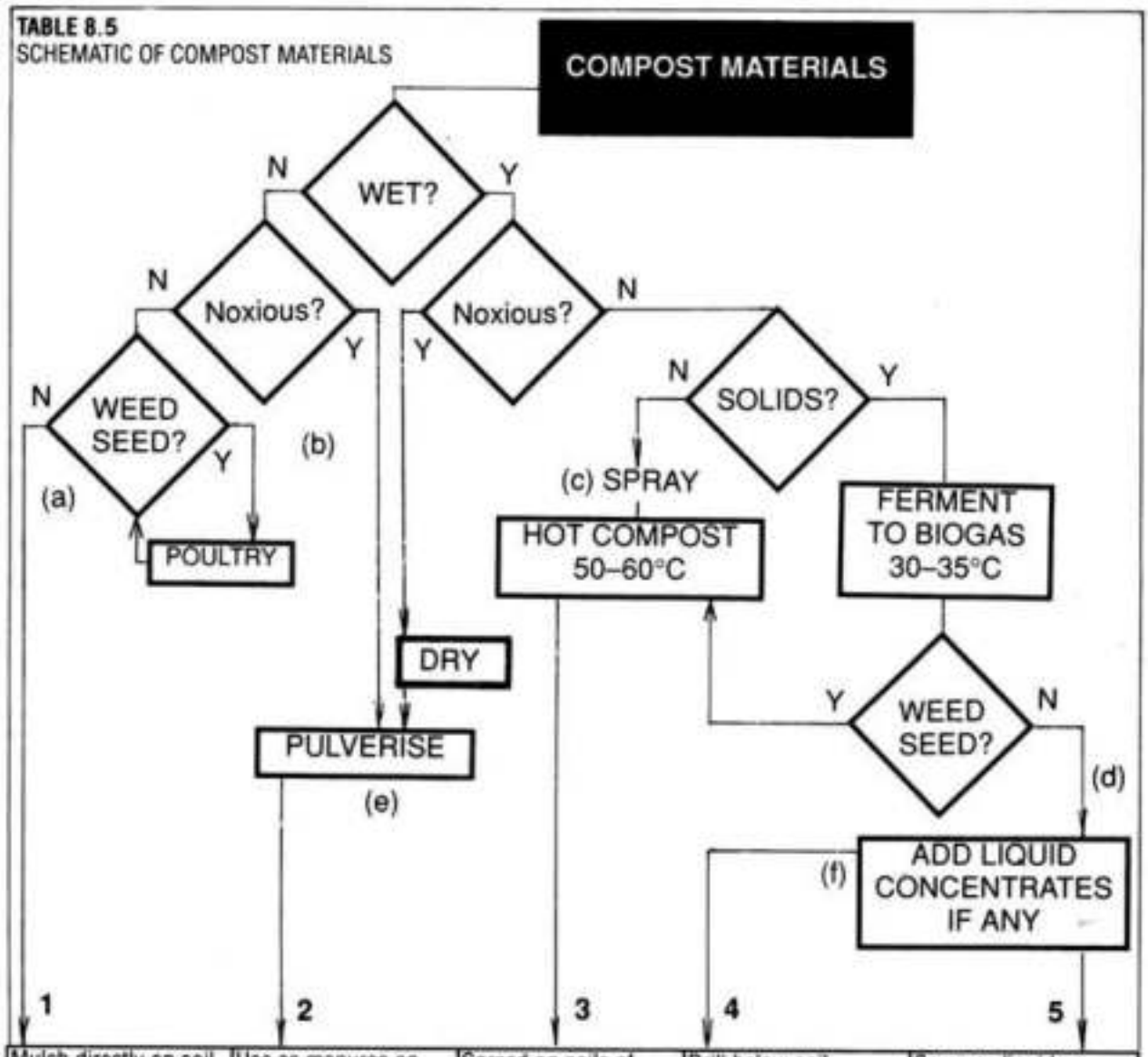
The whole set of disasters outlined above can collapse soils to the cemented, dusty, hydrophobic, salted and desertified areas typical of wheatlands on desert borders. It is a question of improper use, disastrous planning (or no planning), and a total lack of applied goodwill to earth.

Given a good structure, pores develop for the diffusion of gases and exchange of ions, provided that we make the transition to perennial, low cultivation systems of forest and crop.

COLLOIDS AND GELS

Colloids are stable aqueous gels or suspensions of clay, organic, or long-chain polymer particles in a finely-diffused aqueous state in soils. These are particles so fine that they stay in suspension unaffected by gravity, and become active sites for ionic bonding and interchange. Colloids also form gels which hold soil water reserves, and are in part formed by or derived from natural (and more recently, artificial) substances some of which form hydroscopic gels by water

TABLE 8.5
SCHEMATIC OF COMPOST MATERIALS



1	2	3	4	5
Mulch directly on soil surface at >12 cm deep. Least effort for best results in gardens. Controls weeds, lessens labour.	Use as manures on gardens. Energy used but good results obtained.	Spread on soils of intensive plots and seed beds. Most effort and most nutrient (ammonia) loss, but effective for specific materials. Energy yields as biogas, heat.	Drill below soil surface. Good results, no pollution.	Spray as liquid on fields, foliage, or use in aquatic systems. Little effort for good results. Energy yields as biogas.

EXAMPLES:
(a) Nut husks and shells; coffee, teas, and cocoa residues; shredded paper and branches; bark, woodchips, and sawdust; and old carpets, underfelt (*not* pesticide treated ones), bags, canvas(*all made of natural materials*).
(b) Hay with seed heads, weeds in flower, bulbils or roots of weeds.
(c) Sewage and sullage, liquid manure and urine, meat and animal paunches and trimmings, general household wastes. Add lime and superphosphate (1%) to hot compost ; "teas" of seaweed and manure.
(d) Sludge from digesters and weed–free manures.
(e) Chicken and bird manures, litter from animal sheds, blood, bone, feathers, hide scraps, seaweeds.
(f) Dissolved minerals, urine, seaweed and manure "teas".

TABLE 8.6
RECOMMENDED SCALE OF SOIL PARTICLE SIZES (mm).
[After McDonald *et al*]

Fine clay	< 0.002
Clay particles	0.002
Silt	0.002 - 0.02
SAND	**0.02 - 2.0**
fine	0.02 - 0.2
coarse	0.2 - 2
GRAVEL	**2 - 60**
Fine	2 - 6
Medium	6 - 20
Coarse	20 - 60
COBBLES	60 - 200
STONES	200 - 600
BOULDERS	>600

absorption.

Natural
Humus or humic decay and bacterial products provide colloids, as do finely ground graphite and silica, fine clays (particles of 2–200 millimicrons) such as illites, bentonite (usually deposited on clay pans from evaporation of clays in suspension), grain flours and animal (gelatinous) flours, e.g. from hooves, horns, sinew wastes, albumen and so on. Bacteria also secrete polysaccharides which form soil gels.

Synthetic
Soil conditioners which form stable colloids are sold under a variety of trade names (ask a local agricultural supplier), e.g. Agrosoke®, Ikedagel®, Terrasorb®, which are *hydrophilic* (attract water) as are many natural gels from grain products and seaweed. Water conservation of up to 50% is claimed for some of these additives. Most artificial gels are acrylic–based (acrylamid polymers) and supplied as granules able to absorb hundreds of times their weight in water. They are used to great effect in nursery plants, row crops, new tree plantings in deserts, and in transplanting. The acrylics are applied to soils at 6 kg/ha or more, and conserve irrigation water by preventing evaporation (*Small Farmer*, New Zealand, Aug. '84). These substances are of value in seed pelleting.

Colloids also form *hydrophobic* (repel water) substances such as those of clays and some soil fungi products. The surfaces of colloid particles are usually negatively charged, as are root hairs, and thus attract positive ions to their surfaces, e.g. the positive ions of sulphates, nitrates, and of metals (sodium, calcium, magnesium, iron). About 99% of such ions are so held in soils (Leeper, 1982). Colloids from humus are hundreds of times more effective than clay colloids in ion exchange in soils.

Ammonia and sodium can dislodge these ions, and they can become available to plant roots, which attract them by producing negative (H) charges. With too much flushing by sodium, the calcium and metallic ions can be lost to leaching processes and carried to streams, hence to seas or lakes.

Colloids used in water softening capture calcium ions and release sodium ions, allowing soaps to lather. Ferric oxide colloids have *positive* charges and give water a brown stain, typical of waters issuing from acid peats and pine forests. The colloid particles can be flocculated (aggregated) and settle out if aluminium salts (sulphates) are added; and this may happen as a result of acid rain, or can be induced with the acid forms of any negative particles. Salt also flocculates colloids up to the point where excess sodium *deflocculates* clays, with calcium and other ions, which is the effect of high salt concentrations in dryland soils (over 1–5 ppm salt).

Burning destroys the colloidal properties of surface clays, and is another reason why desert soils leach out after fires. Burnt clay particles *no longer form colloids*, and become poor in mineral nutrients, which are then found only in deep soil profiles. Organic humus forms black slimy pools on top of the collapsed soils.

It is the clay particles and colloids (organic and inorganic colloids) that bind water and nutrient in soils. In the tropics at least, most of these colloids are in the biomass of the soil as cellular gels, or are produced as sheathing material by soil bacteria. Without colloids, soil minerals rapidly leach out and become poor in nutrient. Fire, clearing, ploughing, and cultivation destroy such colloids and soil structure, as does excess sodium ions. Thus, to hold and exchange nutrients, we as gardeners need to develop natural or artificial colloid content in soils, from where plant roots and soil fauna or flora derive their water and essential nutrients. Very little clay is needed in sandy gardens to create a colloidal soil environment, and life forms are encouraged and developed by humus, mulch, and perennial plant crops. Good soil structure (to hold the colloids) is developed by careful earth husbandry, together with flocculating additives such as gypsum and humus.

SOIL WATER

The water content of soils is a soup of free–living organisms, dissolved gases and salts, minerals, gels, and the wash–off from throughfall in trees (waxes, frass, tree "body wastes"). Organic and inorganic particles are held in soil water. Soils have a widely variable water–holding capacity dependent on their composition and structure, so that sands absorb and retain water more quickly than clays, but clays hold more water per unit volume. Available water thus varies from 2% (surface sands) to 40% or more of soil volume. We can assist the quantity held in dry sites by swaling, contouring or terracing, loosening soils, adding flocculants, introducing artificial or natural gels (seaweeds or plastic absorbers), or by placing a clay or

plastic sheet layer 30 cm below the surface of gardens.

In soils that become waterlogged, we can resort to raised beds or deep drains to reduce infiltrated water build-up, or plant trees to keep active transpiration going and so reduce soil water tables and re-humidify the air.

Two factors at least affect soil water availability:

• The strength of molecular bonding of water to particles in the soil (ionic bonds). Plant root hairs cannot remove this bound-water at pressures above 15 atmospheres.

• The salt content of the water. Too many salts, and the soil water exerts reverse osmotic pressures on plant roots, and will take water from the roots.

8.11
GASEOUS CONTENT AND PROCESSES IN SOIL

Soils are permeated, where not waterlogged, by the gaseous components of the atmosphere (80% nitrogren, 18% oxygen). This enters the soil via pore spaces, cracks, and animal burrows, and diffuses via pore spaces to plant roots. The exchange of gases, atmosphere to soil and soil to atmosphere—the breathing of earth—is achieved by a set of physical and biological processes, some of which are:

• EARTH TIDES. The moon tides, much subdued on continental masses, nevertheless affect groundwaters in cobbles or boulders, the earth itself (about 25 cm rise and fall across the continental USA), and of course the soils of estuaries and mud flats (where air can be seen bubbling up for hours as the tide rises).

Everywhere, low or high pressure cells and turbulent wind flow creates air pressure differentials that draw out or inject air via crevices and fissures, or burrows. These same effects assist or retard the diffusion of water vapour across soil surfaces, and just as the wind dries out surface soils so it also, by fast flow, draws out other gases from soil. The gases of soil respiration (carbon dioxide), oxidation, aerobic and anaerobic metabolic processes, radon from radioactive decay, and simple or complex hydrocarbons from earth deposits or humus decay pass to air.

Much of the ammonia and carbon dioxide in the atmosphere, and at least 16% of the methane, is supplied by soil processes.

• BIOLOGICAL EXCHANGE. A single large broadleaf tree, actively transpiring, may increase the area of transpiration of one acre of soil by a factor of forty; a forest may do so by hundreds of times. So oxygen, carbon dioxide, water vapour, metallic vapours, ammonia, and hydrogen or chlorine gases are transpired by algae, rushes, crops, trees, and herbs or grasses. Plant groups vary tremendously in the volume and composition of gases transpired. Although we owe much of our atmospheric oxygen to trees, a great many non-woody plant species consume more oxygen than they produce.

Thus, the plant is a gaseous translator, trading both ways with air and soil. Some specifics of this trade are given in the section below on oxygen-ethylene processes.

Animals, too, are very active in opening up soils with small or large burrows; these act as pump pistons (like a train in a tunnel) to draw in and exhaust both their waste gases and atmospheric gaseous elements, which are then diffused to roots via soil pores. Many burrowers (ants, crabs, termites, prairie dogs, worms, land crayfish) raise up mounds or chimneys which then act as Pitot tubes for air flow or to create pressure differentials which draw air actively through their burrows. Or they erect large surface structures of permeable sediments across which waste gases diffuse (e.g. termite mounds). By a great many such devices, animals contrive to live in aerated or air-conditioned undergrounds, and increase gaseous exchange in the soils.

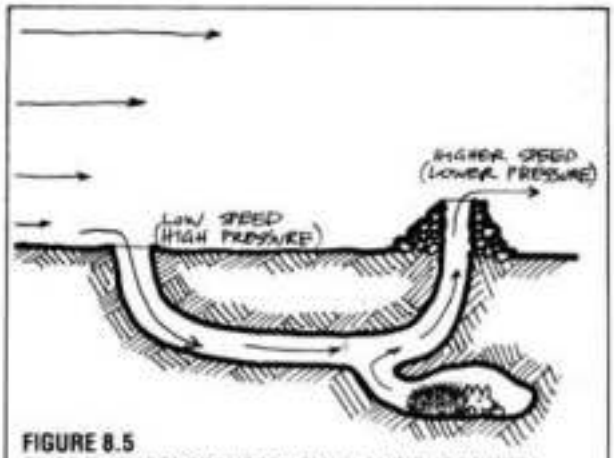


FIGURE 8.5
PITOT TUBE CONSTRUCTED BY A LAND BURROWER
Air flow ventilates burrow and removes waste gases.

GASES MANUFACTURED IN SOILS

By way of titanium or rutile (TiFe), ammonia is manufactured in sands in the presence of sunlight. By way of ferrous iron, ethylene (C_4H_4) is manufactured in anaerobic soil microsites. In anaerobic soils and waters, carbon dioxide, methane, sulphuretted hydrogen, ethylene, and sulphur dioxide are formed, and escape to air as biogas or marsh gas. The same products are present in the mottled soils of hydrophobic clays in winter, soils where crumb structure has been destroyed by misuse, where salt has deflocculated clays and caused soil collapse, or where water periodically floods the soil. Many of these gases are found as a result of humus decay and thiobacillus (sulphur bacteria) action.

Ammonia is released from actively nodulating legumes (trees and herbs), and is used in unploughed soils as a plant nutrient. Thus, gaseous compounds are continually made in the soil itself by process of metabolic growth and decay in the presence of metallic

catalysts and micro-organisms. Moybdenum, vanadium, and zinc all assist root bacteria in the creation of available soil nitrogen (as catalysts).

GASEOUS MOSAICS OVER TIME:
SOIL MICRO-SITES

Like pH, cation exchange, and structure, natural soil is always a mosaic of aerobic and anaerobic patches called micro-sites, where either oxygen (aerobic) or ethylene (anaerobic) sites develop. Ethylene inhibits (in the sense of suspending), microbial activity, and like carbon dioxide, is present as 1-2 ppm in soils (Smith 1981). As the ethylene at an oxygen-exhausted site diffuses out, oxygen floods back and re-activates the site. Under natural forests and grasslands, this cycle, or dance, of oxygen-ethylene is continuous, and most nitrogen there occurs as ammonia, useful to plants and plant roots.

When we cultivate and aerate, nitrogen becomes a nitrate or a nitrite (which then inhibit ethylene production), and *ferric* rather than *ferrous* iron forms, thus making ethylene formation difficult (the process from decaying leaf to ethylene production requires a *ferrous iron* catalyst). Also, plant nutrients are tightly bound to ferric iron and become unavailable for root uptake. It follows that the production of ethylene is essential to plant health and the availability of nutrients.

It is important to realise that the aerobic condition of soils such as we get from ploughing or digging not only creates a condition of "unavoidable" nutrients and ferric iron, but also oxidises humus, which goes to air as carbon dioxide. Also, most plant root pathogens require the aerobic condition. As well, the nitrate form of nitrogen, which is highly mobile, leaches out when bare soils (not plants) occupy the site. In all, ploughing and earth turning create a net loss of nutrients in several ways, thus atmospheric pollution, stream pollution, and low soil nutrient states.

Smith (*ibid.*) therefore recommends *least* soil disturbance, the use of surface mulch (*not* incorporated) as an ethylene precursor (old leaves are best for this), and very small but frequent ammonia fertiliser, until soil balances are recovered. The ideal conditions would be:

- Permanent pasture;
- Forests;
- Orchards with permanent green crop as mulch;
- No-dig or mulched gardens;
- No- or low-cultivation of field crop, or field crop between strips of forest to provide leaves and nutrients; and
- The use of legumes in a similar proportion to that occurring in natural plant associations in the area, at all stages of the succession.

Under these conditions, soil mineral availability is made possible and soils do not lock up nutrients in oxides or produce pollutants.

When we achieve this balance, soil loss and mineral deficiency become yesterday's problems. And when *plant leaf* (not soil) deficiency can be adjusted with aqueous foliar sprays, nature then starts to function again to obtain nutrients from soils via microbes and root mycorrhiza at the microsite level. (Smith, A., 1981, "The Living Soil", *Permaculture Journal* #7, July '81.)

8.12
THE SOIL BIOTA

On semi-arid and poor pasture, it is difficult to keep sheep at a stocking rate of 3-6/ha. The very same pasture may support 2-5 t of pasture grubs, or up to 6.5 t of earthworms/ha , so that (like grasses) most of the animal biomass or yield is underground, out of sight. Even where wheat cropping is carried on *continuously* for 140 cycles (Rothhamsted, UK) the plough layer supports 0.5 t of living microbial biomass (*New Scientist*, 2 Dec '82). About 1.2 t/ha of organic carbon is returned annually to the soil as root and stalk material from grain crop.

So large is the soil biomass that its growth must be very slow, sporadic, and based on a turnover of humus/food *within* the soil rather than a food input from the wheat crop wastes. Humus in this soil has a mean age of 1,400 years, and probably derives from forests that long preceded the wheat; it yields up its nutrients very slowly, and is resistant to bacterial attack. However, it is equally clear that there are periods of sudden food supply from root masses at harvest, and from root exudates during the growth of wheat (30% of plant energy may be lost as sugars or compounds released to the soil via roots). However the soil biota achieve it, they exist on a very meagre food supply for such a biomass, rather like an elephant eating a cabbage once a day! Of the total biomass at Rothhamsted, 50% is fungi, 20% is bacteria, 20% yeasts, algae, and protozoans, and only 10% the larger fauna such as earthworms, nematodes, arthropods and mollusc fauna (the micro- and macro-fauna), and their larvae. Such classes of organisms are found in soils everywhere, in different proportions. Anderson (*New Scientist*, 6 Oct. '83) gives some idea of the complexity below ground, where every square metre of forest topsoil can contain a thousand species of animals, and 1-2 km of fungal hyphae!

Very small animals are able to live a basically aquatic life in soil, in the water film attached to soil crumbs, while larger species are confined to pore spaces and the burrows of macrofauna.

A wheat field is not the place most likely to produce high levels of soil biota, and plough cropping has (in Canada) reduced humus levels to 1% of the original levels over much of the wheat country.

Climatically, the balance and proportion of soil biota varies greatly, with the acid soils of coniferous and oak forest yielding few earthworms, and the humic peats even less, so that the soil recycled by worms also varies from 2-150 t/ha (0.5-25 cm depth of soil/year).

Ecological disturbance or imbalances by predation, aeration, disturbed soils, low oxygen levels, and compaction favour the bacteria over the fungi. Fungi are certainly more effective in wood or large plant material breakdown, and can transport materials not only from place to place (e.g. move nitrogen into decaying wood) but also move nutrient into higher plants via their intimate contact with the root cells of the host plant. Usually, such translocations are modest (a few metres), but occasionally a fungal species can send out many metres of hyphae to invade a tree, as a pathogen and decomposer. Thus, it pays higher plants to give energy to their fungal root associates as sugars, and to gain minerals or nutrients in return.

Over time, the death of these soil organisms returns nutrient to new cycles. Even termite nests die out in 20–30 years, and new colonies start up. Larger animals can have a profound effect on primary litter breakdown (millipedes, woodlice) and are typically plentiful in mulch, but rare in compost. As one can imagine, any accurate account of the relationship between such dynamic mass of species awaits decades of work, but some broad facts are emerging; for example, turnover of nitrogen by earthworms exceeds that of the litter fall of plants. Few species fall into clear-cut classes of food relationships, and the chain of events of predation, faecal production, and burrowing are further complications.

As it is probably impossible to research at a species-specific level, and as the gross compartmentalisation of ecosystem analysis is inappropriate, Anderson (*ibid.*) suggests a more possible study based

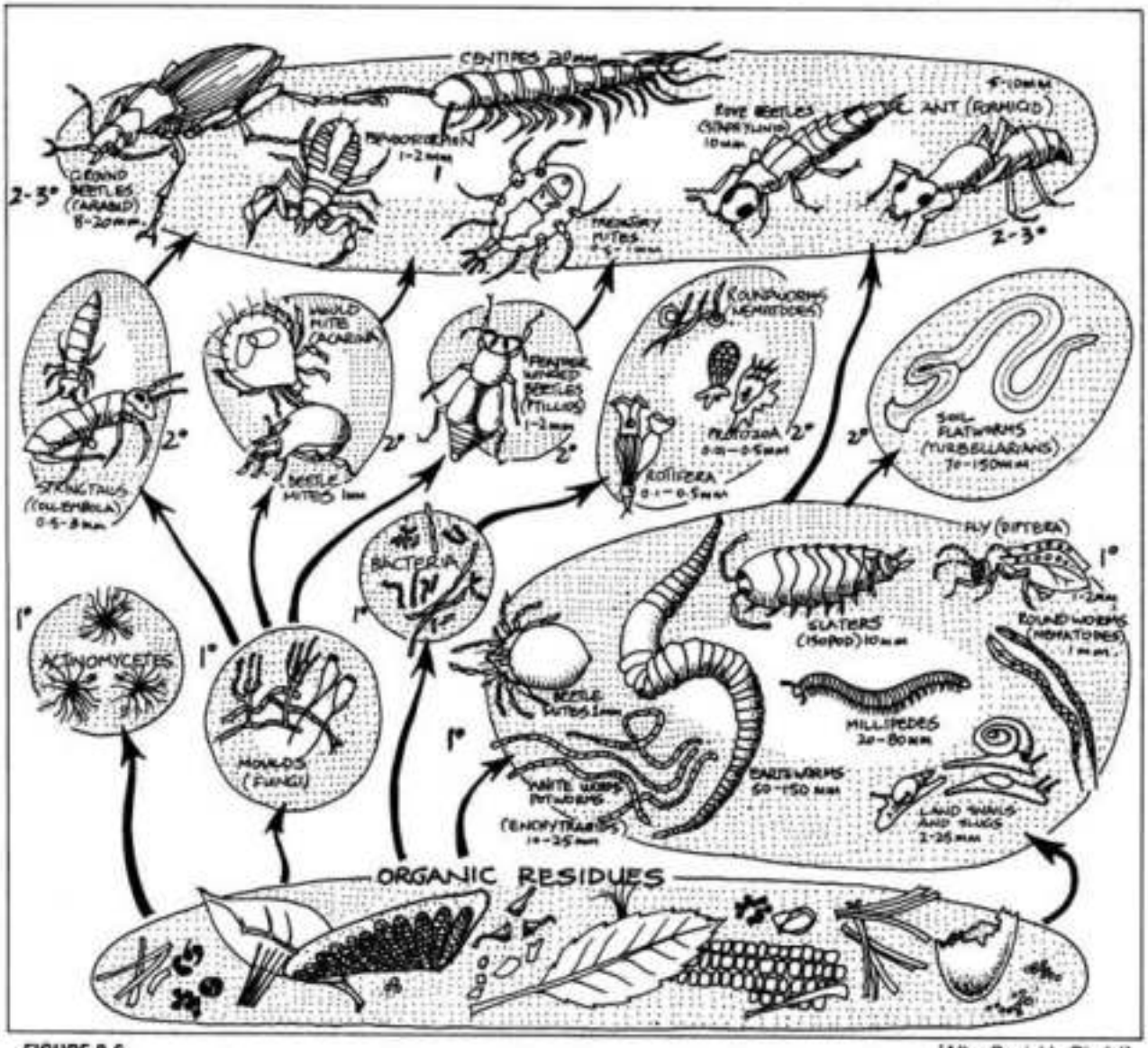


FIGURE 8.6
FOOD WEB OF A COMPOST PILE
Energy flows in the direction of the arrows; lengths in millimetres. 1 = first level consumers, 2 = second level, 3 = third level.

[After Daniel L. Dindal]

on the interactions between *the broad functional groups* of organisms, or a size-food community. Here, he laments, "we know so little about so much."

Large animals (earthworms to wombats) can create major changes in soils locally, by burrowing, soil turnover, faecal production from vegetation, waste products, and even alterations to forest successions after fire. In general, gross disturbances by colonies of larger fauna as in deserts (where rodent biomass can reach 1,000–10,000 kg/ha) shift the balance from soil fungi to bacteria.

We can think of the soil biota as a reserve of otherwise easily leached nutrients (nitrogen, sulphur), both of which elements they gather, store, or concentrate. Their cycle of life and death, which in turn depends on soil temperature and season, releases small or large amounts of these essential elements at multiple microsites. Termites, in addition, may store calcium from subsoils in their mounds, and bacteria store a number of soil minerals. These are held in the mobile living reserves of the soil biota, and are released by their death for slow uptake by plant root associates. Many plant forms directly eat bacteria (algae in water, fungi) or insects and nematodes, so that plants are either direct predators of the soil fauna, or scavengers of the bodies of the soil organisms.

A useful classification of soil biota based on size is as follows (*New Scientist*, 6 Oct '83):

- MICROFLORA and MICROFAUNA: Size range 1–100 millimicrons, e. g. bacteria, fungi, nematodes, protozoa, rotifers.
- MESOFAUNA: Size range 100 millimicrons–2 mm, e.g. mites, springtails, small myriapods, enchytraeid worms, false scorpions, termites.
- MACROFAUNA: Size range 2–20 mm, e. g. wood-lice, harvestman, amphipods, centipedes, millipedes, earthworms, beetles, spiders, slugs, snails, ants, large myriapods.
- MEGAFAUNA: Size range 20 mm upwards, e. g. crickets, moles, rodents, wombats, rabbits, etc.

In terms of sheer numbers per square metre, nematodes (120 million), mites (100,000), springtails (45,000), enchytraeid worms (20,000), and molluscs (10,000) greatly out-number any other species in temperate grasslands. Fungi, however, may be 50% of the total living biomass.

While the tradition of soil science has been to treat and analyse soils as mineral matter (the living component being carbonised or burnt off in analyses as "C" or humus content), the preoccupation of sound farmers, biodynamic groups, mulch gardeners, and "no-dig" croppers has been the quantity and quality of soil life, both as indicators of soil health and as aerators and conditioners of soil. Another factor which deserves more treatment in science is the mass, distribution, migration, and function of roots and root associates, and the role of burrowers (not only earthworms, but larger mammals, reptiles, and a host of insects).

The soil (if not sterilised, overworked, or sprayed into lifelessness) is a complex of mineral and active biological materials in process. No soil scientist myself, I rely on soil life and the health of plants to indicate problems. Diseases and pest irruptions can be the way we are alerted to such problems as over-grazing, erosion, and mineral deficiency. Removing the pest may not cure the underlying problem of susceptibility. Certainly, strong plants resist most normal levels of insect attack.

Soil analysis, helpful though it is, can help us very little with soil processes. Until very recent years, we have underestimated the contribution of nitrogen by legumes *or* soil microfauna. In addition, the measures of soil carbon has rarely been related to the soil biota, whose lives and functions are not fully known. It seems curious that we know so much about sheep, so little about those animals which outweigh them per hectare by factors of ten or a hundred times, and that we do not investigate these matters far more seriously. Our most sustainable yields may be grubs or caterpillars rather than sheep; we can convert these invertebrates to use by feeding them to poultry or fish. We can't go wrong in encouraging a complex of life in soils, from roots and mycorrhiza to moles and earthworms, and in thinking of ways in which soil life assists us to produce crop, it itself becomes a crop.

EARTHWORMS

> Worms have played a more important part in the history of the world than most persons would at first suppose. In almost all humid countries they are extraordinarily numerous, and for their size possess great muscular power. In many parts of England a weight of more than ten tons (10.516 kg) of dry earth annually passes through their bodies and is brought to the surface on each acre of land; so that the whole superficial bed of vegetable mould passes through their bodies in the course of every few years... Thus the particles of earth, forming the superficial mould, are subjected to conditions eminently favourable for their decomposition and disintegration...
>
> The plough is one of the most ancient and most valuable of man's inventions; but long before he existed the land was in fact regularly ploughed, and still continues to be thus ploughed by earthworms. It may be doubted whether there are many other animals which have played so important a part in the history of the world, as have these lowly organized creatures.
>
> (Charles Darwin, *The Formation of Vegetable Mould Through the Action of Worms*, 1881)

From the time of Darwin (and probably long before), copious worm life in soils has been taken as a healthy sign, and indeed more modern reviews have not reversed this belief (Satchell, 1984). Worms rapidly and efficiently recycle manure and leaves to the soil, keep

soil structure open, and (sliding in their tunnels) act as an innumerable army of pistons pumping air in and out of the soils on a 24-hour cycle (more rapidly at night).

Of themselves, they are a form of waste recycling product, with a dry-weight protein content of from 55-71% built up from inedible plant wastes. Only a few peoples eat worms directly, but a host of vertebrates from moles to birds, foxes to fish depend largely on the worm population as a staple or stand-by food. Cultivated worms are most commonly used as an additive to the diets of livestock (fish, poultry, pigs).

However, as processors of large quantities of plant wastes and soil particles, worms can also accumulate pollutants to extraordinarily high levels; DDT, lead, cadmium, and dioxins may be at levels in worms of from 14 or 20 times higher than the soil levels. Eaten in quantity by blackbirds or moles, the worms may become lethal. That is, if the "pests" that are moles, blackbirds, and small hawks abound on farms, there is at least some indication of soil health. Where these are absent, it is an ominous and obvious warning to us to check the soil itself for residual biocides.

As non-scientists, most gardeners deprived of atomic ray spectrometers, a battery of reagents, and a few million research dollars must look to signs of health such as the birds, reptiles, worms, and plants of their garden-farm. For myself, in a truly natural garden I have come to expect to see, hear, and find evidence of abundant vertebrate life. This, and this alone, reassures me that invertebrates still thrive there. I know of many farms where neither birds nor worms exist; and I suspect that their products are dangerous to all life forms.

All modern evidence agrees on the value of worms in fields, as decomposers and manure recyclers. They may be even more valuable as garbage disposal systems, and as fish or poultry food, providing a mass of high-protein food from vegetable wastes.

8.13
DIFFICULT SOILS

CONCRETIONS AND PANS

Several types of concretion or cemented particles occur in soils. These are commonly the following:

• CALCRETE (*caliche, platin, kunkar*) is a hard, mainly level subsurface concretion about 0.5-1.0 m below a granular or sandy topsoil, typical of coral islands (calcium triphosphate), and the downwind areas of desert borders. Calcrete must be broken open to plant trees, or the roots will spread out laterally, allowing wind-throw to occur. On atolls, fresh-water deposits develop below the caliche.

Broken caliche can be used as a building material and also forms a safe roof for tunnels or dugouts. Calcium/magnesium concretion, worsened by the addition of superphosphate, is whitish to creamy. In acid (vinegar), calcrete releases bubbles of carbon dioxide.

• SILCRETE (*cangagua*) is a grey to red shiny hard layer developed below some tropical forest soils, which gives a glassy surface if forests are cleared. The soil is concreted by silica deposits. If such deposits lie below forests, it is unwise to clear the forest itself. Durian: Silica-cemented non-wetting horizon, earthy, brittle, found only in volcanic areas. Red-brown hardpan: occurs in many soil types, not volcanic, semi-arid, and is 10 cm-30 m (4 inches to 98 feet) thick.

• FERRICRETE: Iron-cemented pans and soil layers of varying thickness, sometimes as thin sandy layers of 5-10 mm; also alumina-iron laterites (often capping desert hills with veins of silcrete) or iron-manganese nodular horizons in soils. Ferricrete may lie over pale bauxites, and is also called ironstone, plinthite. Ortstein occurs in podzols as iron-organic hard B horizons. Coffeerock is a thick sandy coffee-coloured horizon, low in iron and easily broken; it is a common horizon in humic podzols. Duricrusts form hard silica-iron caps on hills in deserts.

• PLOUGH PANS are usually clay-based compacted layers developed below croplands in wet periods; these can be caused by mouldboard ploughs.

All of the above need ripping, explosive shattering, or deep mulch pits to establish trees. Sodium in soils may develop a "collapsed" cemented, greyish, gravelly pan (SOLCRETE) impermeable to water. Only deep-rooted trees, reduction of salt, and humus relieve these cemented conditions. Deep drainage of 1-2 m is essential for salted soils.

Concreted soil layers (calcium or silica-cemented) are the calcretes (*caliche, platin*) of dry islands and coasts, or the ferricretes (iron-cemented) of deserts. Any or all may form duricrusts (hard layers) in eroded areas. Under some tropical rainforest (e. g. in Ecuador), an iron-silica pan which follows hill contours, locally termed *cangagua*, lies 3 m below the forests; it is a daunting sight to see this glassy and impermeable surface after the removal of forest and a consequent loss of topsoil. Where *cangagua* is known to exist, perpetual forests used for products other than their wood (honey, fruits, medicines) are the only sustainable use of land.

NON-WETTING SANDS AND CLAYS

Some classes of very fine blackish sands, and sands invaded by hydrophobic soil fungi, are difficult to wet; the water sits on top as droplets. There are several remedies for this in gardens:

• Ridge soil to make basins.

Every square metre, core out sand and drop in a loam or clay-loam plug (4-10 cm by 30 cm deep).

• Compost thoroughly and build up organic material to 8% of surface soil.

• Add a handful of bentonite per square metre, or powdered clay from clay pans.

• Mulch thoroughly, and plant. Keep surface mulch

supplied.

On the broad scale, deep ploughing in autumn (to 45 cm) is used, followed by rotary plough or chopper, mixing of the top non-wetting profile of 10-20 cm (4-8 inches) with subsoils. A cover crop is immediately sown to prevent erosion, and this used as a cover crop or green manure for deep-rooting crop or tree species. The successful establishment of trees permanently curbs the problem.

CLAYS which seal on the surface in light rains are often sodium-rich and "melt" in rain. Remedies are:

- Make low banks across run-off.
- Add gypsum at 2-3 handfuls per square metre, and if possible flush out with fresh water (removing sodium as sulphate).
- If practical, place sand over the surface to 4 cm deep.

For deep cracking clays and lumpy soils add a sand layer, scatter gypsum at a handful per square metre, and mulch.

For acid or deep silica sands it is best to add clay and mulch, and to lay plastic at 0.5 m deep in garden beds (**Figure 8.7**).

FIGURE 8.7
LAYING PLASTIC IN DEEP SANDS
Plastic sheet prevents deep leaching , clays hold water at root level; mulch prevents surface evaporation.

8.14

PLANT ANALYSIS FOR MINERAL DEFICIENCIES; SOME REMEDIES

Figure 8.8 (after Clark and Smith, "Leaf Analysis of Persimmons", *Growing Today*, New Zealand Feb. '86, pp. 15-17) illustrates the *seasonal* levels of important plant nutrients (as 90% dry matter) and micro-nutrients (as micrograms/gm) in leaf. The figures illustrate several things:

1. SEASONAL CHANGE IN LEVELS. Thus, the potential for early intervention in adjusting levels (before it is too late to save the crop).

2. VERY DIFFERENT BEHAVIOUR OF NUTRIENTS:

Type 1: Zinc, Iron, Copper: high in new spring growth, falling over summer, and finally (as leaves are lost to the tree) becoming more concentrated in the last leaves, as uptake by roots concentrates these elements in the last leaves.

Type 2: Boron, Manganese, Calcium: increase throughout the whole season of growth. Not "mobile" once in the plant.

Type 3: Nitrogen, Phosphorus, Sulphur: rapid early uptake, then a gradual decline over the season.

Type 4: Potassium: remains steady over the year, then declines as wood storage and root reserves build up.

As persimmons are not atypical plants, these findings have implications for *pre-emptive adjustment* (e.g. by foliar sprays), and *selective mulch* (e.g. the season at which leaves are taken for compost).

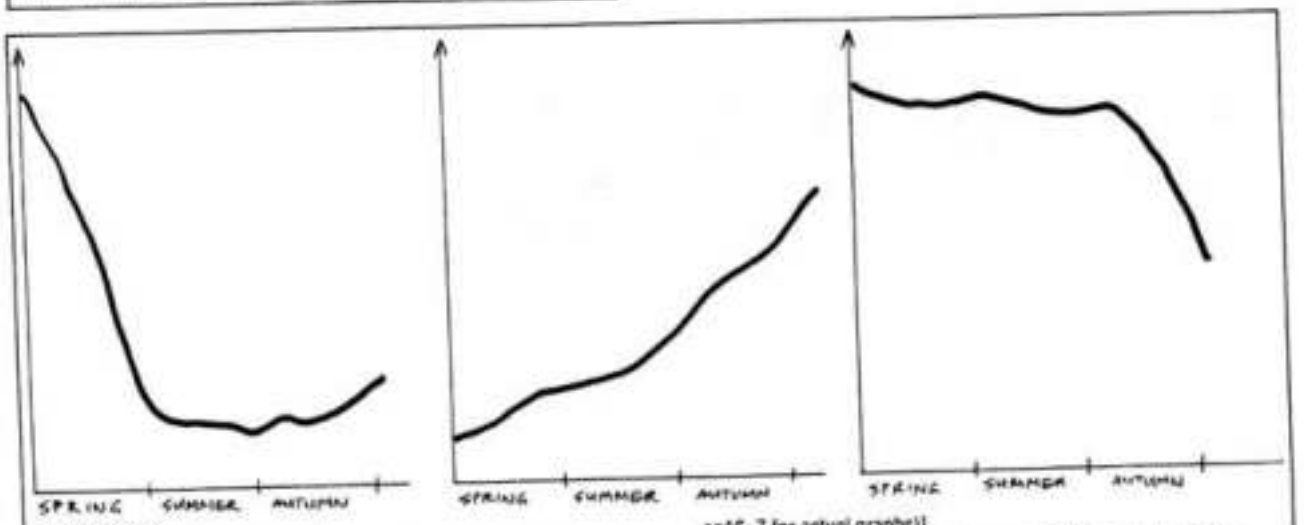


FIGURE 8.8
A 'TYPOLOGY' OF THE ELEMENTS IN LEAF TISSUE (in winter, trees are bare).
Behaviour of basic nutrients in the leaf analysis of a deciduous tree (here a persimmon). Levels vary across the growing season.
[After *GrowingToday*, NZ Tree crops Association, Feb. 1986 (See pp16-7 for actual graphs)].
A Cu, Fe, Zn, P, N, and S. Similar curves, slight increases in late season.
B B, Mn, Mg, and Ca. The non-mobile elements increase steadily in concentration; Mg is not normally regarded as non-mobile.
C K. Remains fairly steady, and is "withdrawn" from leaves in autumn.

TABLE 8.7
KEY TO MINERAL DEFICIENCIES

How to use: Read the first set of choices (A), make one, and follow on to the letter group in the righthand column. Then make a second choice (or find the answer). Some remedies follow, and are given under the numbers in brackets ( ).

First Choices: **Go to**

A. • Leaves, stems, or leaf stalks are affected ....**B**
• Flowers or fruits are affected .....**M**
• Underground storage organs (roots, bulbs, tubers, etc.) are affected .....**N**
• Whole field or row shows patchy or variable yields .....**O**

B. • **Youngest** leaves show most effect, or early effects .....**C**
• **Oldest** leaves or later whole plant affected.....**I**

C. • Pale yellowish or white patches on the leaves .....**D**
• Pale patches not the worst symptom, but death of tips or growing points, or storage organs affected .....**H**

D. • Leaves uniformly colour–affected (yellowish or pale), even the veins, poor and spindly plants (especially in heavily cropped or poor leached sandy areas, acid **or** alkaline .....**{1}**
• Leaves not uniformly affected, veins or centres still green ..... **E**

E. • Leaves wilted, then light–coloured, then start to die. If onions, crop is undersized. If peas, seed in pods barely formed, matchhead size. Coastal sands. Black sheep in flocks may show a brown tinge to wool and are often used as "testers".....**{2}**
• Wilted and dying leaves not the problem.....**F**

F. • At first, colour loss is interveinal (between veins), and only later may include veins. Mature leaves little affected, dying not a feature, and common on calcareous or coral atolls, desert soils. Distinct yellowing (See also J) .....**{3}**
• Veins remain green, pale areas not so yellow, often whitish or lack colour. .....**G**

G. • Areas near veins still green, affected leaf areas become transparent, brown, or start to die. Young leaves first affected. Peas and beans germinating in soil show brown roots and central brown area on leaf cotyledons. pH usually >7.0.....**{4}**
• Leaves smaller than normal, stems shortened, growth retarded. Beans and sweet corn, several tree seedlings most affected. Soils acid, leached sands, alkaline, high in humus, coastal. Leaves may develop a rosette appearance, bunchy tops .....**{5}**

H. • Plants brittle, leaves die or are distorted, growing points die, stems cracked, rough, short between leaves, split lengthwise (cabbages), cracked (celery). Probable on acidic sands, or on heavily–limed high–humus soils.....**{6}**
• Plants not brittle, but stunted, tips dying, feeder roots die, and leaf tips and terminal bud margins dying. Cabbage or cauliflower have young cupped or dead margins; old leaves all right. Young infolded leaves brown–edged, rotting (jelly–like decay). Check on over–watering, excess Na, K, Mg in water, or in or dolomite. Tomatoes show blossom end rot. .....**{7}**

I. • Plant with marked yellow (chlorosis)..... **J**
• Yellowing not the main problem; leaves brown–edged or purple .....**L**

J. • Yellowing between veins or on margins of leaf.....**K**
• Yellowing affecting whole plant, ranging from light green to yellow; plant gets spindly, older leaves drop off. Prevalent in cold peaty soils, leached sands, soils subject to waterlogging. Turnips show purpling on leaves. Plants flower or mature early.....**{8}**

K. • **Margins** yellow, or blotched areas which later join up. Leaves can be yellowed or reddish, purple, progressing to death of leaf area. Later, younger leaves affected. Affected areas curl or become brittle, brownish. Common on acid sandy or soil with high K or Ca readings. Growth slow, plant stunted. .....**{9}**
• **Interveinal** yellowing, looks at first like N deficiency . Old leaves blotched, veins pale green, leaf margins rolled or curled, progresses to younger leaves. Leaf margins of cabbage, cauliflower can die, leaving central tissue only ("whiptail"); cauliflower will not form curds. Common on acid or leached alkaline soils, e.g. shellsand dunes, corals. Difficulty in establishing clover, legumes.....**{10}**

L. • Leaf margins brown, scorched, can cup downwards, dying target **spots** appear in leaves; spots have dark centres, yellow edges; general mottled appearance. Growth reduced, first on young matured and then on older leaves, finally to young leaves. May appear late in plant's growth if a root crop (K is translocated to roots). Leached acidic or organic clay soils. Tomato leaf margin pale. .....**{11}**
• Leaves wilt, droop, die at tips and edges: **Sodium excess.**
• Leaves dull, dark green or red–purple, especially below (under–surface) and at the mid ribs. Veins and stems may also purple, growth is much reduced. Common in very acid, alkaline, dry, cold, or peaty soils .....**{12}**
• Leaves at tips wilt early as soil dries out, then become bronze, then die. Not often seen. Check water supply, salt content of soil: **Chlorine excess.**

M • Fruit rough, cracked, spotted, few flowers. Tomatoes with internal browning, seed chamber open, uneven or blotchy ripening, stem end reddening. On acid soils, leached sands, humus–rich and limed soils. Terminal buds may die and laterals then develop. Top leaves thicken, can roll from tip to base. .....**{6}**
• Fruits rot on blossom end (opposite stalk), or show sunburnt dark areas there. Affects tomato, peppers, watermelons .....**{7}**

N. • Internal dying or water–soaked areas, uneven in shape (in beet, turnip, rutabaga if soil acid, leached, or with free lime. .....**{6}**

• Cavities in root core, then outside collapses as pits; common in carrots, parsnips on acid leached soils. Roots may split open. .....**{7}**

O • Areas of affected crop test acid: soils may be sandy; pH < 5.5: Acid: **Try lime**

• Areas of crop test alkaline: pH > 7.5 : Alkaline: **Try Sulphur.**

• Soil at depth mottled, smells of sulphur: waterlogged: **Arrange drainage.**

• Leaves tattered and dying at crown. Salt winds: **Try shelter.**

• Check for viral disease in grasses: **Try a plant pathologist.**

REMEDIES FROM THE KEY
(FOR GARDENS)

First, keep a fertiliser **diary** for your garden, and leave it for the next person. Tell them what you have done for the soil.

• If you are on leached (washed out) sands, dig up your garden beds, place a plastic sheet liner below, then add a bucket or so of clay and a handful of dolomite per square metre. Also, try a soil gel. Then add compost, and a complete fertiliser like blood and bone. Mulch thickly and replant, then return to the Key if symptoms recur.

• If you are on peats, or have piled on the compost, add some urea or blood and bone, raise your beds, and lime the area.

• If you have lots of lime in the soil, or are on coral sands or dry desert coasts with calcrete, spray weak zinc and copper sulphates **on** plants, iron sulphates in **very** dilute solutions (12 g/10 square metres with lots of water), or add it to a liquid manure. Make pits of compost and grow on the edges of these, use sulphur at about a handful per square metre, or add trace elements and sulphur to compost pits. Or, lay a sheet of plastic on the ground, build up logs around this to 25 cm high, and fill the area with humus (compost plus 50% sand), then mulch heavily. Add blood and bone. On atolls, dig down to near water table and then mulch thickly (make a big growpit 3–4 m wide by 10–12 m long by 3 m deep). Use **any** mulch, especially *Casuarina*, palm, house wastes.

{1} Sulphur. Add plain sulphur (not of medical quality) at one handful per square metre. If you are near a city, you could have enough from fallout!

{2} Copper. Add as fine–crushed ore, or in water as copper sulphate at 7 kg/hectare or spread (1 g/square metre) every 5–7 years.

{3} Iron. Try sulphur first, then if necessary add iron sulphate or spray foliage with very dilute iron solution. Bury old iron in humus pits near trees (e.g. pieces of galvanised iron, old wire or car parts).

{4} Manganese. Try sulphur first, then use very dilute foliar spray of manganese sulphate.

{5} Zinc. Add zinc oxide in acid areas, sulphate in alkaline, also sulphur in alkaline areas. Zinc at 7 kg/hectare or equivalent every 7–10 years.

{6} Boron. Be careful not to add too much; it is poisonous in large quantity. First, lime acid areas and peats, and add sulphur to alkaline areas. If this doesn't work, add borax (sodium borate) at 1 gram/square metre and try cabbages to test reaction. Try not to buy detergents with "borates"; they can poison your soil. **Boron excess** (poisoning) can occur on sea sediments, and are common in reclaimed marine areas (Holland). Raise garden beds, lime, and flush out with fresh water.

{7} Calcium. Use lime as limestone in areas where manganese is plentiful, dolomite if not, or as cement powder in deep red hot tropical soils, then continue to add mulch and use lime only if deficiencies occur. Use gypsum in alkaline salty soils, then flush with fresh tank water and continue to use lime. Bone, bamboo mulch, buckwheat straw are all calcium sources.

{8} Nitrogen. Make sure the soil is well drained to 0.5 m for vegetables, 1–2 m for trees. Check for cobalt levels, deficiency. If legumes are used, make sure they are innoculated, and that manganese levels are not too high. If all this is satisfactory, add dilute urine (20 parts water:1 part urine), ammonium sulphate in alkaline areas, or use legume mulches or interplant (about 48 small *acacia* or tagasaste trees per one fourth acre will do). Use compost, then surface mulch. Build up **worms** and soil life, use dilute bird manure. Don't overdo it, or nitrates will build up in green plants and kill your kids or piglets with bluebaby syndrome. Just relieve the symptoms, then get good soil life going.

Use cobalt for severe nitrogen deficiency, poor clover growth or establishment in peaty or coastal soils. If manganese is high, just add lime to balance this soil (one handful per square metre), or in **alkaline soils** spray on at very low dilutions at 1 g/10 square metres every 10 years or so.

{9} Magnesium. Check if potash is not too high, or add clay to sandy acid soils (plenty of magnesium in most clays). Use **dolomite** for first dressing, then limestone. Epsom salts were used around citrus by old–timers. Or dilute it in water for foliar spray in very severe deficiency situations.

{10} Molybdenum. Get some sodium molybdate, about 10 g, and mix well with 5 kg of sand. Take 1/100 of this (weigh the sand), and put it on per square metre every 10 years.

{11} Potassium. Use ashes on green crop, diluted urine in early growth, then build up mulches, including dried or fresh seaweeds, flue dusts from cement works (fly ash), also "teas" of bird manures, comfrey. Potassium is found in the mineral kainite (20–25%) potassium) in evaporite deposits of deserts.

{12} Phosphorus. Bring pH to 6–6.5 or thereabouts, using lime in acid soils and humus in alkaline. Use bone meal, bury bones, or use tested rock phosphate free of cadmium or uranium. **Stop deep digging** and start mulching with least soil disturbance (build up narrow beds). Encourage soil life, add mulch on top, water with comfrey "tea", dilute bird manure on the **leaves** of plants. Keep this up each time symptoms appear; they will eventually disappear if you have clay in the beds (add some if not). If you have high–iron clays, you will need a lot of bone meal to start with, but it will slowly release later on. If desperate, use a few

handfuls of superphosphate per square metre, then continue with other sources. Feed a patch of comfrey with bird manure and make a comfrey tea in a drum of cold water. Water the plants with this. All animal manures (including yours) contain some phosphorus. Calcined (roasted) rock phosphate is effective on acid soils in high rainfall.

{13} Chlorine poisoning. Sue your Council, or let tap water stand with a handful of lime in it for a day, then use on the garden. Don't take a shower!

{Developed and modified after a format developed by English, Jean E. and Don N. Maynard, *Hortscience* **13**(1), Feb. '78, and with data from the author and Handreck, Kevin A., 1978, *Food for Plants*, CSIRO Division of Soils.}

MINERAL FERTILISERS OR SOIL AMENDMENTS

The present testing method used on specific soil types is to sow down mixed legume (clover), *Brassica*, and grass crop (or any important crop that may be grown). This sowing is then divided into TRIAL PLOTS which are treated at varying levels, and with soil or foliar spray amendments, to test plant health and response, based on a soil test for pH and mineral availability, or on a leaf analysis such as given in **Table 8.7**.

For the home gardener, or keen observer, a deliberate wander through the system, and a good key to mineral deficiencies may be all that is needed to spot specific problems. Problems are in any case rare in well-drained garden beds using composts and organic moulds, and where one-species cropping is not constantly practised.

On a broader scale, as in prairie or forest re-establishment and erosion control, land reclamation, or plantation, every practical farmer and forester uses TEST STRIPS of light to heavy soil treatments (from soil loosening to fertiliser, micronutrient, and grazing, cutting, or culling trials). When such field trials (as side-by-side strips) are run, it is wise to include typical areas of soil and drainage, and to avoid areas under trees, on the sites of old stockyards or hay-stacks, intense fire scars, watering points, and gateways and roads (all of which have minor but special features and need a separate assessment from the open field situation). I have often noted, for instance, the colonisation of chicory, thistles, and tough and deep-rooted weeds on the inhospitable areas of old roads and trafficked areas; this sort of data is of use for some cases, but does not need to suggest that we compact a whole field in order to grow chicory, rather that chicory is a useful pioneer of compacted soils.

Plant response on the test strips, which can be as little as 1% of the total acreage, may quickly indicate how modest and innovative soil treatment, minute amounts of micronutrients, or the timing of grazing or browsing can be managed to give good effects at least cost. There is no assurance as certain as the actual, assessed plant response. To see two small plots of pines, coconuts, or cabbages side by side, the one healthy, vigorous, and productive, and the other (lacking a key nutrient or on compacted soils) stunted, sickly, and unproductive, is a definite guide to future treatments. The same sort of trials are applied to plant mixtures or polycultures, pest controls, and the benefits or otherwise of mulch for a specific soil or crop.

Assessment can be casual (in clear-cut cases), or analytic and careful where only slight differences appear. Such test strips are best securely marked by stout pegs for long-term visits, as effects of some treatments persist, or become evident, over several seasons.

Not until trials are assessed is it wise to widen the area treated, although in commonsense it may always be wise to add humus or manures to non-peaty soils, or dolomite to acid sands. In alkaline and heavy clay soils, trace elements may become insoluble, and these are best added as foliar sprays to mulch or green crop, or to trees.

8.15
BIOLOGICAL INDICATORS OF SOIL AND SITE CONDITIONS

In any local area, the composition, shape or size, and distribution of the plants give many clues to soil type, depth, and extrinsic factors. Some specific factors indicated are:

SOILS: 1 Depth
2 Water reserves
3 pH
4 Mineral status (see preceeding section)

SITE: 5 Fire frequency
6 Frost
7 Drainage
8 Mineral deposits and rock type
9 Overgrazing and compaction of soil
10 Animal (macrofauna) effects

1 SOIL DEPTH: Shallow soils dry out quickly and hold few nutrients. A very good indication of soil depth is to look at one species of tree (e.g. *Acacia*, *Prosopis*, honey locust) over a range of sites; a "height and spread" estimate will reveal areas of deeper soils where the largest specimens grow. The same species will be dwarfish on shallow soils of the same derivation or rock type.

2. WATER RESERVES. Deep-rooted trees which need water—the large nut trees and candlenuts (*Aleurites*) are good examples which occur naturally only in well-drained but water-conserving sites—often show water-lines not associated with valleys, and stand over springs or aquifer discharge areas.

In sands, a great variety of deep-rooted shrubs and trees indicate where a clay base lies at 1-2 m down. This situation is common on desert borders and hills in drylands. In brief, large tree stems reveal well-

watered sites, small stems drier sites. Armed with these observations, we can create sites by water diversion and select sites for large trees or shrubs.

3. pH: Sorrel and oxalis in pastures may indicate compact or acid conditions, whereas several fen and limestone species establish in alkaline areas; large snails and dense snail populations occur only over alkaline soils or in alkaline water. No snails or minute species occur in acid water (pH < 5.0). In the garden, our cultivated plants demand acid or alkaline soils, e.g.

Alkaline intolerant (pH 4.5–6.0):

- Blueberry
- Chicory
- Chestnut
- Endive
- Potato
- Fennel
- Tea
- Shallot
- Coffee
- Watermelon
- Rhubarb

Alkali tolerant:

- Oats
- Rye
- Kale

Acid intolerant (pH 7.0–8.5):

- Cauliflower
- Cabbage
- Asparagus
- Green peas, bush beans
- Celery
- Leek
- Beet
- Lucerne
- Onion
- Chard
- Parsnip
- Broccoli
- Spinach

Acid tolerant:

- Lupin
- Oats
- White clover

This will have a profound effect on our home garden planning, but providing garden soils are mulched, and a little lime is added to compost, *all* plants thrive in high humus soils supplied with some lime at modest levels. It is the perennial species that may need more care in site selection, or with mulch and compost in alkaline areas. Almost all our pollutants, and many of our fertilisers, tend to make soils acid, as does continued cropping or over-grazing.

5. FIRE FREQUENCY. East-west ridges often reveal abrupt species changes at the ridge wherever fire occurs. Fire produces dry, scrabbly, summer-deciduous, thick-seeded species; lack of fire develops broadleaf, winter-deciduous, small-seeded plants with thin seed capsules and a deep litter fall.

Cross-sectional cuts of trees will reveal fire scars as gum pockets or charred sections, and these can then be counted to get the "fire frequency" of the site (**Figure 8.9**). If tree stem sections are marked for directions before sampling, the direction of fires can also be judged.

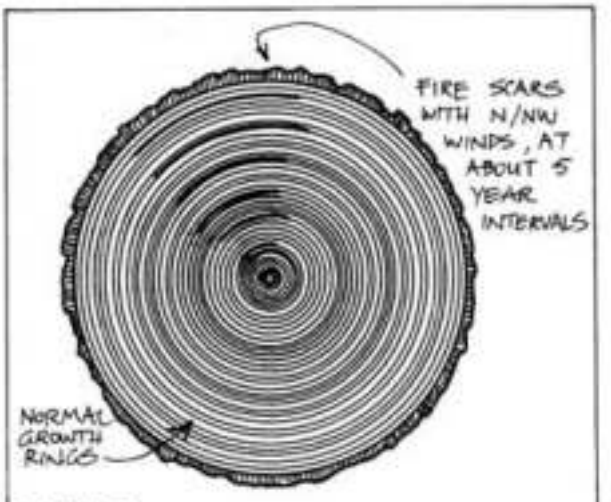


FIGURE 8.9
FIRE DIRECTION SCARS ON TREE RINGS
Show frequency and severity of fires on any one site.

6. FROST. Many species of trees and plants will indicate frost-lines; it is a matter of observing local flora, or planting frost-susceptible species down a hill profile to measure frost intensity. Tomatoes, bananas, and potatoes are all frost-sensitive and will reveal frost-lines on hills in subtropics and deserts.

7. DRAINAGE. Mosses, sundews, and fine-leaved heaths indicate poorly-drained soils, as large trees such as chestnuts (which require 2 metres of well-drained soil) indicate good drainage; these indicators assist survey before pits are dug or drainage measured.

8. MINERAL DEPOSITS. Davidov (*Sputnik*, 12 Dec. '79) gives data on plant systems over mineral deposits (for Russia). The analysis of plant residues often indicates concentration of ores in the underlying soil or rock. Lead and copper-molybdate are so indicated. Leaves or humus from birch, cherry, honeysuckle, St. John's Wort, wormwood, juniper, and heather reveal the above lodes plus tungsten and tin concentrates. "All purpose" plants so discovered are:

Rue or violets..... zinc
Catchfly..... cobalt
Asters..... selenium
Milk vetch..... selenium and uranium
Russian thistle..... boron
Alyssum..... nickel
Honeysuckle..... silver and gold
Horsetail..... gold and silica

General plant ash analysis may reveal more *specific* plant-ore associations. This has further implications for the rehabilitation of mine waste areas, and also to select plant sources for the supply of trace minerals in compost. As plants have the ability to both concentrate and tolerate unusually high levels of specific minerals, there seems to be a field here for the biological concentration (and subsequent removal) of metallic soil pollutants like lead or uranium, and the use of concentrator plants to mine or collect locally rare trace

elements. In fact, some patents have apparently been granted for mining gold deposits using banana or citrus plants deprived of some common elements (potash, phosphate); their leaves then concentrate sparse deposits of gold.

Oysters will concentrate zinc (to 11% dry weight, an emetic dose), abalone concentrate cadmium, and several large fish concentrate mercury and biological poisons from corals (to inedible levels). There are obvious implications for the removal, collection, or use of such species—element relationships, and lead, cadmium, or mercury levels in fish or plants need careful monitoring for public health reasons.

9. OVERGRAZING AND SOIL COMPACTION. Both the levels of grasshopper and pasture grub activity (high on overgrazed landscapes) and the presence of patches of poisonous, inedible, thorny, and unpalatable plants (e.g. Sodom apple, oxalis, capeweed) indicate an over-stocking problem or range mismanagement. The effect is a synthesis between changing soil conditions, plant stress, and the heavy selection by livestock of palatable species, so favouring the survival and spread of spiny or inedible species. Too often, the pastoralist blames the weeds and seeks a chemical rather than a management solution; too seldom do we find an approach combining the sensible utilisation of grasshoppers and grubs as a valuable dried-protein supplement for fish or food pellets, and a combination of soil conditioning, slashing, and de-stocking or re-seeding to restore species balance.

10. MACROFAUNAL EFFECTS. The site of a seabird rookery, a rabbit warren, the ground nest of a goose or eider clutch, the pellet-pile of an owl, or the decay of a large carcass will cause a sudden and often long-term change in the immediate vegetation, as will termite mounds and harvester-ant colonies. Once such sites are recorded, and the plant assembly identified, similar sites can be located and recognised. The data can be used as an aid to conservation, an indication of soil drainage (rabbits choose good drainage), as a result of specific nutrient supply (guano on seabird rookeries), or as a way to establish tree clumps following natural indicators.

A large proportion of wind-blown, nitrogen-loving, and inedible plants, or plants carried by birds as seed, depend on the specific habits of birds or mammals, on their dung, or on soil disturbances. The role of animals in the distribution of plant seed, and plant root associates, is well-recognised; their role in soil change, less commonly noted.

8.16
SEED PELLETING

In pioneering the rehabilitation or stabilisation of soils, many of the local deficiencies in soils can be overcome by seed pelleting, which is a process of embedding seed in a capsule of substances that give it a good chance of establishment despite soil deficiencies in local sites, or microsites.

• SEED PRETREATMENT. If seeds have thick coats, or need heat or cold treatment or scarification to break dormancy, they must be treated before pelleting.

• INOCULATION. Purchase and inoculate legume seed with their appropriate microbial or fungal spores. Soak the seed in inoculant solution, then dry the seed. Mix dried seed with a primary coat as below.

• PELLETING. Use a lime, clay layer, and a trace of fine rock flour, calcium, or phosphate mixed into a damp but plastic slurry around the seed. This is then extruded (e.g. via a meat mincer with the cutting blades removed) to a shaker table or tray covered with dust, and on a slight incline. Dust is added as needed to dry and shape the pellet, or to set a desirable size of pellet (**Figure 12.18**).

The dust, or outer pellet coat, should incorporate a soil conditioning gel or polymer, a colloid-forming substance (fine graphite), a bird repellent (green dye helps repel birds), an insect repellent such as powdered neem tree leaf (*Azadirachta indica* or *Melia azedarach*) or diatomaceous earth, and perhaps some swelling clay such as bentonite.

Pellets are now dried and scattered, drilled, or sown on sites to await rain. The protected seed germinates when the pellet absorbs water, and the emerging root finds its nutritional needs satisfied, while the root associates also become active in nutrient transfer to the plant.

The same vibrating table that we use to pellet seed serves, when fitted with screens, to clean and sort seed from the soil below trees or from seed and husk mixtures, and the mincer can be returned to the kitchen none the worse for wear. Fukuoka achieves the same result by pressing seed-clay mixes of grains through a coarse sieve, onto a dust-filled pan which is shaken to round off the pellets.

8.17
SOIL EROSION

As all else depends on a stable and productive soil, soil creation is one of the central themes of permaculture. Soil erosion or degradation is, in fact, the loss of production and hence of dependent plants and animals. Soils degrade in these ways:

• Via wind: by dust storm and the blow-out of dunes and foreshores.

• Via water flow by sheet erosion (a generalised surface flow off bare areas and croplands), gully erosion (caused by concentrated flow over deep but unstable sediment), and tunnel erosion (sub-surface scouring of soils below).

• Via soil collapse or deflocculation following increased salt concentrations in clay-fraction soils.

Thus, the placement of windbreaks, tree crops, and fast-spreading grasses stabilises erosion caused by

wind, while permanent crop, terracing forestry, and (in the case of gullies) diversion and spreader drains plus gabions help reduce or heal scoured areas. Tunnel erosion may call for de-stocking, contour drainage, and the establishment of deep-rooted plants, while the problems of desalting need the combined factors of reafforestation (to lower groundwater tables) following deep interceptor drains to cut off salt seepages in surface soils (see Chapter 11).

Erosion follows deforestation, soil compaction, disturbed soil-water balance (increased overland flow and rising water tables or salt seepages), overgrazing, plough agriculture on the broad scale, episodes of high winds or rains in drought periods, or severe disturbance caused by animal tracks, roading, and ill-advised earthworks.

Insofar as landscape design is concerned, soil erosion repair is the priority wherever such erosion occurs. Apart from the physical factors, no designer, or nation, can ignore the economic or political pressures that inevitably create erosion by requiring or permitting inappropriate land use and forcing production or over-production on to the fragile structure of soils. Third world debt and western world over-production are both primary factors in soil collapse. In a conservative society, the very basis of land use planning would encompass the concept of permitted or restricted use of soils, carefully plotted in regions following analyses of slope, soil stability, minimal forest clearing (or reafforestation), and permitted maximum levels of crop production, or livestock density, following the procedures of good soil husbandry.

In assessing erosion in the U.K., Charles Arden-Clarke and David Hodges (*New Scientist* 12 Feb '87) point out that "many of the recent outbreaks of severe erosion are clearly linked to falling levels of organic matter in the soil... the more organic matter there is in the soil, the more stable it is." This stability is because of good soil structure and infiltration of water, whereas an inorganic soil may break down under rain. With the following increase in overland flow, most soils will then erode as rills or gullies, or the destroyed surface can powder and blow away without organic matter to bond it.

On many delicate soils (over chalks) the only answer is to replace crops with pasture or forests. Intensive arable use and winter cropping both create more erosion. The very radical conclusion is that mulching, green manure, grass leys on rotation, hedgerows, and minimal cultivation are not only urgent but imperative. Thus, "the time to examine the organic (farming) approach has passed, the time to adopt it has arrived." (*ibid.*) At long last, some scientists are saying that enough evidence is enough; we need to turn to known effective land management based on permanence and organic methods. This will take the combined good will of farmers, scientists, financiers, and consumers.

8.18
SOIL REHABILITATION

Careful gardeners take care not to break up, overturn, or compact their valuable soils, using instead raised beds and recessed paths to avoid a destruction of crumb structure. Responsible farmers try to govern the speed and effect of their implements in order to preserve the soil structure, and can get quite enthusiastic about a dark, humus-rich, crumbly soil. We seldom give farmers time or money to create or preserve soil, but expect them to live on low incomes to serve a commodity market, whose controllers care little for soil, nutrition, or national well-being.

No matter on what substrate we start, we can create rich and well-structured soils in gardens, often with some input of labour, and always as a result of adding organic material or green manures (cut crop). No matter how rich a soil is, it can be ruined by bad cultivation practices and by exposure to the elements: wind, sun, and torrential rain.

Worms, termites, grubs, and burrowers create soil crumbs as little bolus or manure piles, and they will eventually recreate loose soils if we leave them to it in pasture. But we also have other tools to help relieve compaction; they can be explosives, special implements, or roots.

We use the expansive and explosive method rarely, perhaps to plant a few valuable trees in iron-hard ground by shattering. People like Masanobu Fukuoka[3,4] are more patient and effective, casting out strong-rooted radish seed (daikon varieties), tree legume seed, and deep-rooted plants such as comfrey, lucerne, *Acacias*, and eventually forest trees. Much the same subsurface shattering occurs, but slowly and noiselessly. The soil regains structure, aeration, and permits water infiltration.

A measure of the change wrought by green manures, mulch, and permanent windrow is recorded by Erik van der Werf (*Permaculture Nambour Newsletter*, Queensland, Dec. 1985 and Mar/Apr 1986). Working in Ghana at the Agomeda Agricultural Project, he reports on the improvement of crumb structure by measuring the bulk density (weight per volume ratio (g/cc) of soil samples) is given in **Table 8.8**.

TABLE 8.8
Improvement in Crumb Structure

Soil Treatment	Bulk Density g/cc
Annually burnt bush	1.35
Bush left 2 years without fire	1.27
Farmland, cultivated 2 years	1.29
Farmland, permanently mulched and cropped for 3 years	0.92*

*Even with cropping, the mulched soils show how humus alone restores good aeration; soil temperatures were lower by 10°C, and both crop grain yields and a three times increase in organic matter production were noted.

We can use rehabilitative technology on a large scale, followed by the organic or root method, by pulling a shank and steel shoe through the soil at depths of from 18 cm (usual and often sufficient) to 30 or even 80 cm (heroic but seldom necessary unless caliche or compacted earth is all we have left as "soil").

In field or whole site planning, a soil map delineating soil types can either be purchased or made based on local knowledge and field observation. In designing, it helps future management if uses, fencing, and recommendations for soil treatment and crop can be adjusted to such natural formation as soil types. An aid to SOIL TYPING can be found in basic books on soils. These publications give practical guides to landform, floristics (structural) typing, and soil typing and taxonomy (categories or classes of soils).

We can recommend low-tillage systems, pay close attention to water control during establishment, and get soil or leaf analyses done. We can also make careful trials of foliar sprays, the additions of cheap colloids to sands, the frequency and timing of critical fertiliser applications (often and little on sands, rarely or as foliar sprays on clays). Crops suited to natural pH (it is often expensive to greatly modify this factor) and rainfall should be selected for trials. Close attention needs to be paid to the soil stability and thus the appropriate use for soils on slope.

In particular, priorities should be set for erosion control in any specific soil or on specific sites or slopes, and earthworks or planting sequences designed to establish soil stability, for if we allow soil losses to continue or worsen, all else is at risk. The next stage in the design is to assess the capacity of soils for dams, swales, foundations, or specific crops (this may need further analysis, test holes by auger, or soil pit inspection).

Thus, if we have adopted a pre-determined set of values based on soil and water conservation and appropriate uses of sites versus erosion and high energy use, any site with its water lines and soil types noted starts to define itself in usages.

How we need to proceed in soil rehabilitation is roughly as follows:

1. WATER CONTROL. Drainage and sophisticated irrigation are needed to rehabilitate salted areas, and soil mounding or shaping to enable gardening in salted lands (as explained in Chapter 11 on arid lands). We need to rely much more on natural rainfall and water harvest than on groundwaters. Drought is only a problem where poor (or no) water storage has been developed, where tree crops have been sacrificed for fodder or fuel, and where grain crops are dependent on annual rains.

Although many sands and deeply weathered soils are free-draining, waterlogging can occur wherever soil water lies over an impermeable soil layer or where water backs up behind a clay or rock barrier; anaerobic soil results. Remedies lie in any of three techniques:

1. Raised garden beds: paths are dug down for drains, and beds raised; in very wet areas give paths a 1:500 slope to prevent erosion. **Figure 8.10.A**

2. Deep open drains every 10–80 m (clay–sands) upslope and downslope or on either side of garden beds. **Figure 8.10.B**

3. Underground pipes (tile drains; fluted plastic pipes are best) laid in 1.5 m deep trenches and backfilled at 1.5 m (4.5 feet) deep and from 10–80 m (32–262 feet) apart, starting on a drain or stream and with a gentle fall (1:1000–1:600) to the ridge. **Figure 8.10.C**

Water retention in soil is now greatly aided by long-term soil additives. These are gels which absorb and release water over many cycles of rain. This is a practical system only for gardens or high-value tree crop (where the cost amortises).

2. SOIL CONDITIONING. Compacted, collapsed, and eroded soils need rehabilitative aeration, and a change in land use.

3. FERTILISATION. We can reduce and replace past wasteful or polluting fertilisation by sensible light trace element adjustment via foliage sprays *if* undisturbed soil systems and permanent crop have been developed. Foliar spray of very small amounts of key elements greatly assists plant establishment, as does seed pelleting using key elements deficient in plants locally. We may then be able to utilise much of the phosphate that is locked up in clays, and using legumes, create sufficient nitrogen for food crops from sophisticated interplant and green manures.

4. CROP AND PLANT SPECIES SELECTION. Many older varieties of both annual and perennial crops will yield with less fertiliser and water applications than will more recently-developed varieties. There is a growing trend amongst farmers and gardeners to preserve and cultivate these varieties not only for the reasons above, but also for flavour. Many older apple varieties, such as some of the Pippin and Russet types, are more flavourful than, say, the market-variety Red Delicious. There is still a large diversity of food crops left in the world; the key is to grow them and to develop a regional demand. Many older apple or wheat species are not only pest-resistant, but have higher nutritive value, and can produce well in less than optimum conditions.

There are different species of plants that can live in almost any type of soil, starting the process back to rehabilitation. It is often the case that so-called noxious weeds will colonise eroded landscapes, beginning a slow march towards stabilisation; these can be used as mulches.

Soils can be created or rehabilitated by these basic methods:

- Building a soil (at garden scale);
- Mechanical conditioning; and
- Life form management (plants and macro- or micro-fauna).

BUILDING A SOIL

Gardeners normally build soil by a combination of

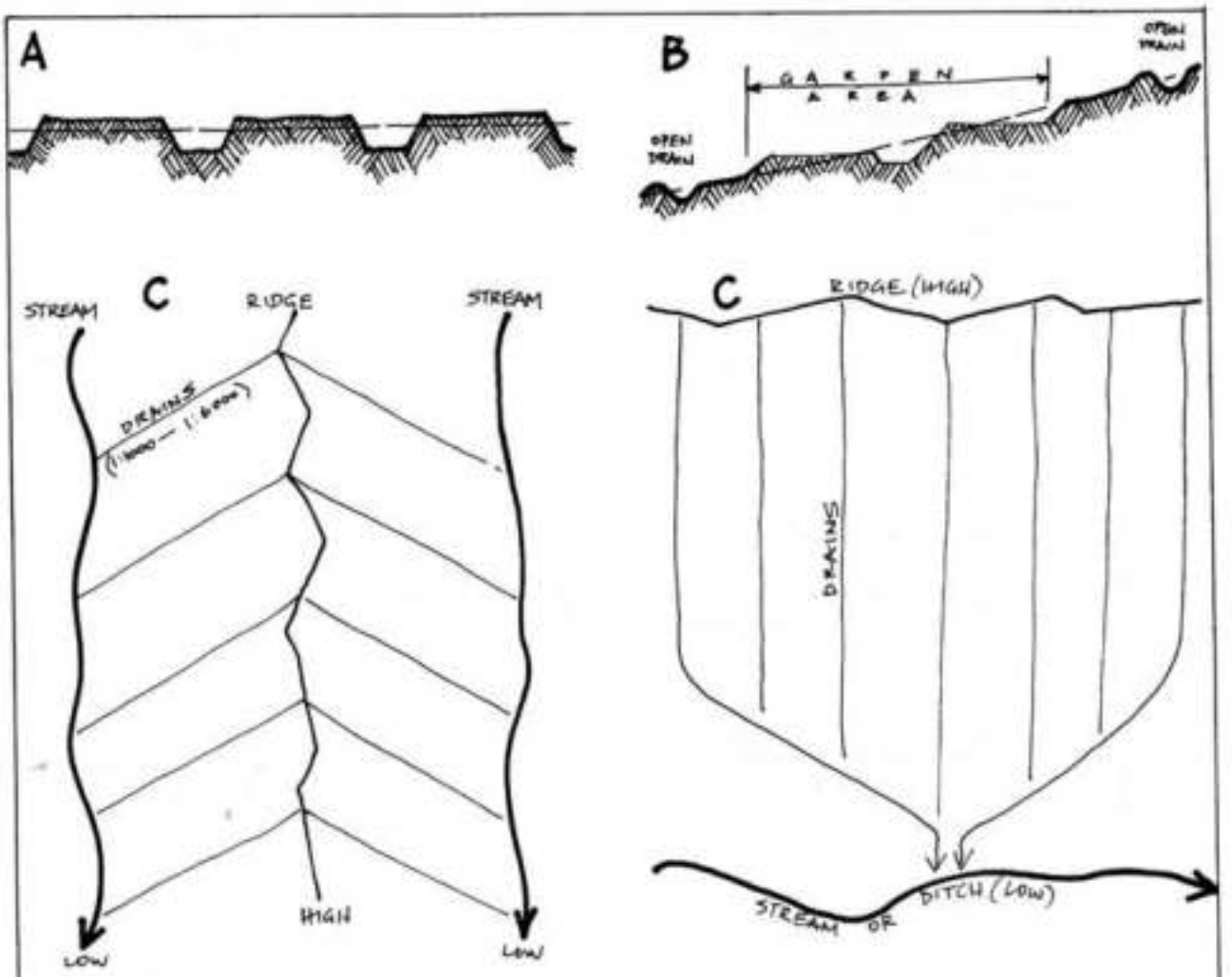


FIGURE 8.10
DRAINAGE OF WET SOILS
A Raised garden beds
B Deep open drains
C Underground pipes or ditches at about 1:200 slope will drain fields.

three processes:

1 Raise or lower beds (shape the earth) to facilitate watering or drainage, and sometimes carefully level the bed surface;

2 Mix compost or humus materials in the soil, and also supply clay, sand, or nutrients to bring it to balance; and

3 Mulch to reduce water loss and sun effect, or erosion.

Gardeners can, by these methods, create soils anywhere. Accessory systems involve growing such compost materials as hedgerow, herbs, or soft-leaf plots, or as plantation within or around the garden, and by using a combination of trellis, shadecloth (or palm fronds), glass-house, and trickle irrigation to assist specific crops, and to regulate wind, light, or heat effect.

By observing plant health, gardeners can then adjust the system for healthy food production. Many gardeners keep small livestock, or buy manures, for this reason.

Large-scale systems (small farms) cannot be treated in the above way unless they are producing high-value product. Normally, farmers create soils by broadscale drainage or by soil "conditioning". As most degraded soils are compacted, eroded, or waterlogged, they need primary aeration (by one of the many available modern machines, or by biological agents), then careful plant and livestock management to keep the soil open and provided with humus.

Daikon radish, tree or shrub legumes, earthworms, root associates for plants (rhizobia) all aerate, supply soil nutrient, or build soil by leaf fall and root action. The management of livestock for least compaction and over-grazing is part of the skill of soil building and preservation. Many organic farmers introduce worm species to pastures as part of their operation, and sow deep-rooted chicory, radish, or comfrey for green manures.

SOIL TREATMENT ON COMPACTED SITES—SOIL CONDITIONING

On the common degraded soils of marginal areas, we can observe compacted, eroded, lifeless soils; they are overgrazed and often invaded by flatweeds and non-forage species of plants. They are boggy and wet in winter, and they are dry, cracked and bony in summer, having little depth. The reconstitution proceeds as follows:

At the end of winter, or in autumn after some rain, when the soil will carry a tractor, a chisel plough is pulled 5–10 cm (2–4 inches) deep over the area, either on contour parallels or on low slopes, starting in the high valley bottoms and driving slightly downhill to the ridges. Unless there are absolutely no legumes or grasses already growing, no extra seed is applied. The response is increased penetration of roots, germination of seed, and a top-growth of pasture.

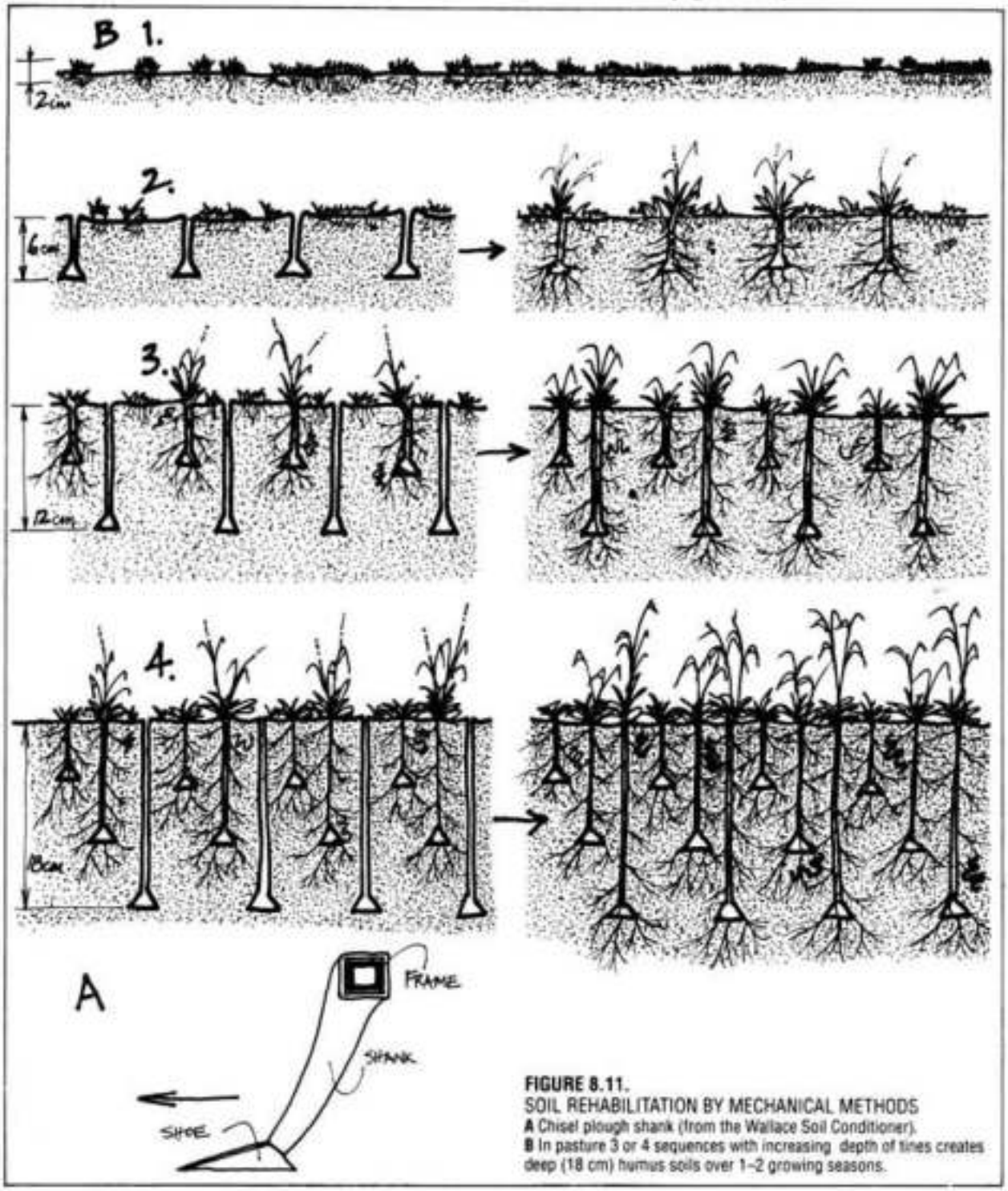


FIGURE 8.11.
SOIL REHABILITATION BY MECHANICAL METHODS
A Chisel plough shank (from the Wallace Soil Conditioner).
B In pasture 3 or 4 sequences with increasing depth of tines creates deep (18 cm) humus soils over 1–2 growing seasons.

A chisel plough or soil conditioner is a rectangular steel frame (tool bar) towed by tractor or draught animals, to which a number of shanks are attached. These are narrow-edge (axe-edged) forward-curved vertical flat bars to the point of which a slip-on steel shoe is attached. The shanks clamp to the tool-bar frame, and the points to the shank. Even one implement of 5 shanks (25-50 b.h.p. tractor) covers a lot of country. There are now at least six or seven makers of soil-loosening machines, in the USA, Europe, and Australia.

Geoff Wallace has produced a soil conditioner of great effectiveness. A circular coulter slits the ground, which must be neither too dry nor too wet, and the slit is followed by a steel shoe which opens the ground up to form an air pocket without turning the soil over. Seed can be dropped in thin furrows, and beans or corn seeded in this way grow through the existing grass. No fertiliser or top-dressing is needed, only the beneficial effect of entrapped air beneath the earth, and the follow-up work of soil life and plant roots on the re-opened soil.

This new growth is then hard-grazed, or cut and left to lie. The plants, shocked, lose most of their root mass and seal their wounds. The dead roots add compost to the soil, as does the cut foliage or animal droppings, giving food to the soil bacteria and earthworms, and softening the surface. As soon as the grazing or cutting is finished, chisel again at 23-30 cm (9-12 inches), on the same pattern as before. Graze or cut again, chisel again at 23-30 cm. Graze or cut.

During this process, often a matter of a one-year cycle, the pasture thickens, weeds are swamped with grasses and legumes, myriad roots have died and added humus, and thousands of subsurface tunnels lead from valley to ridge, so that all water flows down into the soil and out to the ridges. Earthworms breed in the green manure, bacteria multiply, and both add manures and tunnels to the soil. A 23 cm (9 inch) blanket of aerated and living soil covers the earth.

Dust, deep roots, rain, and the bodies of soil organisms all add essential nutrients. The composted soil is, in essence, an enormous sponge which retains air and water, and it only needs a watchful eye and an occasional chiselling in pasture (or a forest to be planted) to maintain this condition.

If tree seed, soybeans, millet or other crop is to be planted, the sequence is as follows: after a few hard grazings or mowings, a seed box is mounted on the chisel plough frame, and the seed placed in the chisel furrow; the grazing or mowing follows germination of the seed. These new plants (sunflowers, millet, melons) grow faster than the shocked pasture, and can be let go, headed, or combine-harvested before the grasses recover. There is never any bare cultivation, and grain growers can move to a minimum tillage method of cropping, with fallows of pasture between crops.

Soil temperature is greatly modified, as is soil water retention. Geoff Wallace (*pers.comm.*) recorded as much as 13°C (25°F) increase on treated versus untreated soils in autumn. This increased temperature is generated both by the biological activity of the soil and the air pockets left by the chisel-points at various depths, and enables earlier and more frost-sensitive crops to be grown.

Nodulation (of nitrogen-fixing bacteria) is greatly increased, as is the breakdown of subsoil and rock particles by carbonic acid and the humic acids of root decay. Methane generated from decay aids seed germination, and water (even in downpours) freely passes into, not off, the soil. After a year or so, vehicles can be taken on the previously boggy country without sinking in. Drought effects are greatly reduced by soil water storage.

Water, filtered through soil and living roots, runs clear into dams and rivers, and trees make greatly increased growth due to the combined factors of increased warmth, water, root run, and deep nutrients.

Fukuoka[3] (in Japan) uses radish and *Acacia*; Africans use *Acacia albida* or *Glyricidia*; New Guineans use *Casuarina*; and Mediterranean famers use *Tamarix* for biological "chisel ploughs" where land is too steep and stony for implements. Otherwise the "graze or cut and let lie" method is still followed. On such difficult terrain as boulder fields, dunes, steep slopes, and laterites, forests of mixed legume/non-legume crops (citrus, olive, pine, oak) are the best permanent solution to soil conservation.

No matter how we aerate soil (or condition it), whether with humble implements like a garden fork levered slightly, by planting a daikon radish, or by sheer mechanical power, we can soon lose the advantage of looseness and penetrability by over-stocking, cropping, heavy traffic, or heavy-hooved animals stocked in wet weather. All of these pug or compress the soil into a solid state again. Final solutions lie only in following on with permanent and deep-rooted plants (forests or prairies), and by maintaining good management (minimum tillage) cropping.

Any reduction in cultivation saves energy and soils, and wherever no-tillage systems can be devised, and heavy hoofed animals kept to a minimum, soil structure can be repaired.

Intense fire, intense stocking, intense cropping, and intensive production all threaten soils. Thus, mechanical soil rehabilitation can be a one-time and beneficial process, or another way to waste energy every year. It is the usages that follow on re-habilitation that are beneficial or destructive to soils in the long term.

Mechanical loosening of soils is appropriate (on the broad scale) to almost all agricultural soils that have been compacted. Soils with coarse particles, of cinder, or dunes do not benefit from or need loosening, and very stony or boulder-soil mixtures are appropriately rehabilitated not by mechanical but by organic (root penetration) methods, as are soils on steep slopes. Some soils (like volcanic soils with permanent pastures) may never lose structure, and will maintain

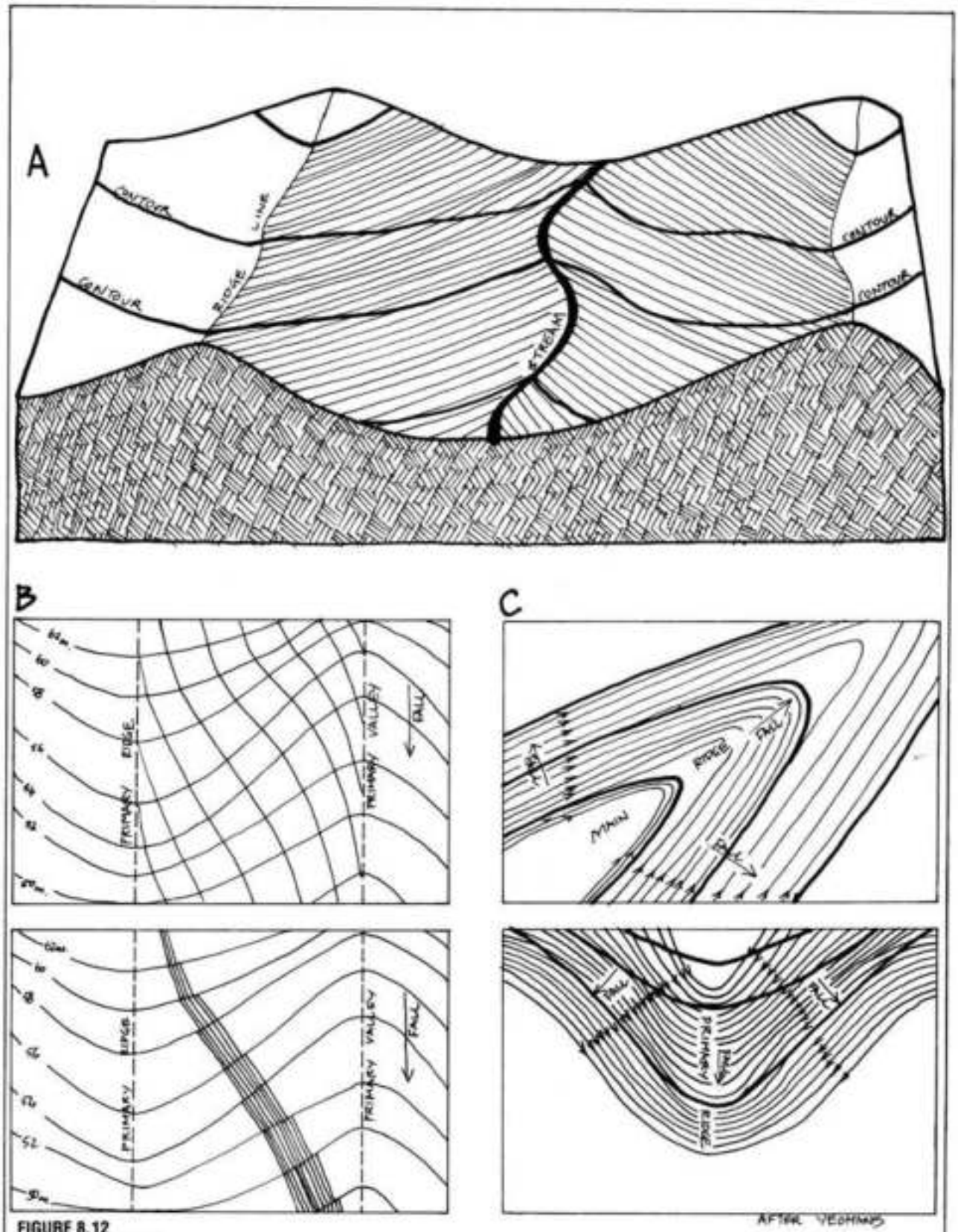


FIGURE 8.12
SOIL CONDITIONING
A Ideally, chisel lines run "downhill" from valley to ridges.
B Here, water flow crosses contours at right angles (no chisel lines) and creates sigmoid (S) curves in the landscape.
C In conditioned landscapes, chisel lines prevent fast run-off and absorb overland flow, leading water to ridges.

free internal drainage after years or centuries of grazing. Thus, we use rehabilitative energy only where it is appropriate.

Soil conditioning can be sequential, allowing a year between treatments, or all-at-once at 20 cm or so, in order to prepare for tree crop planted immediately. The time to use implements is also critical, and early spring or at the end of a gentle rainy period is ideal, as the soil is not then brought up to the surface as dry clods, nor collapses back as being too wet.

There is only one rule in the pattern of this sort of ploughing and that is to drive the tractor or team slightly downhill, making herring-bones of the land: the spines are the valleys and the ribs slope out and down-slope (**Figure 8.12**). The soil channels, many hundreds of them, thus become the easiest way for water to move, and it moves *out* from the valleys and below the surface of the soil. Because the surface is little disturbed, roots hold against erosion even after fresh chisel ploughing, water soaks in and life processes are speeded up. A profile of soil conditioned by this process is illustrated by **Figure 8.11**.

There is no point in going more than 10 cm in first treatment, and to 15-23 cm in subsequent treatments. The roots of plants, nourished by warmth and air, will then penetrate to 30 cm or 50 cm in pasture, more in forests. For disposal of massive sewage waste-water, Yeomans[5] recommends ripping to 90 cm or 1.5 m, using deep-rooted trees or legumes to take up wastes.

I have scarcely seen a property that would not benefit by soil conditioning as a first step before any further input. Pasture and crop do not go out of production as they do under bare earth ploughing with conventional tools, and the life processes suffer very little interruption.

In small gardens, the aeration effect is obtained in two ways:

- By driving in a fork and levering gently, then removing it.
- By thick surface sheet-mulch; worms do the work.

To summarise briefly, the results of soil rehabilitation are as follows:

- Living soil: earthworms add alkaline manure and act as living plungers, sucking down air and hence nitrogen;
- Friable and open soil through which water penetrates easily as weak carbonic and humic acid, freeing soil elements for plants, and buffering pH changes;
- Aerated soil, which stays warmer in winter and cooler in summer;
- The absorbent soil itself is a great water-retaining blanket, preventing run-off and rapid evaporation to the air. Plant material soaks up night moisture for later use;
- Dead roots as plant and animal food, making more air spaces and tunnels in the soil, and fixing nitrogen as part of the decomposition cycle;
- Easy root penetration of new plantings, whether these are annual or perennial crops; and
- A permanent change in the soil, if it is not again trodden, rolled, pounded, ploughed or chemicalised into lifelessness.

Trees, of course, act as long-term or inbuilt nutrient pumps, laying down their minerals as leaves and bark on the soil, where fungi and soil crustacea make the leaves into humus.

8.19
SOILS IN HOUSE FOUNDATIONS

Soils cause perhaps 60-80% of all house cracks and insurance claims for faulty construction and "tree damage". About 20% of the soils we build on will subside or heave depending on water content. Specifically, black cracking clay, surface clays, and red-brown clay loams are subject to swelling and shrinking. Solid stone and brick houses are most subject to structural failure, with wood-frame and veneer less so.

Over-irrigation of gardens, causing the water table to rise, is a primary cause of soil swelling. The removal of trees assists this process, as do paved areas, and burst or leaking sewage and water pipes. Some notorious white or yellow clays collapse as dam walls when wetted. It is as well to consult your local soil expert for large constructions as trials can be expensive.

While the effects are most noticed to 2 m deep, probes to 10 m deep need to be monitored for groundwater levels. Soils subside and shrink with excessive drying (too many trees too near the house) and swell and heave with excessive watering and no trees. Adelaide (Australia) is an area where most damaged houses are on blacksoil clays, but several other areas also suffer these effects, and in some, large buildings need to be built on foundations capping deep piles (to

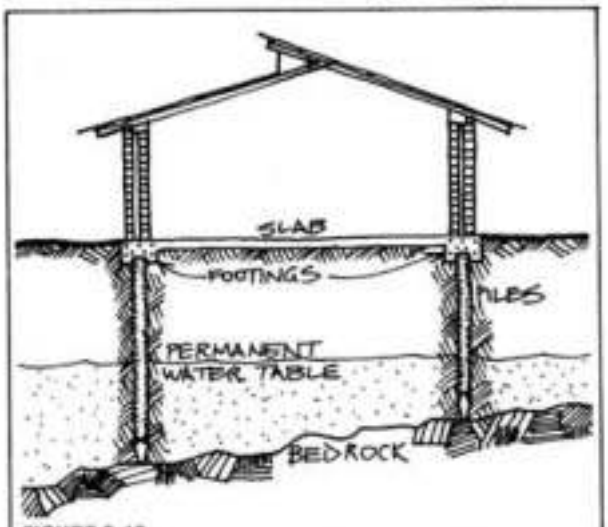


FIGURE 8.13
PILES SUNK INTO WATER TABLE OR BEDROCK
to stabilise house foundations in swelling clay soils.

20 m) sunk to the bedrock or deep into the permanent water table (**Figure 8.13**).

Most Australian native trees have an efficient water removal via roots, so that eucalypts remove 2–3 times the water of pines or pasture (to 10 m radius). Generally, householders should keep large trees at least one half the mature height from the house when building in high clay-fraction soils; sands and sand-loams are usually stable, as are rotten or fractured rock and sandstones.

8.20
LIFE IN EARTH

Before we ever learned to cut open the soil, it was thoroughly dug, aerated, and overturned by multitudes of industrious burrowers. The unploughed meadows of Europe and America are as soft as a great mattress, and are well aerated due to the moles, gophers, worms, prairie dogs, rodents, and larvae eternally at work below ground, even under the snow. Termites, ants, and crustaceans all do their part. The results are obvious from the good soils and great productivity of unploughed ground which has not been compacted by hooves or machines.

Termites and ants are the earthworms of the deserts and drylands, carrying tons of organic material to underground compost piles, in some of which they may grow fungi to feed their colony. The upthrown earth, whether from ants or moles, forms a specific niche for annuals to seed on, and wind-blown pioneer trees to occupy. If birds are the seedscatterers of the forest, burrowers are the gardeners.

Underground and beneficial fungal spores eaten by squirrels or wallaby and activated by their digestive enzymes break hibernation to occupy new ground and help the new roots of acorns and eucalypts to convert soil minerals and liquids to food. Gophers and moles industriously carry roots and bulbs to secret stores and sometimes forget their hoards, so that sunroot, gladioli, daffodils and hyacinths spring up in unexpected places above ground. This is how comfrey and sunroot spread, despite their lack of viable seed. They depend not on bees, but on moles and gophers for their increase. Foxes eat fruits, and defecate on gopher mounds, which are the dug-over areas for new trees.

Wombats may tunnel, overturn, and even topple many hectares of trees, leaving a richly-manured, open, and fertile bed for new forest evolutions. Rabbits industriously garden thistles, and their tunnels give shelter to possum, squirrels, bandicoots, snakes, and frogs.

Worms and crustaceans, in their damp and sometimes semi-liquid burrows, move up and down like a billion pump plungers, sucking in and expelling air (and thus nitrogen) to roots, and in effect giving the soil its daily breath. Many creatures mix up special mudbrick soils with body secretions, and from

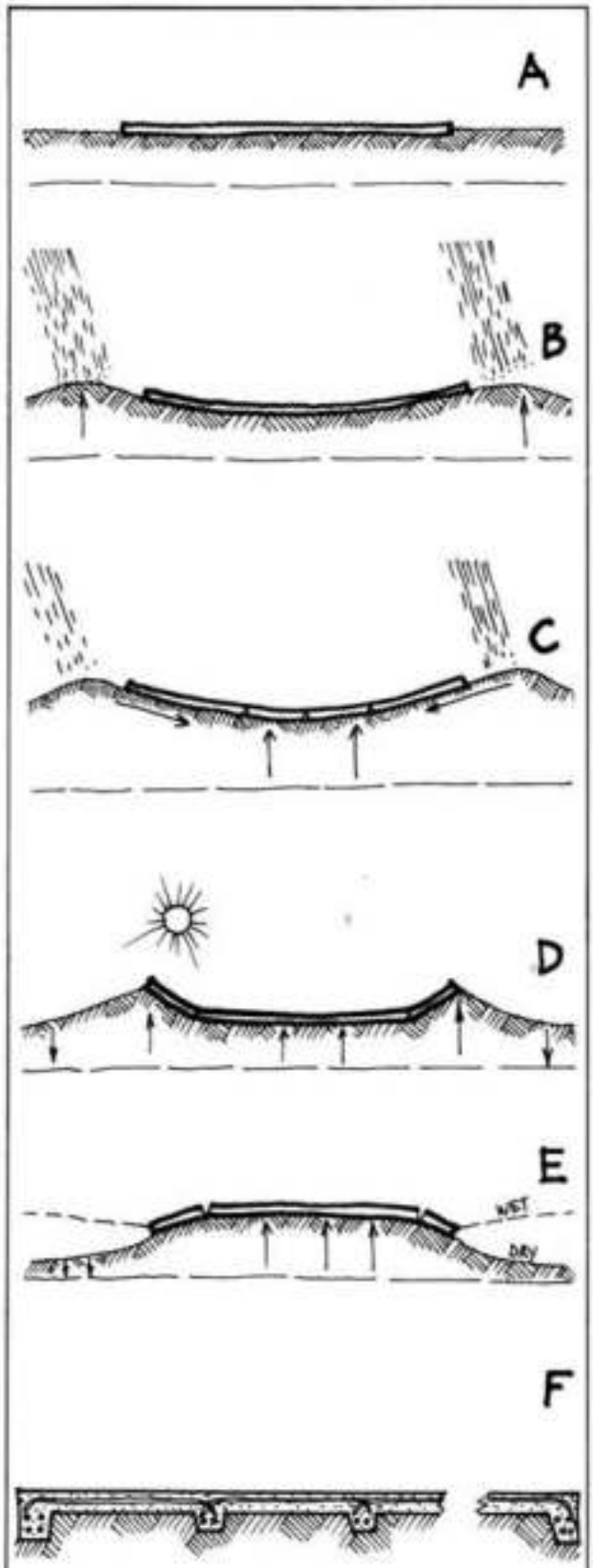


FIGURE 8.14
A–E HOW A MOUND DEVELOPS UNDER A HOUSE
F Slab plus beam construction helps stability.

swallows to termites create homes from stabilised soils. Seeds and spores are buried, excavated, hidden, activated, and forgotten by burrowers, and recycled to life or humus as chance and nature dictate.

Roots die seasonally, invade and retreat, and leave minute or massive tunnels for animals, fungi, and new roots to follow. I once tried to dig a parsnip out of newly drained swamp ground, following it along an old root trace, but gave up after 2 m. I did persist in following a 4 cm long engaeid "land crab" or earth lobster to 2 m down and 2 m along, and have often dug out rabbit and mouse burrows to find their nests, mating circuses, air vents, nursing chambers, disposal chutes, and escape hatches. Many old gopher burrows are filled with plant remains and faecal wastes.

A few dedicated souls in the history of science, from Sir Albert Howard to modern ecologists, try to excavate and discover something of roots, but as a simple bluegum (*Eucalyptus globulus*) can easily embrace an underground 1.5 ha, a forest is so complex and even intergrafted below ground that the canopy seems simple. Many desert plants lead a long and sturdy underground life while thin, straggly, and ephemeral in air. Some insects, like swift moths (*Hepialidae*) spend 7–8 years underground as large bardi grubs (a succulent treat for Australian diggers), with only a few days of nocturnal foodless life in air, mating and laying eggs before disappearing again to the root sheaths and soil, as their near cousins the ghost moths and witchetty grubs do in aerial stems. The bardi grubs, too, open thousands of shafts to the air, and cycle tons of nutrient underground, as do their relatives in air and sunlight. Their predators follow these hoarders and burrowers below the soil, and hunt them in darkness and secrecy.

The implications for designers are that many of these effects may be put to use, or their uses appreciated; it is as valid to plant an *Acacia* for the considerable by-product of swift moth or ghost moth larvae as it is plant a mulberry for silkworms, and to use moles instead of mole ploughs, or gophers as daffodil gardeners (unpaid). Even on shores and the bottom of lakes and seas, the burrowers work to carry nutrients below to roots and to bring up fresh minerals for decomposition, while assisting the flux of liquids and gases across the surfaces of mud media.

Roots have their own PENETRATIONS (depth), PATTERNS or spread, SCHEDULES, seasonal MIGRATIONS to or from the surface, and equivalents of deciduous drop or bark decortication, dying off and sloughing off root branches and bark. It follows that there is a topography of plants underground that parallels that of plants in air. There are also basic differences, in that special storages or fire-resistant organs found underground as ligno-tubers, tubers, bulbs, and rhizomes are very common.

Some species secrete phenols or creosoles to inhibit other plants (bracken, tamarisk, *Juglandaceae*, *Brassicas*); others encapsulate or surround hapless competitors (*Eucalyptus*, willows, tamarisks). Some trap nematodes and other would-be predators, or poison them out (marigolds, fungi, *Crotalaria*). While agricultural crops exploit from 0.6–4 m (2–12 feet) below the earth, some trees may penetrate to 50 m (164 feet) in deep desert sands. Around the roots of dune trees, calcium and other minerals are deposited as stone-like secretions by root-associated fungi and bacteria. Root space sharing is also scheduled, so that spring bulbs have fed, flowered, and died before the tree roots begin their upward thrust for nutrients and water. Tap-rooted late starters such as thistles and comfrey reach deep for late summer moisture, while a very few plants and fungi take advantage of the autumn rains for flowering and dispersal.

Where there is no season of cold death, as in the low latitudes, aerial roots may develop, or strangler figs send down roots from high in the crotches of other trees to the earth, there to build great buttresses as they strangle their host tree in a root well.

For designers, the diversity of roots in soil can be used as effectively as the diversity of crowns and canopies. Unstable slopes are pegged with the great root "tree nails" of chestnut and pine, oak and walnut. Even after a hundred years, the steep slopes of this island (Tasmania) are only just starting to collapse as the roots of the cleared forests rot, and could still be saved by pines, *Acacias*, or chestnuts. Bamboo not only holds landslides, but for light structures provides an earthquake-proof mattress of roots. The root mats of swamp vegetation save bulldozers from watery graves, and the fibrous web of the prairie defeats the wind.

GEOLOGY AND LIFE FORMS

Many rocks and strata on earth arise from the actions of living organisms. Whether it is the nodules of manganese in oceanic depths, deposits of diatomaceous earth, coal, or limestone, or opals and amber, all were once the products of living organisms. Much of the strata we see, except much-changed granitic and volcanic deposits, were formed from or modified by life. All soils are life-created, as are the corals and coral sands of many oceanic islands.

Life is also busy transporting and overturning the soils of earth, the stones, and the minerals. The miles-long drifts of sea kelp that float along our coasts may carry hundreds of tons of volcanic boulders held in their roots. I have followed these streams of life over 300 km, and seen them strand on granite beaches, throwing their boulders up on a 9,000 year old pile of basalt, all the hundreds of tons of which were carried there by kelp. Round stones are dredged from great depths in the mid-Atlantic; this does not mean that they were formed there, but more likely that drift kelp carried them there in their roots. Before they fly to Japan and Alaska, some millions of petrels (*Puffinus tenuirostris*) annually fill their crop with Tasmanian pebbles, seeds, and charcoal, which will be voided somewhere in the Pacific.

Life moderates every erosion process, every river basin, every cliff and rock fall. It shapes and reshapes earth in a thousand ways.

The hydraulic weight of great forests, such as were once in the Americas, would have exceeded any water catchment weight we can now afford to build, and dispersed it over a greater area. This greatly moderates climate, and with it geological processes. It is possible, in Iran, Greece, North Africa, USA, Mexico, Pakistan, and Australia to see how, in our short history of life destruction, we have brought the hard bones of the earth to the surface by stripping the life skin from it for ephemeral uses. We can, if we persist, create a moon-landscape of the earth. So poor goatherds wander where the lake-forests stood and the forest deities were worshipped. The religions of resignation and fanaticism follow those of the nature gods, and man-built temples replace trees and tree spirits.

8.21
THE RESPIRATION OF EARTH

All of the skin and organs of the earth breathe; it is a regular respiration. The "diaphragm" or energy for this may be provided by the moon tides in water, earth, or air. Locally, the filling up of soil by rainwater forces an exhalation of air; the drying-out an inhalation. Fast winds disturb boundary layers, create low pressure and soil exhalation; slow winds and high pressures force inhalation. Millions of earth animals open breathing tubes, and arrange them (for their own sake) to force an exchange between the atmosphere and the waters, the soils, or sea-sands in which they live. Water is as much breathed as air.

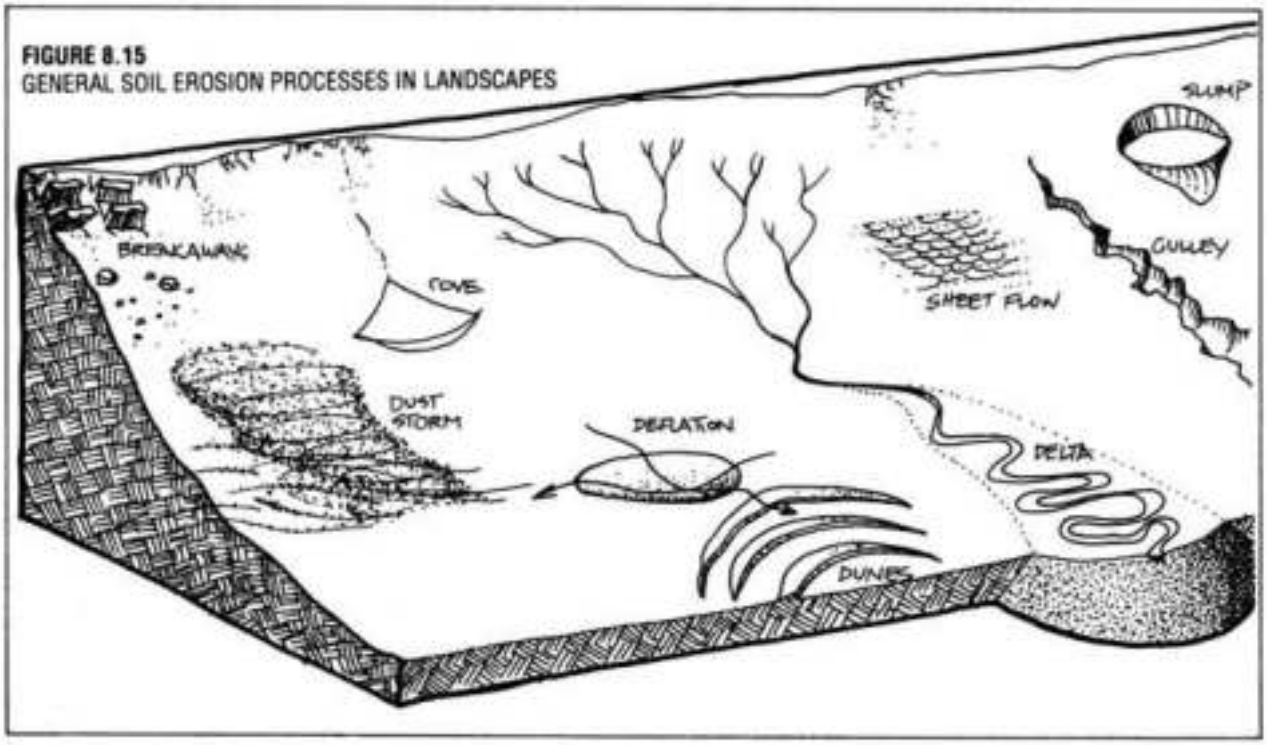
Deeper respirations come from deeper flows and fissures, and radon gas or methane seeps out from the earth. When the earth itself expands, great flows inward and outward must occur through the multitudinous fissures that open up in rigid sediments. This earth respiration transports and transforms fluids and their associated loads, solutes, states, and ionic potential from earth to atmosphere to ocean, setting up the potentials that create thunderstorms or hurricanes. We are of this same respiration. The burrows of spiders, gophers, and worms are to the soil what the alveoli of our lungs are to our body. We can assist this essential respiration by assisting life and natural processes in soils.

> If you kill off the prairie dogs, there will be no one to cry for rain.
> (Navajo warning)

Amused scientists, knowing that there was no conceivable relationship between prairie dogs and rain, recommended the extermination of all burrowing animals in some desert areas planted to rangelands in the 1950's "... in order to protect the roots of the sparse desert grasses. Today the area (not far from Chilchinbito, Arizona) has become a virtual wasteland." Fierce run-off, soil compaction, and lack of fresh seedbed have carried the grasses away (Barre Toelken, in *Indian Science Quest '78*, Sept/Oct).

Using prairie dog burrows as water sinks, and causing water run-off to flood down them, thus germinating stored underground seed, had the opposite effect on the Page ranch, now a dryland

FIGURE 8.15
GENERAL SOIL EROSION PROCESSES IN LANDSCAPES



rehabilitation exhibit of the University of Arizona. Here, prairie dogs and a new and thriving patch of permanent bunch grasses thrive in an area where overgrazing, ploughing, or soil compaction has ruined other grasslands.

> Water under the ground has much to do with rain clouds.
> If you take the water from under the ground, land will dry up.
> (Hopi elder in *Tellus*, Fall '81)

At Black Mesa, near the Four Corners area of the Hopi Indians (USA), a scientist studying thunderstorm occurrence (using computer analysis) noticed an unusual number of storms occurred in that area. She was told by the Hopi of the area where the earth breathed, emitting air as the moon affected the groundwater tides. This air proved to be heavily charged with negative ions, which may have initiated the thunderstorms and consequent rain.

Of the breathing of the earth, there has been little study, although it was regarded as a known phenomena to tribespeople. The earth must breathe, by at least these processes:

- The movement of burrowers in their tunnels;
- The movement of groundwater by tides or replenishment of aquifers (often seen in wells, especially near coasts and lakes); and
- The evaporation of moisture from soil surfaces by the sun.

8.22

DESIGNERS' CHECKLIST

1. It is a *primary* design strategy to prevent topsoil losses and to repair and rehabilitate areas of damaged and compacted soils.
2. Permanent crop, soil bunds, terraces, and low-tillage systems all reduce soil and mineral nutrient loss.
3. Soil rehabilitation and pioneer green crop should precede other plant system establishment.
4. Adequate soil tests, plus test strips of crop examined for deficiency or excess symptoms, leaf analysis, and livestock health should be assessed to guide soil treatments.
5. If soil types can be specified, fencing, cropping, and treatment should coincide with these specific soil assemblies, and specific crops for such type researched.
6. Soil life processes need to be encouraged by provision for green crop, humus, mulch, and the root associates (mycorrhiza) of plants. A useful earthworm may need to be introduced.
7. Drainage, hence pH and soil water capacity, need specific treatment or assessment, and will largely determine crop and tree types.
8. Minimal use of large livestock and heavy machinery is to be recommended on easily-compacted soils, as is burning and clearing.
9. Use pigeon and animal manure where major elements are scarce, as in third world areas (also use of greywater and sewage, or wastes).

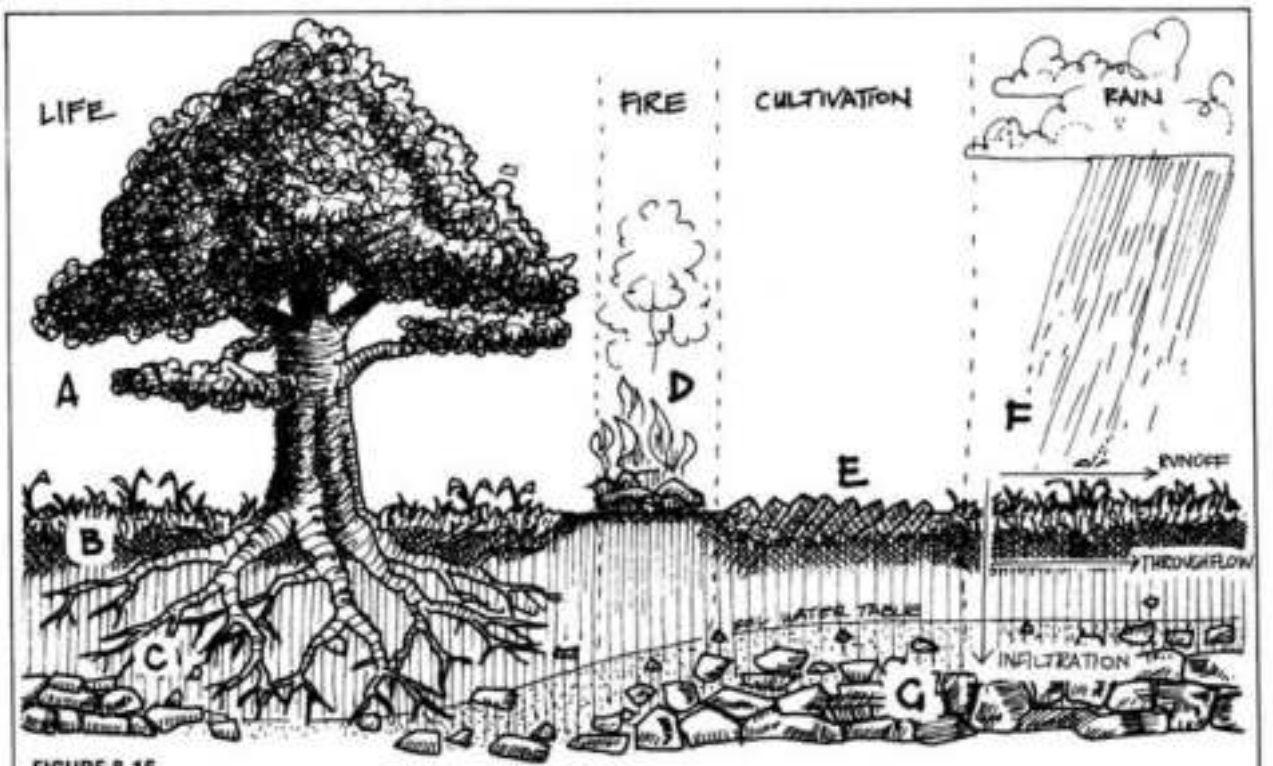


FIGURE 8.16
Soil creation (A–C) and factors aiding erosion and mineral loss (D–F).

10. Before draining waterlogged soils, recommend crops to suit this condition. Never drain wildlife habitats, fens, or bogs which are species-rich.

11. Choose the right soil-shaping or earthworks to suit crop, drainage, and salt threat.

12. Using an auger, check soils for house foundations. Using a (wetted) soak pit, time the absorption of greywater for sewage disposal at house sites.

13. Preserve natural (poor) sites for their special species assemblies; pay most attention to human nutrition in home gardens, and select species to cope with poor soil conditions on the broadscale.

14. Fertilise plants using foliar sprays containing small amounts of the key elements, or pellet seeds with the key elements which are deficient locally. Pelleted seed and foliar sprays are economical ways to add nutrients to plants.

8.23

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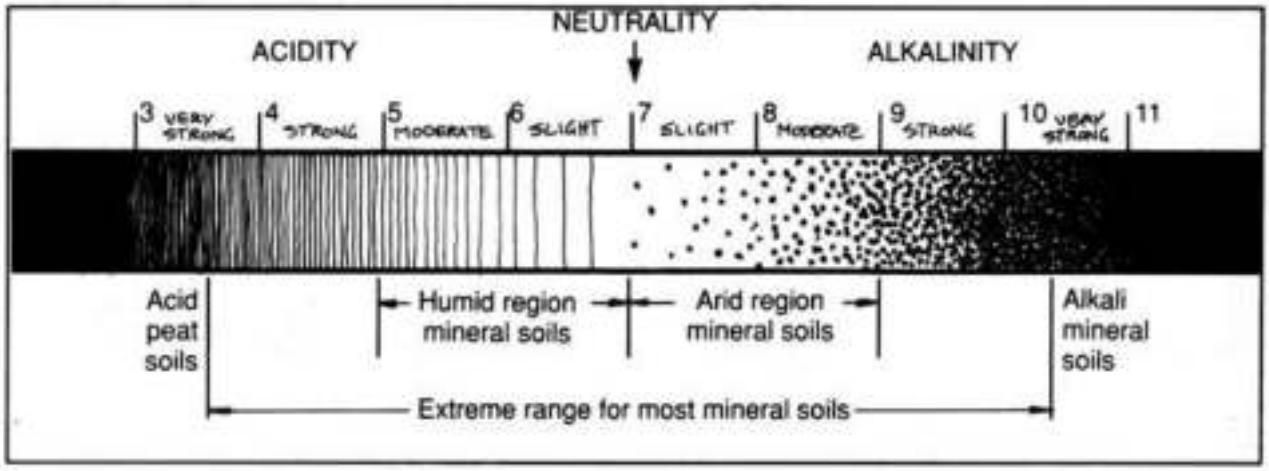


Chapter 9

EARTHWORKING AND EARTH RESOURCES

Moving of the earth brings harms and fears
Men reckon what it did and meant
But trepidation of the spheres
Though greater far, is innocent
(John Donne)

And did the earth move for you?

9.1 INTRODUCTION

Few people today muck around in earth, and when on international flights, I often find I have the only decently dirty fingernails.

For the soil scientist, soil has endless classifications; to engineers, it is a material; to potters, their basic resource; and to housekeepers, footprints on the floor, or part of the eternal dust. However we look upon earth, we will all return to it, and help create the soils our ancestors made, ruined, or form part of. Climate, vegetation, animals, and soil are intimately connected, and each will have influences on the other. It is a great subject, like that of water, and this chapter will concentrate more on its use in structural design than on uses as a growing medium.

People, and other animal species, have mined soils and earth deposits for specific earth resources since their inception; examples are animal migrations to salt licks, and specific dusting sites in which birds and mammals roll or bathe to rid themselves of parasites. People have used silica minerals (obsidian, chert, chalcedony) as tools, and have ground iron oxides or graphites as pigments for many thousands of years. Soils rich in iron oxides have long been mixed with acorn meals to fix the bitter tannins as insoluble ferric tannates ("black" breads), or to supply missing elements in the diet.

There are several clays (illite, smeltite, kaolin, ferrous oxide "red" clays) traditionally used by tribal and modern peoples to absorb poisons (from *Solanum spp.*, yams), to reduce diarrhoea and digestive upsets, or to relieve feelings of nausea (kaolin clay). Although little work has been carried out on this factor, we should record all uses when specific clays are so used, and how they are combined with specific food to reduce or eliminate poisonous or unpalatable toxins from foods. Some earths may be eaten to supply trace elements, as clay and clay–salt licks are commonly visited by deer, kangaroo, cattle, and antelope. Earth-eating (geophagy) is a widespread and seemingly natural habit of children and tribal peoples. As well as clays, the white, mineral-rich ash of trees is widely used as a food dip at campfires by Australian Aborigines. Cooking food in clay is prevalent throughout the world.

Earthworking for agriculture and monuments has existed for at least 17,000 years. Mineral smelting, pottery, and peat or coal mining for fuels increased the scope of earthworks, and this was quickly followed by the development of large machinery intended to remove vast amounts of ores and fuels for modern industry, which built quickly from 1800 on, so that the last 200 years of our existence has seen the greatest development of earthworking and mining.

The common use of self-transporting machines really dates from the post-war years (1947 and on), following the wartime development of tracked tanks, earth scoops used for airfield construction, and large pneumatic tyres for this type of equipment. While civil engineers have to some extent kept pace with these developments, neither the public at large nor those in architectural or agricultural fields have fully realised the potential of earthworking machines in the modern sense.

Our power to move the earth with modern machines is now almost unlimited; we can, if we wish, raise new

hills or plane off existing ones, and create or obliterate minor landscape features. Small earthworks are so immediately effective, cheap, and permanent that it continually amazes me that people will suffer local drought, seawinds, noise, erosion, or even flooding without spending the few hundred dollars on a well-built and planted earthbank that would solve the problem. They will build expensive tankstands or towers rather than a cheap hill, and suffer death by storm and fire rather than make a very safe earth shelter for their families (it serves as an outdoor cellar at other times).

Earthworks are necessary and ethical where they:

- reduce our need for energy (underground housing in deserts);
- diversify our landscape for food production (fish culture ponds);
- permanently rehabilitate damage (contour banks, interceptor banks);
- save materials (house site design); or
- enable better land use, or help revegetate the earth.

As with all techniques, it profits us to make as many uses of earth shaping as we can; it is shameful to see quarries, mines and roads serving a single purpose, and usually left as a sterile system, when they could be shaped or planted to assist landscape diversity.

A whole set of skilled and well-tried waste or soil reclamation strategies has developed as methods of stabilising devastated landscapes, both for natural instability and the carelessness of engineers. An excellent handbook for those involved in such painstaking work, and one covering many climates and areas, is that of Dr. Hugo Schiechtl (*Bioengineering for Land Reclamation and Conservation*, University of Alberta Press, 1980). I cannot too highly recommend this book for would-be earthmovers.

Earth can be moved for productive reasons, many of them classifiable as landscape restitution:

- To create shelter; to assist with foundations and to make areas level for floors;
- To terrace hill slopes for stable padi crop, wet terraces, or gardens;
- To raise banks or to dig ditches as defences against flood, fire, attack, or wandering vegetation-eaters;
- To drain or fill areas (to direct water flow or run-off);
- To create access roads to those places we commonly visit;
- To get at earth materials (ochres, clays, minerals, fuels);
- To make holes for any number of reasons and of greatly varying sizes from fence-posts to dams, wells to deeply drilled bores.
- To create special storages and enlarge living space (cellars and caves);
- To stop erosive forces carrying off soils (soil conditioning and erosion control);
- To prevent noise pollution (embankments); and
- To permit recharge of groundwaters (swales and ripping).

We also move the earth to play and to plant. For all these reasons, we have devised hand-held and mechanical diggers, ditchers, augers, drills, blades, buckets, shoes, rakes, ploughs, rippers, delvers, scoops, earthplanes, loaders, rock-cutters, draglines, excavators, and dredgers. We also move earth with explosives, hydraulic jets, and as an unintentional result of erosive processes generally.

Erosion has itself been used to build soil terraces on lower slopes in more than one culture, but it is debatable if the terrace idea was not as a result of attempts to stop erosion before the idea of using erosion to create terraces later developed.

Until the Second World War, earth was moved by sheer numbers of people, by hand or horse and car, or by a few people working with wheelbarrows or baskets over a long period. All this has changed. Why put up thousands of mud bricks when a machine can compact a 6–8 m thick wall immune to flood, fire, and earthquake in a few hours? Or labour long hours over a hole when we can blast a fence-post in a hard shale base for a few cents?

In this section, I will not attempt to deal with large, complex, or precise civil works, those necessary for sewage layouts, the landscape excavations for large buildings, or large dams, ports, or aerodromes. I will instead limit myself to those on-farm, private, useful, relatively small, and rehabilitative or sustainable earth-moving systems that an individual might employ to shelter a house, or to control water in a productive landscape.

9.2
PLANNING EARTHWORKS

It is best to plan all aspects of the earth-moving process *before* the machines or labourers arrive on site.

1. Make an initial decision where you would like to place the (e. g.) road, dam, house site, drains, etc., using a contour map and plan if necessary.

2. Test the soil by auger holes, soil samples, and soil pits to determine if the soil is good enough to suit your plans (a good clay soil for dams is essential). Seek professional advice or do more research before deciding conclusively on placement.

3. Peg out the site, using a level (which can be simple or complex), a measuring tape, and a good many stakes with red or white cloth attached (so that the earth-moving machine can follow them).

4. Plan a place to store all the TOPSOIL removed during the excavations. Never allow topsoil to be mixed with subsoil, but *carefully* remove it, to be later returned to the site as a growing medium and to stabilise subsoil erosion.

To stabilise the site immediately, have on hand as many seeds and plant materials as needed. These can be purchased from a nursery or grown in pots on the site several months before the planned earthworks (see

9.3 Planting After Earthworks).

When soil is moved, it becomes loose, so that soil air space and hence total volume may increase to 145% of the original. Even when compacted by machine, the fill may occupy a space 10% larger than the cut it came from. Although conscientiously compacted clay in dam walls may settle as little as 1% over time, loose fill will eventually settle to 75% or less of its uncompacted volume; this has great relevance to house foundations and wall stability.

When topsoil is replaced over fill, the area should not be over-compacted, or we risk waterlogging, but when it is replaced over deep or solid subsoil in a cut, we will probably need to first rip or loosen the base subsoil to allow root penetration, just as we need to rip old roads, quarries, parking areas, or heavily-trafficked fill before planting trees and meadows.

To prepare a house site (with drainage), we can proceed as follows:

- Careful survey. Place pegs *outside* the site. Call in the bulldozer.
- Strip off topsoil carefully and mound above and at either end of the site.
- Cut house/garden level; use subsoil fill for access roads only.
- Call in ditcher or backhoe to cut foundation and drainage trenches. Pour foundations and slab, paths; place drains and pipes.
- Call in small blade and bucket machine (a Bobcat or wheeled tractor) to replace topsoil and neaten the site where needed. Some soil can be mounded to the windward side for hedges.
- Plant or seed all topsoil to prevent erosion.
- Fine-tune with barrow, rakes; check drainage.

9.3
PLANTING AFTER EARTHWORKS

Every time we move soil, we should be ready to follow straight on with planting or seeding. That is, we need to have planned the planting and stabilisation of the area, and to have the plant materials on standby to implement our plan *as soon after disturbance as possible*.

There are two reasons for this:

1. To prevent erosion, which can be severe on bare slopes at only 2% slope, especially in rains; and
2. To prevent invasion by unwanted volunteer plants, which may become difficult to displace later.

If a full set of ground covers, pioneers, and long-term plants can be set out in new earth, a great deal of time and work is saved. A broadscale scatter of mixed seed, raked in, will prepare the way for permanent placements. We are most fortunate if we can immediately mulch bare soil sites with hay, hessian (burlap), or woodchips, to break the force of rain and to suppress unwanted weeds.

If you have prepared for bulldozing, you have seed, divisions, cuttings and potted plants ready to go before the machine pulls out. Seed can be garden-collected or purchased; just scatter and if possible rake in. Some mixes that work in most soils:

- Sunflower, or mixed parrot seed with sunflower, millets, pulses, chard, parsley, lupin, and clovers.
- Parsnip (fresh seed), salsify, daikon radish, radish, turnip; all of these "spike" the soil.
- Bulbs of lilies, grape hyacinth.
- Roots of sunroot, comfrey, chicory, horseradish, ginger, sweet potato, tumeric.
- Divisions of bamboo, banna grass, pampas grass, aloes, agave, New Zealand hemp.
- Seedlings or sets of elephant garlic, asparagus, globe artichoke.
- Cuttings of small fruits; elderberry, willow, poplar, mulberry, Pride of Madeira (*Echium fastuosum*).
- Tubed seedlings of *Acacia*, *Prosopis*, tagasaste, New Zealand mirror plant (*Coprosma*), pines, eucalypts, shrubs.

All compete very well with self-sown weeds, and with very little help or none at all establish a varied and useful early and perennial crop system; a few annuals self-sow and seed down another year. Many species can be further divided or cuttings set out, and stakes can be set at the perennials so they are easily located. Excess grass is cut back in the following years.

Clover can be late-sown to allow vegetable seed to get away. Grasses are not sown, but will invade if spaces appear, and can be grazed by geese in a few years. Failed plants can be replaced with successful

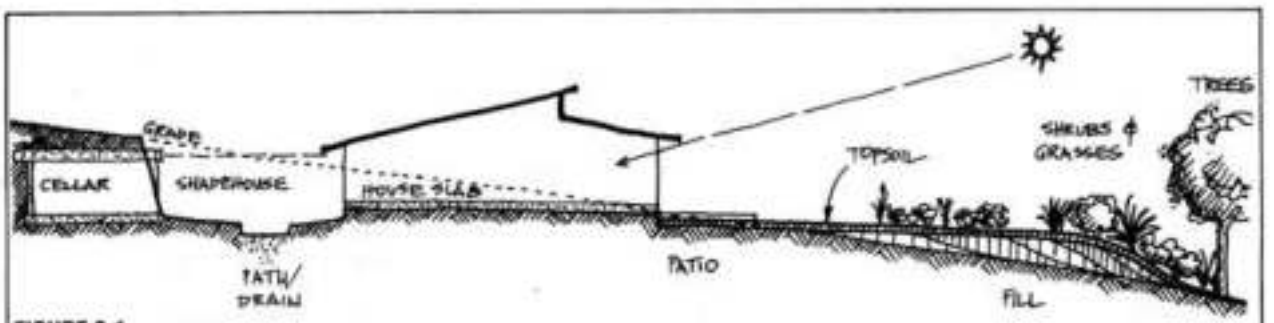


FIGURE 9.1
PREPARING A HOUSE SITE
Careful soil-shaping provides many benefits to a house site.

plants late in the cycle.

It is always an advantage to smooth-finish banks and surrounds so that a mower or scythe can be used until the selected plants take over. Trees are a danger on dam walls; if they fall (and they often do in those conditions) they take part of the wall with them, but bamboos, ginger, sweet potato, pepino, and clump grasses assist bank stabilisation. Trees at the *base* of walls are advantageous in shading, removing water, and reducing weeds.

The "net and pan" planting pattern of **Figure 11.84** is an effective control in overgrazed, eroded, mined or bulldozed sites. If tyres are available, the "pans" can be made from these, filled with mulch, and the diversion drains led in above the tread level. For people with access to logs, these can be staked cross-slope, on a slight downhill grade so that water is made to zig-zag across the erosion face, and hence absorb into the ground.

Even small logs and branches, pegged across erosion channels, build up a layer-cake of silt and leaves, beside which can be planted willow, *Acacia*, or any other fibrous-rooted and hardy species, which then act as a permanent silt trap. Mulch behind logs and barriers quickly stabilises the seed bed for planting. Fallen leaves and scattered dung also accumulate in these mini-deltas to provide plant nutrients. Small wire netting fences, with stone-weighted hay uphill, will trap silt and spread water, as will cross-swales of lemongrass or Vetiver grass.

On very steep slopes, there is often no recourse other than to plant pampas, bamboo, lemongrass, and root-mat pioneers and to make upslope plantings of chestnut, *Acacia*, carob, olive or other large species which will cascade seed downslope over time. Where implements such as chisel ploughs can be used, these are effective in erosion control. Planned chiselling and planting makes a permanent and stable change on hillside. Details on gully control in drylands and in tropical humid areas are given in subsequent chapters.

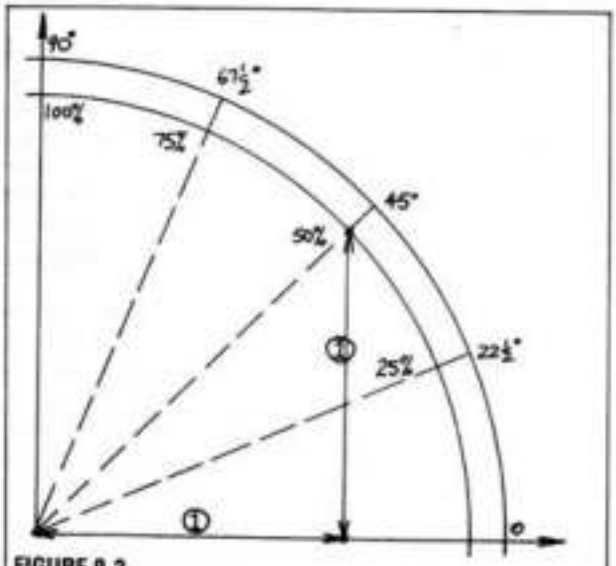


FIGURE 9.2
SLOPE MEASUREMENT
Slope can be expressed as degrees, percentages, or proportion (45° = 50% = 1:1).

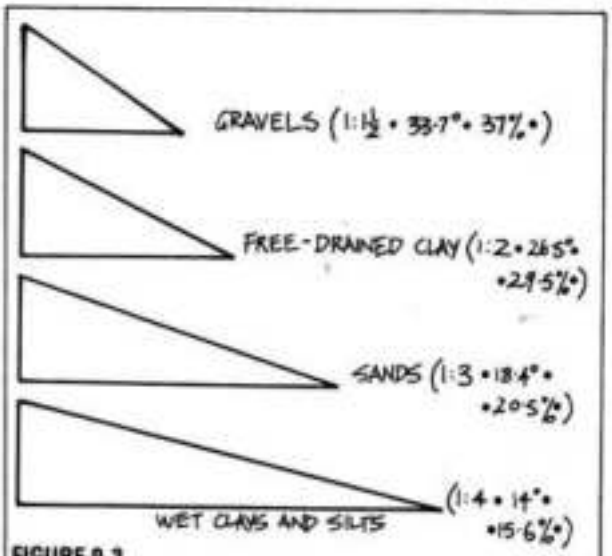


FIGURE 9.3
SLOPE MEASUREMENT (Proportions)
The recommended proportions of slopes for stable rest angles over a range of soil materials.

9.4
SLOPE MEASURES

Slopes are measured and expressed in several ways. First, the slope can be measured as DEGREES FROM THE HORIZONTAL, or the base angles of **Figure 9.2**.

This is expressed as "a slope of 15 degrees", and is sometimes used by geologists to describe the dip (angle) of rock strata.

Next, the 90° between horizontal and vertical can be divided into 100 parts, and expressed as PERCENTAGES, a measure used by engineers.

Finally, slope can be expressed in PROPORTIONS or ratios of base to height, e.g. 1:4 is a slope 1 unit high, with a base 4 units long. This is the rise of slope over distance, often used for drains and pipes, in units used by hydrologists. Many irrigation drains use slopes of 1:500 to 1:2,000, or a fall 1 m in 500 to 2,000 m, and these are referred to as "grades" (**Figure 9.3**).

Coarse slopes are often expressed in degrees, low-slope drainage across slopes as a proportion (1:2,000). Any units serve for proportional or degree measures.

There are suitable irrigation grades for soils and drains. Fine sands need very gentle drainage slope (1:,2000) and earth cuts in sand need an easy angle of rest, about 1:4.5. **Table 9.1** makes clear some slope implications.

Stable natural foothill slopes are not straight but down-curved (concave). When building a road, it is well to remember that they will achieve a concave curve by slump over time, so it is best to cut this curve

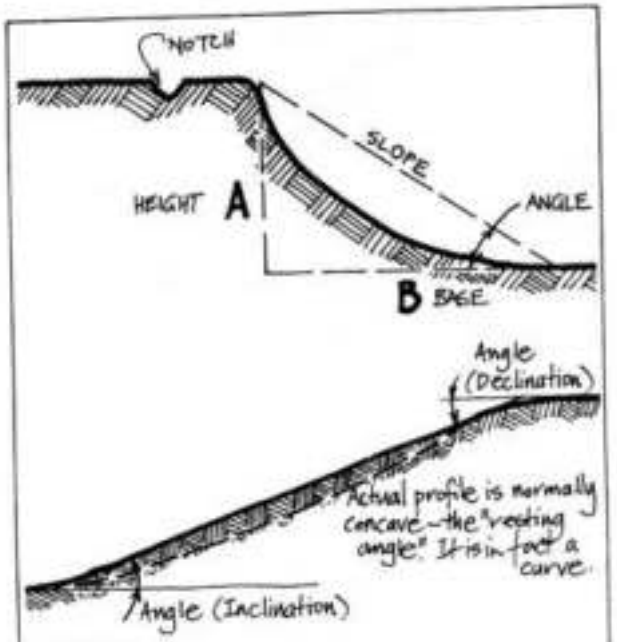


FIGURE 9.4
CONCAVE SLOPES
A These duplicate the natural slump concavity of soil and are more stable than straight slopes.
B Straight slopes can be expressed as degrees of inclination or declination.

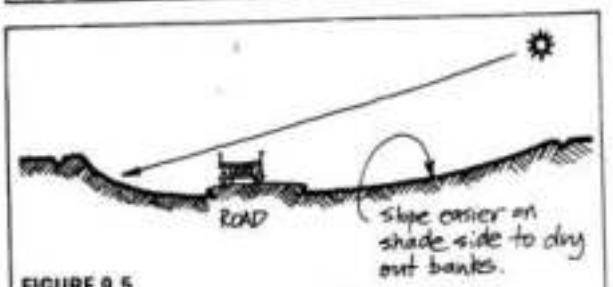


FIGURE 9.5
SLOPES CUT TO DRY OUT ROADS
Trees or steep banks to sunward may keep roads muddy in wet climates.

Table 9.1
SOME FEATURES OF COARSE SLOPES (given as percentages)

100	Vertical bank; safe only in stone or very dry stable sediments, soft rock.
90	Vertical bank; the walls of dry desert dugouts in stone can be quite stable at this slope.
80	Precipitous. Safe only in stable rock or loess.
70	Precipitous. Safe only in stable rock or loess.
60	Very steep; a bulldozer can be used up or down, not on the traverse (cross–slope).
50	Very steep; 1:1 proportion or 45°. Strictly not for tree clearing, needs permanent forest.
40	Steep; the maximum a track machine (bull dozer) can safely traverse and work.
30	Steep; as above; can be cautiously harvested for firewood or coppice, also benched for access.
20	Moderate; usually accepted as the maximum slope for safe cultivation and erosion control; wheeled tractors are used at about 18%. The maximum slope of good road surfaces is accepted as13%; anything over this should be concreted or sealed.
10	Moderate; may need contour banking and careful use. 4–6% is considered ideal for railroads, without special cogs or cables, to assist the grip of the wheels.
0–10	Low; can erode if soils are cultivated, but these slopes are usually stable for crop agriculture, terraces, and swales.

into the slope to start with. Natural lower slope faces in humid areas are also down–curved, and should be made to curve down or to be concave. Earth banks will assume this profile in time (indicated by a dotted line in **Figure 9.4**). Soils have type–specific resting angles with concave profiles.

Slope angle (the dotted line) is therefore a straight–line approximation of real soil slopes. The notch at the top of a cutting runs water off the face to safer slopes, and is a standard feature in embankment stabilisation. Average safe slopes used by engineers are:

- Gravels 1:1.5
- Clay (well–drained) 1:2
- Clay (wet) 1:4

To dry a road, the sun side should be cut further back and so allow sun in; conversely, to shade areas, banks can be as steep as the soil will stand (**Figure 9.5**).

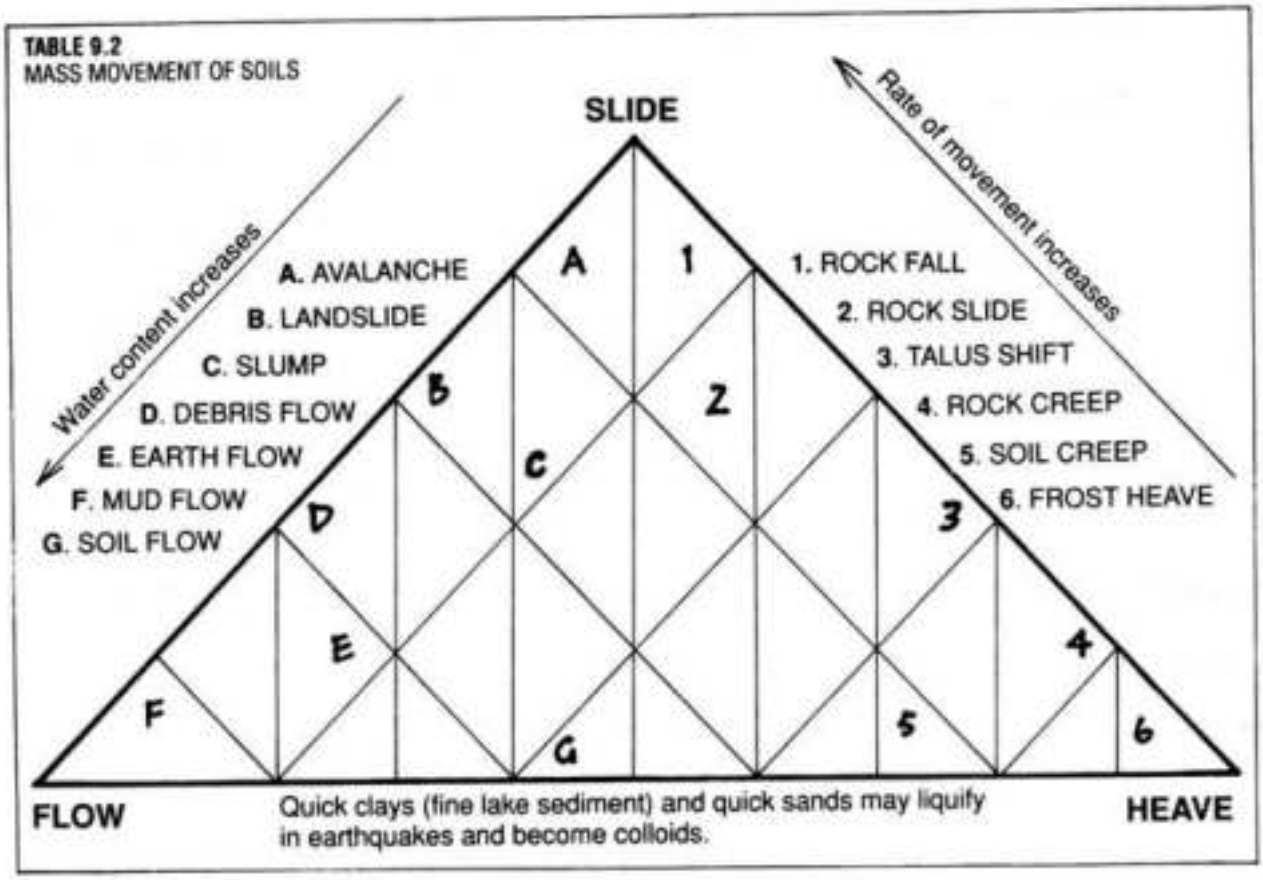
When we cut or "bench" into a slope, the natural erosion processes try to re–establish the original slope, and if left to their own devices will do so. Benching at the base of sloping and unstable tilted strata will therefore bring down the whole hill, and incur endless costs in road–clearing and slump removal. Slumps in unstable hillsides will carry with them, or bury below them, houses and people.

A great many film stars perched on unstable ravine edges in the canyon systems of Los Angeles will, like the cemeteries there, eventually slide down to join their unfortunate fellows in the canyon floors, with mud, cars, and embalmed or living film stars in one glorious muddy mass. We should not lend our talents to creating such spectacular catastrophes, but to the avoidance of obvious problems and by re–location before disasters occur. Local government often delineates areas of instability where building is not permitted due to mudslides, fire, and earthquake.

In the dry hill scrublands of California and France, or on desert borders, intense fire upslope can generate sufficient heat to bake soils. When such fires occur in steep, unconsolidated shales and mudstones, the baked earth (heated to 6 cm deep) forms water–sealed slab surfaces (such hydrophobic crusts will no longer form crumb structure).

Valleys in such areas can then expect catastrophic mud flow unless early misty rains fall to restart vegetative growth, and to that end the ashes can be sown down with oat, lupin, and shrub seeds, but if

TABLE 9.2
MASS MOVEMENT OF SOILS



heavy rains fall before plants take hold, water can penetrate below the glazed surface, and mass movement (bulking) of mud and glaze will then occur. The wall-of-mud effect, and the inevitable cascade downhill may well block roads in any such mud-flood emergency, threatening resources in the valleys. Mud flows are a feature of unstable sediments in wet-dry climates.

Thus, the water run-off after fire (as in Adelaide, Australia in 1984) can be catastrophic, and hot fires can have a long-term effect on soils and soil loss. The combination of fire in late summer, followed by a sudden autumn onset of rains is typical of Mediterranean lands, and of devastated soils. For a designer (and town planner) areas of known soil instability should be avoided as settlement sites, and kept in permanent forest; most are designated on soil maps, or can be researched.

9.5
LEVELS AND LEVELLING

Levels are taken to ensure that spillways work, drains run, and houses sit level enough so that one can play at marbles without them all falling towards one corner.

There are tools of levelling, of which the most ancient and even the most reliable is that level assumed by the surface of water. One can always check a horizontal against the sea horizon, or make sure a drain or gutter works by using a little water to flow down it. Even sophisticated instruments like the theodolite use a bubble level to set up the base plate, and then to check the telescope against this with its bubble before preceding with tilt or swivel measures. There are a few simple levels that can be handmade and are of great use to farmers and homeowners:

HOSE ("BUNYIP") LEVEL. A hose level can be made from easily-purchased materials, and is useful to survey some metres or even kilometres of diversion drain, level a house site from corner to corner, or set a wall or spillway at a pre-determined level. The materials needed are (as put together as in **Figure 9.6**):

- 20 m (65 feet) or so of clear plastic hose, diameter about 10 mm (1/2 inch).
- 2 corks or stoppers that fit into the ends of the clear plastic tube, each with a breather hole.
- 2 small cork balls that freely fit inside the clear plastic tube below the corks (optional)
- 2 stakes (2 m or 6.5 feet), marked with the measurement of your choice (centimetres or inches); dressmakers' tapes glued or screwed on to the stakes serve this purpose.
- 4 clamps or tape to connect the clear hose to the stakes.

To prepare for use, uncork one end and fill the entire hose with water. Be sure *all* the bubbles are out of the hose; this is only certain with a completely clear hose.

Place both stakes together, tops level, on a piece of *level* concrete or wood. Keeping the stakes *vertical*, mark the water level in the clear tubes by unclamping and

moving the measuring strips until the water level (or both cork floats) are at precisely the same measurement marked on the stakes. Recork the tubes.

In the field, one person walks past the other alternately, driving a stake every 6 or 15 m (20 or 50 feet) to guide diggers or machine operators, and allowing for the rise (or fall) of drains by allowing one cork ball to be an inch or so lower than the other at the next peg, moving the pole up or downhill to achieve this. The stakes must be kept vertical when measuring.

1 cm in 5 m is 1:100 x 5 equals 1:500 fall, ample for most diversion drains to carry run-off to dams. Dead level lines can also be run across landscape, and dam walls checked for level or (if used for roads) a gentle rise. I recently saw a 12 km drain flowing gently all the way in sand at 1:2000, laid-in not by a skilled surveyor but by two women hired for a week and trained in 30 minutes on a hose level.

THE PLANE TABLE is a sturdy tripod which can hold a U-shaped piece of plastic tube or glass, corked and de-bubbled as for the hose level, except this can now be swivelled about to sight in all directions (**Figure 9.7.B**). Lacking tubing, a bowl of water on which floats a piece of painted wood with two nails of equal length as "sights" will do (**Figure 9.7.A**).

Although Model B is self-levelling, it may be necessary to tap in one nail a bit on Model A by way of adjustment.

To check a plane table, set up two marked stakes (with easily-visible white masking tape) a little up hill from the point you will stand at, driving the tops to level using the table.

Viewing the stakes from position B with the plane table, check that the level shows new level marks (b) to be exactly the same distance (d) below the stake tops (measure this). One can then proceed to level, from position B, anything that can be staked, painted, or nicked by another person (**Figure 9.8**).

This is a very handy across-valley level to set in siphons, or to find out where the outlet of a dam will send water by pipe and gravity flow, or to see if a hill on which you want to place a tank at a distance is higher than your shower head at home.

Levelling need only be done once if done right. If in real doubt, buy a dumpy level or theodolite, and read the instructions, or if wealthy and incompetent, hire a surveyor (whose real job is mapping). Thousands of miles of drains have been surveyed, and levels set, by very simple tools. Plane tables of various designs are used by surveyors, but these usually include a telescope for long distance work.

Ralph Long of Australia has devised a tractor-mounted level which he has successfuly used to cut

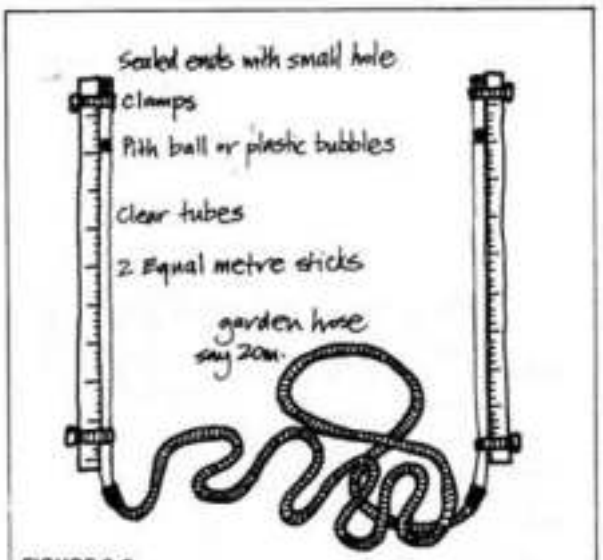


FIGURE 9.6
"BUNYIP" HOSE LEVEL
Used by two people (about 15 m apart) to peg out a contour line around a hill.

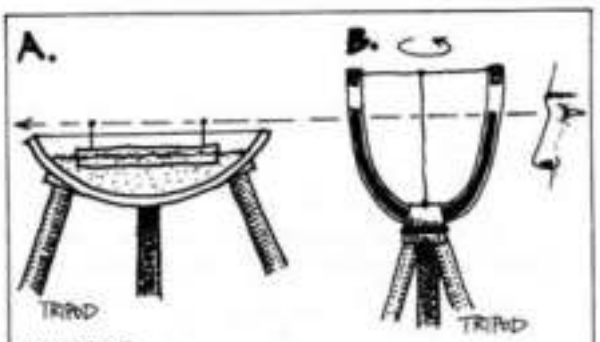


FIGURE 9.7
THE PLANE TABLE
Simple water levels can give sights across valleys or over long distances.

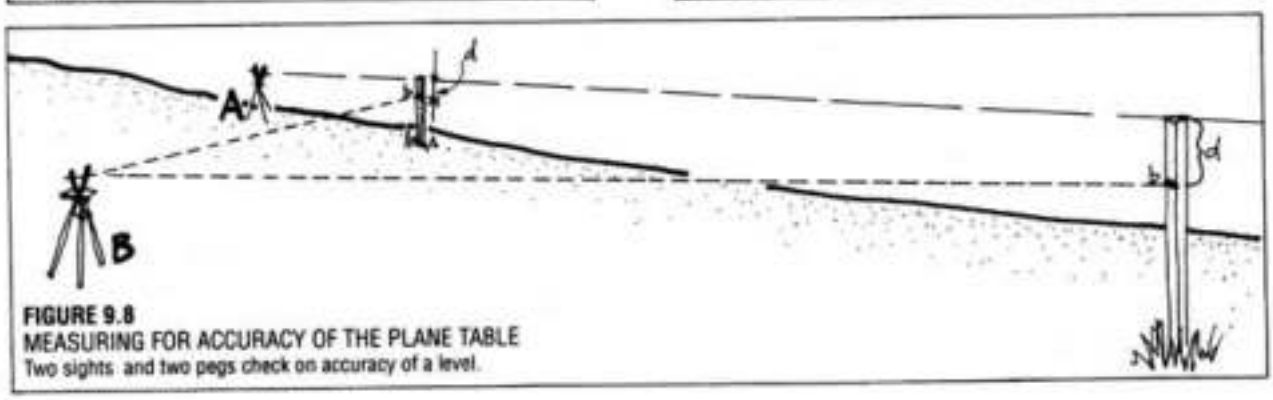


FIGURE 9.8
MEASURING FOR ACCURACY OF THE PLANE TABLE
Two sights and two pegs check on accuracy of a level.

drains, using the tractor itself as a check on levels. This is a bubble level which can also be fitted to any vehicle on farms, and is called the Long Inclinometer® (*Permaculture Journal* #22, 1985).

THE "A" FRAME. This is made from two wooden or metal legs, nailed or welded firmly together at the apex, and fixed about two-thirds down their length by a welded or nailed and glued cross-piece. A plumb bob or weight hangs from a cord at the centre of the apex, and a mark is made on the cross-piece at the cord line. The "A" frame is then reversed, and another mark made where the cord touches the cross-piece. The mid-point between the two marks is that point where the cord hangs when the feet of the frame are level (**Figure 9.9**).

In use, a person swivels the frame about one leg, and sets in the second leg to the place where the cord hangs vertical. A peg is put in, temporarily, to judge where to place the next leg. Many metres of drain have been set in using A frames, often made on the spot from lumber, cord, and a weight for the plumb bob.

9.6
TYPES OF EARTHWORKS

BANKS

It is cheaper to construct a bank than to step or retain the earth, *if* the bank can be made stable. Wherever a four-way bucket (Bobcat or drott) or power shovel can be used to dish the bank, they will remain stable at greater slopes than a straight cut, as we have frustrated soil slump by giving it the profile it would achieve had it slumped. Banks or cuts of more than 4 m high need careful stabilisation.

Unlike dam walls, cuts for roads are not normally compacted, nor do they necessarily have much pressure on them. The greatest cause of slump is water flow through or over banks and the lie of strata in shaly

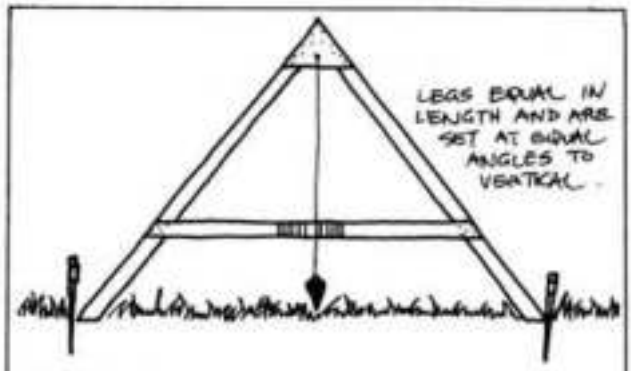


FIGURE 9.9
THE A-FRAME LEVEL
About 2 m wide; legs are reversed so that plumb line cuts "level" mark on crossbeam. Used for centuries to lay out contours and drains at desired slope or flow rate.

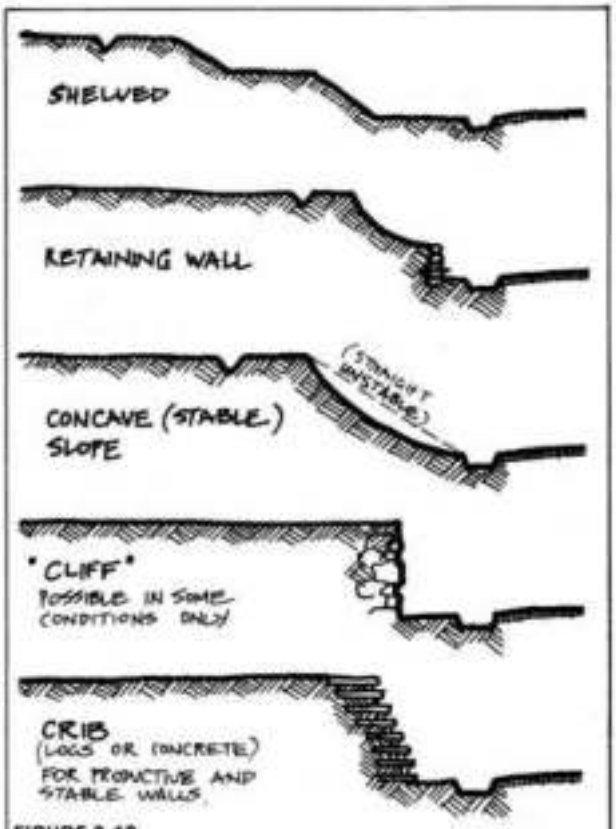


FIGURE 9.10
ESSENTIALS OF WATER AND SOIL SLUMP CONTROL.
Many methods can be used to prevent slump from cuts above terraces or roads; vegetation helps all these systems.

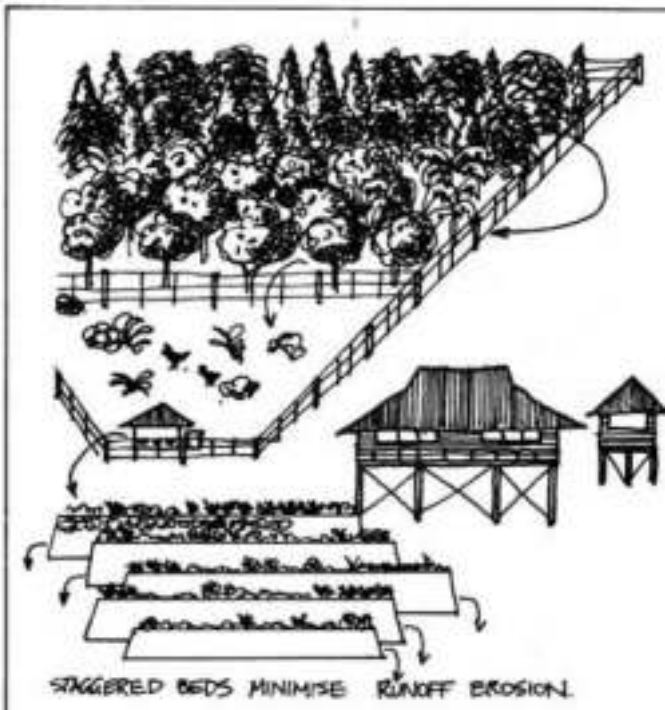


FIGURE 9.13
KICK-DOWN SYSTEMS AND STEEP TERRACES
Using steep slopes to assist the movement of nutrients and water.

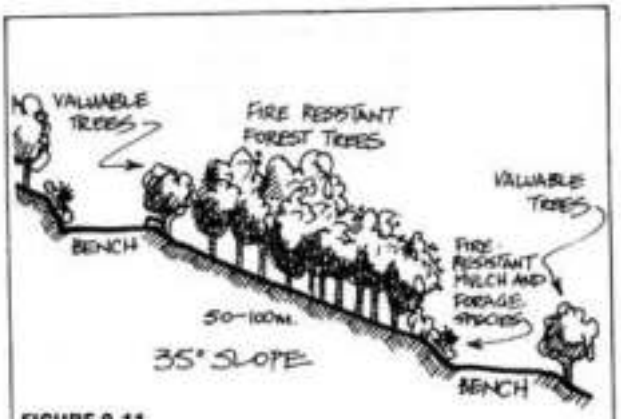


FIGURE 9.11
BENCHES ON STEEP SLOPES
offer good harvest and management access to steep slope forests. Trees stabilise bench areas, fill, or slope.

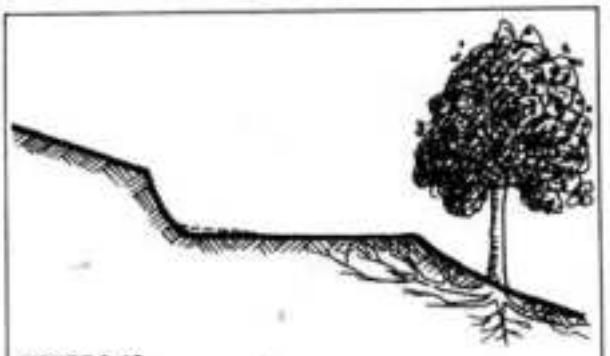


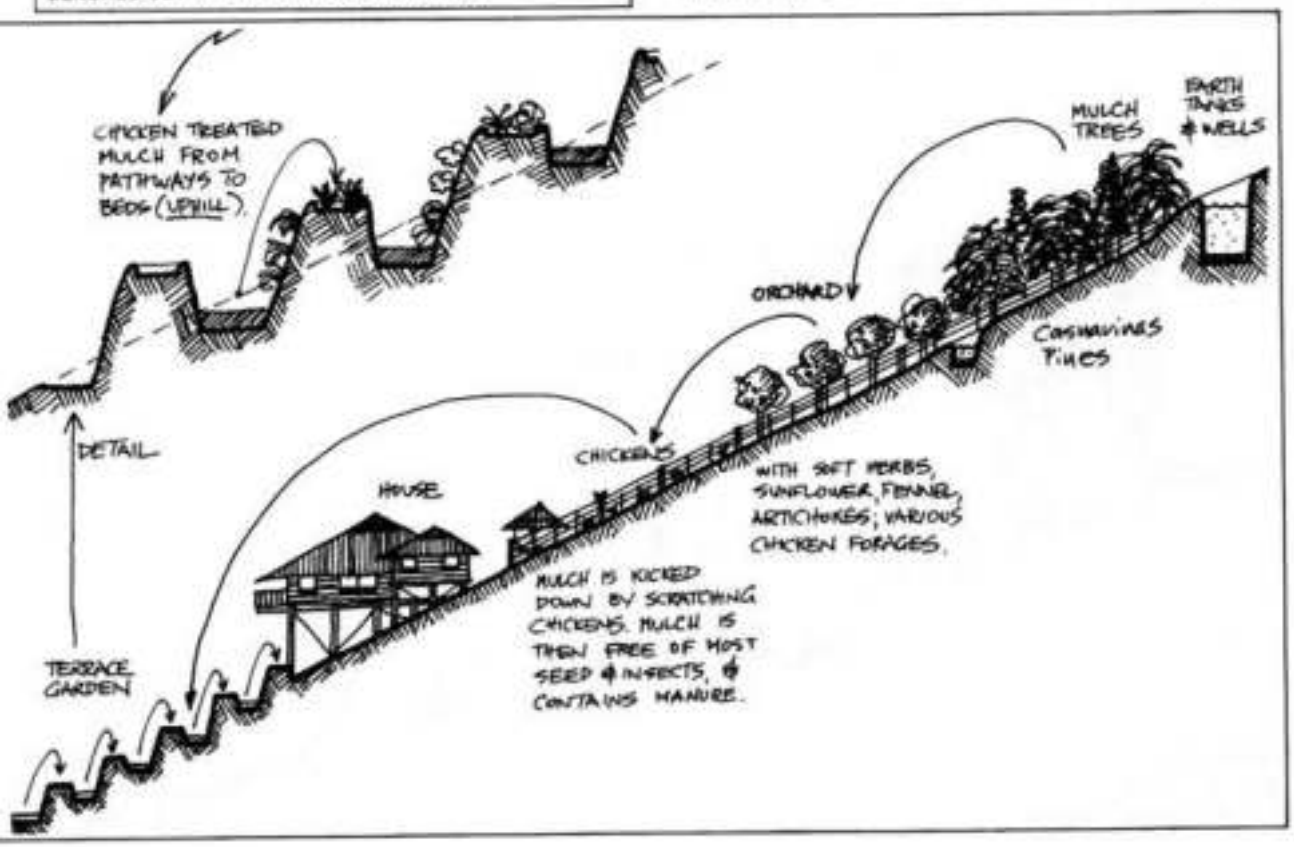
FIGURE 9.12
BENCHES CUT INTO HILLSIDES ON CONTOUR

ground. All normal soils with some clay and stony banks are fairly stable, given that the angle of rest of these materials is preserved, the banks cut somewhat concave, and drainage fitted. In severe slump areas, re-routing of roads or expensive drainage and concrete retaining walls may be last resorts, but **Figure 9.10** shows the essentials of water and slump control; only some may be needed but all can be used.

BENCHING

A bench is a flat, near-contoured cut made in a slope. Very severe slopes of 30–40° can be bench-cut if a bulldozer can start on safe ground (typically, from a ridge of 20° or so). Benches are used to make roads and house sites, and are very useful in long-term forestry if a steep hill is benched every 100 m or so (**Figure 9.11**). Benches greatly aid access, planting, and eventually harvest. The first fast-growing trees to plant are those on the lower (loose soil) side of the benches; these can be nut or fruit trees, for harvest, or for seed crop.

Small-holders on very steep hillsides must work with the slopes, or expend much energy on carrying water and fertiliser. Orchard and mulch *above* poultry *above* garden is the easiest system. All the better if the ridge or hill above that system is planted to mulch-producing trees such as *Casuarina* and pine, oak and beech. Thus, mulch and bedding is thrown down-hill as greenfeed and seed for chickens, and they kick-down to the lower fence where the gardener accepts the manured and shredded mulch for the essential (terraced) garden



beds (**Figure 9.13**).

Benches can be fertilised, ripped, and sown to legumes or soft-leaved mulch plants, and periodically cut or grazed off. If cut, mulch can be raked to trees on either border. As benches on very steep slopes will rarely be travelled upon, they can slope slightly outwards to drain. Benching should not necessarily continue across water runnels unless pipes, gabions, or culverts are fitted in the watercourses; small watercourses can be bridged.

Benches are quickly made to a survey line pegged every 6 m (20 feet) or so followed by a bulldozer with blade set to side-cast (angled). A run with a raised blade will shave back or slightly step the uphill bank. In *stable* soils, benches can slope *into* the hill and so form swales to infiltrate water for trees below the bench. Cross-walls can be made every 20–30 m to prevent gutter flow. Such benches are not so much roads as tree shelves, and are a blessing in steep country. A quiet traverse with a donkey or cart serves to distribute plants and fertiliser (or mulch) and to gather in the crop. Narrow (1.5–3.0 m) benches are quickly over-hung by tree crop, shaded, stable, and accessible (**Figure 9.14**).

Wherever benches cross drainage channels, pipes or rock-lined swales must be made to carry water across, and these (and their maintenance) are the greatest long-term expense, so they need to be well made and durable.

Although the true finesse of earthworks is best entrusted to the experienced machinery driver, designers need to designate stages, spoil areas, topsoil stores, bank slopes, and so on. Also, they must remember that it is expensive for a bulldozer to travel far pushing a load before the blade to create banks (about 6–9 machine lengths is maximum), and that much faster and better work can be done cross-slope and downhill than upslope by any machine but a bucket digger.

Side-casting is a different matter, and graders and bulldozers both can bench soils effectively for miles, as no dirt is carried but rather cast out to one side of the blade, which is ANGLED to the direction of travel to do so. Thus, a great deal of time, fuel, money, and timber can be saved if a site is carefully pegged out *to suit the machines called in*. Imagine yourself as a driver, and make it as easy as possible to cut the shapes you want.

On anything but a simple job, two or more machines may be called for, as in preparing a house site and its sewage lines, or in digging and carting a clay deposit. Bulldozers can loosen and pile up material but not load it, bench but not trench, or at least not smaller than the blade width.

TERRACING

Terraced lands, given a reserve of local green manures or composts and adequate water, are potentially very stable production systems. Exceptions to this arise when we:

- Attempt to terrace in unstable soils or sediments;
- Risk hydraulic pressures on hill slopes from impounded or infiltrated water;
- Create terraces that are unstable at the bund or wall face;
- Extend terracing as annual crop over too large a proportion of the landscape, and so lose leaf or tree nutrient input to crop; and
- Make very large series of terraces in high rainfall areas, so that run-off is concentrated.

With a useful assessment of the above factors in

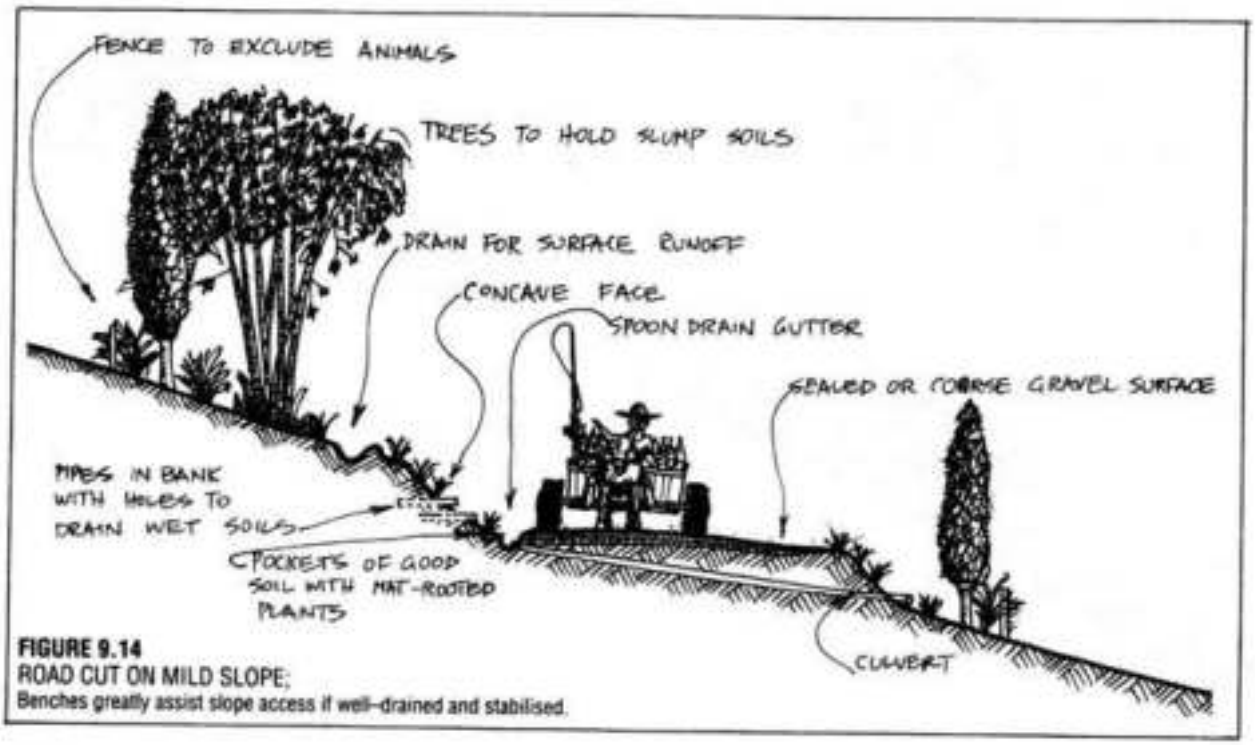


FIGURE 9.14
ROAD CUT ON MILD SLOPE;
Benches greatly assist slope access if well-drained and stabilised.

mind, we can gain long-term production from short series of polycultural terraces (wet and dry crops), with stable bunds (either rock-walled or at a 1:3 slope). Trees, on bunds and between, above, and below terrace series, should form 40–60% of the total landscape plan, and both soils and installed water inlets and outlets should permit safe and controllable irrigation.

The great benefits of terraces are these:

- Very easy crop access on slopes;
- Easily controlled and effective irrigation procedures;
- Minimal soil loss due to overland water flow, or to slope cultivation; and
- A potential gain in silts or nutrients in irrigation or run-off waters and from leaf fall.

As with dams, terracing is most effective where slopes are least, as earth moved versus area of cropland developed becomes impractical or inefficient as slopes steepen. At about 30° slope, but preferably at 10–18°, terracing becomes worthwhile.

Terrace construction always begins on the lowest terrace level, with the removal and stockpiling of topsoil over the whole area of the lower terraces, and proceeds uphill as each terrace is made, so that the topsoil of the next highest level is cleared on to the preceding lower terrace. Stockpiled soil at the lowest terrace is finally carted or lifted to the last of the series uphill (**Figure 9.15**).

Every terrace system is ideally designed to allow perennial bund and terrace wall plants, specifically for *wall stability* and *green manure crop*.

As for the extent and series size in a terrace system, it is wise to limit both on the basis of:

- Heavy rainfall (hence expected run-off) in tropics; and
- Expected rainfall harvest in arid areas, where total terrace areas should not exceed one-twentieth of the catchment harvested, and where perennial or adapted crop (never water-demanding crop) should form the selected species.

Thus, all terrace systems should aim to occupy no more than 30% of tropical or 5% of dryland areas, and in the tropics tree crop should be developed to maintain fertility of the terrace areas. Water catchment areas should be developed to do the same for arid areas, so that run-off brings leaf mulch to terraced slopes.

In humid cool or tropical areas, wet terraces (10–20% of all terrace areas) can be devoted to a fish-plant polyculture, giving yields of fish, shellfish, and water plant products. Yields of protein from water cultures can exceed all land-based systems if managed at the same levels of husbandry and care.

Wherever people occupy *very steep* sites (slopes of 20° or more), especially in areas of high rainfall, it is preferable to abandon broad terracing for a series of 4–6 narrow production terraces, each series carefully drained to spill excess rain down permanently vegetated slopes (**Figure 9.12**).

Thus, by ridging the terrace tips, mulching paths, and staggering path spills in short series, we can get the advantages of terrace on quite steep slopes without risking erosion and soil loss. Needless to say, machines are inappropriate for such construction, and steep slope terracing of this nature is always hand-cut.

9.7
EARTH CONSTRUCTS

Wherever earth is dug, banks are raised. There is a great concentration on the holes, and far less on the mounds, so that "spoil" in mining becomes a pollutant. This need not be the case, providing topsoil is first removed

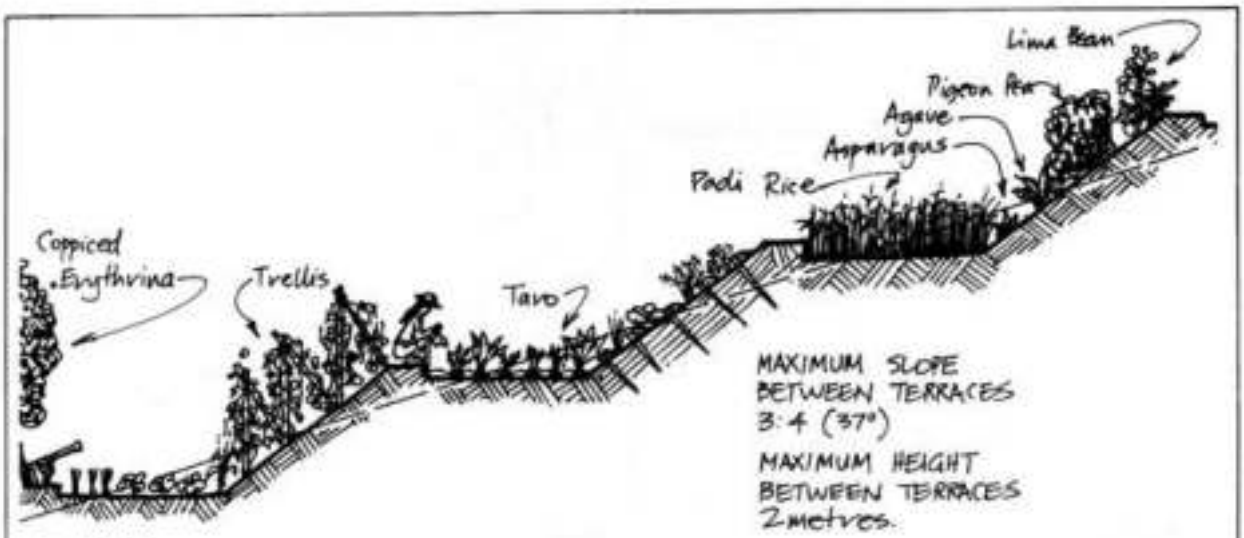


FIGURE 9.15
TERRACE SERIES
Stable garden terraces of earth provide a total growing surface.

and then returned to cover the spoil, in stages or as a whole job.

Just as land can be hollowed out, so roads and banks can be raised above marsh or flood levels, and to deflect winds, noise, or water. Banks raised by machines can serve the following purposes:

1. Shelter for houses and fields;
2. Plant sites for windbreaks (on the crown of the bank and in its lee);
3. Walls of houses or storage barns;
4. Containments for large inflammable fluids, and fireproofing;
5. Noise deflectors and absorbers, e. g. at airports and along highways;
6. Tracks and plant sites in marshes and on clay soils subject to flooding;
7. Patterns to deflect and direct wind and water to storages or energy systems;
8. Flood or tide control systems (polders and levees);
9. Railways and road grade adjustment;
10. Earth ramps and stands; and
11. Earth walls or "ha ha" fences.

These are further elaborated as below:

1. SHELTER FOR HOUSES AND FIELDS. Either in flatlands or on high exposed sites, an earth crescent bowed into the cold winds is the fastest way to create shelter and warmth on its lee side. Even a few blade sidecasts run along a field boundary provides cover for hedgerow and windbreak species and may act as a swale for root water collection. High banks of 2.5–3.5 m (9–12 feet) close behind house sites, whether excavated or raised, create instant shelter over the occupied site, shelter which may be further reinforced with trees (**Figure 9.16**).

This is a long term and considerable heat energy saving in cold climates, and a shading or cooling wind director in warm climates. **Figure 9.17** shows an actual ground design for a flatland site with cold southwest, hot northwest, and cooling northeast winds, all controlled by one earthbank and the pond formed by the excavation.

2. PLANT SITES FOR WINDBREAKS. Low sidecasts heap up topsoil, create shelter, and catch or delay run-off, as well as reduce root competition for a year or two, all good reasons to sidecast for long windbreak sequences, and in wetter ground to establish willows, poplars, and tamarisk above water-logged ground (**Figure 9.18**).

3. HOUSE OR BARN WALLS. Unrealised by most architects and home builders, machines exist which can raise and compact a complete house or barn wall in a morning's work. All we need to add is floor and roof (another two days work) to be in a long-term, fireproof, silent, energy-conserving and sheltered house. This technique is suited to open-space situations, cheap barns and large outbuildings. As the walls are raised, a smaller tractor and roller can compact them. Almost any earth will do, providing the compacted rest angle is watched. This technique is not suited to sands unless wall corners are bagged (stabilised with soaked bags

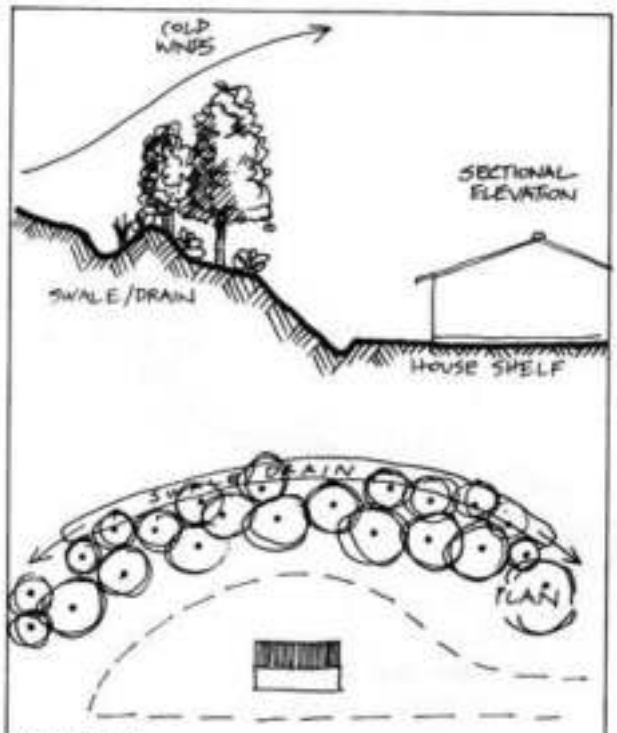


FIGURE 9.16
RAISED BANK BESIDE HOUSE
In areas of heavy rains, house sites must be carefully designed to deflect downhill overland flow.

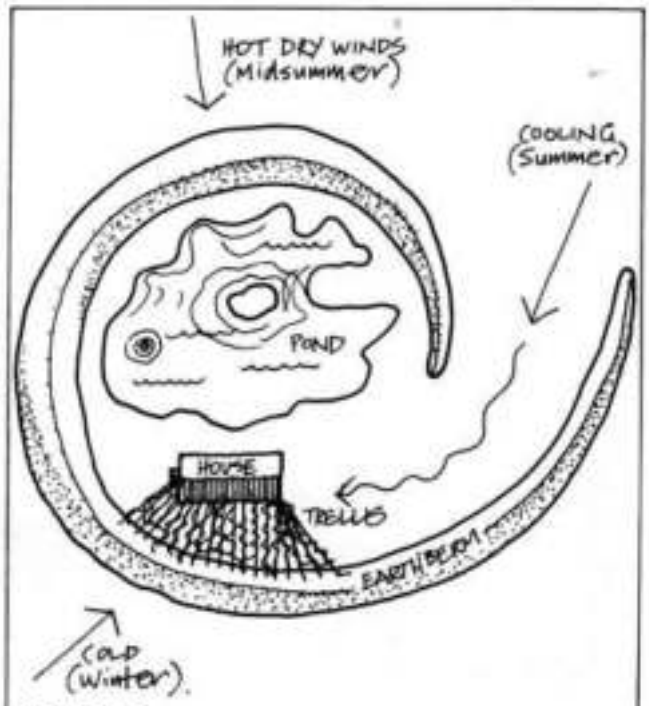


FIGURE 9.17
RAISED BANK AROUND HOUSE;
this structure modifies several external climatic factors, and achieves privacy.

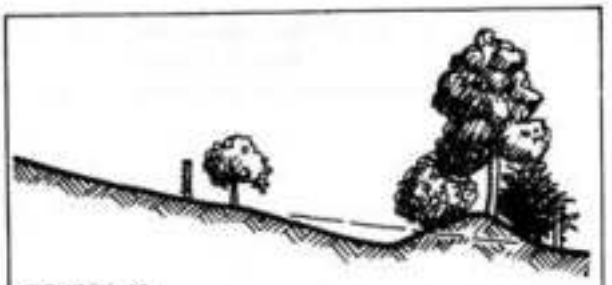


FIGURE 9.18
BANKS FOR WIND BREAK ASSISTANCE,
shelter, flood-proofing, fire-proofing, noise reduction, and drainage adjustment.

filled with cement and sand or sandy soil). **Figure 9.19**.

4. CONTAINMENTS. Whether for inflammable fluids or as fire-proofing, and especially effective against radiant heat, earth walls can surround tanks. Above-ground wildfire radiation refuges in bushland are earth-covered and may be built off forested roads and near isolated bush houses.

5. NOISE DEFLECTORS OR ABSORBERS. Traffic noises are effectively blocked from housing by earth walls, and plants on these banks decrease noxious fume effects. Deflection of noise is effective for long wave-length noise only.

6. TRACKS AND PLANT SITES IN MARSHES. Earthbanks, islands, and mounds in marshes give multiple opportunities to access and place trees and structures. Mounds in ponds isolate useful but rampagious species such as thorny blackberries and runner bamboo, while banks allow foot or vehicle access across and into marshes to place and service duck nest boxes, to harvest fruit and vine, and to attend to fish ponds (**Figure 9.20**).

The raising of a bank in marsh is an interesting operation; the best tool is a very light "swamp" tractor with wide tyres or tracks, and a swivel bucket (an excavator). This unit, perhaps using "mats" in very soft or silty ground, can dig and raise an earth bank where the ground is too soft for the operator to walk. Equipment can be light for the first crossing, the aim

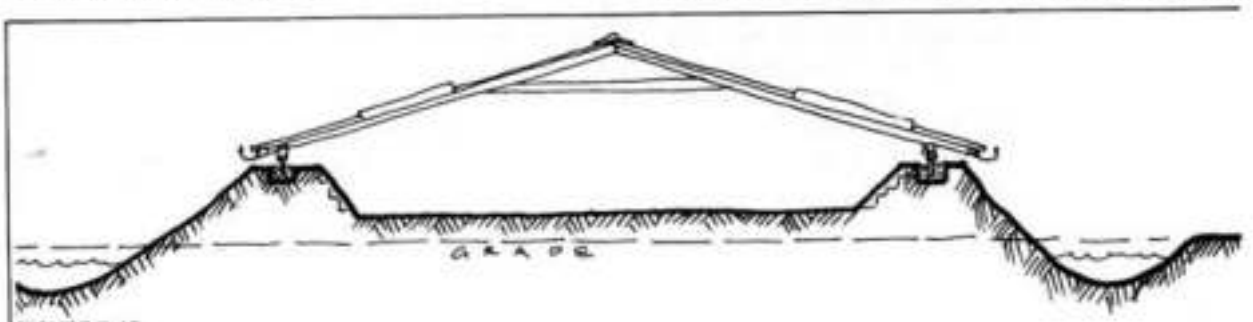


FIGURE 9.19
EARTH-COMPACTED WALL CONSTRUCTION
Using modern earthmoving equipment, a house or barn of this type can be completed in about three days.

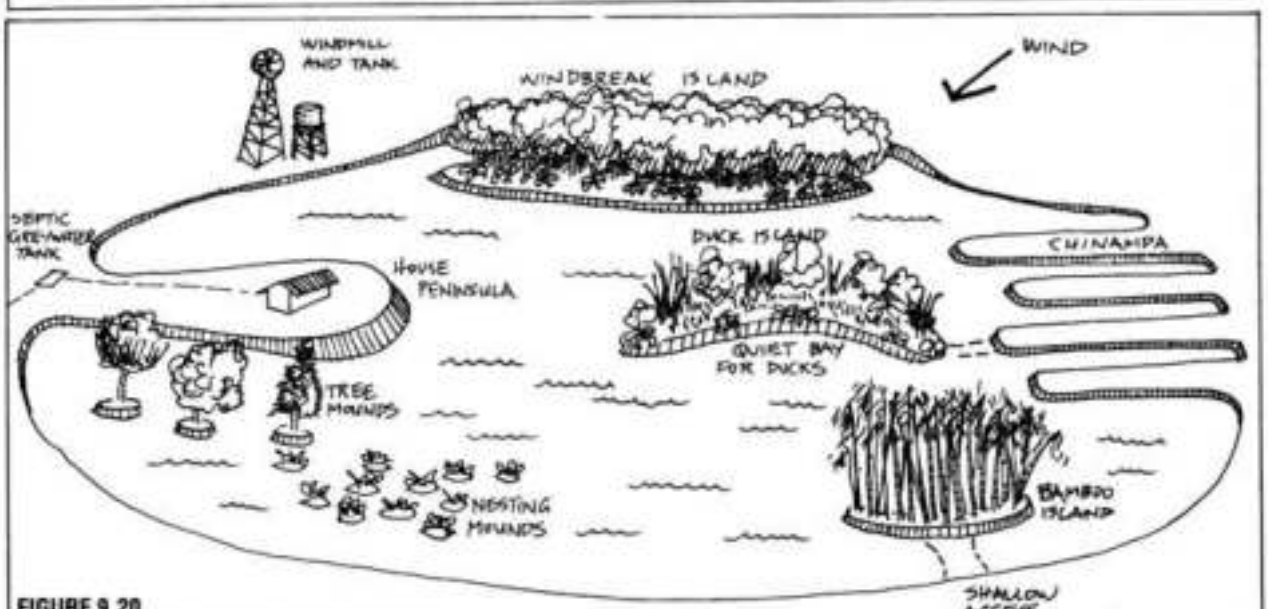


FIGURE 9.20
EARTHBANKS AND ISLANDS IN MARSHES;
several useful structures in and around water provide many niches for plants, animals, and people.

being mostly to throw up a broad earth mound to dry out, so that a safe transit of heavier equipment can be made at a later date and a substantial bank raised for a road-bed or planting. It is easier, of course, and less harmful, to first raise banks, and then create a marsh by building a low berm. Natural marshes need protection for their unique values and for waterfowl.

"Mats" are three bulky wooden gratings, made of 10 cm by 15 cm (4 inch x 6 inch) timbers, which the bucket machine stands on. At each move the machine itself recovers one from behind and places it ahead. Once the first mound is built, larger excavator machines can reach out to dig deep channels and build high banks of great solidity, or the smaller mound can be levelled by light tractor for foot traffic. Draglines are not really an alternative in mound-building, and in timbered swamps are impractical.

7. WIND AND WATER DEFLECTION. **Figure 9.21** illustrates a design based on older Afghan mills of a saddle or ridge wind tunnel for mill power. Systems for water diversion are discussed in Chapter 11.

8. FLOOD AND TIDE CONTROL (polders and levees). Well-maintained earth banks are the only protection of houses and villages in flood plains and below tide level. They are, in effect, reverse dams, the inhabitants living inside and the waters contained outside. Mounds can be built as flood refuge islands in many deltaic areas, containing storage barns and refuges in fields subject to periodic flooding, dangerous to people or animals. Causeways of earth are often used to access low mounds or islands near shore. Bangladesh and other deltaic areas need wooded refuge mounds just for the survival of people.

Such mounds can also be made in *fire-prone* sites, where villages and houses are safe in lakes or on moated islands. Peninsulas should be included in dam construction for this purpose by designers (**Figure 9.22**).

9. RAIL, CANAL, AND ROAD GRADES. These common banks and cuttings are all well-known to all of us.

10. EARTH RAMPS AND STANDS. Earth ramps and stands are of great use for at least these reasons:

- To unload trucks from the side or back (heavy objects and wheeled vehicles);
- To load cattle to trucks, at various levels;
- To unload hay or bales into the upper floors of a barn for use at lower levels; and
- To load and unload boats into water.

Once built, they are permanent in use, and sometimes a whole district can use the facilities of one loading-unloading ramp. The loading face itself must be stabilised with stone, concrete, or beams (**Figure 9.23**).

11. EARTH WALLS OR "HA HA" FENCES. The "ha ha" is a below-grade ditch, which acts as a fence. It is used in classical vista gardens where views are to be uninterrupted, and in zoos for direct viewing of large and potentially dangerous animals. It is also a defence for villagers against stock where the resources do not allow wire fences, but labour or a machine can be obtained. It is essentially a deep pit, dry or wet, with one steep wall faced by stone (**Figure 9.24**). It can be scaled to size for the species excluded.

The same machines that build roads will also build wetlands, swales, and small dams suited to wildfire control and wildlife. Underpasses and guide fences allow migrating wildlife to cross road and rail ways without accidents.

Roadsides can be an area for the preservation of bunchgrasses, sagebrushes, rangeland and meadow plants, and remnant forests along their way, with pull-over areas and vegetation maps, geological features, and archaeological or fossil remains clearly

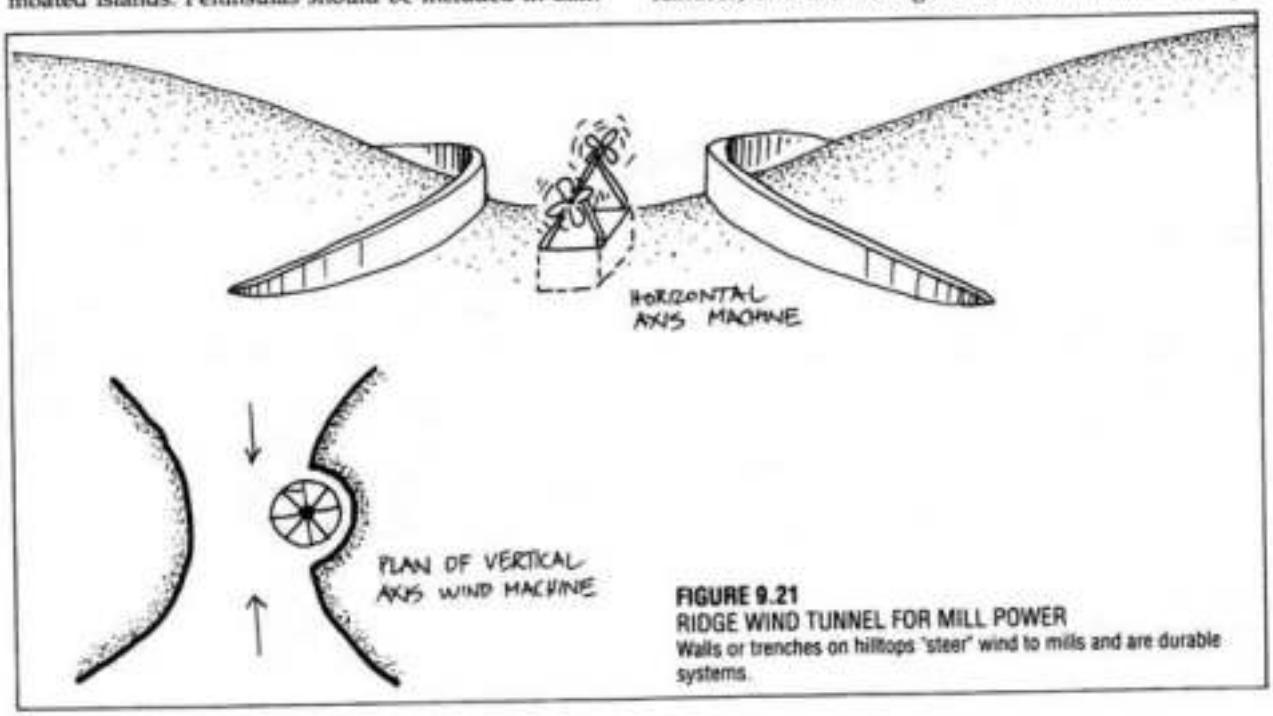


FIGURE 9.21
RIDGE WIND TUNNEL FOR MILL POWER
Walls or trenches on hilltops "steer" wind to mills and are durable systems.

indicated. Such planning must precede actual construction.

We pour kilometres of black bitumen surface, but fail to lay under it pipes for heat pumps that would heat the towns through which the road passes, and we fail to harvest and store road run-off for local irrigation and wetlands. All this will change only when well-intentioned people govern the spending of public monies, or when road engineers are trained in permaculture, and look upon roads as a community resource!

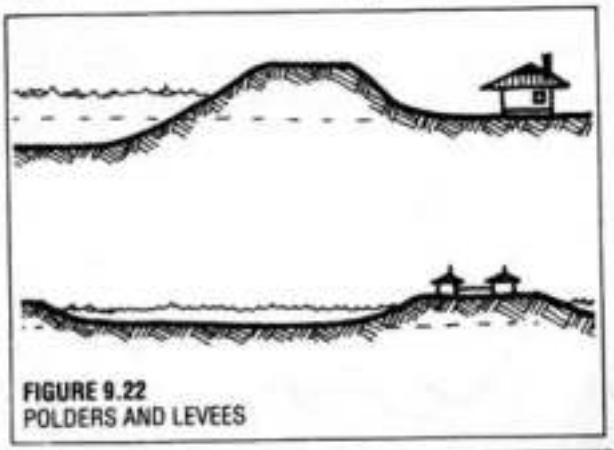


FIGURE 9.22
POLDERS AND LEVEES

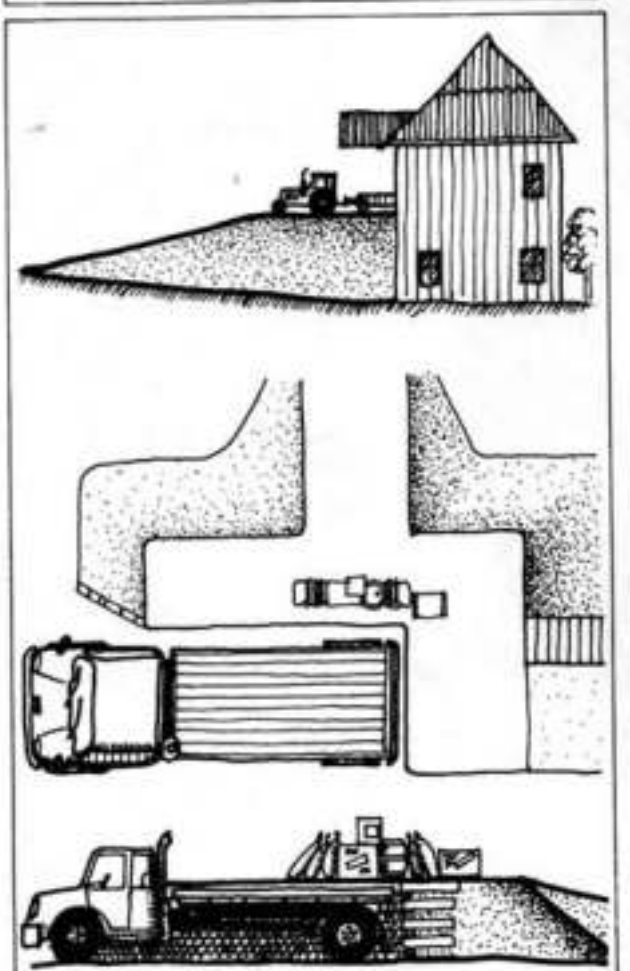


FIGURE 9.23
EARTH RAMPS AND STANDS
Cheap and permanent ramps ensure easier load and unload operations.

9.8
MOVING OF THE EARTH

People have always moved earth: to reach water in dry river beds, to mine pigments for their decoration, to excavate food as bulbs, grubs, or fungi, and to bury their faeces or their dead. The archetypal tool is the digging stick, which gets food of greater variety and more nutrition than the spear. The basic hoe, rake, and shovel exist today in most cultures.

Hand tools have moved most of the earth we see today shaped into mountain rice terraces. There are some very useful and cooperative ways to dig, effective in making miles of low irrigation banks or unloading gravels. The two-person shovel is useful here, one digging in, the other pulling over in a see-saw motion (**Figure 9.26**). Try it, and be surprised at how rhythm and cooperation will move mountains. Sing a little tune to pass the time and get the rhythm:

> **Down** among the **dead** men
> **Let** me **lie**.... etc.

However, the exigencies of education have meant that designers and architects have seldom been personally involved in earth moving. A brief description and nomenclature of machinery and modern tools is not only needed but essential to earth design, given that when we move earth we should do so for permanent and beneficial ends. We can revolutionise eroded and arid landscapes by commencing the process with tools and consolidating it with life forms, especially trees.

EARTHMOVING MACHINES

Just as there are hand tools suited to particular ways of

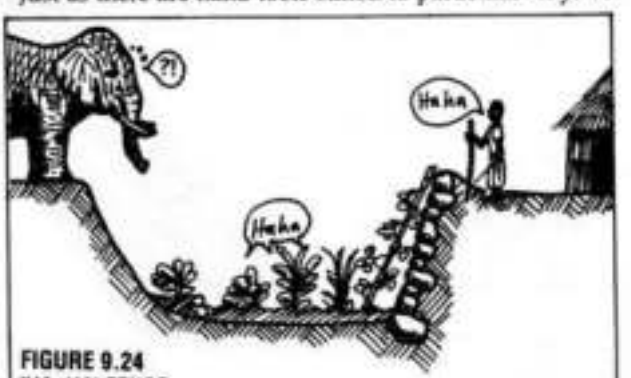


FIGURE 9.24
"HA-HA" FENCE
Much used in areas where post and wire fencing is unavailable or expensive.

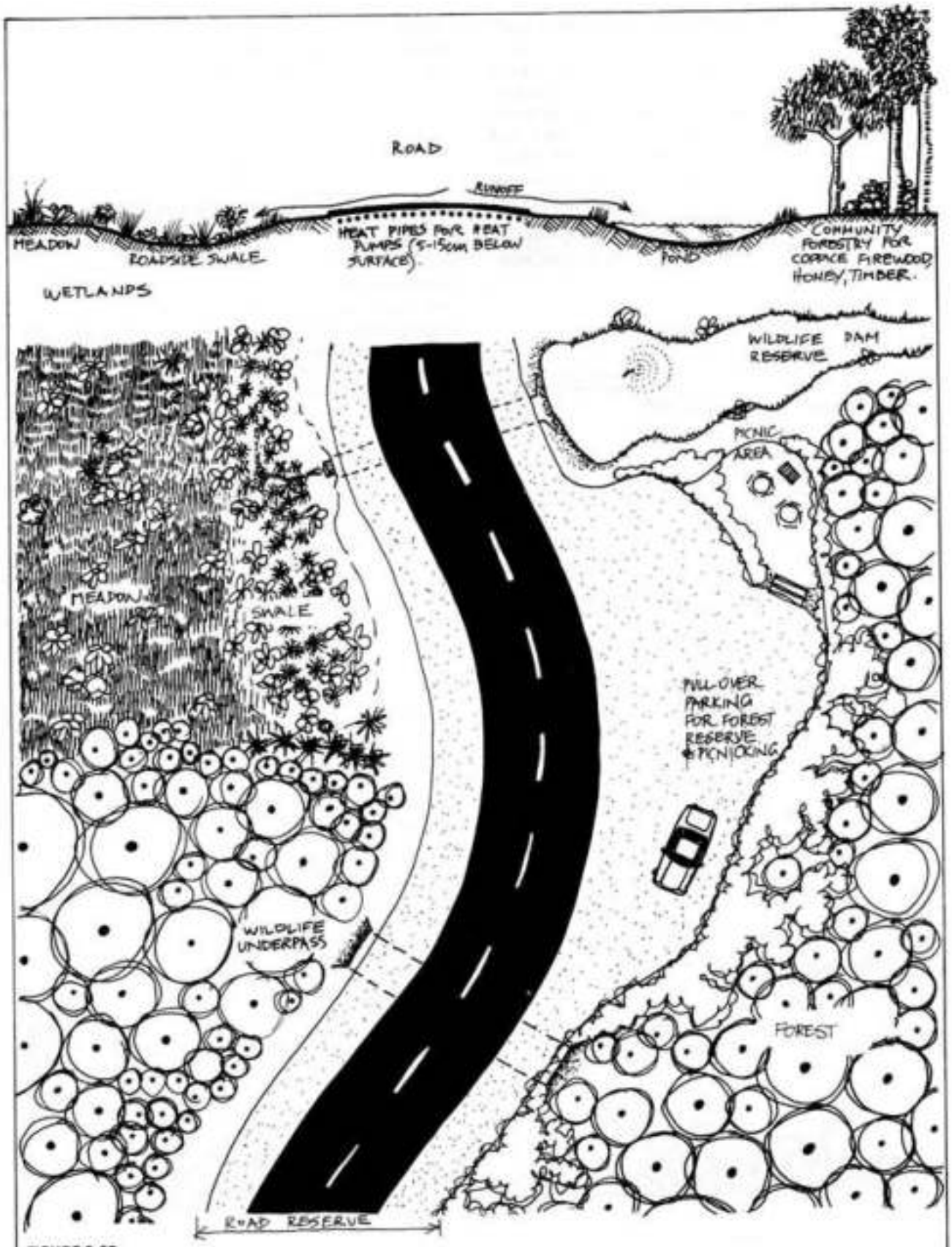


FIGURE 9.25
DESIGN FOR ROAD ENHANCEMENT
Biological planners can make many productive accessories to roadways: roads can provide energy benefits and conservation plantings.

digging, so there are large machines suited to special landscape tasks. Any of these can be supplanted by human labour where it is plentiful. The basic earth-moving attachments are these:

- BLADE (can be mounted on almost any vehicle, or towed); includes "V" blades or delvers.
- BUCKET (for lifting and loading loose material); narrow and toothed for hard ground, or of special shapes for drains.
- BUCKET CHAIN (for foundations, pipelines, narrow deep ditches, underwater dredging).
- SCOOP (can be horse or bullock-drawn, or articulated on an hydraulic or telescopic arm).
- RIPPER (for breaking up compacted soils); usually towed or rear-mounted on tractors.
- DELVER (for one-pass drains; often mounted on a grader, or towed on a frame behind a bulldozer).
- SPINNER (rear-mounted on a special tractor); a fast-revolving disc of about 2-3 m diameter with peripheral buckets.
- BORERS AND DRILLS (holes, fences, explosives, pipes, wells, bores, and the like)
- JET PUMPS (to pump out silt and sand in wet places).

As well as these, there are explosives, which are of special use in marshes and swamps, and some specialised tools for rock and swamp work, for mines, and for massive tunnelling.

FIGURE 9.26
THE TWO-PERSON SHOVEL
A simple, non-tiring digging system for drains, gardens, and terraces.

Our concern here, however, is for the common tools of landscaping and water storage or water channeling. Each has appropriate uses, although most can do something of what the others do. To take them one at a time:

The Blade Machines

The blade earthmovers are the machines for levelling and benching or terracing, and ideally they should be able to lift (and drop), angle, and tilt. They can be mounted forward (bulldozer), in the centre (grader) or at the rear (wheel tractors, for levelling). Tilted, the blade can make shallow V ditches, or put crowns on roads. Angled, it spills earth to one side as steering walls, or makes long shallow drains.

Blades are ideal for levelling house sites, for terraces, for benches on hillside, for side-cutting roads, and for pushing up earth walls. Even a small tractor (17-25 h.p.), patiently worked, can make very large dams and terraces at less fuel cost (but greater time cost) than a bulldozer, while large bulldozers are the most economical of time. They can work difficult, steep, or stony sites and move very large objects such as boulders.

The bulldozer is a blade machine, mainly for pushing and planing earth. It is of greatest use in roading and for dams. It is an excellent machine to put up, roll solid, and spread earth, to dig large shallow holes, move small hills, and bench. The blade TILTS for road crown slopes and ANGLES for casting aside windrows of earth; it also LIFTS to spread and release loads, and DROPS to delve out drains and ditches.

Angled blades are used in long runs to cast earth out continuously to one side (called side-casting). Tilted blades are used to cut channels or to bench slopes, and lift is used mainly for piling up or levelling loads. Blades are normally forward-mounted for sight and control reasons, but on that special road machine, the GRADER, the blade is mid-mounted to give even spreading, and on small farm or wheeled tractors are often rear-mounted. Some small blades rotate about their axis (180° swivel). The grader can be used to make long drains, of shallow angle; these are miscalled spoon drains, but are effectively more angled than spooned in section.

Thus, for all normal bench work, a bulldozer is useful, and for long flat road or levelling runs a grader is better. A SCRAPER is a large, self-filling bucket or land dredge which can both fill and empty itself to plane off or dig out large areas. All large machines can now be laser-guided to accurately level and grade fields at a pre-set slope. Lasers can also automatically work the hydraulics to lift and drop earth, but land forming is mainly restricted to large flattish irrigation areas or civil works, and is normally contracted out to specialists with large machines.

The Four-Way Bucket

This machine (sometimes called a drott) combines all four motions of lift, dig, push, and pull, and is a

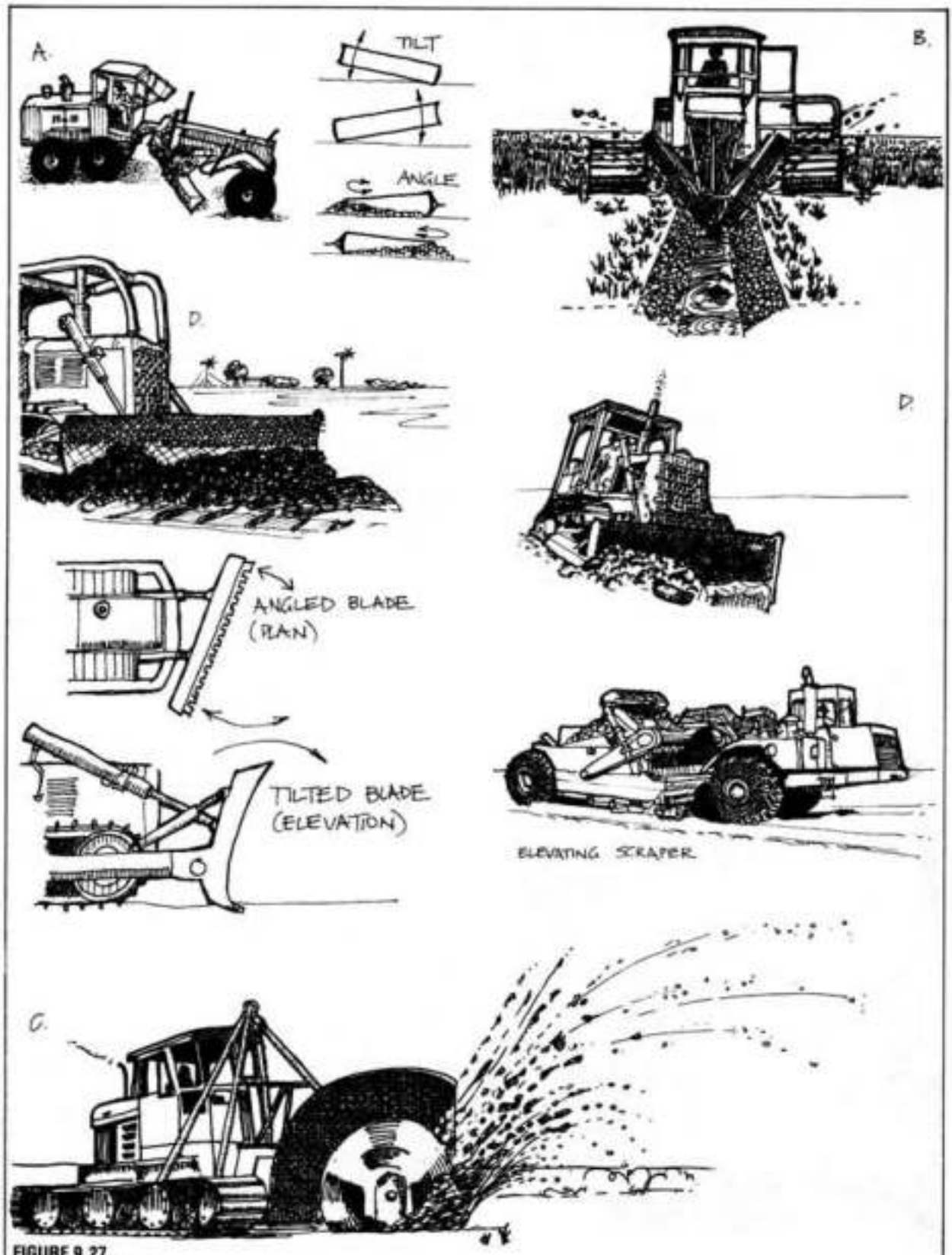


FIGURE 9.27
LARGE MACHINES;
On many machines, tilt, angle, and lift blades enable accurate work on roads and drains. A selection of blades and systems are shown: A - grader, B - delver, C - spinner, D - bulldozer.

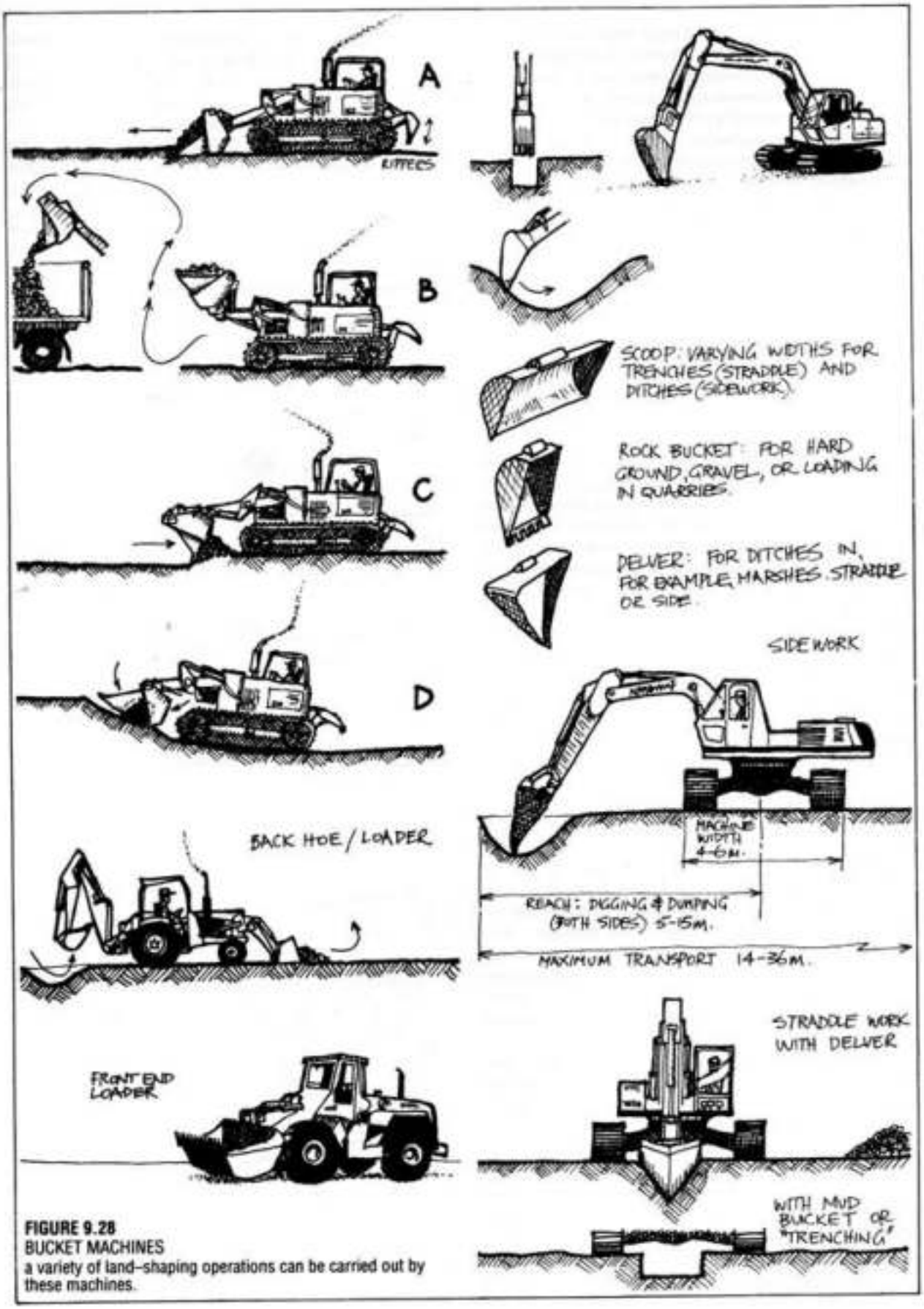


FIGURE 9.28
BUCKET MACHINES
a variety of land–shaping operations can be carried out by these machines.

bridging and universal machine between blade and bucket types. It is usually fitted to a bulldozer body, and is an excellent landscaping machine. It differs from some bucket machines in that it cannot *swivel* the blade separately from the body of the machine, nor can any of the above blade machines. It is sometimes called a clamshell bucket because it can close on loads of earth, or delicately pick up large stones, shave a curve in embankments, or fill a truck with soil.

A small wheeled machine, the Bobcat, is an excellent finishing tool or used alone for light work or for making swales in Zones 2 and 3.

Buckets

These can be simple and fixed or complex and swivelled; the former are often fitted to wheeled tractors as LOADING BUCKETS of great use in quarries, nurseries, and anywhere loose material needs to be picked up and loaded to trucks at heights up to 4 m. They can lift and tip, but not swivel sideways.

A very useful tool for drains, and as a tool in marshes, is the SWIVEL or SCOOP BUCKET machines, which can scoop out, swivel around, and deposit loads. Some of these machines can dig wells to 9 m (30 feet) using hydraulic extension arms, and all can dig sharp-edged pits or drains for special uses. They can normally reach out 6–10 m (20–32 feet), and (standing on dry land) take silt from canals or ponds. To reach out much further, there are two tools, the DRAGLINE, a giant fishing rod or crane which casts out a loose or tractor-tethered bucket dredge up to 18 to 24 m (60 to 80 feet) and hauls it in full, and a two-tractor dragline, where one tractor hauls an endless rope with a bucket across greater distances than the crane dragline.

SCOOPS are often used behind horses or oxen to excavate small ponds or clean out ponds of silt. Unless fitted with a rear spill-door or chain tipper, they are very hard work to tip by hand alone, and tire one out quickly.

A special tool of great efficiency in flatlands and on low slopes is the SPINNER, a large wheel with small peripheral buckets spun at high speed, which throw out the earth as small clods a considerable distance. They are much used in Holland to drain polders, and are the most economical and speedy machines for flatland (shallow) drains. The spinner is one tool that distributes the spoil as small clods as it travels; there are therefore no banks beside spinner drains.

A special TRENCH DIGGER is a chain-bucket system which continuously digs narrow trenches for pipe-laying or to insulate foundations. Commercially, it is called a "Ditch-Witch®" or "Trench-Wench®".

Augers and Drills

These are hand or mechanical post-hole diggers suited to most soils. Other uses are in tree and tuber planting, although care must be taken not to compact soils or to create water-filled holes in clay. The prime use is for posts and fencing at present. Augers have a limited lift and are used to (normally) 2 m (6 feet) or so depth, whereas drills which have extension tubes can operate to great depths. The borings are removed by liquid flushing or are simply compacted and tube-lined. Purely hydraulic drills work to great depths, and bores and hydraulic nozzles are often combined.

Some of the largest vertical and horizontal earth holes (mines and quanats) were once hand-cut by primitive tools, and wells to 30 or even 60 m (100–200 feet) are still hand dug throughout the world. Special large-bore

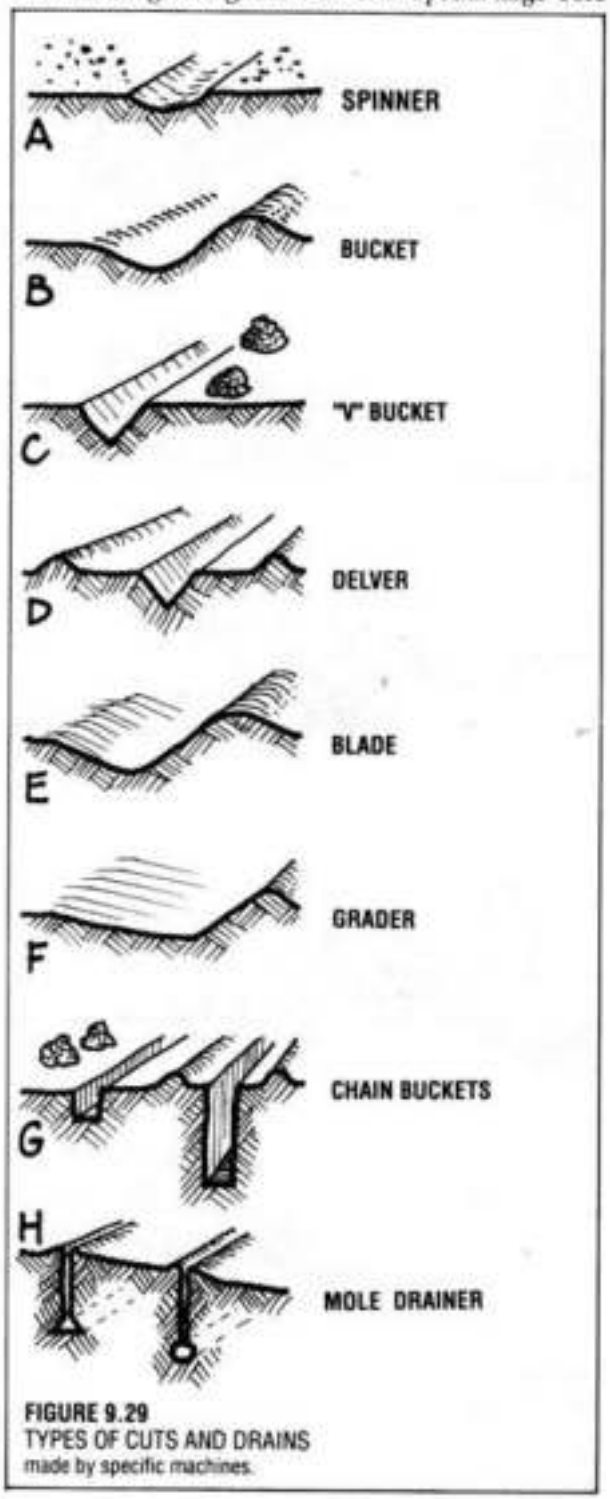


FIGURE 9.29
TYPES OF CUTS AND DRAINS
made by specific machines.

augers to 1 m (3 feet) are used at mines, and most carry extensions to make a 2 m wide shaft. Very large pneumatic blowers are crane-mounted to remove loose materials, and are often locally made as at the Coober Pedy opal mines in Australia. Large-bore drills there are called Caldwells after the inventor and are used for underground housing, excavation, shafts, and tunnels up to 1.5 m (5 feet) diameter.

Explosives

Explosives are of most use to assist auger holes in hard ground, to make holes in otherwise unstable ground such as marshes, or to loosen rock in quarries. With the advent of the swamp tractor, marsh blasting is less common, but the basic ease and effectiveness of explosives should not be overlooked where they can solve some otherwise intractable problems.

Nitroglycerine (cellulose treated with acid, in glycerine, absorbed into wood dust or clay earths) as gelignite, dynamite, or plastique is an inexpensive way to solve some earth-moving problems. Even cheaper is the mix of ammonium nitrate fertiliser and dieseline known in the trade as "chickenshit" (nitrates have from ancient times been gathered from manures, around the soil of toilet pits, or extracted by washing and evaporation from guano).

Old "recipe" books give dozens of reliable recipes for cheap explosives, and even custard powder, flour, or face-powder will blow a room apart, as will the fumes from ether or domestic gases. I once worked as a scientific glassblower, and managed to remove all doors and windows from my room by allowing ether to evaporate from a bottle. Earlier, as a baker in my father's business, I created some spectacular flashes using plain flour near open flames.

Today, we must take a course to obtain a "powder monkey" certificate in order to set our own explosives, or we should hire skilled people. Yesterday (pre-terrorist), we simply made the stuff up and let it go, with unpredictable results and often too much effect.

Hydraulic Jets

There are several ways in which the quiet but powerful action of water jets assist our endeavours. Firstly, a simple jet nozzle fixed inside a pipe and connected to a garden tap may well serve to drill a water bore (a water spear) in a few minutes or hours in sands, gravels, or deep soils. Secondly, an old hose-pipe fastened to a sharpened pile or post and connected to a hose will serve to sink jetty pilings in silt or sand in very little time.

A jet pump (commercially available) will remove silt, sediment, mulch, and even large gravel from a dam, and deposit these behind a retaining wall as rich terrace soil, while the water flows back to the dam. Lastly, jets fired at loose sediment washes down gravels, sands, and soils for mining, as terraces, or to remove land slips from roads and fields. Quite precise control of such action is achievable.

Hydraulic nozzles, "drills", and jet pumps are all made by industry to serve these purposes, and also to steer deep drills in boreholes to specific locations underground when tapping oil, thermal energy, or for venting mines and caves. Again (as with explosives) it is enough to know the range of uses, keep them in mind, and to get good advice if the need arises. Inadvertent jet drilling has a powerful pulling action, and jet pumps with their motors, rafts, or platforms can be dragged below water or across the ground if one is left unattended. Occasionally, a garden hose will bury itself in sandy soils in this way and so be lost.

Powerful air jets now take gravels from mines in much the same way, and a whole series of turbines and powerful pistons operate from pressure applied by water, air, or oil (the science is applied hydraulics, or pneumatics). A jet plus a cutting drill will cool the area and remove waste, in one operation.

Finishing

Rakes and rollers are the tools for finishing excavated earth; the former to fine level, the latter to compact. Compaction is only necessary where traffic or water retention is intended, but where it is necessary may need to be accompanied by water sprinkling in dry conditions. Care must be taken to compact only 15–30 cm (6–12 inches) of soil thoroughly at a time. Even very heavy machines can seldom compact depths greater than 38 cm (15 inches), and impact or hand compaction is effective for less than half that depth. It is necessary to strictly adhere to this careful compaction for dams and house foundations. Modern compacting machines often vibrate, using a pneumatic or mechanical eccentric weight to impact and shake soil as it is compacted.

9.9
EARTH RESOURCES

Whenever earth is moved, it seldom reveals a uniform composition; in fact, most excavation reveals materials already sorted by nature, and of specific use. To mix them up is to set back the clock a few thousand years, and the supervising designer or property owner will do well to follow every excavator (animal or technological) and put aside the following:

TOPSOIL. Topsoil is the often dark, root-filled living surface of the earth. It is to be carefully stripped off, piled aside, and later returned over other material onto banks, over padi or fields, and even below water in ponds. Topsoil can be very thin and rare, and is usually no more than 6–18 cm deep. Where deeper, it can be spread on poorer soils to help them produce, or pocketed for trees in poor soil areas.

PEATS. Excavation in marshes, bogs, or lowlands may reveal 1–9 m (3–30 feet) of semi-compacted fibrous plant material. Most can be stockpiled, otherwise 0.6 m (2 feet) or so returned to the surface as for topsoil. The peat stockpile is most valuable for mixing with sands

and loams for making even more topsoil. It can also be used as a fine growing medium in nurseries, as an insulator in buildings, and only in desperation as a fuel, for those who burn peat are near the base of life on earth; the next step is into barrens and rocks. Peatlands throughout the world now urgently need preservation as threatened habitats of unique vegetation.

Peat preserves timber, animals, and such unexpected treasure-troves as hoards of acorns and firkins of beech butter from the forests which preceded the bogs. A whole archaeology may very well lie in peat, and the pollen record may reveal past history. At the base of Irish bogs the *Fir Bolg* (the little people), their axes, bridges, butter, and forest life are well preserved. They and their forests were banished, as if by magic, by the *Tuatha de Danan* (the Children of Diana) who now dig the peat. Diana was displaced in turn by Mary, mother of God. But all are mixed in the peat and the tongue of Ireland.

CLAY. Good clay is very useful stuff; a depth of it can extend 0.3–6 m (1–20 feet). This resource can be stockpiled, and preferably covered with plastic sheets. Both dried and baked brick can be made of it, dams and ponds sealed, and pots shaped and fired. Some types of clay make good cricket pitches, and other types make fine porcelain or special filters and insulators. Fireclay is 58–75% silica, 25–36% alumina, 0.25–2% iron oxide; silica bricks 95% silica, no alumina, and <2% of lime.

SAND. Clean, it may make grinding powder or silica chips, or if yellowish have enough calcium to counter acidity. If fine and black, it may be of use in casting metals or as a material for a black-sand solar collector. If white, it reflects light like snow and can reflect heat to houses and walls. Fat sand (containing some clay <20%) makes ovens and mortar; sharp sand (or mostly silica) makes glass and cement, or can be mixed with peat to grow trees or other plants in nurseries (the best use). Sieved sand gives special sizes for special use as a grit or polish in mortars and grinders.

GRAVELS. Heaped up, it makes good roads, drains, and soft sun-bathing patches much better than lawns (no green stains). Angular, gravel makes good concrete, and smooth, good water filters or enzyme columns. It is a mulch for trees, as is cinder and crushed pumice. 19 mm-size angular gravels are the best for heat stores, where air from solar attics or glasshouses is blown into a heat store wall or tank filled with such gravels. Heat stoves can be placed under floors to heat gravel beds.

SHINGLE. Shingle is good under gravels on roads, for drains, and coarse filters. It is an excellent mulch for condensing water in deserts or dry places, a refuge for snails and decomposers, a filter bed for swimming pools *au naturel*, and so on.

SLATE. Floors, tablets, and billiard tables are of slate, as are roofs. Any rock that can be split can be utilised for walls and houses, roof areas, garden paths, and floor tiles.

BOULDER. Boulders can be used as a coarse mulch, wildlife refuge, and walling and windbreak material which gains and radiates heat. Some boulders are very good as pounders, others excellent mortar and pestles, weights, anchors, and ballast in boats.

To me at least, a bulldozer or excavator is a source of information, and the making of a pond is a rare chance to explore, explain, and store useful information and material relating to the site. On a complex site (old volcano, shoreline, swamp, or desert pediment), one can confirm or deny theories on formation, geology, and geological history. Best of all, experience on many sites gives a predictive capacity on similar sites, and more confidence in finding the right sites for ponds, excavated houses, silos or silage pits, and in finding more earth resources. All this, and just for a careful look at actual operation. It would not be uncommon for excavation to pay for itself on any one of the factors listed, and for yourself or your client to benefit long after the water storage is built, from materials put carefully aside during excavation. If you are wise, *you never leave the site* when earth is being moved; it is very expensive to bring machines back for fine touches, to adjust the work, or to sort out mixed materials.

TRACKS AND SIGNS

Like the snow and windblown sand, newly moved earth and puddled clays reveal to the observer a section of earth life, and makes an imprint of those secretive and nocturnal birds and mammals on site, from beetles to elephants, mice to plovers. After rain, it is a good time to take a notebook and observe the footprints, scrapes, and tracks of any site where earth was freshly moved. A list of species obtained this way adds to basic information resources and may warn of troubles in store from ground foragers. Many cryptic animals avoid traps, but can be detected by their tracks.

The earth hides a great variety of life forms, from secretive larvae and worm-like legless lizards to redolent fungi revealed only on the surface by their garlic-like scent or fruiting bodies. Mice, gophers, and larger mammals leave tunnels, nests, and food stores underground, and all these and other secrets, such as the extent of root penetration and spread, can be revealed for our analysis.

SHARDS AND FOSSILS

Under the earth, almost everywhere, lie the mute stories of prior life. These have more lessons for us than do futurologists, who after all can only look forward by looking back first (or they would not know which way is forward). The camps of our ancestors are revealed in soils by shells, tools, shards, ashes, bones (and can be so dated). Buried trees give growth rings to tell the story of older climate, air quality, and to accurately date their own burial. Pottery shards may encode astronomical or technological data, and bones reveal past diseases and wars. As the Ganges River today bears its children's bodies, their clothes, adornments, and possessions to sea, to race blindly over the continental shelf to the ooze below, and as we carelessly drop broken pottery on the

ground, so in the far future other people (or other minds) may want to know about us, how we lived and perhaps when and why we died. Today's disposal pits may well become tomorrow's mines. They are ourselves in past cycles, an expression of life preserved for our education and guidance.

9.10

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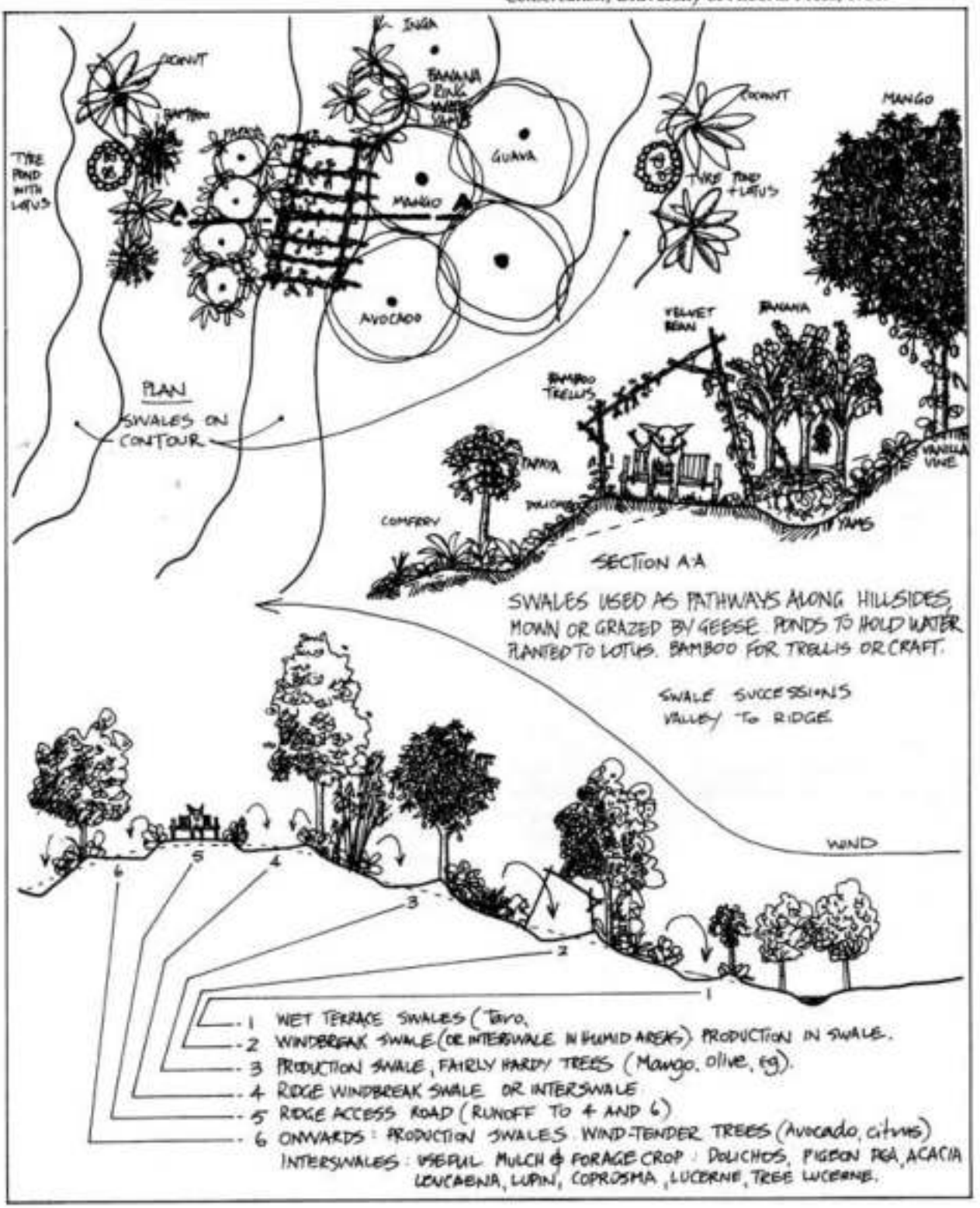


Chapter 10

THE HUMID TROPICS

10.1 INTRODUCTION

The subsets of climatic zones included in this chapter specifically exclude arid tropics, which are included in Chapter 11, together with cold arid areas. As plants and techniques do not split off neatly into climatic areas, the following three chapters should be read in total for any one site. A subtropical site, for instance, can have quite severe frosts, cold winds, torrential summer rains, and 7–9 months of drought, so that it needs the strategies, earthworks, and species suited to temperate, arid, and tropical humid climatic regimes. However, it is true that soils and climatic characteristics do dictate the specific broad design responses.

Some special topics of the humid tropics are those of soils, mulch sources, planning for polycultures, and appropriate house construction, each of which is given a section.

In the wet tropics, heat and high rainfall would leach most mobile nutrients from soils, except for the biomass of the great variety of plants, which contain 80–90% of the available nutrients. Humus is an essential soil fraction, and humus creation must be given considerable emphasis as prerequisite to sustainability.

Inappropriate strategies are those of bare-soil cultivation, or intensive clearing and burning in short cycles (less than 8 years or so) for cropping. Appropriate strategies involve complex and multi-storied plant systems designed to yield basic staples, create mulch, and preserve soil nutrients.

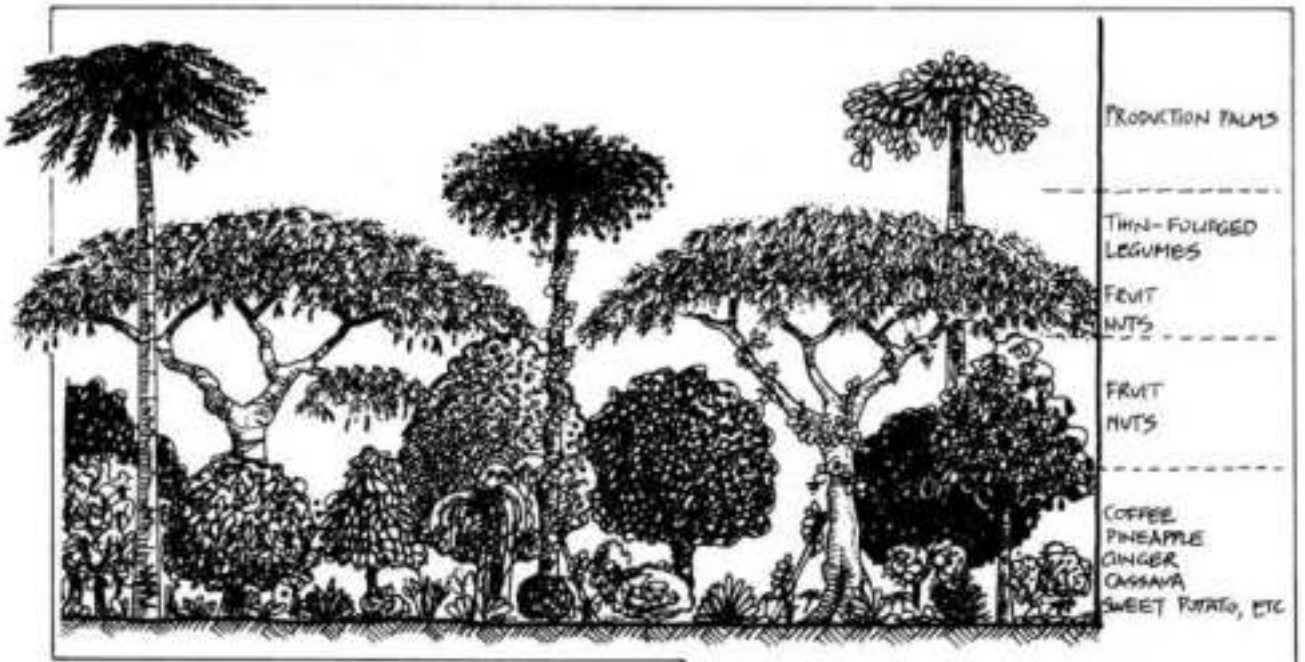
James Fox in *Harvest of the Palm* (1977), has been one of the few who have analysed the social changes and loss of self-reliance following the abandonment of ancient and balanced palm polycultures in Indonesia. Ancient tropical civilisations have been noted for their stability, indicating that sustainable land use patterns are an essential prerequisite for social harmony.

The Food and Agriculture Organization of the United Nations (FAO) admits to failure in transferring mechanised monocultural sustems (barely sustainable in temperate moist areas) to fragile African or tropical soils. It is a wonder that this was tried at all in modern times; the clearing and cultivation of tropical soils has for decades proved disastrous, and most ecologists would have predicted this failure by the early 1950's.

Complex perennial fodder and food systems are known to be stable, but are not as yet part of the officially funded agricultures from such sources as the World Bank. Deserts present even more fragile systems and need greater skills to stabilise and manage. The most inappropriate advisor is an agriculturalist trained in "modern" techniques. What is needed is continuous, local education of experienced people and a lateral transfer of their evolved skills. Emphasis in such education should range from an analysis of health and environmental problems to practical solutions, with sophisticated plant/animal/technological assemblies adapted to local food preferences, nutritional needs, and cultural requirements.

Romantic literature on the "easy" tropical life leaves out the skin cancers, rodent ulcers, dengue fever, filaria, malaria, chronic bowel and skin disease, and the constant battle with rampant growth that is an everyday experience at Latitudes 0–25°. That, and the pythons, ticks, termites, rain, mould, and lethargy caused by heat exhaustion. With the increasing loss of atmospheric ozone, it is folly for fair or red-haired Europeans to expose bare skin to the tropical sun—a cause of skin cancer in Australia and "*haole* rot" (a form of fungal bleaching of the skin) in Hawaii.

Humid heat induces a lethargy compounded by chronic illness in many populations. Water-borne and mosquito-transmitted diseases are almost impossible to totally control, given the aerial resevoirs of water developed by palms and bromeliads. In houses, induced cross-ventilation and careful construction for mosquito control are essentials, as are plant systems



based on a tree-species polyculture; the two combine very well to reduce climatic extremes.

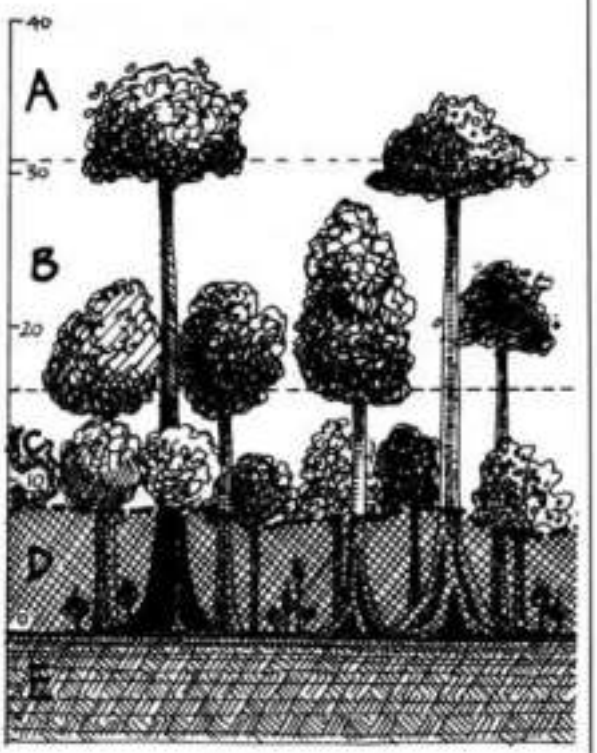
We can largely emulate the tropical forests themselves in our garden systems, establishing a dominant series of legumes, palms and useful trees with a complex understory and ground layer of useful herbaceous and leguminous food and fodder plants; vines and epiphytes can complex this situation as it evolves. In the wet-dry tropics, more open palm polycultures are appropriate; the excesses of heat, light and rain are best modified by an open canopy of palm fronds and the fern-like leaves of tree legumes.

10.2
CLIMATIC TYPES
(Based on Trewartha, 1954)

WET TROPICS

These are the river basins and wet coasts from Latitudes 0–25°. Major localities are the Amazon and Congo basins, Central America, Sri Lanka, Malaya, Borneo coasts, and New Guinea. This climate covers about 10% of the earth's surface (5% of the human population). It is heavily occupied only where terraced alkaline volcanic soils enable sustained cultivation (Java). It contains remnant tribes of hunter-gatherers (often pygmoid) in remaining forests, and is rapidly being ruined by over-exploitation of forests, mining and extensive cattle rearing, mostly developed by large corporations. Hence, there is a recent tendency for catastrophic wildfires to develop in logged areas such as Borneo, and for soils to be leached to low fertility, or eroded to ferricrete or silcrete subsoils.

The sun is mostly overhead, with temperature fluctuating little at about 21–32°C (70–90°F). Humidity is



A·B·C: Zones of direct sunlight.
D: Zone of reflected or transmitted light.
E: Root zone.

FIGURE 10.1
STRUCTURE OF A WET TROPICAL FOREST
Dense planting is possible, and beneficial near villages; species assemblies are simplified on the broadscale. Levels in natural forests are also indicated (after Moore, *New Scientist*, 21/8/86).

constantly high, frost unknown. Rainfall is from 152–328 cm (60–129 inches), with rain most days and frequent thunderstorms (75 to 150/year), usually towards evening or late afternoon.

The landscape features perennial streams, deeply weathered and rotten rock over bedrock (regolith), and rounded hills. There is rapid water run-off and evaporation, with swamps confined to coasts and lowlands. Rivers usually have flood-plains and extensive alluvial plains and deltaic deposits. Access inland is often by rivers and tributaries.

The vegetation is luxurious, best developed as broadleaf rainforest with lianas and epiphytes, very much mixed as to species—up to 800 tree species per square kilometre. The shaded floor of the forest contains little growth and has subdued light. Mangroves are extensive on appropriate coastal and estuarine sites. Growth is rapid, uninterrupted and continuous. Insects and birds are plentiful and varied. Most fauna is nocturnal and arboreal, and there are abundant fish and aquatic species. Ground grazers are rare and large herd species do not occur.

About 85% of nutrients are held in plants or animals, so the soils themselves are infertile especially if clear-cultivated, tending to erode and leach to insoluble oxides of iron and aluminium. Only terraces, flood-plains and new volcanos keep some soil fertility replenished or held if land is cultivated.

Staple cultivated foods are plantain and banana, cassava, yams, coconut, corn, taro, paddy rice, ducks, pigs, poultry, and fish. Trade and plantation crops are spices, copra, palm oil, cacao, rubber, banana, manilla hemp, rare hardwoods, balsa, tropical nuts, chicle, and drug plants.

Housing is usually raised, steep roofed, thatched, with permeable walls, and screened. Health problems relate to sewage disposal, insect vectors, and skin fungi.

Design essentials are for:

- Hygenic faeces disposal.
- Clean water sources.
- Integrated and benign insect control techniques.
- Gradual replacement of ground crops by trees.
- Preservation of natural stands of trees.
- Development of river versus road traffic.
- Evolution of natural products .
- No-dig (mulch) techniques on root crops.
- Domestic foragers for snail and insect pests.
- Appropriate medicinal plants.

WET-DRY TROPICS

These adjoin the wet tropics but are poleward of them. They take up about 15% of earth's surface from Latitudes 0°–25°, unbalanced in favour of the southern hemisphere. The Campos, Llanos, Gran Chaco areas of South America, parts of Central America, encircling the Congo basin, and many central Pacific islands (Hawaii) are all wet-dry tropical areas, most now developed to grazing.

Winter, the low-sun period, is the dry time, when clear skies and intense sunlight take day temperatures to 38°C (100°F) or more. Humidity is low, and strong dessicating winds may blow. Summer, the high-sun period, is like the wet tropics, but episodic flooding is more common and natural erosion therefore greater. There are no frosts, and temperatures range 21–27°C (70–80°F) in the wet season, 32–38°C (90–100°F) in dry season. Rainfall is 25–152 cm (10–60 inches), decreasing towards desert margins. Windward inland slopes and coastal mountains may receive excessive rain to 1016 cm (400 inches), but rain is erratic and least predictable towards the desert margins. Rain shadows evolve on leeslopes or in the lee of mountains.

The landscape is of intermittent streams, some wadis and flood plains, karst (limestone) areas with sinkholes, cenotes, and absence of surface water (Yucatan, Mexico). Hills are rounded, but gully erosion can develop rapidly on slopes. Extensive inland swamps may develop in flooded areas, and lakes in rifts are common (Africa). Rivers often have dangerous barways of silt and sand due to active erosion sequences.

These regions contain the vast savannah grasslands of the tropics, with thorn-bush and flat-topped *Acacia* trees (Africa), evolving to steppe grassland on plateaus, with baobabs and dry-deciduous trees. Grasses reach 1–6 m (4–20 feet) in the wet season, and are often burnt off. African areas contain enormous numbers of herd species: zebra, gnu, antelope, and therefore large carnivores. Arboreal species occur only within tree islands and the gallery forests of valleys. There are termites, ostrich, rhea, locust, and large numbers of reptile species and insects.

Soils are generally more fertile and alkaline than the wet tropics, especially where they are less leached by rain towards the deserts. Cultivated land is still at risk from erratic rain and erosion, leaching, and wind effects. Due to overgrazing and fire, erosion may extend the desert into these areas, or into dry-summer subtropics. Serious soil erosion results from short-term shifting cultivation (less than 15 years fallow period).

Staples are corn, millet, wheat, beans, potatoes, cucurbits, peanuts, cattle and goats, sheep, and game products. Herding of low-yield large herds is a major erosion hazard. Plantation crops are sugar, cotton, peanuts, pineapple, sisal. Exports are cattle and sheep products, and hardwoods from gallery forests.

Houses and granaries are generally mud or pise with thatch.

Design essentials are for:

- Small domestic water storage and reticulation.
- Hedgerow against winds.
- In-crop tree legumes such as *Acacia albida*.
- Improved stock varieties and stock management.
- Natural herding system of local herd species.
- Mulch use of grasses.
- Increased tree crop of high forage value.
- Decreased fire frequency.
- Tree stands for fuel and structural timber.
- No-tillage (cut and mulch) grain techniques.
- Low bunds for water retention.

• Chisel plow and sod-seeding techniques.

• Greater reliance on in-village tree crop near wells and ponds.

• Reclamation of eroded lands using pioneer species.

• Keyline techniques of flood control.

• Soakage pits and impoundment of run-off by low bunds or swales across slopes.

• Tree forage and tall grass hand-fed to domestic stock.

• The use of manures in gardens.

• The development of domestic fuelwood systems near villages.

MONSOON TROPICS

These are really a sub-type of wet-dry tropics, but influenced by nearby continental land masses and oceanic winds onshore. They are confined to the Indo-Thailand region, northern Australia, East Java, Timor, southern New Guinea, and extend Latitude 0° to 35° north in India. Despite only about 8-10% of the world's land surface, monsoon areas contain large human populations.

Late summer heating of the continents causes onshore sea winds and (with luck) heavy rains. The dry (winter) season reverses winds from cool interiors to coasts, giving a cool period not experienced in the wet-dry tropics (temperatures: 13-21°C—55°-70°F). Temperatures rise, and dry hot winds develop (to over 38°C—100°F) in spring, with heat increasing until the onset of the monsoon . About 60% of the rain falls in summer, but rain is erratic and varies from 102-1016 cm (40-400 inches), depending on topography and distance from the coast. Floods and droughts are equally unpredictable, but common. Most activities are determined by the monsoon rain (transport, fishing, farming).

Tropical forests once clothed the hill slopes and river plains, and grasslands extended towards deserts as savannah. Population pressure, deforestation, and marginal agriculture has devastated this ecology in India. Dry-deciduous broadleaves are common, teak and bamboo once extensive. Tree canopy is less dense than in wet tropics, so that dense understory is also developed. Mangroves occupy river mouths and low coasts. Large native animals are now rare in the Indian sub-continent, but reptile life is abundant, as are feral or native deer, buffalo, and primates. Monsoon Ausralia is better vegetated, with scattered eucalypt and *Acacia* trees, riverine forests, and very low human populations to date. Large marsupials, feral buffalo, and marsh waterfowl are abundant.

Soils are lateritic, often very hard in the dry season, and of low nutrient status. Some are cracking clays. Housing is often mud-pole structures, thatched, steep-roofed, with wide eaves and good drainage for wet period.

Design essentials are similar to those of the wet-dry tropics.

10.3

TROPICAL SOILS

Special problems arise with tropical soils, in that except in areas of recent vulcanism such as Indonesia, soils are old (not renewed by glaciation) and deeply leached. Most of the silica and calcium is in low supply. In clays, aluminium ions substitute for some silica ions, giving soil particles a net negative charge. Especially in the oxidic kaolinitic soils (common in weathered volcanics) only kaolin clays and oxides of iron-aluminium remain. In these soils, the charge or cation exchange capacity (CEC) of the soils is *affected by pH*. Once cleared, the humic particles leach out to about 30% of prior levels, and infertility appears in such crops as banana and sugar cane. There are a few ways to restore the soil's ability to hold nutrients (Wayne Ralph, "Managing Some Tropical Soils" in *Rural Research* No. 117, pp. 15-16):

• Restore humus with green crop, and especially perennials such as *Leucaena* and tree legumes generally Any cultivation loses humus as carbon dioxide, so try to grow plants with intercrop.

• Now, add *small* quantities of superphosphate at frequent intervals so that plants can take it up before leaching. If possible, add fine crushed basalt, a scatter of cement powder, and use shredded bamboo or cane mulches for silica and calcium. Increase pH with lime after trees and green crop are growing well.

• Whatever is added or available as fertiliser, give as a light spread *all year at 6-week intervals*, until plants are well grown. If at all possible, substitute perennial for annual crop, and *never* practice frequent cultivation.

Basalt, cement powder, coral, and bamboo mulch supply essential nutrients and increase soil pH, hence increase the negative charge on soil particles and their ability to hold calcium, sodium, phosphates against leaching.

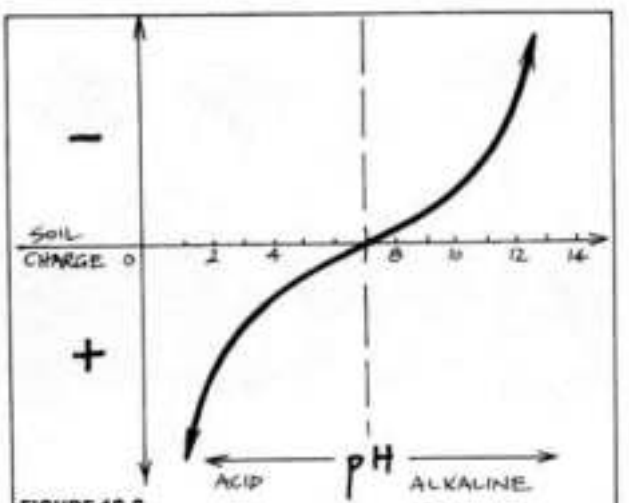


FIGURE 10.2
TROPICAL CLAYS
Cation exchange capacity (CEC) and ionic bonds on soil particles change with pH as diagrammed.

On coral cays, the calcium-rich sands bind to phosphate to form insoluble calcium tri-phosphate, so that a sort of cement (*platin* or calcrete) forms. This may be naturally evolved from the guano of seabirds, but superphosphate rapidly forms the *platin* by its greater solubility. In calcium rich tropical soils, fine rock phosphate yields more slowly and is therefore more likely to provide long-term benefits. A return of crop wastes as mulch is also essential, which can *reduce* pH in coral sands (pH 8-9) to a level nearer to pH 6.5 or 7, which is suitable for gardens.

In fresh volcanic areas, or areas with volcanic dust deposits, soils are sufficiently rich to sustain intensive agriculture without such aids, but constant cropping will exhaust even these soils.

There are many excellent tropical soils such as the alkaline volcanic soils of Indonesia, which support rich terrace and palm polyculture systems, and many tropical high-island soils where dolomite tops, or forms a mosaic with, recent volcanics. Apart from testing for minor elements, the addition a of mulch-manure mix creates excellent gardens on such soils, and plants show only minor nitrogen deficiences. These deficiencies can be eliminated by legume intercrop and manures.

In the long term we must rely on tree and ground legumes to keep up soil health in the tropics. Destructive approaches (now very well demonstrated) combine forest clearing, bare-soil cropping, and careless water run-off management to make desolate baked clays, brick-like and hostile, out of once-rich tropical forests. We have (as yet) no categories of "crimes against nature", but these will prove, in the future, to be some of the worst.

DEEP GRANITIC SANDS

In soils over rotted granites, such as are found on the high islands of the Indian Ocean, the Deccan in India, and where granites are left as inselbergs (domed hills), a peculiar problem arises in that open, coarse, granitic sands, often very deep, will not retain mulch beyond one growing season. There are two approaches to these free-draining and low-nutrient soils:

Broadscale

Palms, *Albizzia* spp., *Inga* spp., *Acacia* spp., a general planting of adapted leguminous trees, and other native vegetation will establish a light canopy of leaves if small amounts of nutrient are added at regular intervals. Palms planted in mulch-filled pits will then establish a high crown cover, and the detritus from legumes can be used to establish more valuable fruit trees, always retaining a *complete root web* of legumes. Palm trunks are ideal trellis for vanilla and passionfruit crop. Niches and clefts in the granite mass itself will hold pockets of soil and mulch for valuable trees, and vines will establish there to cover the granite slabs, which maintain heat and ripen crop effectively.

It is the mycelial web of the pioneer legume roots which enables us to maintain the benefit of applied nutrients, to reduce water use, and to establish fruiting trees (mango, cashew, pomegranate, persimmon, citrus, tamarind, lychee, custard apple, avocado) in such sparse and drought-prone soils. Drainage is, of course, excellent, and deep-rooting trees thrive. Palms suited to these sites are date, coconut, doum, and *Borassus* palms.

Gardens

It is effective to excavate long trenches in the loose sand (1-2 m wide, 1-1.5 m deep), to lay in a sheet-plastic base (upturned at one end only) or to line the trench thickly with cardboard, paper, carpet, and leaf and then to backfill with sandy loam. The deep sealed layer holds water and leached mulch, and household waste water can be led into these trenches to provide root water and nutrients.

Otherwise, we can build log-boxes above ground level, carpet the box base with plastic or thick paper,

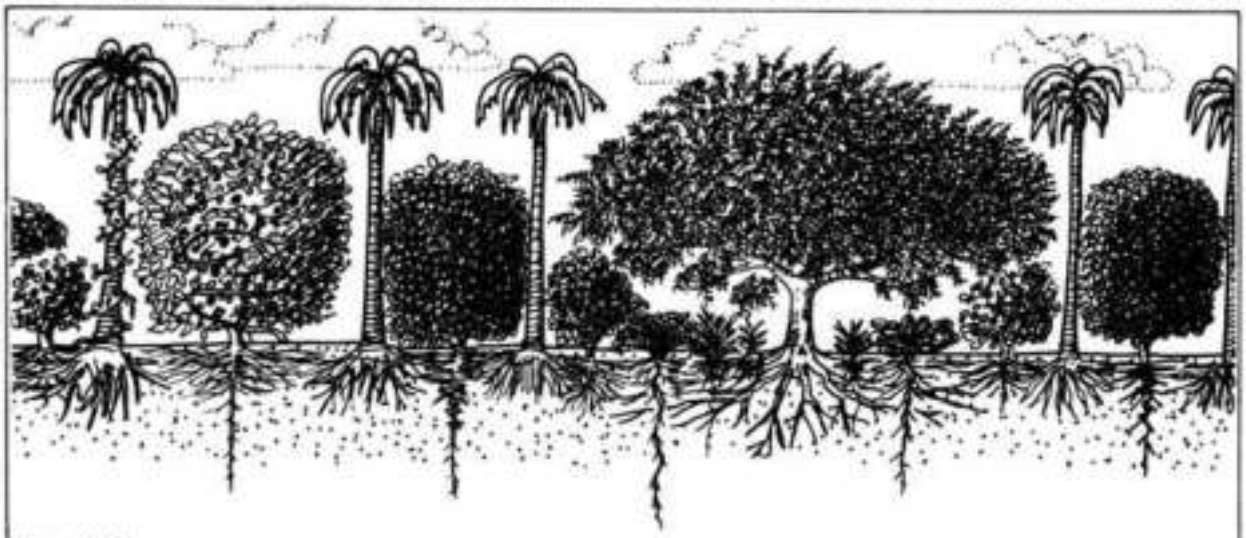


Figure 10.3
BROADSCALE TREE CROP IN LOOSE GRANITIC SANDS

and fill with humus-sand mixes for green crop and vegetables, top-mulching as needed. Large domestic water tanks, gleyed ponds, solid granite dams, and underground plastic-lined cisterns back-filled with sand will hold water.

SOIL LIFE IN THE TROPICS AND SUB-TROPICS

Termites, ants, and some worms are the obvious soil mesofauna of many arid and humid subtropical areas. Both ants and termites are very active in the transport of rotted rock and subsoil to the surface, in opening up galleries for the infiltration of water, and in the breakdown of woody and leafy plant material. Some species create large mounds, others build underground compost heaps for fungal culture, and all are active burrowers and builders.

Termites may have a decisive role in the dynamic and delicate balance between the erosion of surface soil and the replacement of the soil by subsoil and rotted rock particles. They certainly have an important role in plant succession and distribution in savannah areas, or where termite and ant mounds are the only well-drained or elevated sites in a landscape subject to floods, or where impermeable clays underlie thin peats (usually with acid anaerobic soils). In these situations the spoil heaps present an ideal site for pioneer vegetation or adapted crop planting.

Harris (1971) records that both the leaf-cutter ant in South America and termite mounds in Uganda assist forest spread or establish islands of taller vegetation in grasslands on their mounds or colonies. I have also observed this in the granite country in Hyderabad, India, and on acid peatlands in Tasmania. Such mounds protect soils from fire, waterlogging, and poor aeration. In humid areas, some such sequence as tall grasses (*Pennisetum, Eragrostis*) are followed by shrubs such as castor oil bean, *Prosopis*, and thorny legumes. Finally, an understory and forest may develop from larger trees such as tamarind, *Vitex, Sapium*, or palms dominant.

Thus, we can start this process or a modest version of it by seeding into termite or ant mounds using similar species; even low ant-heaps may present a site for ground cover pioneers in grasslands. Harris records crops such as sisal, cotton, and tobacco deliberately cultivated on large mounds in grasslands. Palms and coffee can have much of their outer bark removed by termites without suffering loss of production. Termites may greatly assist the primary breakdown of logs, coarse stems, and hard leaf material used as mulch in plantations of coffee, tea, or bananas.

It is a matter of specifying (by observation and local report) which useful crops or trees are left alone on mounds, which are attacked but remain productive, and which actually benefit by association with a local termite or ant species. Planting in ant or termite mounds is a particular example of niche gardening widely applicable to the tropics. I have successfully germinated daikon radish in ant heaps in grasslands as part of a changeover to crop production.

Ant and termite mounds present a rich deposit of calcium and potash, better aeration of soil, and a faster infiltration of water to release minerals from such rocks as granites, which noticeably rot or erode faster when buried in a free-infiltration soil environment.

SOURCES OF HUMUS FOR TROPICAL SOILS

As humus in the soil provides a good CEC, we must look to the provision of such humus as a priority. Some sources are:

- Logs and branches of trees. These are sometimes rotted in wet terraces or piled up as rough mulch around new tree plantings. Palm wastes are often plentiful.
- Detritus from stands of bamboo, pines, *Casuarinas*.
- Aquatic weed mats and emergent water weeds.
- Crop wastes and manures, household wastes.
- Hedgerow, forage, and specially-grown mulch plants.
- Green mulch and ground cover.

Logs and Branches (Rough Mulch)

The rapid breakdown of wood under the combined influence of rain, heat, termites and fungi means that we can lever whole logs together, or in line cross-slope to act as planting sites. This technique is most useful on bare clay soils, eroded areas, and isolated atolls (using the trunks of old palm trees).

In Hawaii, a traditional strategy is to rot the logs of

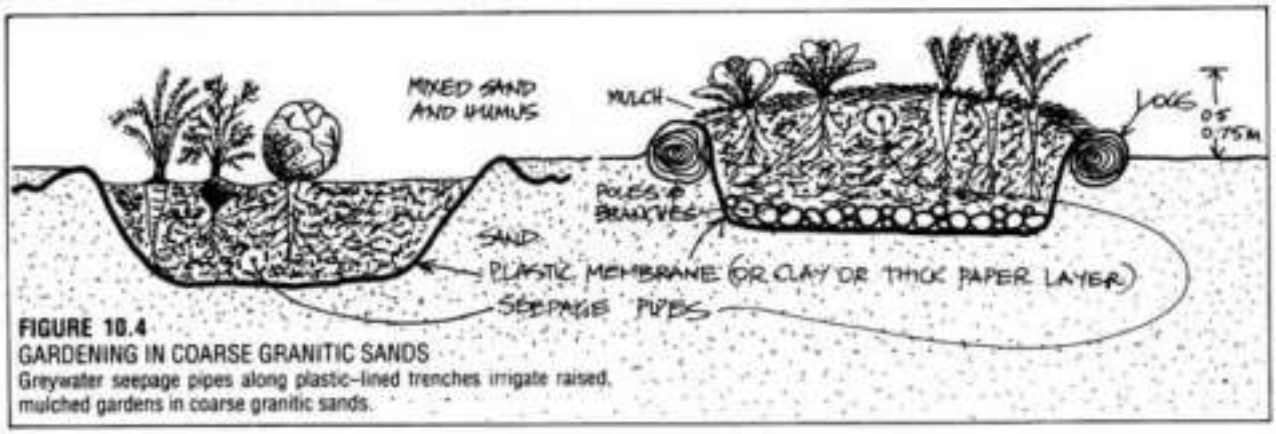


FIGURE 10.4
GARDENING IN COARSE GRANITIC SANDS
Greywater seepage pipes along plastic-lined trenches irrigate raised, mulched gardens in coarse granitic sands.

the kukui tree (*Aleurites moluccensis*) in the shallow water of taro terraces. As logs rot, an edible fungi appears which is taken off as crop. The remaining log is then crushed and spread in the taro terrace. Leaves and branches of kukui and other forest trees were gathered for the same purpose (terrace mulch).

Marjorie Spears, in Queensland, Australia, has successfully built temporary roughwood terraces across a deforested slope using rejected logs, and created a complex and rich garden based on this strategy and green legume mulch. Logs are available from palms, although fast-growing *acacia* species can be previously close-planted for this purpose (**Figure 10.5**).

Detritus

Several plant species (most palms, bamboo thickets, *Casuarina*, and many *Acacia* species) provide silica-rich mulch, as do grain and nut husks and residues from copra operations. This can be applied as shredded or chopped mulch to crop or to the base of newly-planted trees. The silica is released for growth, and has the secondary effect, in alkaline island soils, of reducing pH (from 8.5 to 6.5 in my trials on coral islands).

Of particular value are the fronds and spathes of palms, shredded or whole, and the stems and spathes of bamboo. Both have essential structural uses, and larger stands can be used to produce mulch.

Aquatic Weeds

Floating aquatics, including the water-fern *Azolla* (several species), the water-lettuce (*Pistia*), water hyacinth (*Eichornia*), and algal mats or fern fronds, plus reeds and rushes gathered from ditches, are excellent crop mulch. *Azolla* has largely replaced kukui (*Aleurites*) as a taro mulch in Hawaii. *Pistia* has been successfully used in Africa, and water hyacinth in many areas.

Azolla and algae such as *Anabaena* (one species of which "nests" in the glutinous sacs in *Azolla*) provide nitrogen. In the dry-wet tropics, shallow flood-water bunds collect or produce these plants, which can be gathered as rolls of dry material when the water dries out in the winter period, thus providing garden mulch in abundance from temporarily impounded water. John Selman of Cooktown (Australia) has used algal rolls in this way for his garden plants.

Crop Wastes and Manures

The husks of corn, kitchen wastes (including bones), and human and animal manures are invaluable tropical garden mulches and nutrients, and most need only burial near tree roots or in growing mounds for safe disposal. Cardboard and newspaper, where available, are valuable grass-suppressing weed mulches, and a cover of nut husks completes the job. In the Seychelles, cinnamon leaves and branches from pollarded stumps are considered an excellent mulch for vegetable crop, and the bark is a valuable spice.

Hedgerow and Mulch Plants

All hedgerow (*Hibiscus*, *Casuarina*, banna grass, palms, leguminous trees such as *Gliricidia*, *Acacia* and *Prosopis*) are almost continual mulch sources. The legumes provide in-crop shelter (see later section on avenue cropping). Lower garden windbreak, especially lemongrass (*Cymbopogon citratus*) and comfrey (*Symphytum officinale*) are as useful in preventing kikuyu grass intrusion as they are for repetitive cutting for mulch in the vegetable garden. Many people now use both these species as a combined kikuyu barrier and mulch crop (**Figure 10.6**).

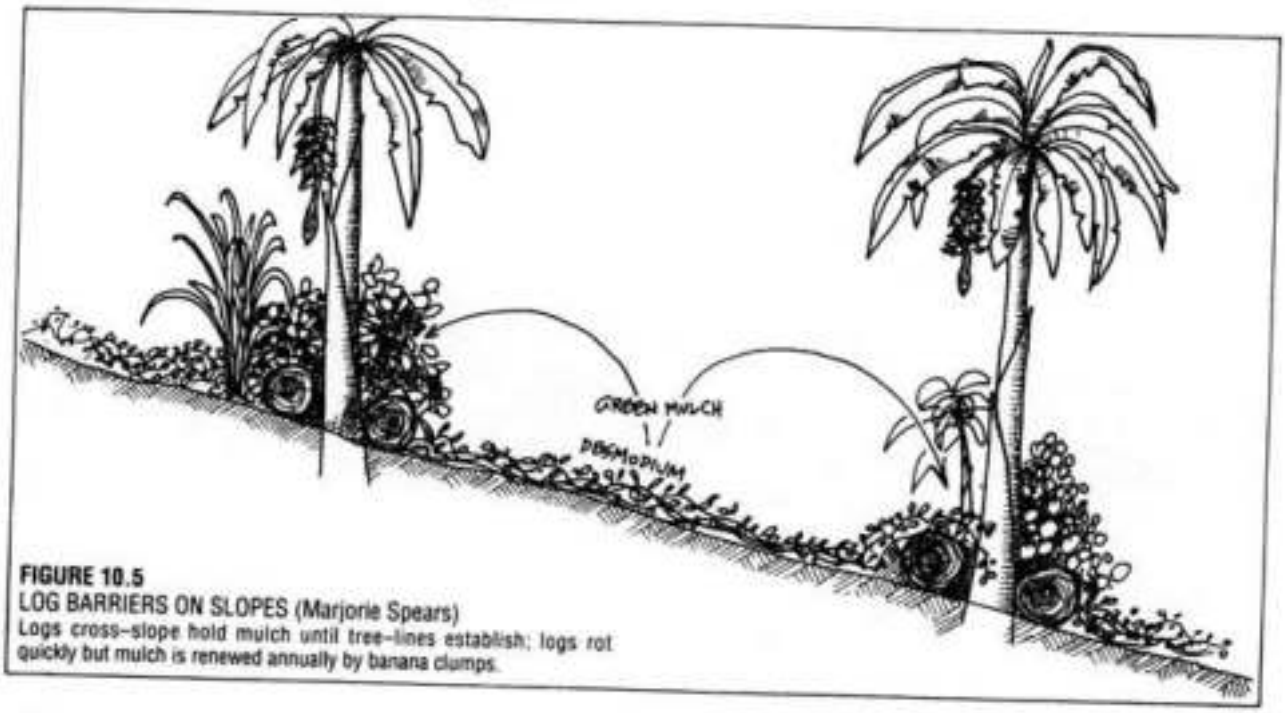


FIGURE 10.5
LOG BARRIERS ON SLOPES (Marjorie Spears)
Logs cross-slope hold mulch until tree-lines establish; logs rot quickly but mulch is renewed annually by banana clumps.

Green Manures and Ground Covers

In and around gardens and trees, soft herbaceous plants such as nasturtium, comfrey, marigolds, tobacco plants, and the tops of mature taro plants and other *Araceae* not only suppress grass, but provide a constant source of "slash" mulch. Even more valuable are such soft legumes as *Sesbania*, vetch, Haifa clover, cowpea, lablab bean, soya bean, *Desmodium*, *Suratro*, and *Centrosema*. These can be slashed or (in wet–dry tropics) interplanted with grains to give a nitrogenous ground cover, aiding in the suppression of grasses. Lablab dies down just before grains ripen in the winter dry season.

Thus, a combination of growing and gathering mulch enables us to create a rich humus for gardens over clays or sands, in loose volanic cinder, on *a 'a* lava, and in loose coral atoll sands. Each of these situations can successfully produce mulch.

Some difficult mulch such as *hibiscus*, *Lantana*, and weeds which tend to resprout from cuttings or seed if mulched (several grasses and hedge species) can be routed to gardens via poultry or cattle pens (where seeds are removed and foliage eaten). They can also be shredded for anaerobic digestion in biogas plants, bagged in large plastic bales exposed to the sun (where they "cook" to a weed-free silage), or simply bundled and immersed to rot in covered water pits. In fact, some such re-routing is ideal for the primary processing of plant wastes that promise to infest gardens if untreated. Pigs eliminate or eat the nut-grasses, rhizomes, bulbs, and sedges that resprout from compost.

All else failing, even a plastic sheet mulch has excellent effects on row crop, preventing rain splash and nutrient leaching, and at the same time condensing groundwater at night. It does not, however, add to the humus content of soils, nor to the cation capacity of soil structure, and may even release unwanted chemicals to the soil.

The value of surface mulch in weed suppression is a major factor in lowering garden work. For this reason, any mulch should be thickly applied 20–25 cm (8–20 inches) deep when first establishing home gardens. Later mulch can be derived from green herbage and borders or windbreaks.

TABLE 10.1
CROP YIELDS UNDER SELECTED MULCHES

MULCHES	Maize	Cowpea	Soyabean	Cassava
Rice husks	3.7	1.1	0.8	**28.3***
Pennesetum Straw	3.3	1.2	**1.4**	14.2
Elephant grass	3.3	0.9	1.3	16.6
Millet straw *(Panicum)*	3.6	**2.1**	**1.5**	15.5
Legume wastes	**4.3**	1.0	1.1	15.5
Sawdust	3.7	0.9	**1.9**	20.5
Bare ground	3.0	0.6	0.6	16.4

*Heavy yields are emphasized.
[After B. N. Okigboand R. Lal, *Residue mulches and agriculture.*]

B. N. Okigbo and R. Lal in *Residue Mulches and Agrisilviculture* (International Conference on Ecological Agriculture, Montreal, 1978), in mapping strategies to cope with increasing land pressures, found that no-tillage systems maintained or gained yields for maize in Nigeria, and increased yields from mulched crop for cowpea, soya bean and cassava.

I have selected out some natural mulches from the more extensive original table given. Mulch trials are compared with bare ground (on the last line of **Table 10.1**)

Maize had a marked positive response to legume straws or waterplant (*Pistia*) mulch, while the legumes themselves responded well to grass and sawdust mulch, and cassava to both legume and grain husk wastes.

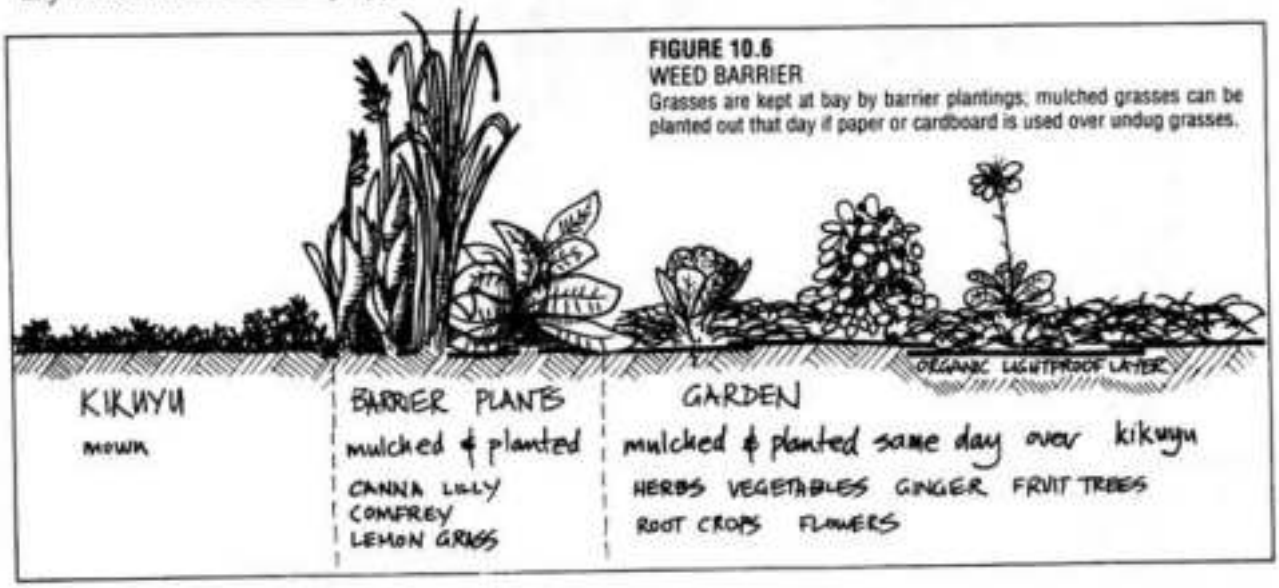


FIGURE 10.6
WEED BARRIER
Grasses are kept at bay by barrier plantings; mulched grasses can be planted out that day if paper or cardboard is used over undug grasses.

Although plastic mulch has a good effect on all crops, it does not add humus to soils, and is therefore not as appropriate to a remote village situation where soils must be built up from wastes and from mulch.

However, every type of organic mulch increases yields, and we should therefore use all available materials for soil restitution. Mulch provision is the cornerstone of tropical home gardens, and green mulch and tree legumes the essential accompaniment of main crops and tree crops.

Special mulches may be used in tropical areas, grown to provide N, P, K (legumes, comfrey, *Pultanea*), and to increase or decrease pH. Pine and legume mulch may benefit the growth of bromeliads (pH 4–5), buckwheat and nut husks serve to raise the pH of garden soils, as do many bark mulches.

For fire control, too, it pays to rake under bamboo and clump canes, and re-route the leaf mulch through animal bedding or poultry strawyards. Branches of legumes and forage trees may also be used in the same way, on their path to the garden.

In the rampant grasslands that replace fallen forests, there is little else we can do than to strip-mow and mulch while trees re-establish. The timing of slashing is important, as seed-free mulch (called second-cut grass) is best for placing around valuable crop. Seed-head mulch should not be placed in gardens or areas where it might be a nuisance. All species of weeds and grasses give weed-free mulch when not in seed. Many useful tree species provide leaf mulch, and so are excellent also for interplanting with crop, for example tamarisk in dry areas, *Casuarinas* in sand, and legumes in all areas.

There is absolutely no excuse for burning any organic wastes in the tropics, as even large logs quickly rot under the onslaught of fungi, termites and beetle larvae. At the same time, logs provide cross-slope barriers against monsoon erosion, until new trees take hold.

Coconut husks have a variety of uses, not the least of which is as mulch for a valued crop such as vanilla orchids. Their one drawback is that they hold small sections of water which will breed mosquitoes, but on many islands they will also be available (with palm fronds) to shred to a first-class mulch of high potash value, to burn and steam to activated (filter) charcoal, or to be used as a solid fuel. Shredded bark and broken shells are ideal mulches for ginger, tumeric, and vines.

I have not found any crop or tree suited to the specific locality that does not grow, produce, and thrive in mulch, nor any widespread pest that grossly affects a total polyculture yield. Ginger, taro, beans, bananas, palms, fruit trees, flowers, yams, sweet potato, melons, etc etc. have been trialed in thick mulches of straw, fronds, nut husks, cardboard, and sawdust. A thick mulch almost totally eradicates kikuyu grass and other persistent grasses. In the field situation, extensive mulching is often impractical, particularly if it is carted in from off the site. However, a pioneer crop of quick-growing tree *Acacias*, bananas, legumes such as lablab, deep-rooting comfrey, and a grove of bamboo and palms will provide continuous mulch for gardens and main crops, fruit trees and valued plants.

Growing in exhausted or poor tropical soils is possible, but the early work of rehabilitation takes hard work, seed, essential fertiliser resources, and a strategy

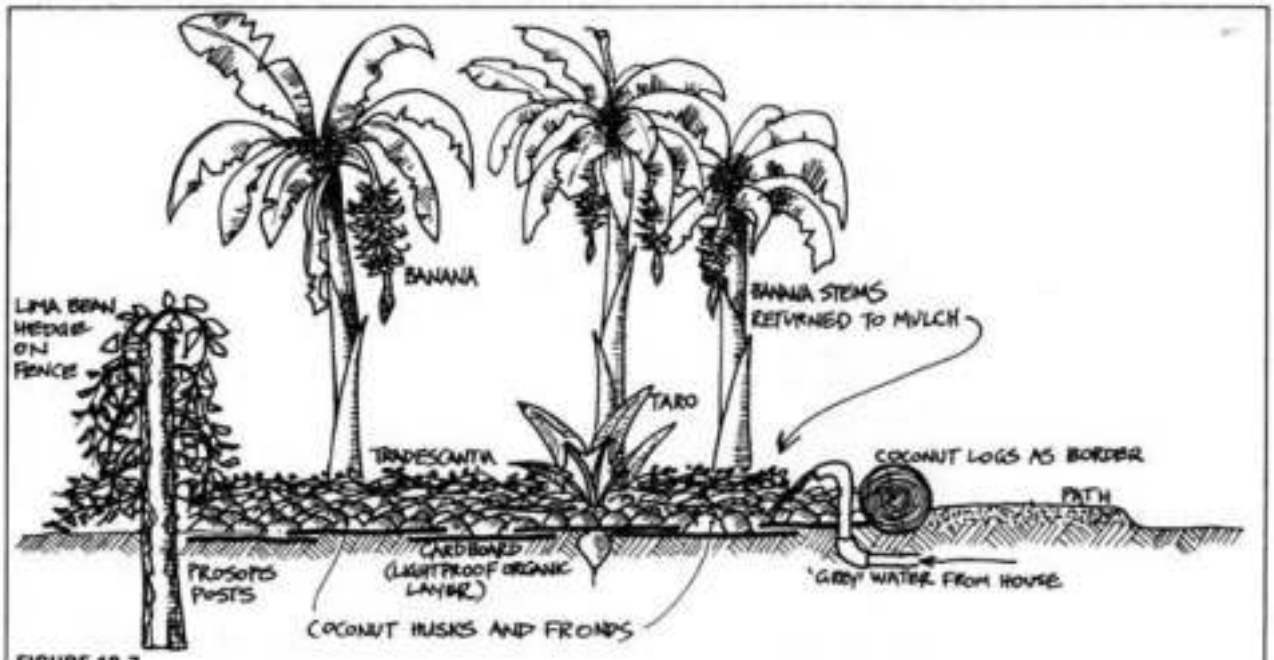


FIGURE 10.7
MULCH IN GARDENS
Held by a log edge, coconut husks and coarse fronds or grasses provide mulch for home gardens; greywater irrigation is ideal.

of starting small and expanding the system at the periphery. Dense planting of nucleus areas plus mulch is the key strategy.

10.4
EARTH-SHAPING IN THE TROPICS

On level ground or gentle slopes (2–8°) in the wet–dry tropics, a series of large contour banks or swales have an excellent soil preservation effect. Coupled with the gradual development of a terrace, the retention of wet-season water, and mulch-providing hedgerow, this ensures a stable situation. Between the main hedges, mulch hedgerow and borders can be developed in crop, or the terraces can be flooded seasonally for irrigated crops (**Figure 10.8**).

On very flat sites (less than 4°), a series of raised mounds or ridges can operate to drain crops in very wet areas, or to impound water for absorption in drier areas. Pits can also be used only where rainfall is less than 76 cm (30 inches), or where soil drainage is good. Thus, cassava, yam, and cucurbits are mounded in areas where drainage is a problem and rainfall intense, and pitted in dry areas or savannah-dry seasons. Pits retain mulch and moisture, as they do in desert areas.

Almost every slope benefits from earth-shaping for soil conservation. Hand-made slope terraces need to be narrower (to 3.5–6.5 m—12–15 feet) than machine-made systems.

Garden terraces on *very* steep humid slopes must be kept narrow, and in sets of 6–8 downslope, otherwise instability may result. Borders can be kept vegetated with trees (**Figure 10.11**).

Classical wet rice and taro terrace has water continuously led into the top terrace of the series, and each has a drain and sump to regulate water level. Fish

FIGURE 10.9
MOUNDS, RIDGES, PITS
Mounds increase yields of yams; ridges of cassava and sweet potato; pits for taro, arrowroot, and mulch grasses. Terraces need such detailed earthworks.

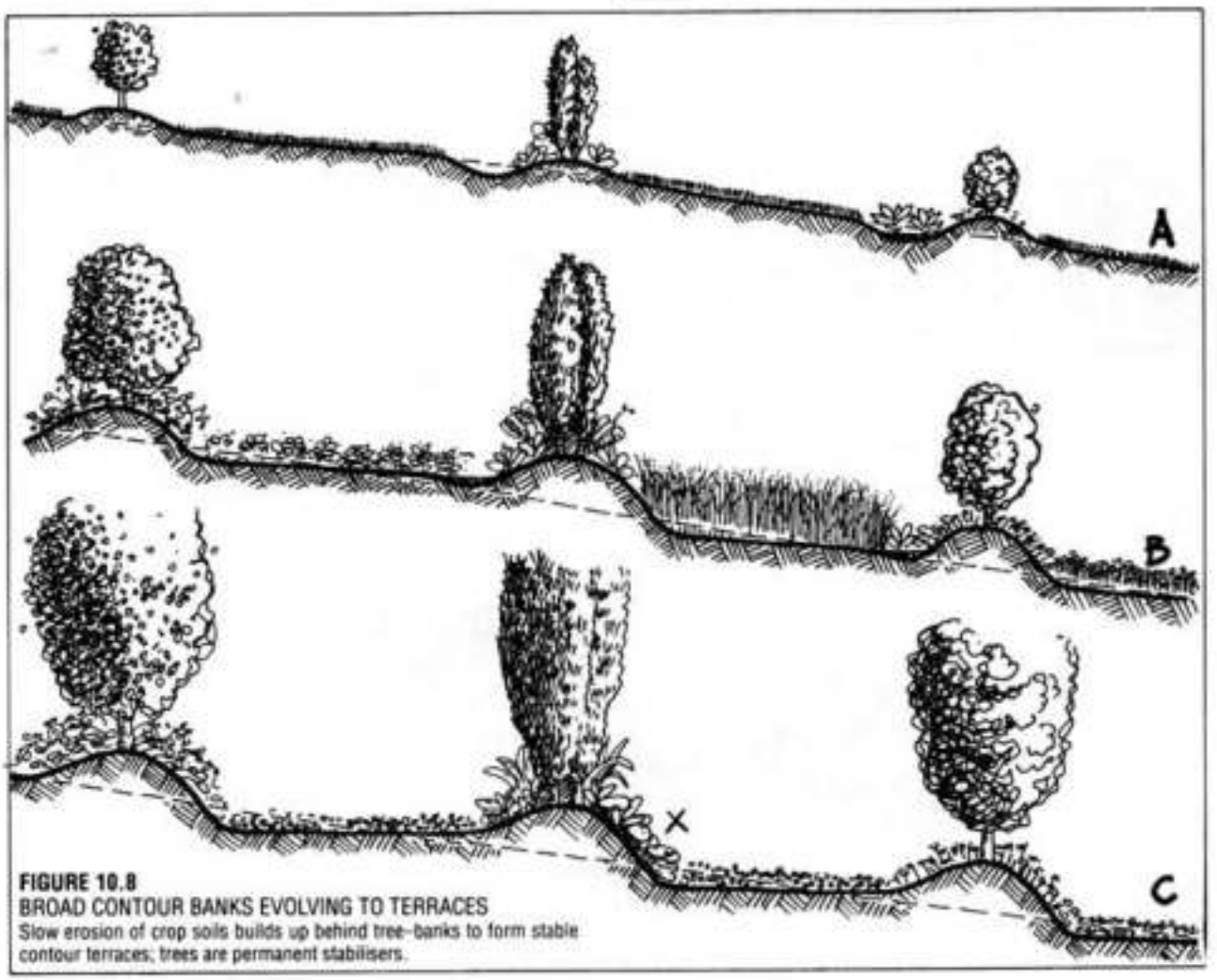


FIGURE 10.8
BROAD CONTOUR BANKS EVOLVING TO TERRACES
Slow erosion of crop soils builds up behind tree-banks to form stable contour terraces; trees are permanent stabilisers.

may be grown in the deeps of such terraces (**Figure 10.12**).

In stable clay or clay-loam soils, terraces not only hold and infiltrate water, but permit mulch application with minimal leaching losses. Where no streams exist to feed the terrace system, DRY TERRACE holds the soil against erosion in cropped areas. Lacking streams, a deep mulch keeps terrace soils moist. Where a stream, or part of a stream, can be led to upper terraces, wet crop such as rice, taro, watercress, kangkong, and water chestnuts (Indian or Chinese) can be cultivated in water-level controlled padi. This is the rich WET TERRACE culture of Asia and Oceania.

Essentials are: about one-half to one-third of the total terraced area should be devoted to *mulch tree crop* providing fodder for livestock or direct leaf and branch mulch to terraces. Ideally, the upper one-third of hills, the very steep slopes of 30° or greater, terrace side-borders, and the outer faces and crowns of bunds (walls) should be planted to productive and mulch-producing tree and ground crop. This not only adds to the terrace stability—many of which have existed in production for up to 5000 years, e.g. the wet terrace cultures of the Ifugao people of the Philippines—but will also provide a local manurial-mulch crop for terrace cultures. Included in such mulches are the crop wastes of the preceeding crop.

Specific Growing Situations on Terraced Lands

- Banks and bunds: the rim of the terraces, and stepped bunds made for tree crop.
- Slope faces and walls.
- On trellis out from bunds.
- In and around ditches and drains.
- On steep (unterraced) slopes.
- The flat area of the terrace itself.

Dry Terrace Crop Species

- Millet: summer or dry periods.
- Dryland rice: spring-summer.
- Barley, wheat, rye: winter and cool periods, spring wheat varieties, *Brassicas*, fava beans.
- Amaranth: summer grains, spring greens.
- Quinoa: summer grains.
- Rape/mustard: winter oils and oil seed.
- Lentils, peas: intercrop and nitrogen fixing grain legumes.
- Grams and pulses: intercrop and nitrogen fixing.

Fodders

- Tagasaste, banna grass, comfrey, *Leucaena*, crop wastes and straw.

Garden Terraces Near Homes

- Banana, papaya, melons, chilies, peppers, cucur-

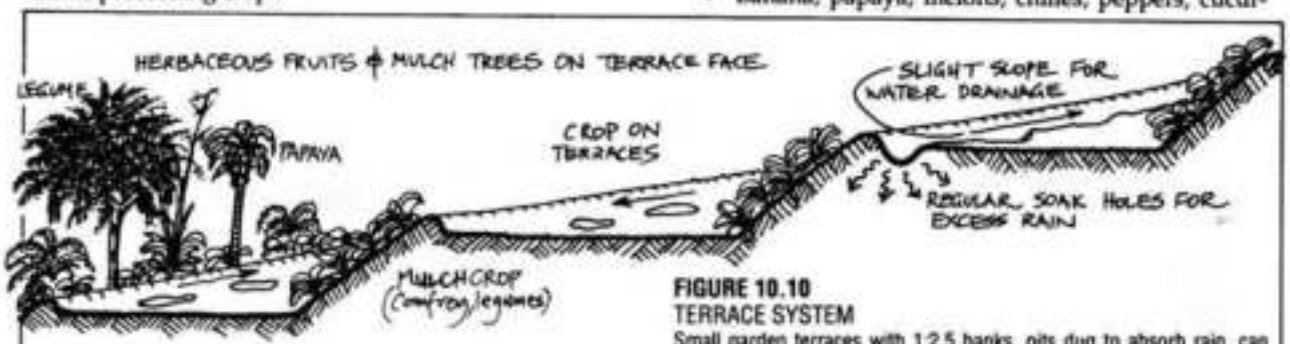
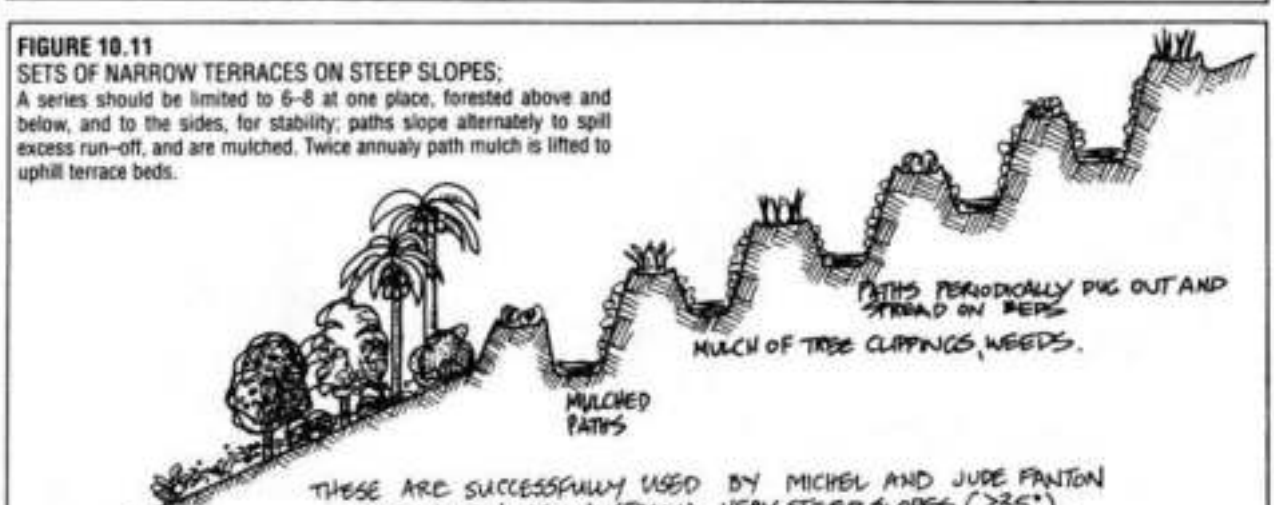


FIGURE 10.10
TERRACE SYSTEM
Small garden terraces with 1:2.5 banks, pits dug to absorb rain, can be fully planted to vegetable and herbaceous perennial crop.

FIGURE 10.11
SETS OF NARROW TERRACES ON STEEP SLOPES;
A series should be limited to 6–8 at one place, forested above and below, and to the sides, for stability; paths slope alternately to spill excess run-off, and are mulched. Twice annually path mulch is lifted to uphill terrace beds.



rbits, maize, beans, sugar cane, cultivated green-crop *Brassica*, edible *Chrysanthemum*, edible *Hibiscus*, rosella, horseradish tree (*Moringa*), coconut, mango.

Vine Crop Off Bund Faces

- Chayote, cucurbits, beans, passionfruit, kiwifruit.
- Bamboo on borders provide trellis material, as do rot-resistant timbers.

Mulch Crop and Fodders Above to the Borders

- Tree legumes, banna grass (*Pennisetum*), lemongrass, Vetiver grass, comfrey, bamboo and palm fronds, *Aleurites* spp., *Cinnamonum* spp.

Slope Stability

- Contour strips of Vetiver grass, lemongrass, banna grass with tree legumes not only replace contour ridges but trap soil particles, and is a cheap way to "terrace", even on steep slopes. These strips provide mulch for trees and intercrop (**Figure 10.13**).

Essentials and Variations on Terrace Systems

- Borders; and uphill, steep-slope, forest crop planted and selected for mulch value and fodder, or:
- Animal sheds (ducks, pigeon, poultry, pigs, bees) over top terraces; manure on a "washdown" system.
- In-crop mulches such as beans, *Azolla*, clovers.
- Staggered, short sets of terraces for steep slopes and high rainfall, compared with more continuous and longer series for winter-dry irrigated terrace.
- Deep areas in terraces for fish/crayfish/ shellfish refuges.
- Vines over all or part of the terrace to aid such crops as taro.
- Bunds planted in clover, beans, comfrey, lemongrass, fruit crop.
- Splash stones or splash plates for falling water; methods of draining terrace.
- Border drains in terrace to keep soil dry for mid-season crop.

10.5
HOUSE DESIGN

Optimum comfort levels for people are at dry-bulb temperatures of 20°C (68°F) in still air (winter), and 25°C (77°F) in summer, subject also to individual preferences. Above relative humidity levels of 40%, we effectively add 1°C to dry-bulb temperature for every 4% increase in humidity. As average summer humidity in wet-dry tropics commonly exceeds 50%, and long periods of humidity of 70% or so are experienced, there are times when sensible temperature exceeds 30°C (86°F), and heat stress results.

In homes, a useful indicator is a wet-bulb thermometer, where the mercury bulb is kept damped by a cotton wick drawing from a beaker of water. Below 18°C (65°F) wet-bulb temperature, we can remain fairly comfortable.

Factors that accentuate heat are nearby radiant surfaces and lack of air movement. For a nearby radiant heat source (wall or pavement) that exceeds 38°C (100°F), we can add 1°C (per degree radiated) to the air temperature, and conversely, we can subtract 1°C for any air flow above 1 m/second.

Evaporative cooling in dry air greatly reduces heat, but as the high humidity periods of tropics do not enable us to cool by sweating, we must therefore use every strategy available to de-humidify air (mainly by cooling), to cast shade, to develop cool surfaces, and above all to induce cool air currents in houses. Overshading trees, attached shadehouse, white exterior and interior surfaces, and clear-path breezeways are essential design strategies both in equatorial and sub-tropical climates.

In many continental subtropical locations, we are faced with dual problems of quite intense winter cold, with some frosts (and rare snows), and very humid and hot summers. Thus, the sort of house we need to build has several unusual characteristics, and needs perhaps more careful planning than either equatorial houses (where reducing heat is the only problem) or temperate and boreal housing (where providing heat is the only problem).

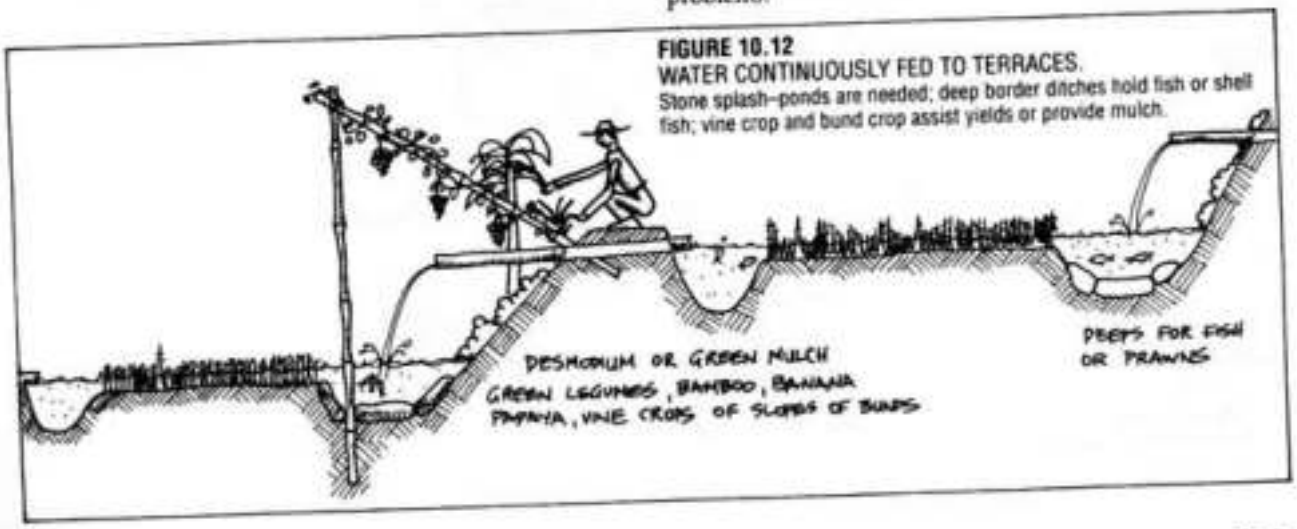


FIGURE 10.12
WATER CONTINUOUSLY FED TO TERRACES.
Stone splash-ponds are needed; deep border ditches hold fish or shell fish; vine crop and bund crop assist yields or provide mulch.

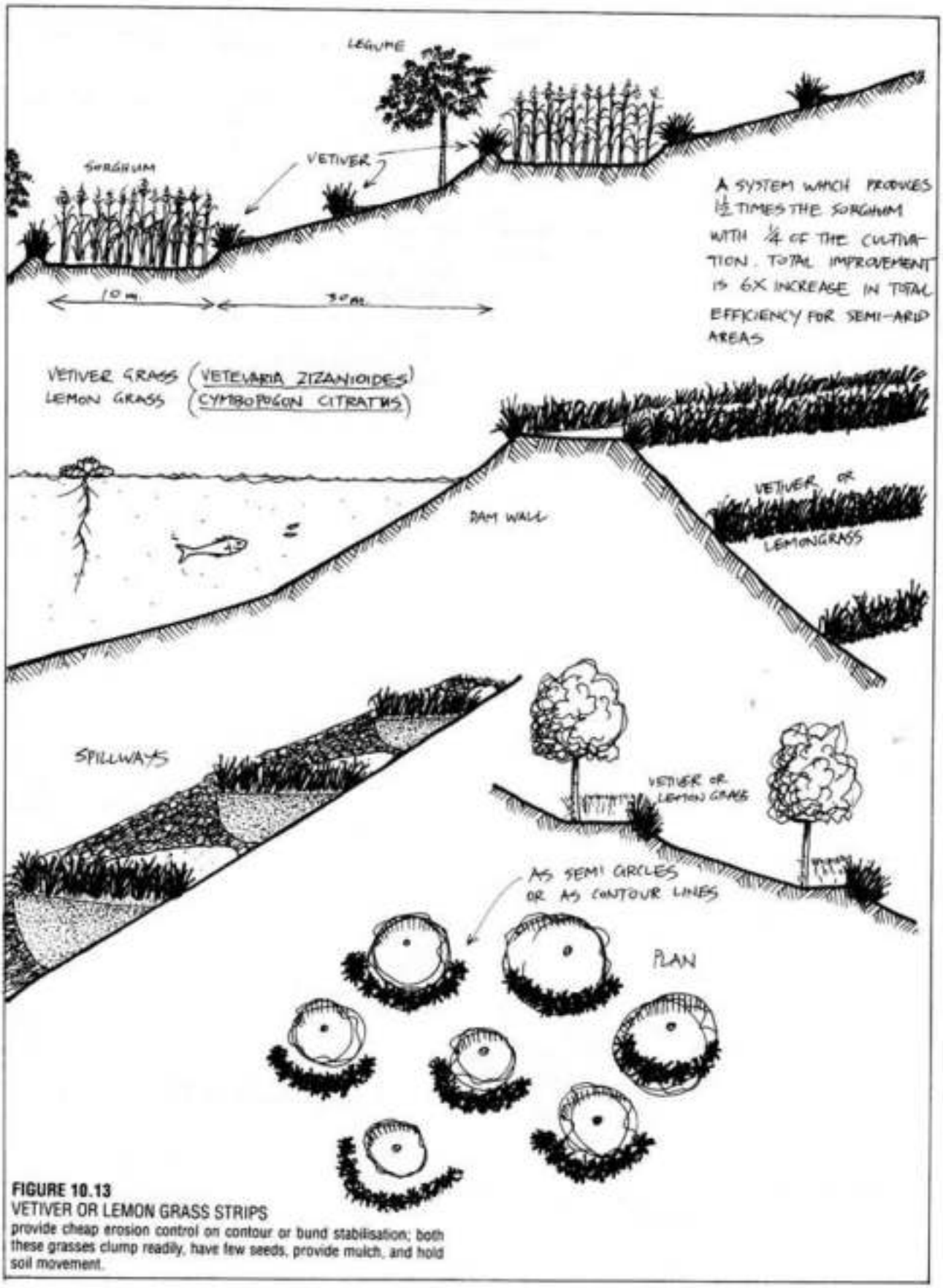


FIGURE 10.13
VETIVER OR LEMON GRASS STRIPS
provide cheap erosion control on contour or bund stabilisation; both these grasses clump readily, have few seeds, provide mulch, and hold soil movement.

The subtropical house needs to both heat and cool. For heating, it needs to have an insulated slab floor or trombe wall, and for the cooling system it needs induced or forced cross-ventilation from a cool or shaded area to an updraught area.

The secondary effects of high humidity range from the merely annoying (salt will not pour) to far more serious effects (clothes, food, film, and books mildew). Thus, we face two sorts of problems in house construction:

- Human comfort.
- Safe storages; for these we need both cool and warm storages, but both need to be *dry*.

Human comfort is greatly aided by these factors:

- SHADE: Light and heat are both excluded as incoming radiation in shade. Shade is particularly critical on massive walls or over water tanks close to homes.
- TRANSPIRATION: Plants can assist cooling by transpiring. Partial shade helps this factor in understory species except in extremely wet conditions.
- COOL BODIES: Large heat resevoirs used as water tanks and relatively cool blocks of (shaded) stone, concrete, and mud brick absorb heat from the air and from warm bodies. Conversely, hot radiant bodies adversely affect us.
- AIR FLOWS: Even low air flows from shaded areas greatly aid both transpiration and evaporative cooling. To create such air flows we need to develop both relatively hotter and colder air sources and to provide a

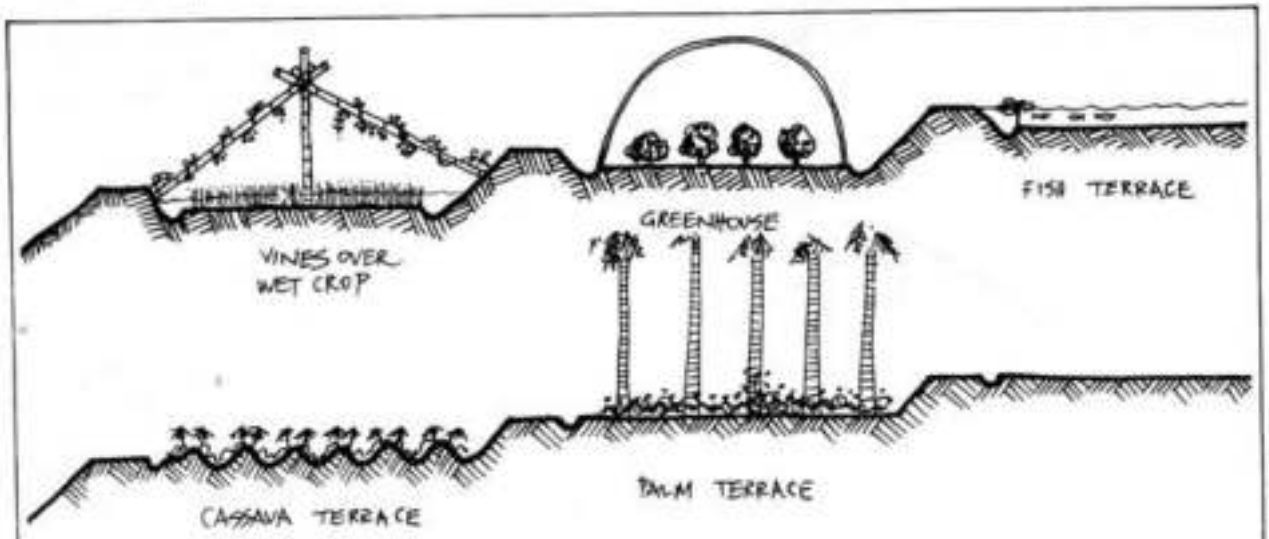


FIGURE 10.14
VARIATIONS ON TERRACE CULTURE.
Wet terrace (padi), fish crop, shadehouse or grow-tunnel, ridge crop, palm, and grain culture vary production and stabilise terrace cultures; alternate dryland and wet (padi) crop suits summer-wet sub tropics.

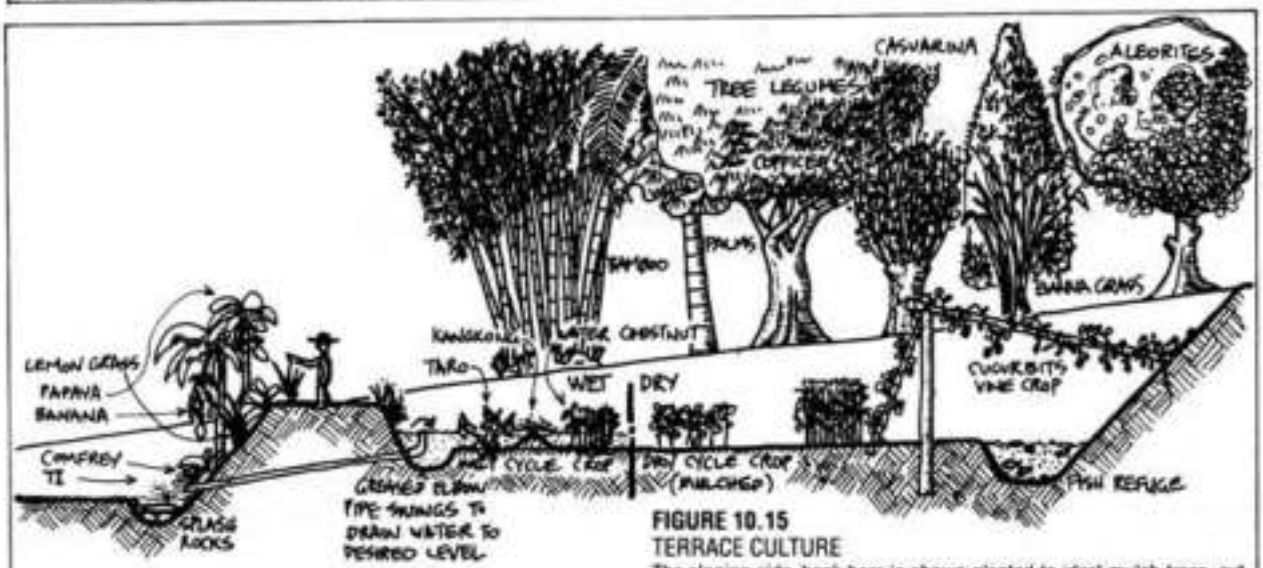


FIGURE 10.15
TERRACE CULTURE
The sloping side-bank here is shown planted to ideal mulch trees, cut or coppiced to enrich terrace crop production. Drain pipes are adjustable to dry out terraces.

cross-flow airway. Even a fan, simply stirring the air, aids in human comfort.

• REMOVING HEAT SOURCES: All massive cook-stoves and hot-water systems are best placed in a semi-detached kitchen in the tropics. Commonly, these are reached via a vine-covered shade area, are themselves shaded by palms or trees, and have wide eaves and ceiling vents for hot air escape.

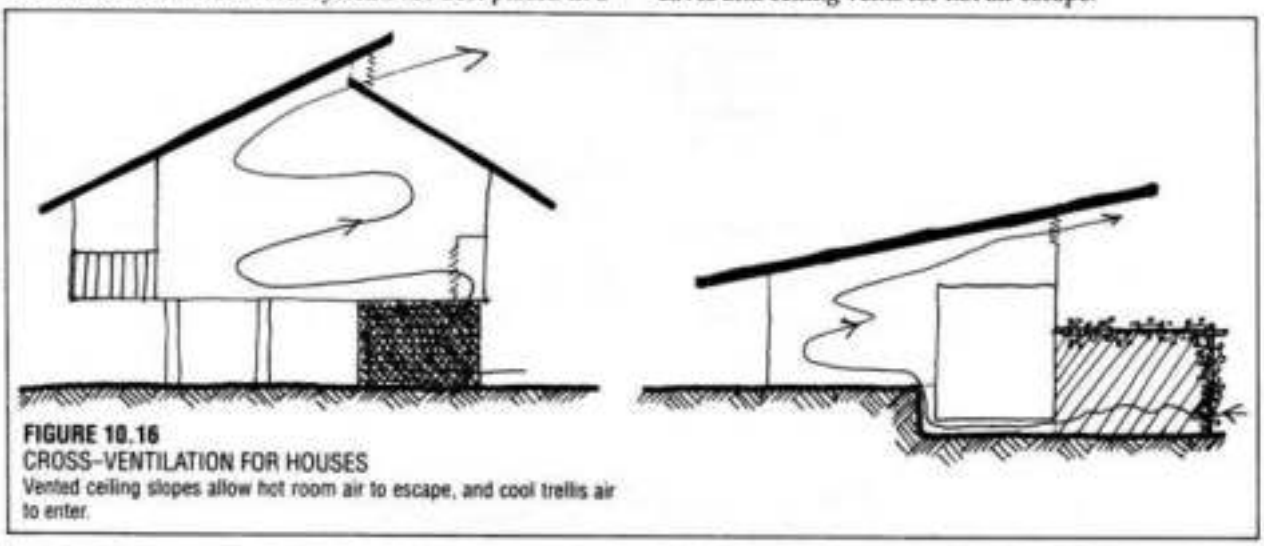


FIGURE 10.16
CROSS-VENTILATION FOR HOUSES
Vented ceiling slopes allow hot room air to escape, and cool trellis air to enter.

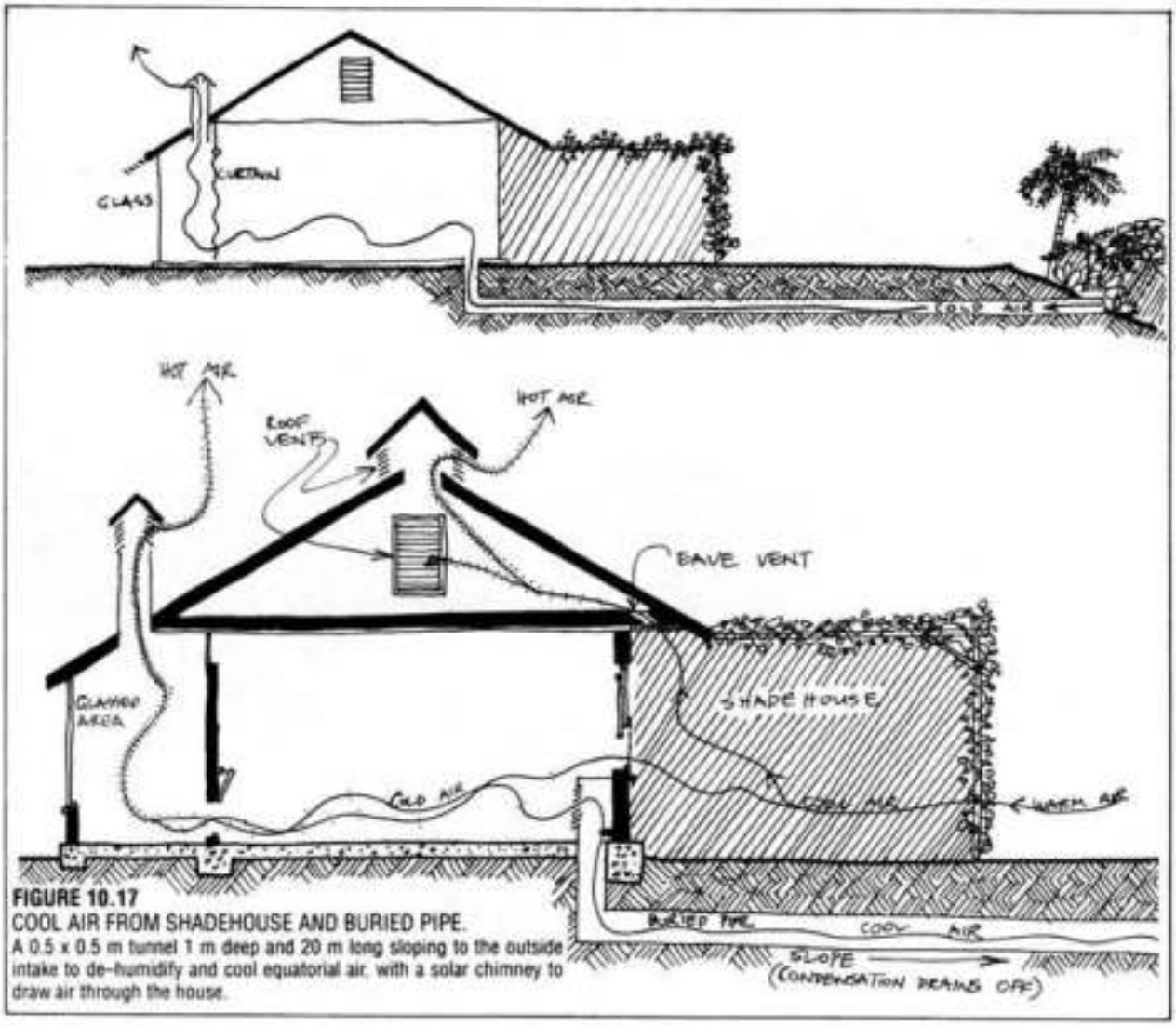


FIGURE 10.17
COOL AIR FROM SHADEHOUSE AND BURIED PIPE.
A 0.5 x 0.5 m tunnel 1 m deep and 20 m long sloping to the outside intake to de-humidify and cool equatorial air, with a solar chimney to draw air through the house.

Heat can be used via metal roof areas, hot-water storages, and attached glass-houses or solar chimneys to vent hot air and create updraught, which in turn provides a heat engine to draw in cool air. The essentials of good cross-ventilation are that the flowing air has a simple pathway to follow (no unnecessary corners to turn), and that large vents are used to allow a good volume of air through workrooms and storage areas (**Figure 10.16**).

Probably the best cooling systems in tropical houses are those which use a hot roof or metal chimney to draw in cold air from earth-cooled underground tunnels or pipes. As this cool air is dense, it will naturally flow downhill or sink to lower levels; this cool air can be drawn into houses via a positive exhaust system, or actively fannned into rooms.

To cool a pipe and lead off the heat continously, we need to construct a trench 1 m deep and 15-20 m long cut in the earth, drain off the condensed water (ideally making it self-draining to a lower slope), and provide this trench or pipe with a sloping floor. The intake end can be box-screened to keep out mice, and shaded by plants. Outlets can be floor grills or a louvred "cupboard" opening to the pipe or pipes in the trench (**Figure 10.17**).

Natural cross-ventilation can occur if a well-sealed room has a roof vent or chimney to create an updraught. Some forms of air scoop may help this process

The cold tunnel solution is very effective, and can be used together with evaporative cooling in desert housing, but it is also expensive, and difficult to fit to an existing house. For this reason, many homes can be sufficiently cooled by the use of vertical shutters acting as air scoops—a satisfactory solution on subtropical tradewind coasts. Or a shadehouse can be added to the poleward side of a house and cross-ventilated to a well-vented GREENHOUSE on the sun side of the building.

BASIC ESSENTIALS OF THE EQUATORIAL HOUSE

Some essentials of truly tropical housing (no cold season) are:

Site Choice

- Orientation is to *prevailing winds*, not to the sun. Cooling is by cross-ventilation.
- Shaded valley sites greatly aid cooling and shelter.
- Induced ventilation is essential, achieved by siting in palm groves or overshaded by trees, which should be permeable to wind at ground (house) level. Palms and trees can be pruned up the trunk.
- Site sheltered from hurricanes, *tsunami*, and vulcanism, sited on stable soils that resist mudflow in heavy rains.

House Design

- Walls white or reflective, overshaded by wide eaves and palms or trees.
- Heat sources such as stoves and hot water systems detached from the main structure (e.g. outdoor kitchens).
- Wall-material light, even permeable to wind (woven matting and mosquito screens).
- Mass, if any, internal to rooms, smooth and white-painted. The whole house can be of light construction on the outer walls.
- *Vertical* louvres and window shutters aid in

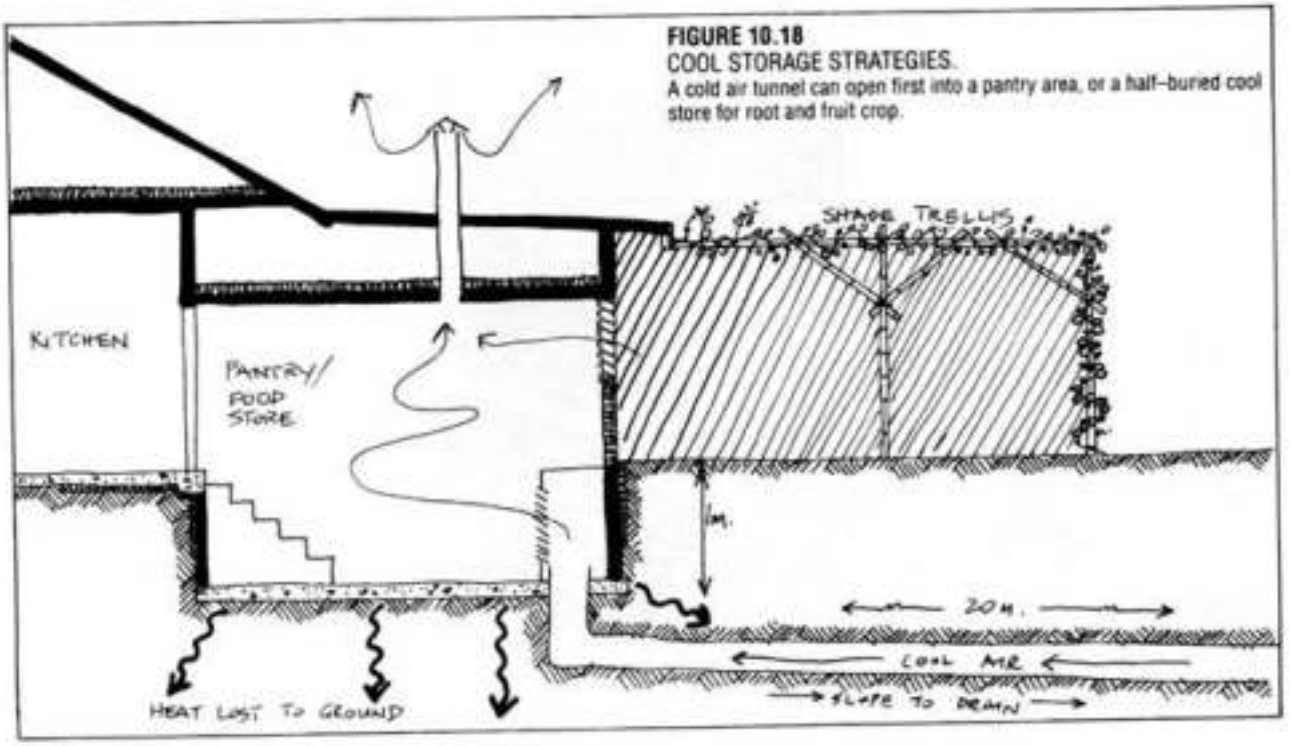


FIGURE 10.18
COOL STORAGE STRATEGIES.
A cold air tunnel can open first into a pantry area, or a half-buried cool store for root and fruit crop.

cross-ventilation.

• In hurricane areas, a strong central core or refuge may be needed, or an earth-bank shelter raised to protect the house; cellars should be entered above ground due to flooding danger in hurricanes, or well sealed against flooding.

• Very strong cross-bracing, deep ground anchors, and strapped timbers may be necessary if powerful winds are known to the area. Large bamboo groves placed to the windward will bend to the wind without breaking, protecting the house.

• Where thatch or tile is impractical, use a vented sheet metal roof. In this case a thin (12 mm board) ceiling is necessary, and soffit lining can be of permable netting or screened to allow an air flow to the roof space and thence to the exterior via high roof vents.

10.6
THE TROPICAL HOME GARDEN

SEASONS: The wet season is the "hungry gap", where plants are growing, but too young to harvest. Early in this season the soil is soft enough to plant and establish trees, but plants must be well-timed as the dry season is long-lasting. Planting too late is to risk drought before ripening of the crop. Vegetable crop is started at either end of the wet season. Water storages (Chapter 7) are essential, no matter how modest, for garden, tree crop, and diversity in yield. Moulds, mildews, and root fungi are encouraged by humidity, and it is best to use resistant plant varieties or root-stocks.

SPECIES: Mango, papaya, sapote, banana, limes, coconut, cashew, macadamia nut, breadfruit, mound-planted avocado and pineapple, durian, and so on are the garden and orchard framework, as are any productive palm crops. Large legumes such as *Inga*, *Gliricidia*, *Leucaena*, *Cajanus*, and so on are essential interplants.

In the vegetable garden, yam and sweet potato yield better than, or in place of, potato. Adapted small-fruits and tomatoes of wilt-resistant strains grow well. Amaranth is a good green and grain crop. Lima, velvet, and *Dolichos* beans trellis on tree legumes. Forage and ground legumes provide green mulch and help suppress grasses, as do comfrey and lemongrass. Chilies, peppers, and the range of tropical vegetables are preferred to temperate species.

Bamboos, balsa, teak, palms, and mahogany provide structural and craft materials, rattans can be encouraged along waterways and in mangrove edges. Oil palm, jelly palm, *Bactras*, *Maurantia*, salak palm and doum palm provide trusses of useful fruits.

PESTS: Large insect pests (locust, cicadas, sucking bugs) are plentiful; guinea-fowl or chickens on range are some defense. Native rodents and pigs can be damaging, and pythons rather than foxes take poultry. Termites and ants largely replace worms in soil-building, and buildings must be constructed to resist them. Geckoes in houses eat many insect pests, as do wolf spiders.

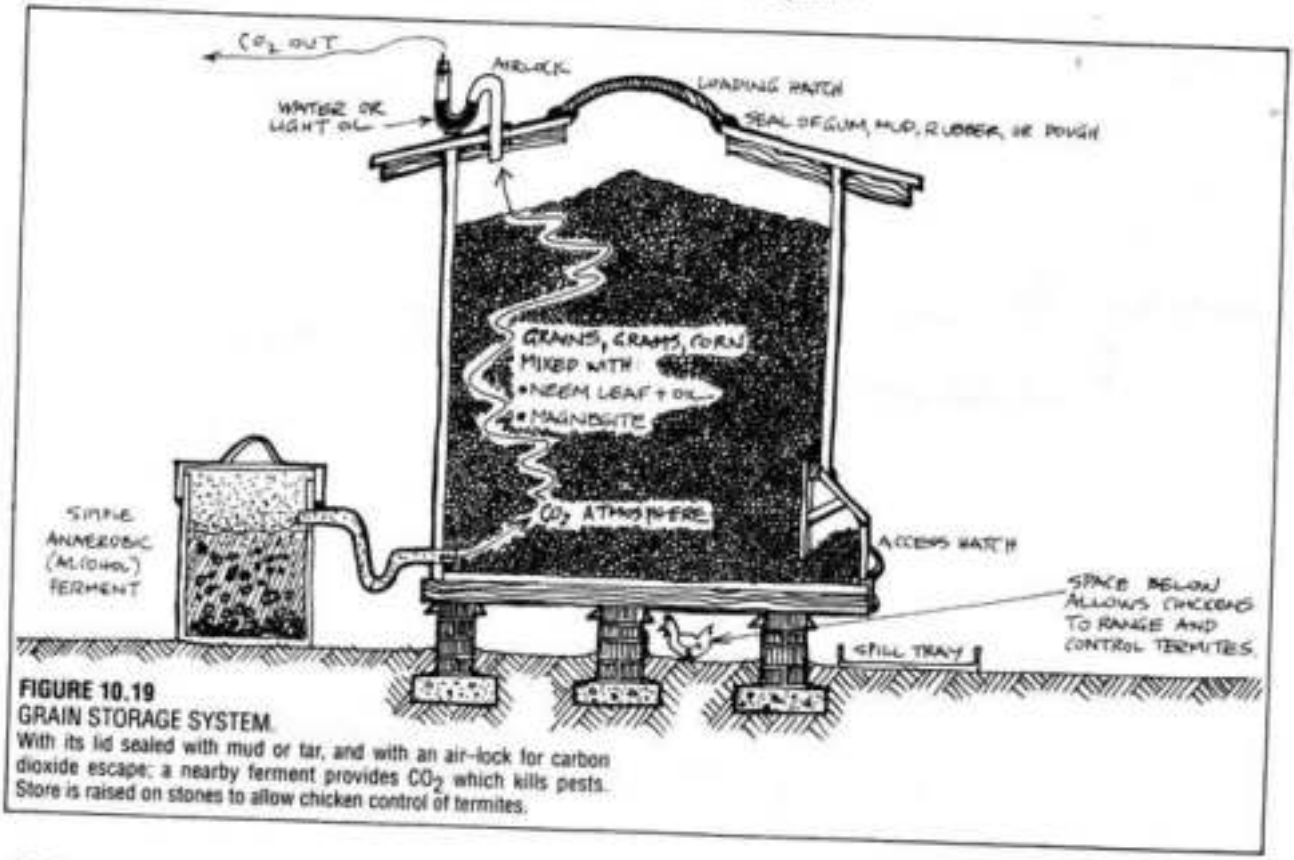


FIGURE 10.19
GRAIN STORAGE SYSTEM.
With its lid sealed with mud or tar, and with an air-lock for carbon dioxide escape; a nearby ferment provides CO_2 which kills pests. Store is raised on stones to allow chicken control of termites.

DOMESTIC ANIMALS: Pigeons and bees are most easily protected from predators by elevation on pole structures, or over shallow ponds. Guinea fowl, francolin, pheasant, and bantams provide essential foraging and insect control services. The guinea-pig aids small tree establishment as they "chip" the base of young grasses, and small pigs of Taiwanese strains provide orchard-fruit garden scavenging duties. Waterfowl and aquatic species add yields to water storages and assist in grass control.

HURRICANE DAMAGE: can be limited by raising large earth banks, selecting valley garden sites, screening plantings with bamboo groves, establishing a general tree canopy through garden and plantation, or a combination of these strategies. Oversize swales aid wet-season water run-off control and diversion to storage.

SPECIALIST CROP: There is a wide range of specialist crop potential, from rubber (*Hevea*), betelnut, chalmougra oil, and chicle to essential oils and medicinals. Many are suited to primary processing in remote locations, or conversion to commercial-quality end-products. The high value of processed product enables smallholders or cooperatives to pool research and processing facilities, and to select high-yielding varieties.

INTERPLANT: As well as the essential legumes, a scatter of *Banksia*, *Casuarina*, *Gigasperma calaspora*, and *Pultenea* with their mycelial associates will fix phosphate and return it via leaf mould. Several plants "pump" sugars or carbohydrates into soils, while leaf-sucking insects and scale insects exude sugars

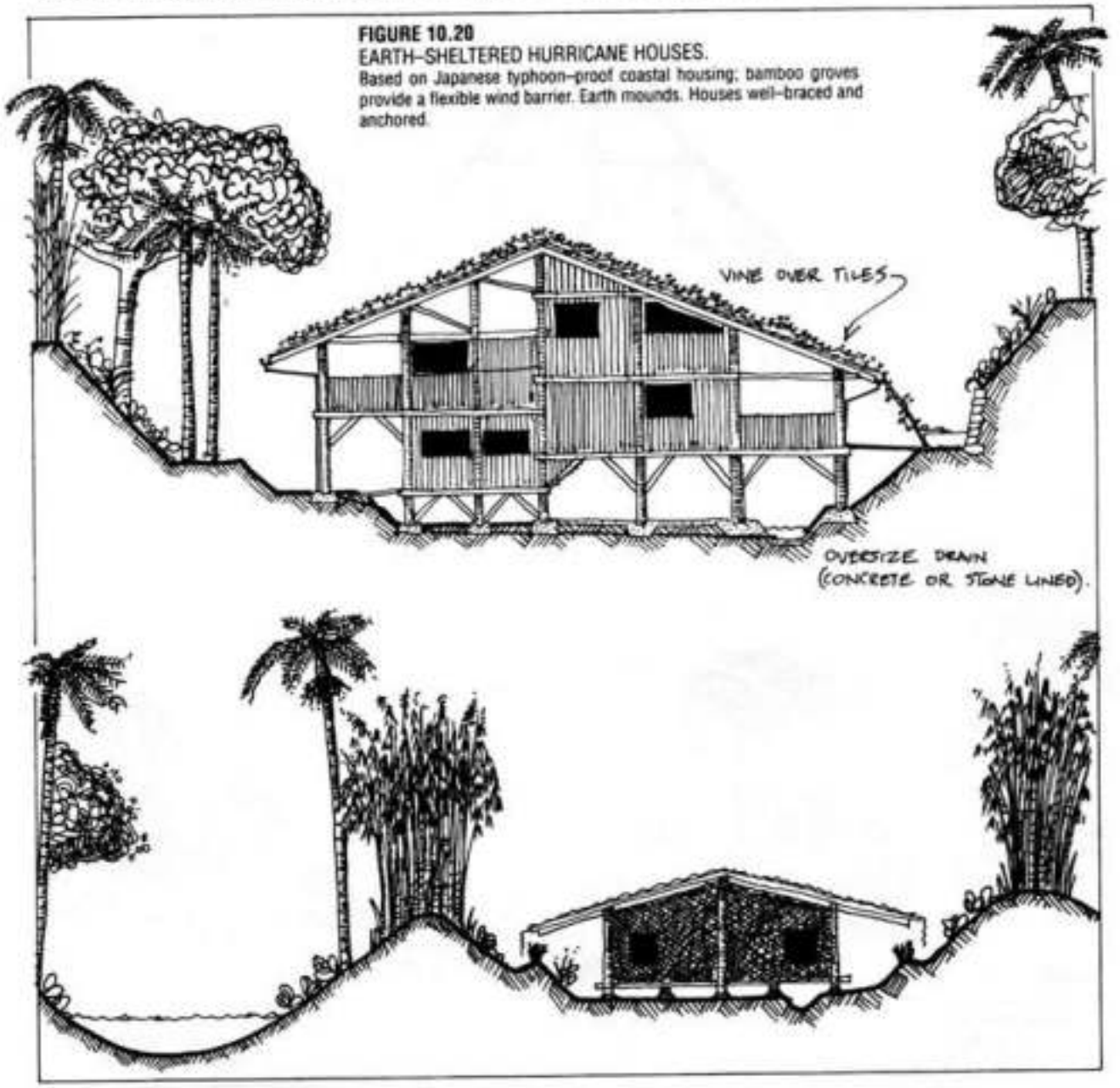
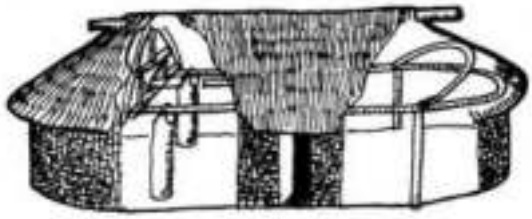
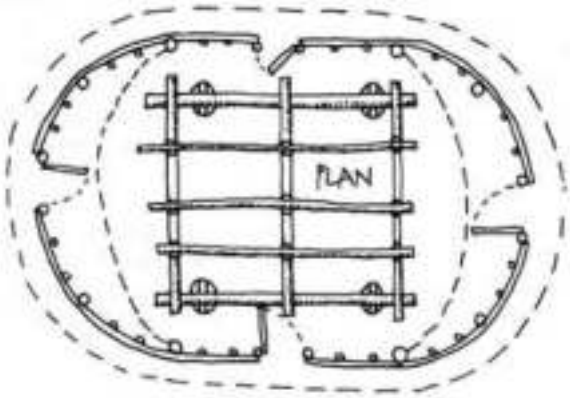


FIGURE 10.20
EARTH-SHELTERED HURRICANE HOUSES.
Based on Japanese typhoon-proof coastal housing; bamboo groves provide a flexible wind barrier. Earth mounds. Houses well-braced and anchored.

FIGURE 10.21
EQUATORIAL HOUSE.
Based on the Fijian buré. Earth-sheltered and well-fastened (traditionally by complex rope cross-binding) this house is ideal for hurricane areas, cool living, strength, cheapness, and uses only local materials.





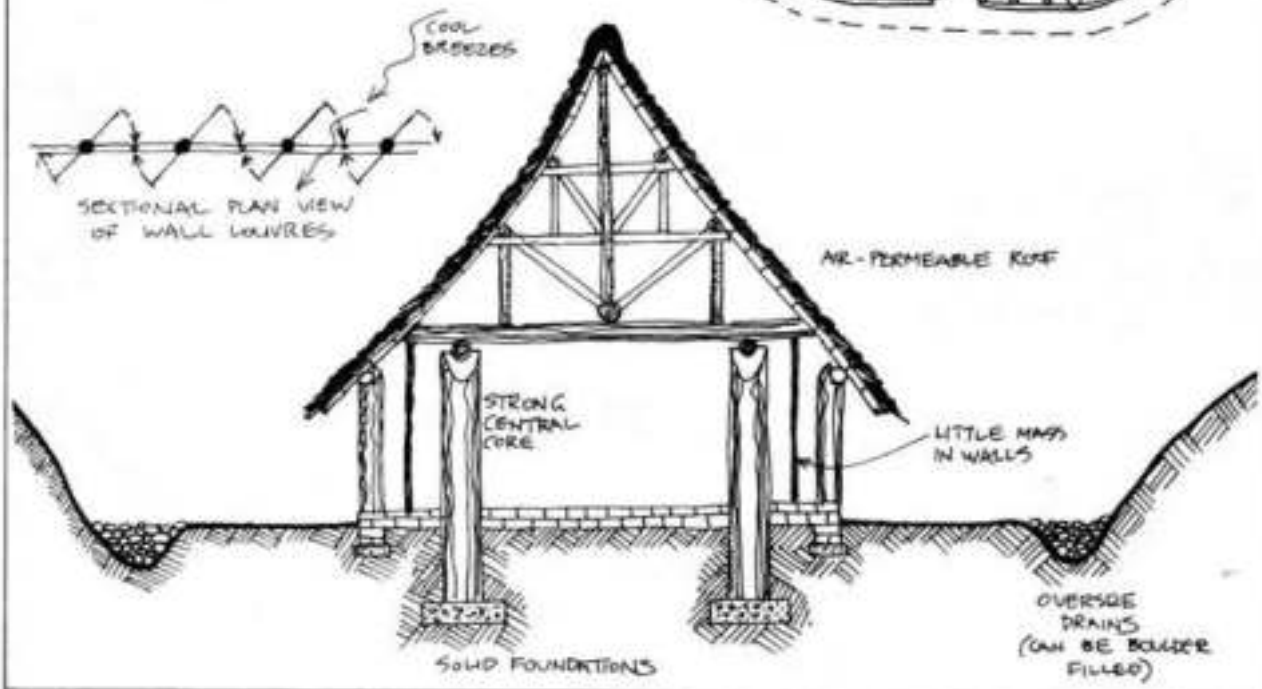


FIGURE 10.22
HURRICANE GARDEN.
Sunken between earth berms or in natural sheltered valleys; palm and bamboo to seaward. Heavy emphasis on root crop for emergency food, fast regrowth. House well-braced and anchored, low profile.

from stems. Dilute molasses or cane and sorghum sugar juices and stems also activate soil fauna. Marigolds, neem tree leaves or berries, and pyrethrum daisy control soil pests and provide insecticides or water insect control. The neem tree is often planted to overhang ponds, so that the berries that drop control water-flies and mosquitos.

Established tough grasses of the savannahs resist gardens, and need to be mulched or overshaded with tree canopies. Essentials are:

- To mound or raise garden beds for good drainage in the wet season.
- To use mulch and mulch-tree species to create topsoil for gardens.

Where logs exist, they make ideal garden bed edges to hold mulch and soil.

Gardens have been devised for many tropical areas, usually containing the following:

- Designed for full nutrition for an average family.
- Water conservation and safe water disposal (hygiene) a necessity.
- Species chosen to suit local cultural preferences.
- Sufficiently varied to survive reasonable climatic change, or seasonal irregularity.
- Protein sources, livestock; their forages, or grain/legume replacements for meats.
- Water routes and use.
- Basic foods or staples
- Fresh vegetable and fruit for vitamins, minerals, varied uses.
- Some fuels, medicinals, flowers.

The elements in **Figure 10.23** are those that make up the house structure itself, and those that make up the garden, hedgerow, livestock and path access structures. The best way to use this section is to read it through very carefully, study the plans and diagrams, and then improve it, or better it to fit to a specific site.

THE HOUSE

Room size and number is adjusted to family size, but is basically a simple, easily-heated and cooled structure, preferably on slab or raised pise floor, and preferably edge-insulated. The induced cross-ventilation acts to cool and heat as per **Figure 10.16**. In addition, vertical sashes or shutters to each room help to scoop air in.

In hot periods, the main living area is outside rear, or under a similar porch trellis to the front if the people prefer to be seen from the road (as is the case in most close-knit societies). The side trellises are seen in **Figure 10.17**. Materials can be local, as can any insulation. Glass is needed, as are some pipes or drains of stone, and a tank.

THE GARDEN

How the Garden Works (See Figure 10.23)

First, it accepts all water and wastes of use. Only plastic and glass or metal are not used, although some cans *may* be buried for slow zinc and iron release). Second, it provides most mulch and a lot of fodder or forage, which when bulked out by house-scraps should feed rabbits, guinea pigs, some poultry, and even fatten a small pig. Next, it is very accessible and well-designed on a need-to-visit-and-tend basis. It is also very natural in appearance and function. If no septic tank is present, a dry toilet will do, and the manure can be put under trees (in pits). Even "toilet paper" can be built into the hedges (E) (*Nicotiana* is great, as is *Leucaena*).

Accessories

Hot water for showers can be achieved by a hot-water collector or at least a coil of black pipe on a roof or bare area. With a couple of oil lamps or a photovoltaic array, a solar oven on castors, an efficient cooker, and a small solar food drier, life should be fairly cheap and healthy. Adventure can be sought in teaching neighbours how to do it, writing novels, or joining an adventure-camp group—or even a permaculture group (they behave *very* diversely!)

GANGAMMA'S MANDALA

In Taiwan and the Philippines, small intensively-planted home gardens are planned to feed a family of five all year. I have added to these designs my own permaculture "least-path" layouts to give a very concise and effective model of sustenance garden design for tropical and subtropical regions. These can also be adapted to temperate regions, using suitable species. The overall pattern can be altered to fit almost every site form, but is presented here as a flat site pattern. Although the building of such a garden is fast and simple, its design is sophisticated.

The whole design owes much to the work of the East-West Institute in Hawaii, and the Samaka gardens of the Philippines, but the layout is purely permaculture. I have named it "Gangamma's Mandala" after one of our Karnataka (India) permaculture design graduates.

Steps in the process are:

1. At the centre of a 100 square metre (1075 square foot) or larger area, describe a circle 2 m (6 feet) across and excavate the topsoil (or subsoil) to a dish shape, ridged on the perimeter, and about 0.6–1 m (2–3 feet) deep from hollow to rim. This is the banana/sweet potato/papaya circle garden, as per **Figure 10.26.1**.

The whole circle is then covered with wet paper or wet cardboard, banana leaves, or any mulch material, and the hollow is filled (or over-filled as a dome) with rough mulch of short logs, coarse twigs, hay, rice husks, and sawdust or indeed any humus-creating materials. A little scatter of manure, ash, lime, dolomite, or fertiliser can be added. If stones are available, bank them to the outside of the rim.

The rim is then planted to 4–5 papaya (a tall variety), 4 or so bananas (dwarf types), and 8–10 sweet potato. If available, yams or taro can be placed *inside* the rim. Later, beans can be planted to climb the papaya and banana stalks. In the banana circle, we can place a grid

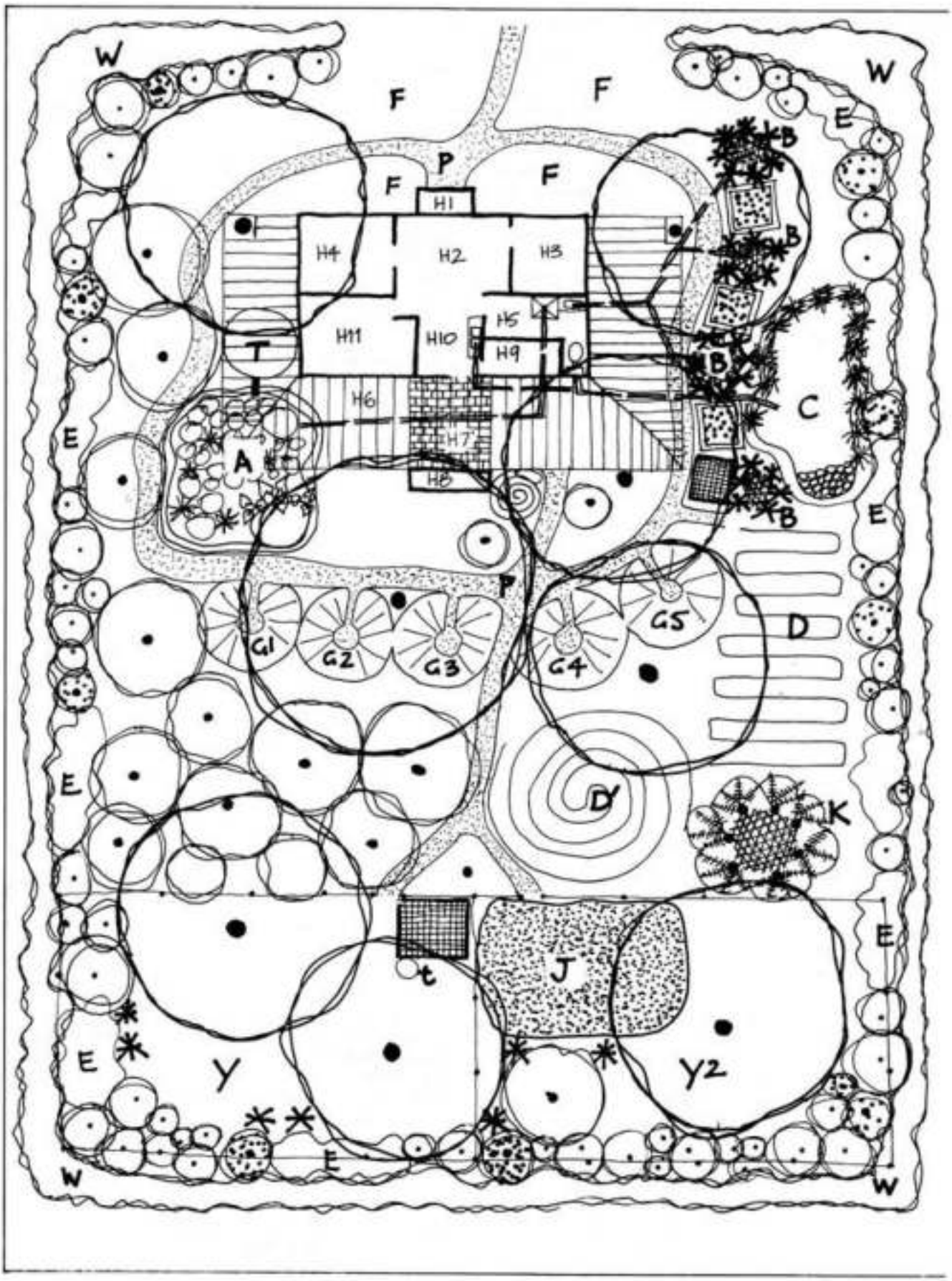

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FIGURE 10.23
ELEMENTS OF A TOTAL DESIGN FOR A GARDEN.
Based on a Brazilian design by Margrit Kennedy and the writer; climatically appropriate house of local brick and tiles amortizes in 4–7 years if a garden is developed. All water is caught or directed to gardens.

H1: An entry; in the subtropics this is a glasshouse, fitted with a wide ceiling vent and drawing cold air in from **H6**—the shadehouse. Note the straight-through airway via living area (**H2**) and winter kitchen (**H10**).

H3, 4, 11: Bedrooms and study/library if needed or possible. All open off or into the central kitchen (**H10**)/living axis (**H2**).

H5: The bathroom/toilet. From here, shower water goes to the 'wet' area of garden (**A**) or to mulch/ forage crop (**E**); toilet and sink water goes always to (**C**). Handbasin water goes to (**B**), banana circles.

H6: Is the shadehouse, which can extend around three sides of the whole, and has entries, trees (or their trunks) in it, minor trellis resting against it, and a crop below.

H7: is the part-paved area of the summer kitchen, and **H8** the outdoor cooking stove and bulk-cooking stove, the ashes of which go to **A**, **C**, and the garden.

H9: Mudroom/pantry off the kitchen, with outside basin/sink for primary vegetable processing.

Table scraps go to livestock *or* below mulch in boxes (**B** series) of the garden; sweepings to mulch.

T is the tank, catching roof water. There is a small tank (**t**) on any animal shed. The tank can also be filled from a reticulated water system (on a float-valve). All tank overflow goes first to (**A**), the wet garden bed, which is in part under the house trellis, in part in the open. There is a path (**P**) around the whole house and to the outdoor kitchen, animal house, etc.

The garden has the following main elements:

A is a wet food patch with earth bank edge (detail **Figure 10.24**). This receives clean water and grows wet crop, e.g. taro, rice, kangkong, watercress, Chinese water chestnut, etc. The bank is planted to dry staple foods, e.g. yam, sweet potato, cassava, etc., which benefit somewhat from the wastewater. Some of this crop is under partial shade, which taro appreciates, as do some other sub-aquatics.

B are banana circles (see **Figure 10.26**). They can also be papaya circles or mixed papaya/banana/pigeon pea/tomato/yam circles, or any such combination. They are watered from the hand basin and kitchen sink and mulched inside from the hedge (**E**).

C is the 'dirty' water patch (**Figure 10.25**). It contains *no direct food plants* and *no root crop*, only vigorous, damp-tolerant, manure-tolerant green forage crop, e.g. comfrey, banna grass, lemongrass, legumes. These are regularly cut and removed either to the animal pens as green feed *or* to the little potato boxes (**B**) *or* to the garden beds (**G** series). The area is sunken and surrounded by a bank on which can grow pigeon pea, papaya, banana, or all of these and more.

D & D' are avenue crops of maize, corn, or some main crop of value. Two layouts (spiral and zig-zag) are shown (detail **Figure 10.27**). They consist of self-mulched and stable intercrop systems such as maize/ beans, yam/beans, cassava/beans, or melon/beans, with plants of *Leucaena*, *Gliricidia*, *Sesbania*, or some such productive legume as a fixed hedge. Sticks from these go to the fire; ash returns to the garden. Hedge clippings from **E** or exotic mulch (paper, carpet, wastes) can be put on these beds.

E is a low, raggedly-trimmed hedge of forage-mulch species, and is used for privacy, as a windbreak, and a sometime food source. Just *outside* it is a very dense weed barrier (**W**). In two places this hedge is *inside* two chicken pens (**Y** and **Y2**). Where there are "spots" it means a few well-chosen clumps of sympodal, edible-shoot, solid bamboos form part of the hedge. These are partly for food, partly for mulch, partly for the trellis repairs.

F is the front yard of traditional or showy flowers, if the culture demands it. It has a few basic medicinals, pleasant scents, a fibre plant or two (to help the trellis), a few ornamental food plants (cacti, agave), and is rarely watered so all plants there are hardy.

G are "keyhole" garden beds (**Figure 4.10**); these can be extended to either side of the house for large families, and more to the rear if necessary. All the preferred vegetables, especially greens, are here. The nearest bed to the kitchen has the usual bulk culinary herbs, but some of these are also on the small spiral herb bed (**Figure 4.34**) beside **H8** (the outdoor stove), and a few wet-area herbs are in pots under the trellis in the A pond (mint). Some rare dry-area herbs may be at or near the front door (**F**).

The two trees near **H8** are a lemon or lime and an allspice or caper tree (shrubs, really). They placed near the house as they are the most-used trees in the system.

The rest of the **G** beds are carefully-planned seasonal vegetable crop. They are mulched from the hedge and the (**C**) pit. Some food scraps, ashes, mulch and shredded paper or plant waste are dug in to them in little pits, as are their own crop wastes and the cuttings from the windbreak plants (**W**). They are always in action, full of plants. Water is bucketed or reticulated from a mains system. Shower or bath-water can also be used, if run along a length of low-pressure leaky pipe.

J is a Fukuoka-style grain plot, mostly for people and partly for poultry. It has a low surround of dry-tolerant mulch such as *Centrosema*, but is also mulched from the hedge **E** and the palm clump **K**.

K is a circle or clump of 6–12 palms, of 1–4 species depending on site, tastes, availability, and needs. They ideally would be 2–3 coconuts, 2 oil palms, 2 dates, and a sugar palm, but may be simpler. The inside circle is mulched with their chopped fronds, their husks and wastes, ashes, and green hedge material or mulch brought in from other sources. In this deep mulch, a yam or vine will grow in the wet season.

Every dense black spot is a tree trunk; these are carefully-selected trees, and their crown spread is indicated. They can overshade the house roof, and may even be placed inside the house trellis, with holes in the roof to allow the trunk out. These few trellis trees have light crown and/or fruits that fall or that can be brought down by a child off the roof. They are intended to shade the roof area and can be tough, spreading legumes (*Prosopis* is good) yielding a food crop for livestock, or they can be palms, or a thin foliaged tree.

Other trees are producing staple fruits, a few avocado (on mounds 1 m high and 5 m across in wet areas), citrus, a few nut trees, and an oil palm. They have soft ground-cover below (nasturtium, soft legumes, comfrey) and this is sometimes slashed as mulch for the tree, sometimes fed to livestock.

The little hatched areas are the roofs of rabbit hutches and chicken roosts or pigeon lofts, quail houses, or guinea-pig rest areas (depending on the culture and preferences). A lot of the hedge (**E**), the wet mulch (**C**), the tree herb layer, and the spare corners are devoted to plants chosen just for the animals. Each little roof catches some water and leads it to a small tank or the garden or both.

Y–Y2) These are two fenced areas. They are changed over to suit the animals, and while one is rested, it can be cropped if space allows. Both are well-shaded animal runs. The fence can be of woven bamboo, palm rib, banna grass stalks, or of wire netting. Both areas are limed if sour.

The house trellis areas are very carefully fitted up with vine crop, spaced to let *some* light through (30% is fine). Basic vines such as chayote, kiwifruit, beans, cucurbits, and grapes are carefully chosen for the house trellis, which can extend 1–1.5 m above the whole roof area if the roof is sound and solid. One or two non-bearing vines can, in fact, be let rampage over the roof with great benefit to the cooling of the house. Note, however, the type of gutters needed in this case to catch the roof run off (**Figures 7.21** and **7.22**).

On the sides of this trellis, more ephemeral bean and cucurbit crop can be grown on leaning trellis of bamboo, or separate bamboo trellis can divide the G beds. There is no vertical limit to some vine crop, and if water permits, every palm in the K clump can eventually carry a high vine (granadilla, grape, or kiwifruit), as can any large leguminous tree (grape; kiwifruit is too dense). *Under* the trellis a few shade-tolerant plants will grow (coffee, taro).

or platform of wood over the mulch, and this then becomes an outside shower or wash-up area.

2. A circular sunken path 0.6–1 m (2–3 feet) wide is covered with sawdust or gravel around this central circle garden, and off it, 5–6 "keyholes" or indentations are made. The system now looks like **Figure 10.26.2**.

3. Around each keyhole a bed 1.5–2 m (5–6 feet) wide is first edge-banked with soil 100–200 cm (4–8 inches) high to prevent water run-off, and the beds are then papered and mulched (as for the banana circle). The whole garden now looks like **Figure 10.26.3** in plan. The thick lines represent low earth ridges.

Thus, we have six major keyhole beds, each of which is separated from the next by a thin strip of lemongrass *(Cymbopogon citratus)* or Vetiver grass *(Vetiveria zizanioides)*. Just outside the periphery ridge, strips of lemongrass, comfrey, and arrowroot *(Canna edulis)* form a kikuyu grass barrier, and behind that, a taller border of cassava/banana/papaya/pigeon pea/*Leucaena*/*Crotolaria* forms a hedge or windbreak. All these borders give mulch, forage, barrier effects, or food. The whole mandala is fenced or has a spiny woven hedge boundary for cattle exclusion, if necessary.

The mandala has now been earth-shaped and mulched to prevent water run-off and to conserve moisture. We now proceed to plant, using buckets of good soil to place the following zones of plants:

A. On the track edge border of the central path and keyholes, within stoop-reach of the path, plant those frequently-plucked or everyday greens of high value. Here, the placement and selection criterion is that *all the plant, or most of it, is picked for much of the year*. These are the PATHSIDE GREENS; they include all the chive and shallot species, plenty of parsley, coriander, thyme and sage, celery, broccoli, edible chrysanthemum, chard, and any such long-bearing or perennial greens (e.g. various perennial spinaches). This is therefore a narrow border to the inner side of the keyhole beds, planted in the ridge soils there.

B. Behind or outside the pathside plants, we plant a 1 m (3 foot) wide strip of species which are *frequently picked over a short to long season*, e.g. tomatoes, eggplants, bell peppers and chilies, bush or staked beans and peas, kale, corn, okra, and so on. These are the NARROW BED plants, all within reach of a path or keyhole. As yet, we do not need to step on any beds to harvest.

C. Just out of reach, on the outer borders of the keyhole beds, we place most long-term root crop (potatoes, sweet potatoes, carrots) or any crop we CUT AND REMOVE (cauliflower, head lettuce, and cabbage). Thus, for this crop we step (once) on the bed to harvest and replant, following root crop with fava beans or dahl (dried beans or lentils).

All beds are replanted as they are harvested, and a top mulch of straw, sawdust, bark, dry manure, or chips is added annually. Rabbits, guinea-pig, chickens, or small livestock are fed from weeds, waste vegetables, household scraps, and forage greens from the border hedge (comfrey, cassava, *Leucaena* or lemongrass). Vetiver grass, lemongrass etc. are cut 3–5 times annually for mulch. The roots of Vetiver grass prevent rodent burrowing from outside the system, as do the root masses of *Euphorbia* species.

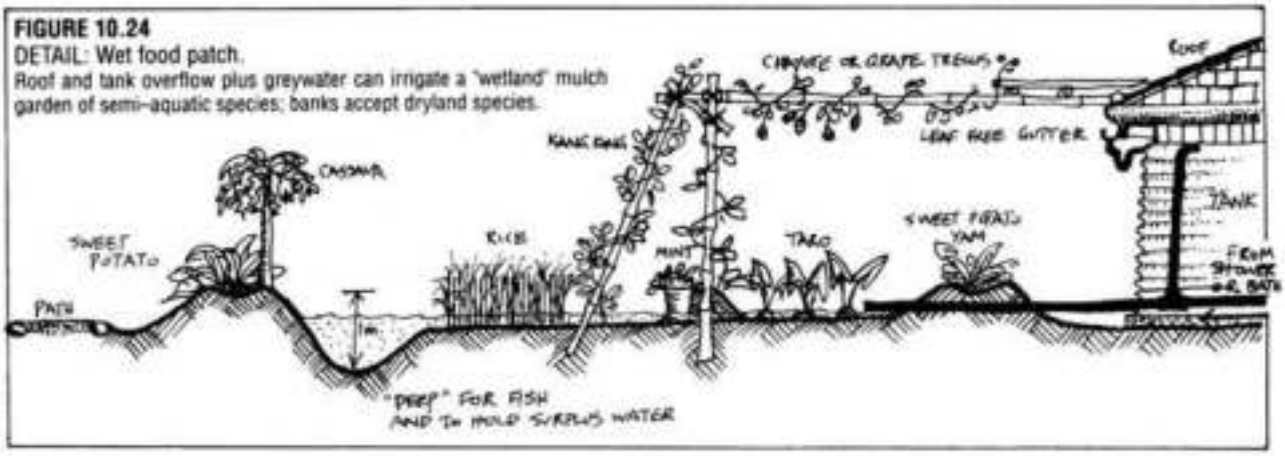
All trees, shrubs, and tubers are planted before papering and mulching, then about 30 cm (1 foot) of trodden-down and wetted mulch is added. Tray seedlings 8–10 cm (3–4 inches) high, and large seeds such as peas or beans, are each planted in a hole burrowed in this mulch, with a good double handful of soil to each hole. Small seeds (lettuce, carrot) are scattered thickly on lenses of soil 50 cm (1.5 feet) across and 5–8 cm (2–3 inches) thick, placed and firmed on top of the trodden mulch, followed by dusting of a 1 cm (1/2 inch) thick layer of fine soil. All seed can be pre-soaked. The whole bed needs a good soak with a sprinkler at each stage.

If no weed seeds are included in the mulch, the beds are weed-free. It takes 9–15 months to build up worms and a good soil. Any surplus compostables can be pushed under the top mulch layer.

A larger system, designed for a community kitchen at a rural centre in Karnataka state (India), uses a core assembly of 4–5 banana circles, and has 8–12 keyhole beds. In this case, a keyhole accesses the banana circles (**Figure 10.26.4**).

Any one of these banana circles can contain a small

FIGURE 10.24
DETAIL: Wet food patch.
Roof and tank overflow plus greywater can irrigate a "wetland" mulch garden of semi-aquatic species; banks accept dryland species.



pond for frogs and water convolvulus, or taro. We can plant a *Leucaena* or palms for high shade and mulch, at the junctions of the keyhole beds. The hedge surround eventually provides the annual mulch (**Figure 10.26.5**).

This garden is intensively-planted, has very little path per bed area, is easy to build and maintain, provides everyday greens, minerals, vitamins, allows no water run-off, and can be built on *any* substrate (rock, concrete, roof areas).

We can here combined basic nutrition, soil building, rainwater harvest, eventual self-mulching, various weed and animal barriers, small livestock fodder, overhead shade, non-dig gardening, "least-path" access, direct waste water disposal, and a pleasing design.

AVENUE CROPPING

The system described here is adapted from Ray Wijewardene, 1981, *Conservation Farming*, IITA-Sri Lanka Program, Dharmapala Mawatha, Columbo 7, Sri Lanka. It is a deliberate fuelwood/mulch/soil improvement crop integration of great use in the tropics but adaptable to any climate, with good species selection (**Figure 10.27**).

The essentials are simple enough:

- Correct spacing to shade the ground fully but to allow cropping between the tree legumes.
- Lopping to leave stems 0.5-1.0 m above ground (a suitable tree legume is tagasaste or *Leucaena*).
- Sowing of crop just before rain or irrigation, to beat the growth of weeds.
- Possible two-crop sequence, with mulch also returned from crop wastes.

A very similar system is used in Africa with *Gliricidia*, and more recently in New Zealand with tagasaste as the green crop. A parallel system (regular or irregular in ground plan) is successful in establishing small trees, which otherwise perish from frost or in open grass competition.

At least two problems arise in sustained coppicing of legume trees. Firstly, such coppice should be confined to warm wet periods, allowing mature leaf to carry over into dry, cool, or frosty periods. Secondly, constant coppice weakens trees over 5-8 years, and replanting is necessary. Very few legume trees will sustain constant coppicing, and other strategies are called for. Perennial thin-crowned leguminous trees can be spaced throughout the orchard and garden, or fast-growing and short-lived legumes can be allowed to grow and die, or can be ring-barked or felled on a 2-5 year cycle.

However, with permanent high legume cover, mulch can be obtained all year from a variety of non-legume hedge and understory. Such species as *Nicotiana*, *Echium fastuosum*, *Lantana*, cinnamon, even clumps of daisies, wild ginger, lemongrass, Vetiver grass, *Pennisetum*, and crop wastes from maize, *Sesbania*, and soft ground legumes or comfrey provide constant mulch under high legume cover, so that the coppicing of susceptible legumes themselves is reduced or eliminated.

In any evolved system, avenue cropping or mulch provision can be sustained by a carefully-planned system of mixed non-coppiced tall legumes giving a seasonal leaf drop (*Erythrina*, *Tipuana tipu*), and a row series of non-legumes for ground mulch.

BARRIER PLANTS

There are several reasons to erect barriers of plant species:

- As a block around the annual garden to resist invasive grasses (such as kikuyu and buffalo grass, knotweeds, etc).
- As a corral for animals, or to keep grazing animals out of a compound, or to guide animals to a gate or

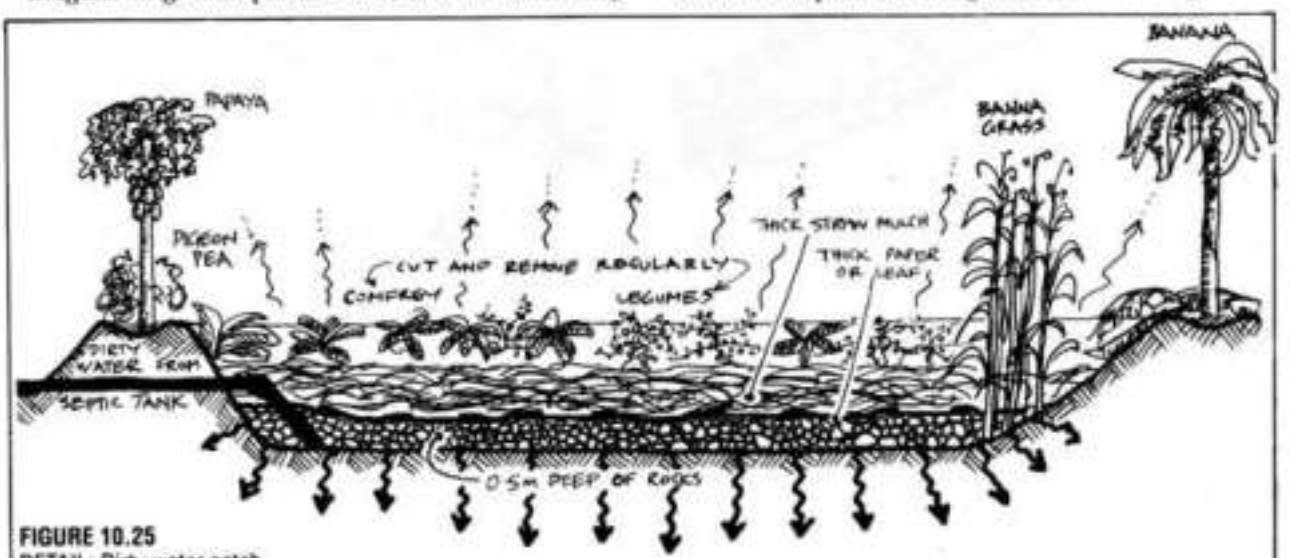


FIGURE 10.25
DETAIL: Dirty water patch.
Sewage fed to a mulched 5 x 8 m stone-pit allows a surround of useful species; mulch can be grown in the pit.

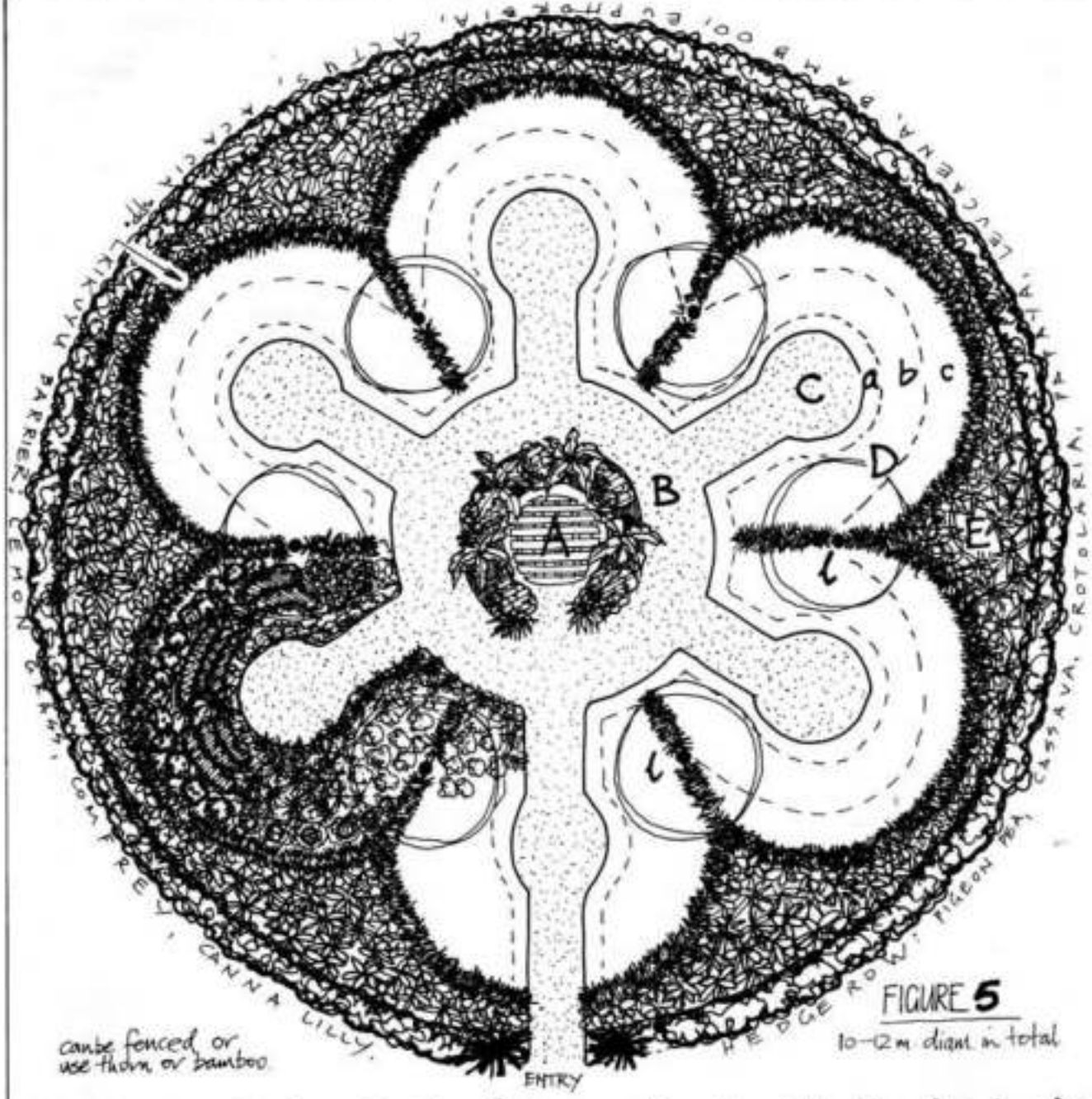


FIGURE 5
10–12 m diam in total

GANGAMMA'S MANDALA

A Banana–Papaya circle with shower-wash grid fitted.
B Sawdusted, rice husks, or gravel paths
C Keyhole paths as B above
D Keyhole beds **a** pathside plants **b** narrow bed plants **c** one visit plants
E Weed, wind, animal barrier hedge sequence, e.g. (inner → outer) Vetiver or lemon grass, comfrey, arrowroot; taller hedge of cassava, papaya, crotalaria, leucaena, pigeon pea, and banana.
l In garden trees are leucaena or palms for shade in hot regions.

FIGURE 10.26
GANGAMMA'S MANDALA.
An ideal 'least path', zero-runoff, acessible layout for tropical home gardens. FIGURE 10.26.4 shows how this mandala can be scaled up for group gardens at schools, villages, etc. Gangamma is an Indian permaculture student.

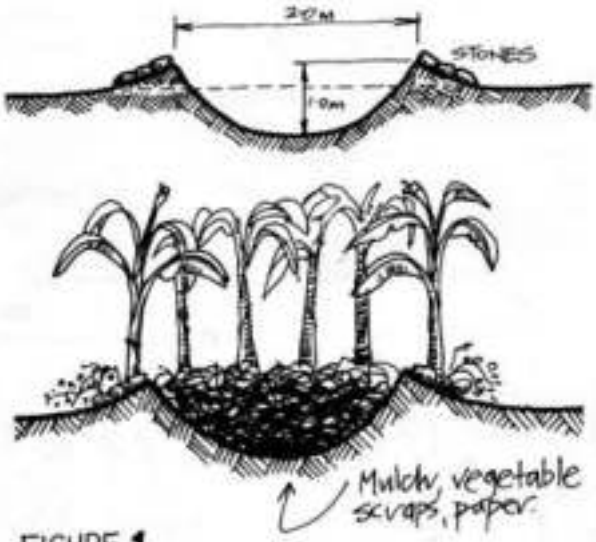


FIGURE 1
Sectional elevation of banana/papaya circle

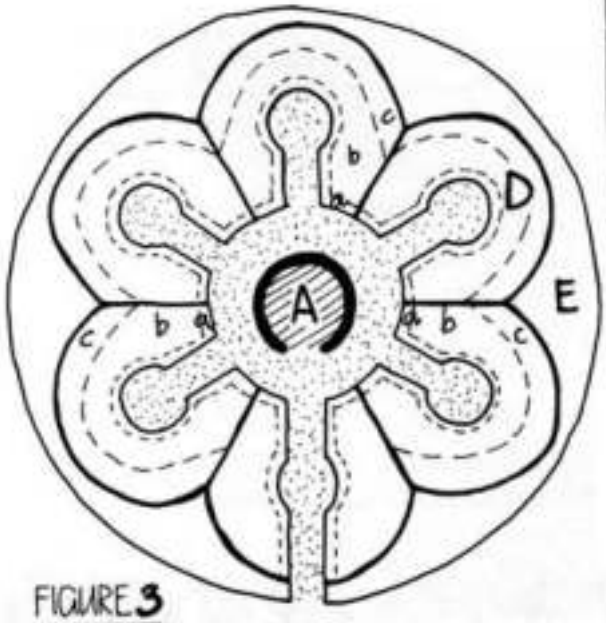


FIGURE 3
D Keyhole beds about 1.5m across.
E Hedgerow & barrier plants.
ZONES IN KEYHOLE BEDS:
a Pathside greens.
b Narrow bed plants.
c One visit crops.

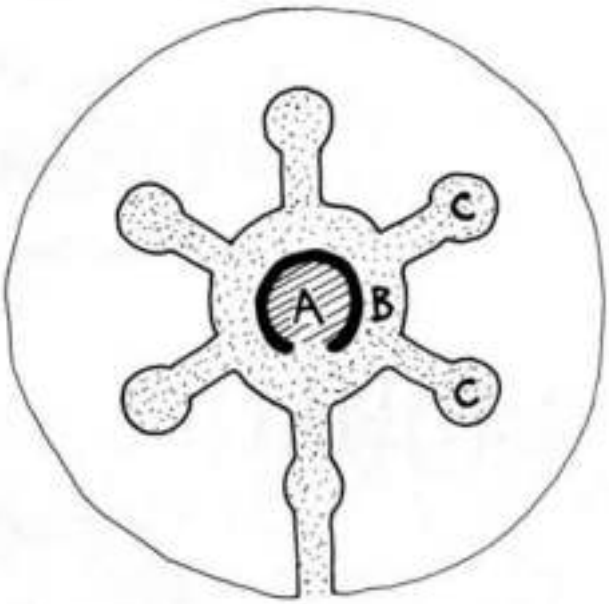


FIGURE 2
A Mulch or circle garden = "banana circle."
B The annular path.
C The keyhole paths.

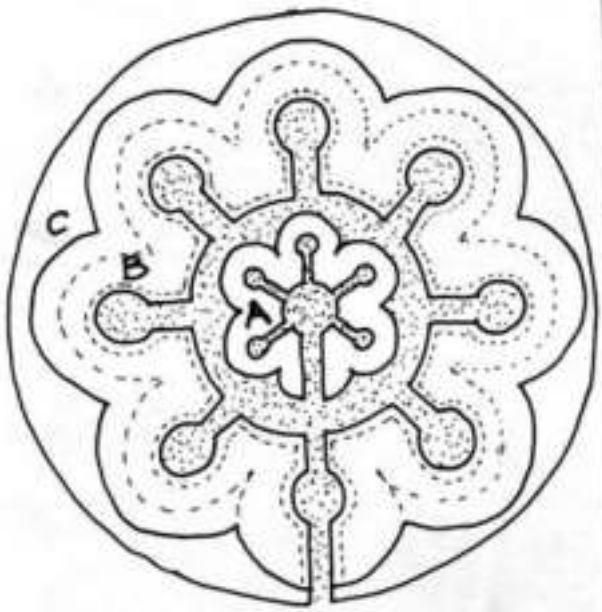


FIGURE 4
A 5 "Banana circles"
B 8 Keyhole beds
C Hedge and barrier.

corral.

• Against hot, dry, or salt-bearing winds, on seacoasts, cliffs, or exposed sites.

• As contoured strips to disperse overland water flow, to catch silt, and to prevent erosion of soils.

Garden Barriers

Around annual, mulched gardens laboriously freed of weeds, a band of grass-barrier plants prevents weed re-invasion. There are 4-5 forms of plants which are effective, and all of them can be used if space permits:

• A deep-rooted broadleaf (e.g. comfrey).

• A clump grass which does not seed down or is not browsed (e.g. lemongrass, Vetiver grass).

• A carpeting plant such as sweet potato, nasturtium, or *Impatiens*.

• A dense low shrub (*Oncoba, Corposma, Echium*).

• A bulb such as *Canna, Agapanthus*.

In total, the same plants can form a fire barrier, provide ample mulch for the garden, and if initially cared for, establish in one season. When first placed, they need to be mulched, manured, and watered.

Animal Barriers

Corrals or cattle-goat-sheep barriers can be strengthened with one or two strands of barbed wire, but should have the potential to resist on their own. Thus, they involve thorny or distasteful shrubs. These can either be planted as a hedge, or as a coppice crop which is cut and built into a thorn fence (boma). The latter enables more flexibility in changing the arrangement of compounds, while the former is less trouble.

Species ideal for such bomas are *Lycium ferocissimum, Acacia tortilis, Oncoba spinosa*, and *Euphorbia tirucalli*. Of these, only *Lycium* and *Oncoba* may not need

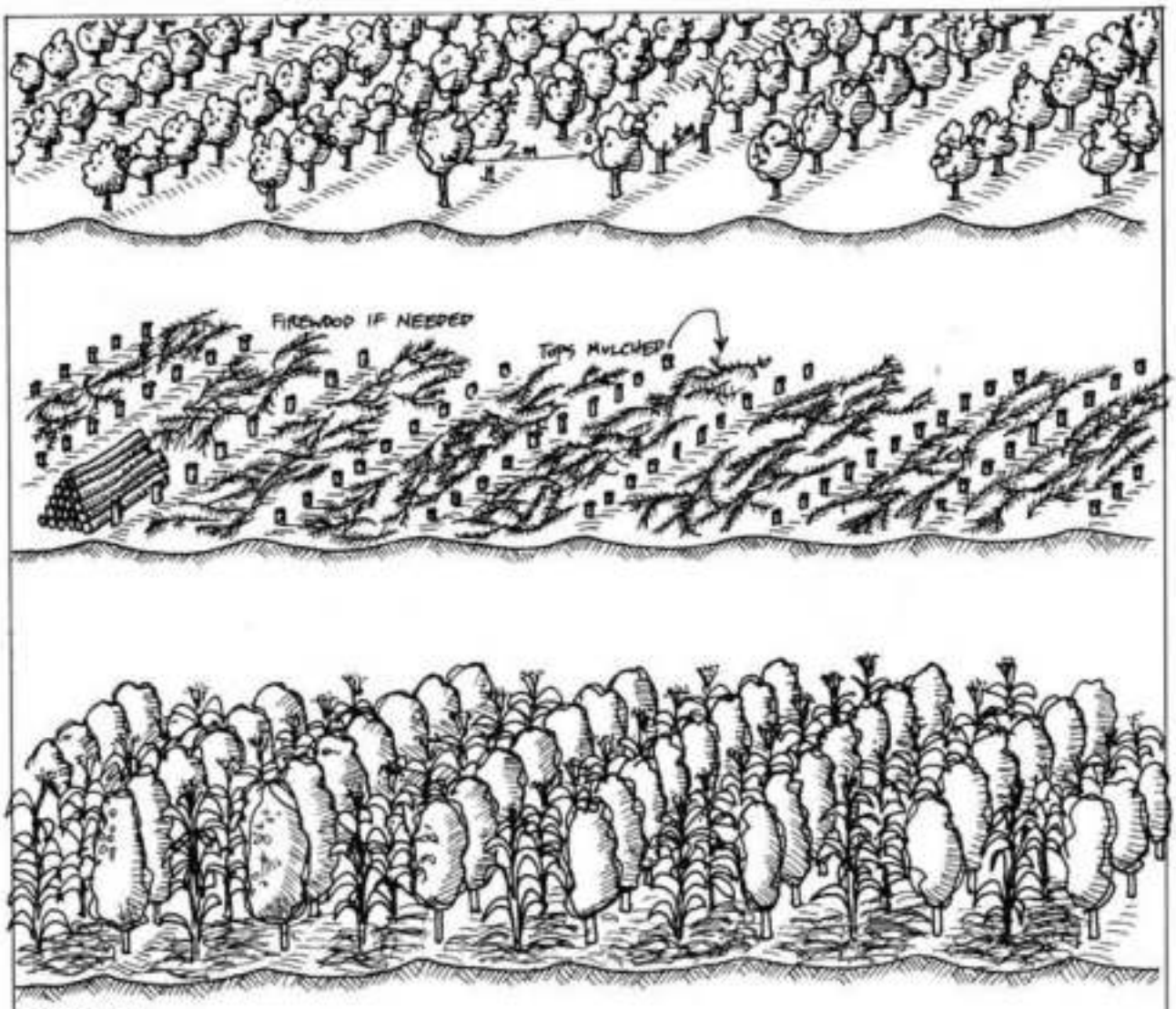


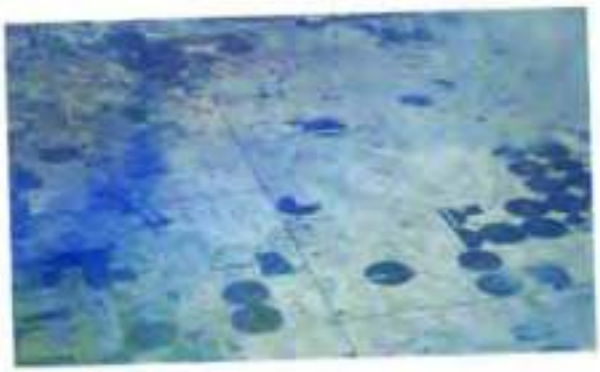
FIGURE 10.27
AVENUE CROPPING.
Coppicing legumes (*Leucaena, Cassia, Acacia, Glyricidia*, etc) cut annually provide nitrogen and mulch for intercrop such as maize, sweet potato, ginger, pineapple; crop wastes are returned to field; firewood is a by-product.

1. PRINCIPLES AND DESIGN

1. MAUI, HAWAII.
Lower slope clearing for cattle lifted the cloud base here and on Moloka'i. This loss of cloud cover reduced precipitation and lead to the desertification of the verdant offshore island of Kahoolawe, now unoccupied, desolate, and used for a bombing range by the US Air Force. Our ability to change the face of the earth increases at a faster rate than our ability to forsee the consequences of that change. (Birch's Principle No.5).

2. PT. AUGUSTA, SA, AUSTRALIA.
At first, acid rains from cars and power stations supply sulphur and nitrogen to forests and fields. This 'fertiliser', in the long-term, becomes a fatal pollutant to life systems. The first signs of collapse are plagues of pests like this tent moth caterpillar which invests stressed trees. (Principle of Disorder No. 1).

3. CANTERBURY PLAINS, NEW ZEALAND.
This apparently ordered landscape is maintained only by excessive work and at great energy cost. Such systems are disordered and represent chaos in life systems and produce a variety of pollutants in air and water. (Principle of Disorder No. 2).

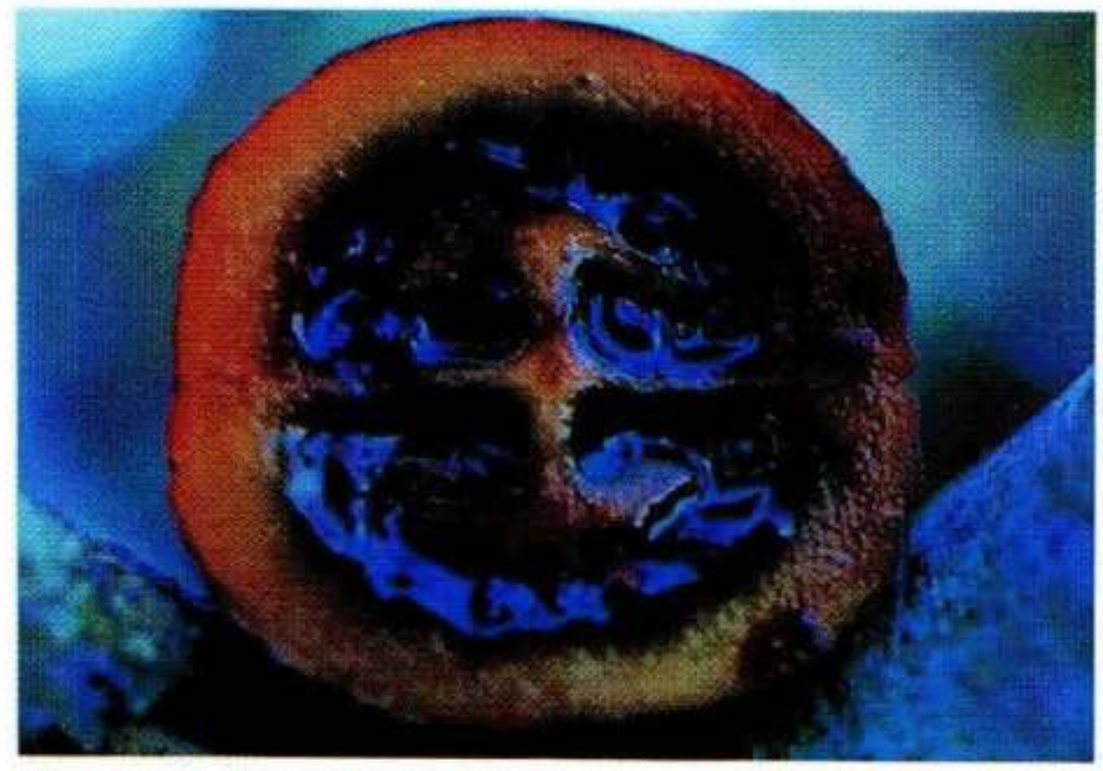


4. OVER MONTANA, USA.
Great energies spent on centre-pivot irrigation can in 3–4 years produce desert by evaporation effects. Water runoff harvesting and perennial plant systems could lead to harmony in this desert landscape. (Principle of Stress and Harmony).

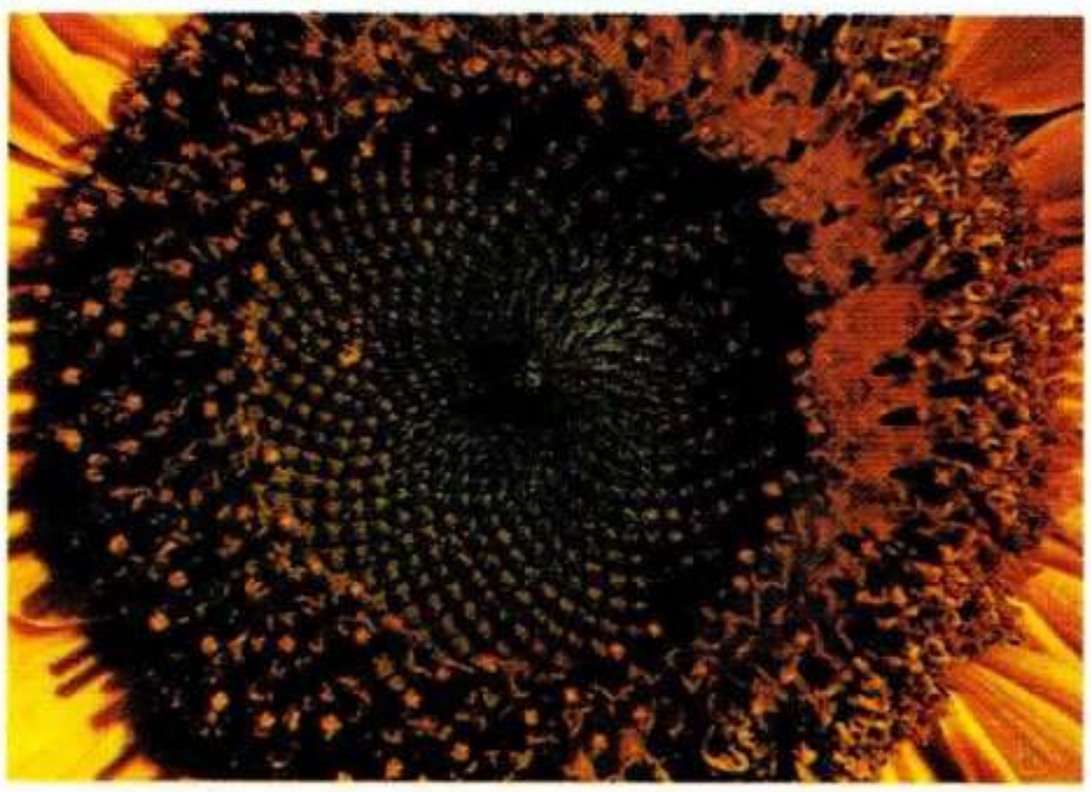
5. WILTON, NH, USA.
Careful site observation of natural processes. Here the author assesses woodlands on SAMUEL KAYMAN'S farm in early spring for forages, microsites, snow melt effects, wildlife refuges, and leaf litter distribution leading to appropriate design strategies. (Methods of Design No. 2 Observation).

6. WOMIKUTTA, CENTRAL AUSTRALIA.
Following observation of runoff in deserts a rock can be used to direct water to one useful tree. Such strategies arise from observation of rain effects and tree distribution around inselbergs. (Methods of Design No. 3–Deductions from Nature).

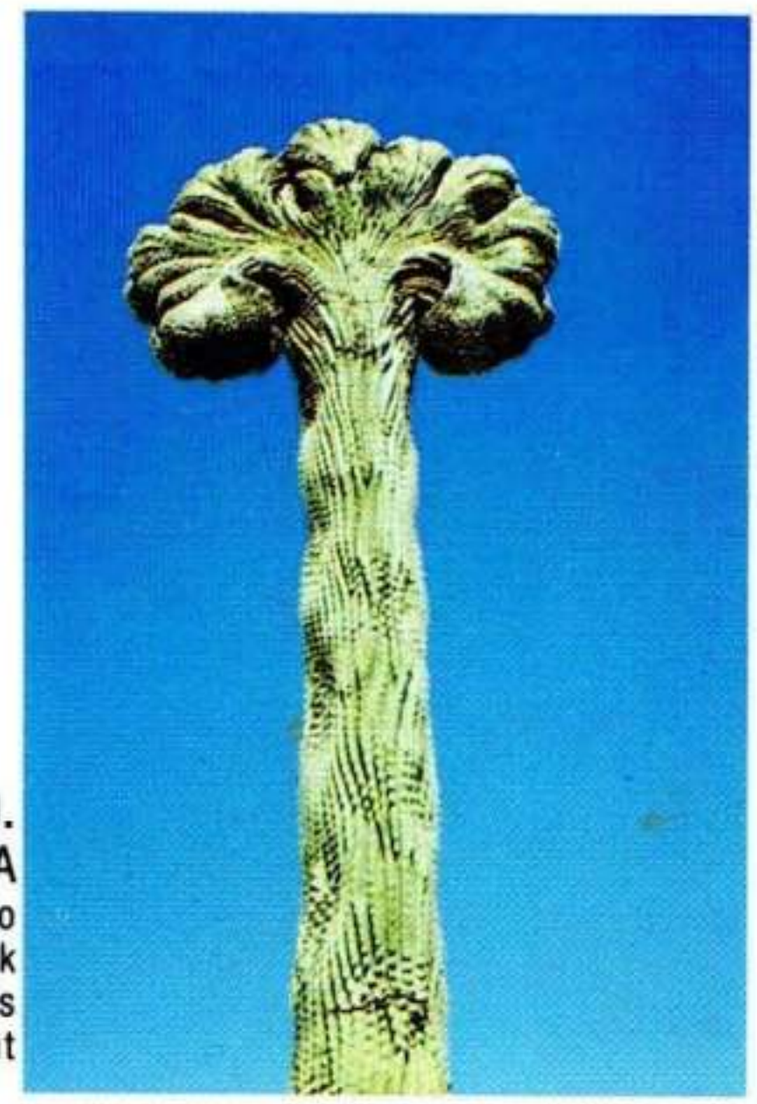
7. BUFFALO, WY, USA.
This section of a cottonwood limb cut by a chainsaw resembles the "general model".



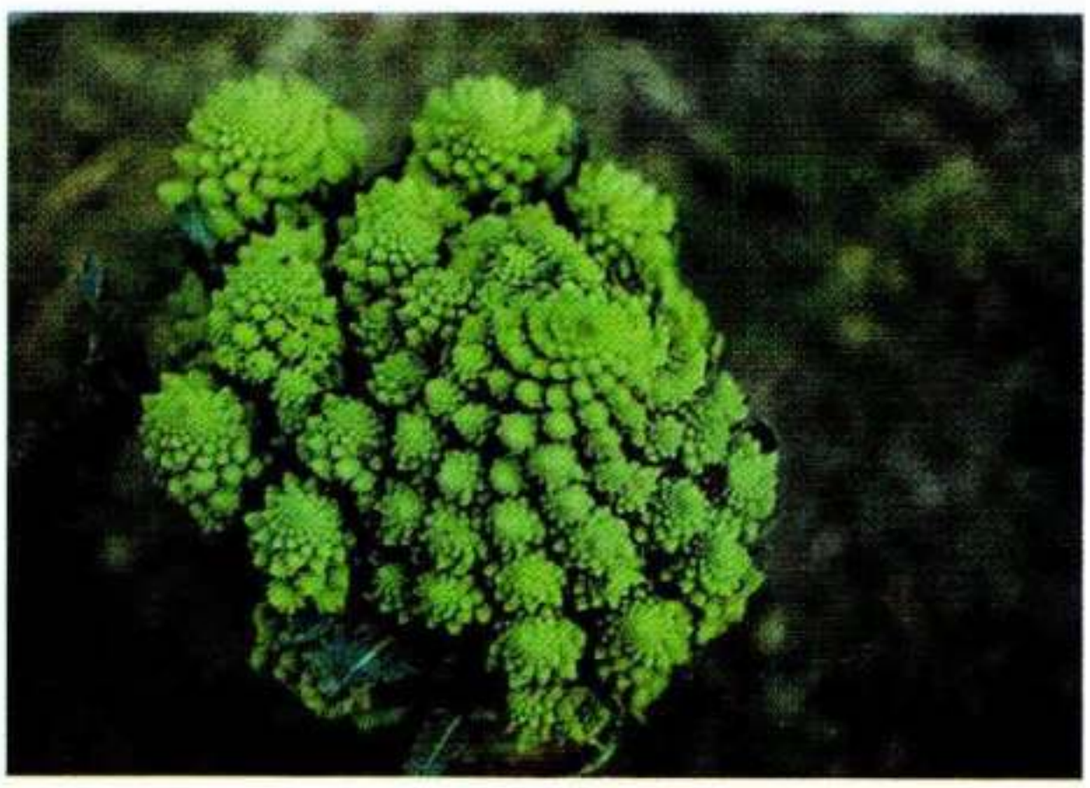
8. STANLEY, TAS, AUSTRALIA.
This section of a tamarillo also resembles the "general model".



9. STANLEY, TAS, AUSTRALIA.
The double spiral of seed in a sunflower head; counts of seed reveal the "summation series" or Fibonacci numbers along each spiral band.



10.
TUCSON, AZ, USA
An aberrant suguaro erupts into an "Overbeck Jet", and the stem reveals increasingly turbulent growth.



11. STANLEY, TAS, AUSTRALIA.
A spiral of spirals of spirals. This range of orders of similar forms is basic to fractals; it can be seen in many phenomena here, a Romanesque broccoli.

12. ERNABELLA, SA, AUSTRALIA.
Pitjatjantjara women transfer traditional patterns to new materials, here using a batik (wax–dye) process to print fabrics. Older patterns were made in sand.

13.
A sea-snail egg seen from its underside. Conical form, crenaliations, and spiral slots all ensure excellent stability in flow and self-induced flushing due to differing flow velocity near the sand surface.

14. VIC, AUSTRALIA.
An estuary reveals the nature of flow here, a Von Karman trail.

15.
Another Von Karman trail in a lava flow.

16. DECEPTION PASS, WA, USA.
The tidal flow in the narrows between Whidbey and Orcas Islands shows another Von Karman trail.

18 & 19. BORE FARM, KENT, UK.
A flowform system. The paired photos show water "switching" naturally into alternate basins; excellent for water aeration in a situation where volume is fairly constant.

17.
The unfolding of agave leaves reveals the imprint of other leaves. Von Karman trails show very similar increasing (or decreasing) magnitudes of flow.

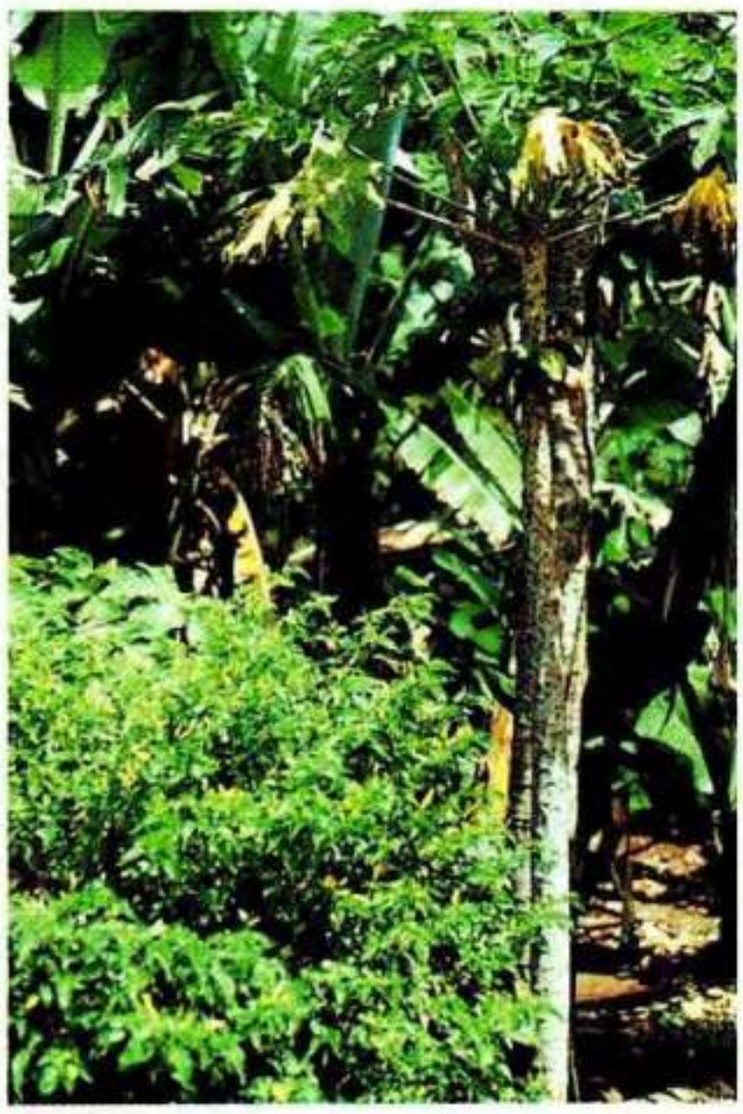
4. TROPICS
Developing a Food System

20. HAWAII ("the Big Island"), HAWAII.
Fresh *a 'a* lava flow has been crushed and levelled by tractor, spot–mulched with compost and *Macadamia* nut husks, and irrigated. See **21** for growth in 1 year. Steve Skipper inspecting. USDA trial.

21. HAWAII ("The Big Island"), Hawaii
Growth of trees in one year on *a 'a* lava site; more extensive mulch enables interplant. Numbers **20** and **21** reveal that mulch plus water can establish valuable trees on apparently hostile sites, here mango, citrus, macadamia, guava.

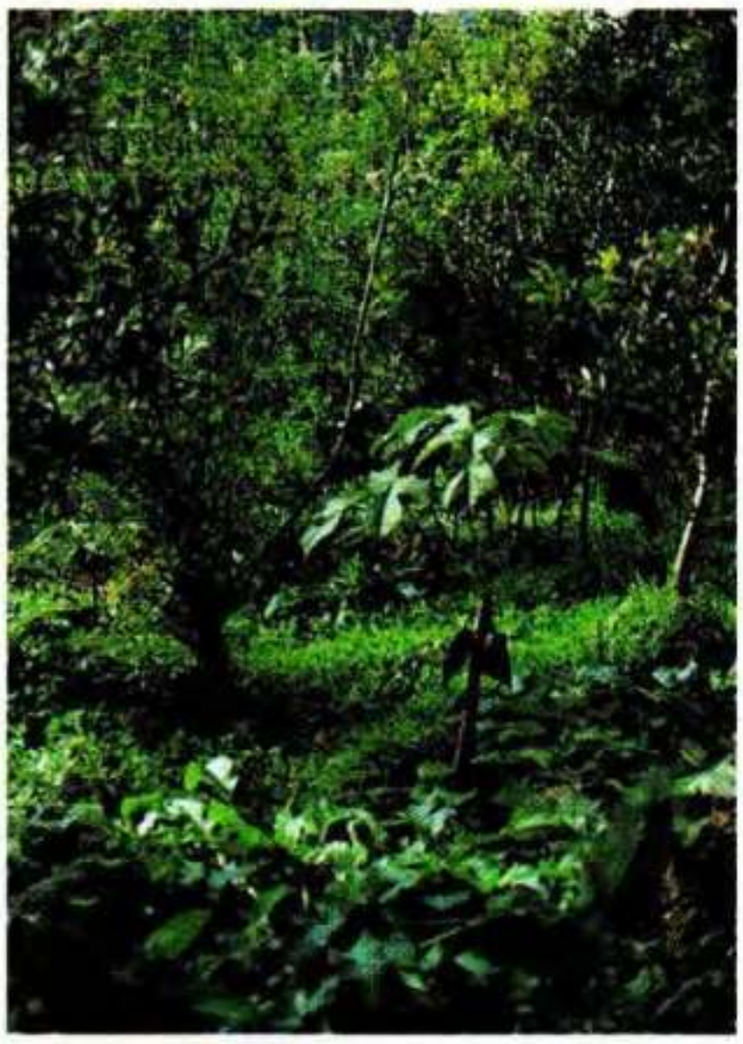
22. MOLOKA'I, HAWAII (Lat. 28°); Sub–tropical chicken tractor system.
Developed by Dano Gorsich. Foreground is 6 weeks of vegetable growth following the clearing of the chicken tractor (5 pens in 0.5 ha). Dano and his wife, and members of the Busby family stand at the front edge of a papaya system which is 2.5 years old. Chickens (Australorps) are moved from pen to pen over the year to clear weeds and grasses; they get most of their food from fallen papaya, seed, insects, and greens. Income from their eggs and papaya at the local cooperative *plus* home garden largely support the Gorsich family.

23. MOLOKA'I, HAWAII.
Traditional Hawaiian garden combines banana, papaya, chili, and taro. Pigs fed from surplus, chickens range below system. Developed by IMU and RACHEL (RAHELA) NAKI. Together with fish and home garden, this is a self–reliant and commercial system.



24. MAUI, HAWAII.
Kikuyu grass. Here, people have planted *Tagetes* (marigold) around their avocado tree to kill, and form a barrier to, the grasses.

25. KAIWAKA, Nth Is., NEW ZEALAND; Instant garden or jungle
About 18 months previously, this was pasture. KAY BAXTER first set up a small nursery, then set out (at one time) a windbreak of eucalypt and blackwood *(Acacia melanoxylon)*, and an interplant of nasturtium, comfrey, sweet potato (ground covers); banana, tagasaste, taro (under-storey); and a scatter of *Acacia*, guava, mulberry, citrus, apple, peach, etc. as fruit crop. Grass is suppressed and the system co–evolves. Mulch from comfrey, tagasaste is thrown around fruit trees.



5. GETTING RID OF WEEDS, GRASSES, RAMPANT SPECIES

See also Plate 22 -Small Livestock

26. KULA, MAUI, HAWAII.
A sea of kikuyu lawn is held at bay by a low barrier of canna, lemon grass, and comfrey. Part of the lawn (Number **27**) has been converted to a no-dig garden by JACK and SANDY LEWIN.

27. KULA, MAUI, HAWAII.
The reverse side of Number **26**'s barrier planting is an "instant garden" of mulch over newspaper and cardboard which, laid directly on the kikuyu lawn, obliterates that grass; the garden was built as a class excercise at a Permaculture Design Course based on field observations of kikuyu behaviour.

28. KUALAPUU, MOLOKA'I, HAWAII.
Electric fencing restrains pigs which root out and eat kikuyu and grasses, leaving *Prosopis* trees unaffected; this can now be planted and the pigs moved on. 100 pigs in 2 ha pens will "tractor" 40 ha in 2 months. (Hawaiian Homelands area).

29. MULLUMBIMBY, NSW, AUSTRALIA.
David McIlraith has "grenaded" an area of lantana with choko *(Sechium edule)*, which has killed out (by shade) the lanatana (and covered his truck!). This patch yields $120/week in fruits. Choko is easily removed by chickens or pigs, and the area can be planted to orchard or crop.

30. MOLOKA'I, HAWAII.
Chickens clear all grasses and weeds for gardens, papaya, and are ranged on the greens outside fence; papaya provides most of food.

6. TROPICS
Beaches, Islands, and Windbreaks

31. OAHU, HAWAII.
Profile of a stable sand beach with beach convolvulus, and casuarina. This shore can withstand severe storms.

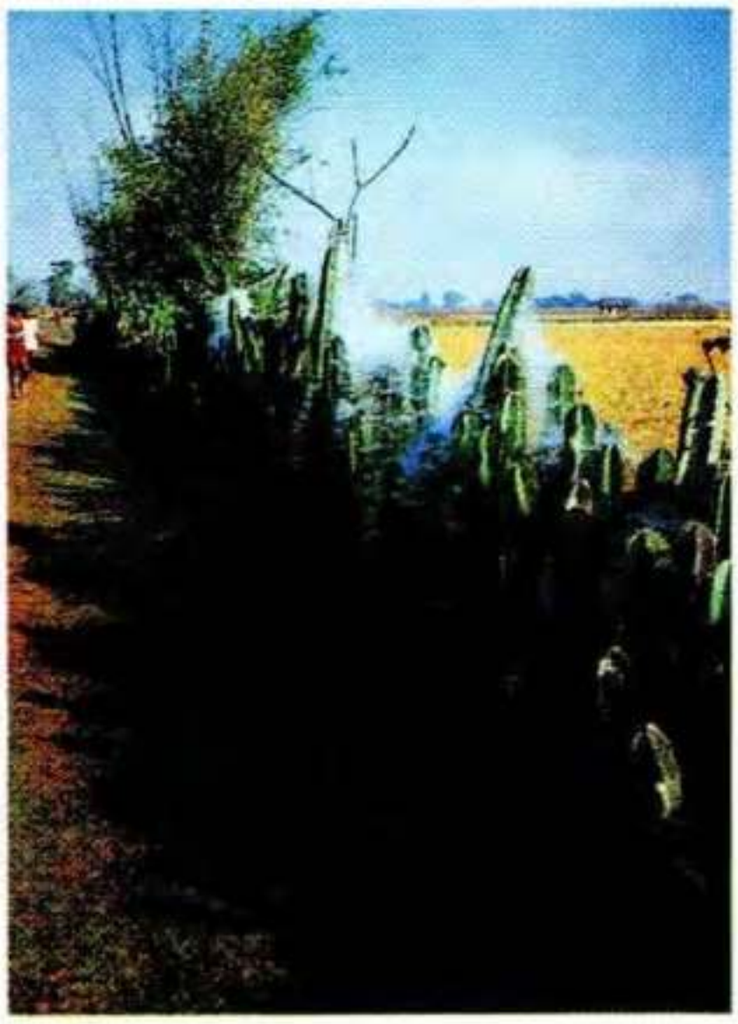
32. MAUI, HAWAII.
Once–stable coast eroding due to beach vegetation destruction; "recreation" can destroy coasts, destabilize snowfields, and erode dunes (sand buggies).

33. NAITAUBA, FIJI.
A hurricane has almost cut this island in half, following deforestation of the shore–line. A fringe of mangroves *(Rhizopora)* is re–stabilising the sea edges; on low coral islands and shores, the removal of coastal vegetation can destroy the island quickly in cyclones.

33. MOLOKA'I, HAWAII.
At the Moloka'i Plant Research Centre tropical windbreak trials indicate the importance of windbreaks in reducing stresses on plants and animals especially on islands with salt laden winds, and consistent monsoons and trades.

35. MOLOKA'I, HAWAII.
A "liveset" (cuttings) hedge of *Erythrina* ("willi–willi") and banna grass *(Pennisetum)* shelters crop against coastal winds; the grass is cut for mulch, and can later be removed as the *Erythrina* bushes out;. Casuarina, Leucaena, or Grevillea is often used as permanent hedgerow.

36. CHITWAN, NEPAL
Traditional low *Euphorbia* hedge provides windbreak, a habitat for spiders, a section of bamboo, and demarcates a cattle lane-way from mustard crop; *Euphorbia antiquorum* is often so used, and *E. tirucalli* in Botswana; all need goggles when cuttings are taken to prevent eye injury from the milky sap.



7. TROPICS
Patterned Systems

37. KURANDA, QUEENSLAND, AUSTRALIA.
Some years of work by MARJORIE SPEAR have evolved a very productive garden over 2.8 ha; sited at the edge of a coastal-facing cliff. Night condensation of mist is heavy. Marjorie has stacked the garden with Acacia, coconut, citrus, ferns, flowers, and mixed fruits to produce maximum yield in least space, with minimum grass or weed maintenance. Systems of this maturity demand management more than development work. Only access tracks are in grass.

38. NAITAUBA, FIJI.
Clumped coconuts (here, 8 together) yield as well as spaced coconut (12 x 12m), free up more ground, enable spot mulch serving all trees, assist harvesting, and concentrate watering. Several plant species (e.g. banana, Macadamia) can be clumped in this way, maximising space for intercrop.

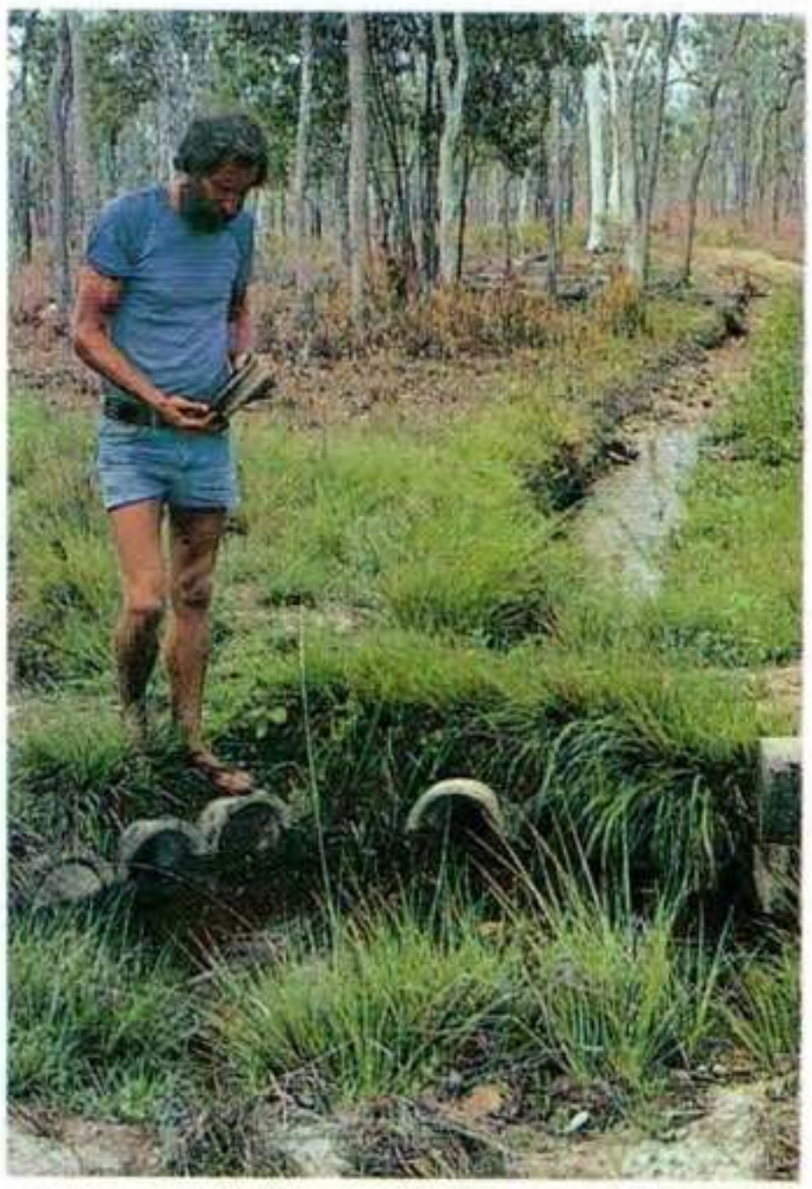
39. KUALAPUU, MOLOKA'I, HAWAII.
CHUCK BUSBY has developed mulched circle gardens—some with trellis fitted—to form nuclei in exhausted pineapple farm soils. Mulching and watering is compact. Shelter is of banna grass. Note that several yams and beans can use banna grass for support or trellis.

40. DETAIL OF NUMBER **39**.

41. NIMBIN, NSW, AUSTRALIA.
MICHEL and JUDE FANTON use lemon grass planted on contour to hold steep slope soils, provide mulch, and create upslope planting sites for *Alectrytes*. Lemon grass is also used in beverages and cooking. Vetiver grass is used in this way in Africa whenever stability is needed on slopes, *Euphorbia tirucalli* in deserts.

42. CHITWAN, NEPAL.
UMA and M. C. PEREIRA have developed a more structured stacked system than in Number **37**, with pineapple and ginger main crop edged with leucaena and lychee trees. Leucaena provide fodder, firewood, nitrogen in soils, and mulch. This system too needs minimal maintenance, and is no-tillage. Unirrigated, but sustains yield, provides surplus firewood, mulch, and supports 3–5 adults on 1 ha.

8. TROPICS
Irrigation and Weed Control



43. MALANDA, QUEENSLAND, AUSTRALIA.
BOB KINGWELL has devised a simple manifold to lead water in 3 directions from a head drain; pipes are plugged or opened to allow flow in channels, using simple concrete plugs with rubber "O" rings.

44.
As for Number **43**, here Bob has fitted a head drain with cross–stops to allow water to back up and flood the field to the right; again simple pipes are used, carefully levelled.

45. GUINEA PIG SHELTER.
3–4 guinea pigs manure, and keep kikuyu from choking, young litchee trees; they forage below the canopy, and are fed food pellets. Owls and pythons eat excess populations.

46.
In lieu of guinea pigs, *Desmodium* restrains kikuyu grass. This uses more water than the guinea pig solution but does not need food pellets.

47.
Flood irrigation of papaya on slight ridges also waters green mulch. *Desmodium* carpets the papaya mounds, and comfrey provides a mulch interplant.

9. DRYLANDS
Grazing and Range

48. COOMA, NSW, AUSTRALIA.
Desertification due to overgrazing. Collapse of soils and forests is evident.

49. WILMINGTON, SA, AUSTRALIA.
Goats reduce ground cover and make regeneration of trees impossible. The area needs swales, long-rotational grazing, intensive cut forage for milk goats (in swales); a scene that could be of any semi-arid area.

50. LAS PALMAS, CANARY ISALNDS.
A tethered milk goat (fed on cut hay and cactus) creates a well-manured niche in bare granite rock. After this, an almond, fig, or chestnut tree is planted; oats regenerate for hay. In this way, extensive orchards are developed in eroded granite country. (See Number **51**).

51.
As for Number **50**. A general view of an almond orchard developed in granite using goat and donkey manures. Small hay fields lie below this slope. Cattle or goat pens can be used in this way in any arid area.

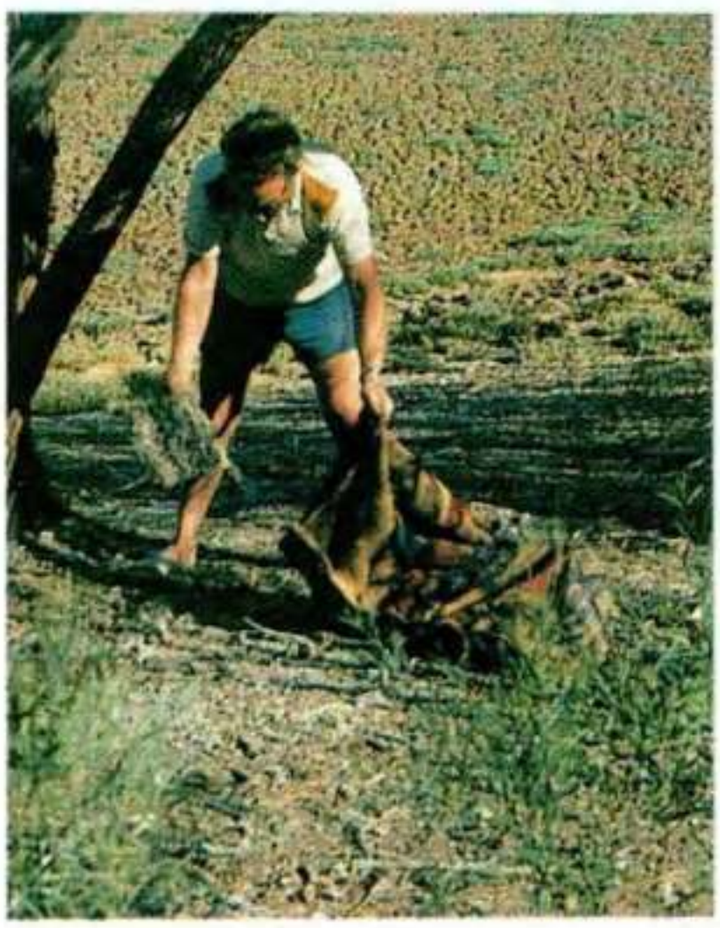
52. WILUNA, SA, AUSTRALIA.
Caves part-excavated by wallaroo (a rock kangaroo) offer shelter below a scarp edge; such shade sites determine the number and type of wildlife (e.g. lizards, wallaroo, pigeon) able to occupy and breed in drylands. Author takes refuge from the sun.

53. PYRAMID LAKE, NV, USA.
GERARD and GUS JAMES of the Pyramid Lake Paiute tribe examine Indian rice grass re-seeded in sands. The seed is acid treated, buried 0.3 m, and the glumes flamed to free seed for cooking. *Oryzopsis* is a staple of the Shoshone in this region, and a good perennial range forage for cold deserts. It spaces itself to about 0.6 m between bunches.

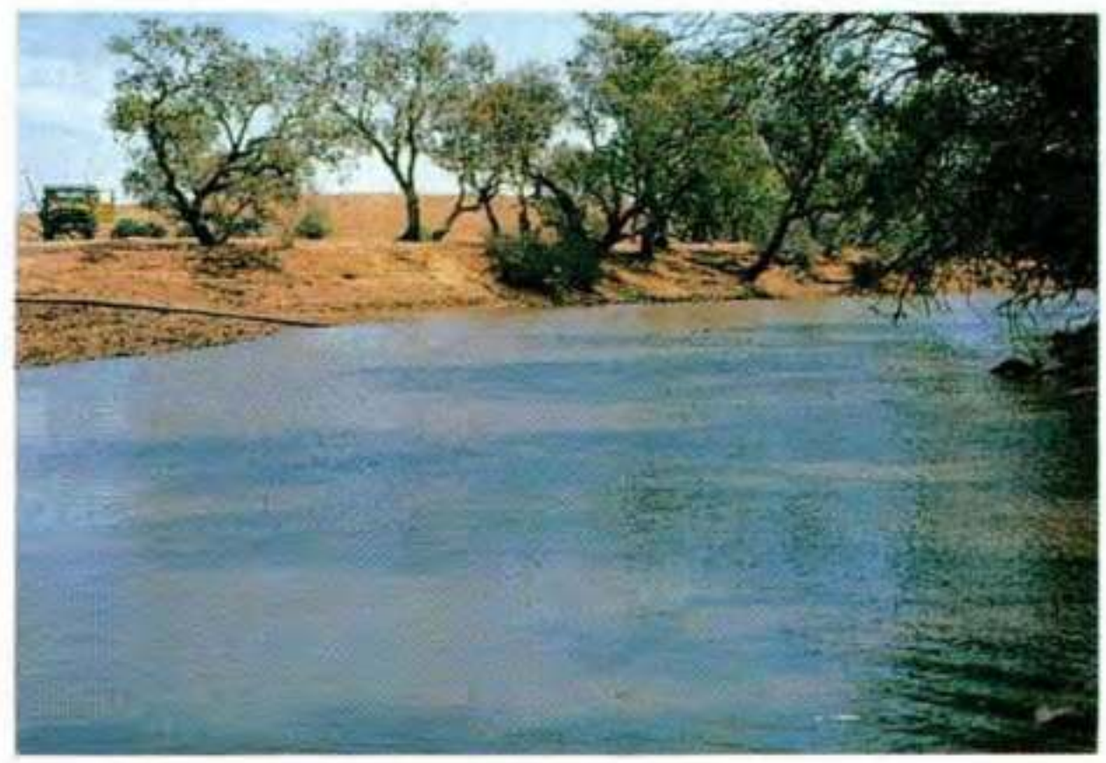
10. DRYLANDS

54. PORT LINCOLN, SA, AUSTRALIA.
Sand dune on hard pavement absorbs water and grows larger trees; the range is in fair condition. Sessile trees prevent sand erosion or trap sand on dune crests and sides.

55. POVERTY FLAT, CEDUNA, SA, AUSTRALIA.
Raised beds, sunken paths, perforated pipe irrigation, mulch, sulphur, and bentonite, combine to produce a rich organic garden on an eroded sandy soil site (water 1,100 ppm salt). Aboriginal students taught by PETER BENNETT produce excellent crops in desperate soil conditions.



56. NEAR FLINDERS, SA, AUSTRALIA.
BARRY PILTZ gathers sheets of guano from below tree roosts beside a dryland dam—pigeons and parrots visit for water and enrich area with guano, below roost trees.



57. NEAR OODNADATTA, SA, AUSTRALIA.
Hard bank (on skyline) constricts flood water to create a scour hole in river sand beds. Such effects can be created.

58. ALICE SPRINGS, CENTRAL AUSTRALIA.
Gabions—rock-filled wire basket structures—stabilise a floodway near Alice springs reducing flood flow, and silt burden in the stream.

59. CHARIKOT, NEPAL
Gabions stabilise this steep hillside gully on the road to Charikot. A Swiss design.

11. DRYLANDS
Housing

60. LAS PALMAS, CANARY ISLANDS.
A rocky arroyo (wadi, canyon, gully) floods periodically bringing down large boulders. (See Number **61**.)

61. LAS PALMAS, CANARY ISLANDS.
An arroyo is part-blocked by concrete/stone barrier on right, and bled off via a coarse trash screen to tunnels *(galeria)* and cave storages linked to irrigation systems at lower levels.

63. KOONIBBA, SA, AUSTRALIA.
A few months growth in greywater produces abundant vegetable food, establishes fruit trees, cools area, and utilizes nutrients previously lost to a waste lagoon.

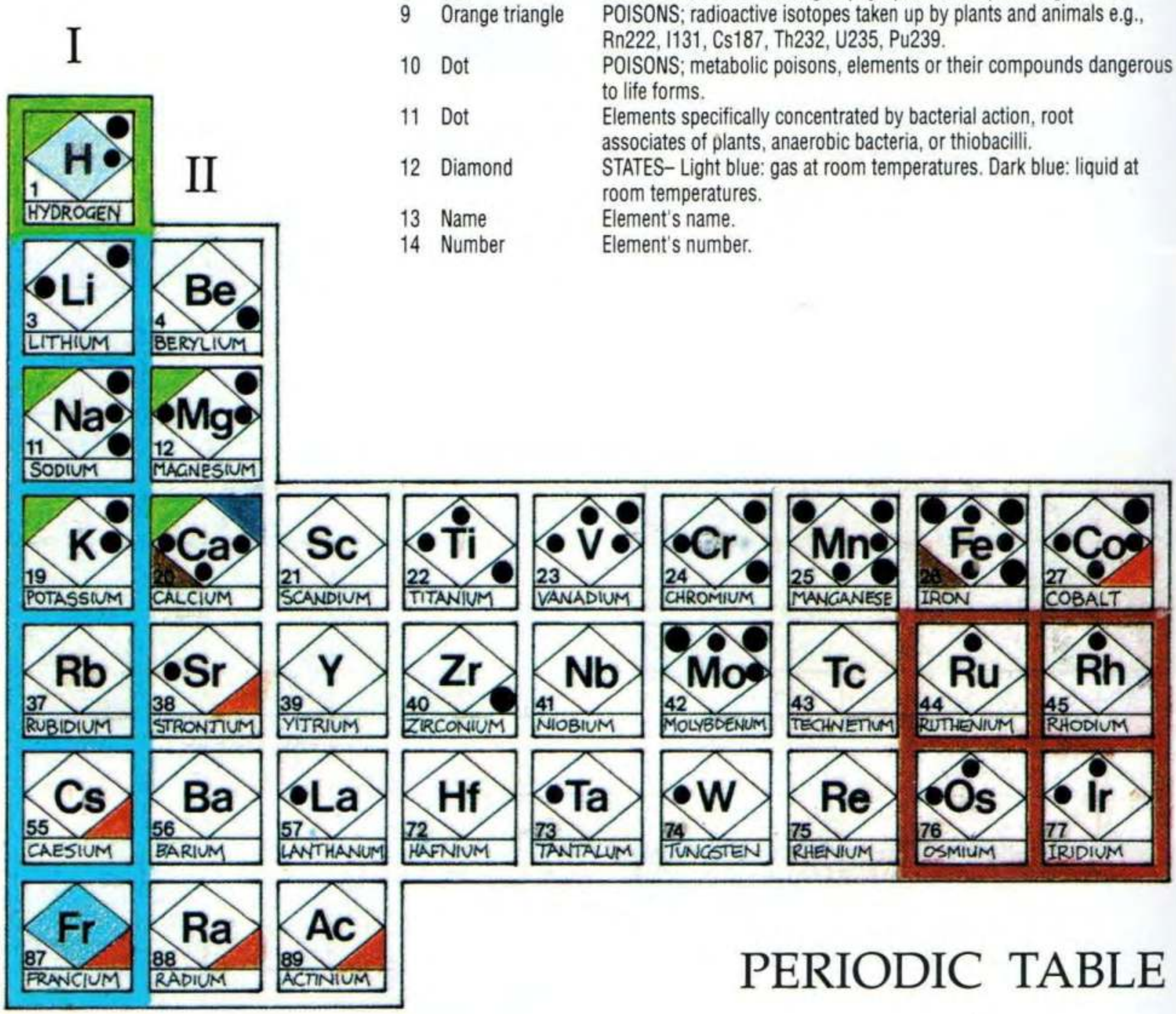
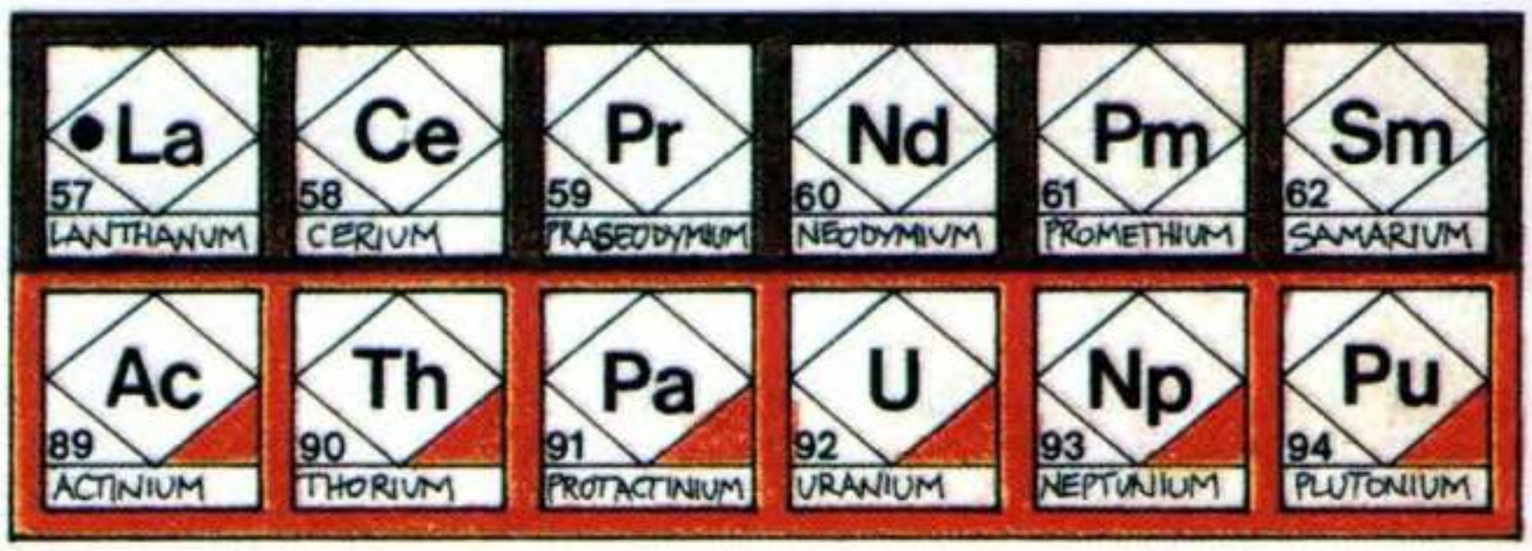
62. KOONIBBA, SA, AUSTRALIA
Aboriginal gardeners dig an absorption trench from a kitchen sink outlet, in brick-hard ground. Trench is plastic-lined, manured, refilled, and planted. (See Number **63**).

64. LAKE WINNEMUCCA, NV, USA.
Recessional boulder benches on the shoreline provide a natural swale system and infiltration, determining vegetation (range) distribution. Gibber deserts (Reg) can be swaled in this way for range species, saltbush, and useful crop.

65. SEROWE, BOTSWANA.
Setting out swales in thorn acacia to infiltrate overland flow for vines and valuable trees. Sorghum and melon crop can be interplanted in thorn forest. (See Numbers **66** *et seq* for swale growth in similar rainfall conditions).

PERIODIC TABLE KEY

1	Brown triangle	THE MAJOR ELEMENTS of which soil is composed.
2	Dot	Elements occuring in minute quantities in plants and marine and freshwater algae.
3	Green triangle	MAJOR NUTRIENTS in plant tissues and soils.
4	Dot	TRACE ELEMENTS necessary to metabolic functions in plants.
5	Dot	CATALYTIC ELEMENTS involved in metabolic function and hydrocarbon processing.
6	Blue triangle	MAJOR ELEMENTS necessary to metabolic function in animals.
7	Dot	TRACE ELEMENTS necessary to metabolic function in animals.
8	Dot	Elements critical or limiting to phytoplankton, aquatic organisms.
9	Orange triangle	POISONS; radioactive isotopes taken up by plants and animals e.g., Rn222, I131, Cs187, Th232, U235, Pu239.
10	Dot	POISONS; metabolic poisons, elements or their compounds dangerous to life forms.
11	Dot	Elements specifically concentrated by bacterial action, root associates of plants, anaerobic bacteria, or thiobacilli.
12	Diamond	STATES– Light blue: gas at room temperatures. Dark blue: liquid at room temperatures.
13	Name	Element's name.
14	Number	Element's number.



PERIODIC TABLE